Appendix A

References, Abstracts, and Executive Summaries of Research Related to Differential Delayed Mortality

Appendix A

References, Abstracts, and Executive Summaries of Research Related to Differential Delayed Mortality

We have reviewed literature related to *D*, independent of a particular study's methodology or study objectives for Snake River stocks of spring/summer Chinook salmon, subyearling and yearling fall Chinook salmon, and steelhead. Sources include papers published in peer-reviewed journals, technical memos, annual reports, and reviews. The database is presented in this appendix as a list of references with hyperlinks to abstracts and executive summaries contained within this document.

A.1 References Categorized by Species/Run and Topic

Table A.1. References Categorized by Species/Run and Topic

Species And Run	Hatchery Or Wild	Pre-Hydrosystem Conditions	Arrival Time And Travel Time	Fish Size	Fish Physiology And Health
Snake R. Spring/ summer Chinook	H	Muir and Coley 1996, Dietrich et al. 2011	Zabel et al. 1998, Zabel and Williams 2002, Muir et al. 2006, Eder et al. 2009a	Zabel and Williams 2002, Zabel et al. 2005, Welch 2007, Mesa et al. 2008, Marsh et al. 2008b, Porter et al. 2009 a, b, Marsh et al. 2010c, Porter et al. 2010 a, b	Congleton et al. 2000, Congleton et al. 2001, Budy et al. 2002, Congleton 2003, Wagner et al. 2004, Congleton et al. 2005, Dietrich et al. 2007, Dietrich et al. 2008, Freyer 2008, Mesa et al. 2008, Eder et al. 2009a, b, Akoosh et al. 2011, Van Gaest et al. 2011
	W	Paulsen and Fisher 2001, Achord et al. 2003, Crozier and Zabel 2006, Zabel et al. 2006, Achord et al. 2007, Budy and Schaller 2007, Holecek et al. 2009, Crozier et al. 2010	Pearcy 1992, Zabel et al. 1998, Zabel and Williams 2002, Muir et al. 2006, Achord et al. 2007, Zabel et al. 2008a, b	Zabel and Williams 2002, Zabel and Achord 2004, Zabel et al. 2005, Muir et al. 2006, Achord et al. 2007, Marsh et al. 2008a, b, Crozier et al. 2010, Marsh et al. 2010c	Congleton et al. 2000, Congleton et al. 2001, Budy et al. 2002, Congleton 2003, Wagner et al. 2004, Congleton et al. 2005, Welker and Congleton 2009
	NA		Scheuerell et al. 2009		Matthews et al. 1986, Schreck et al. 2005, Schreck et al. 2006, Sandford et al. 2012

Table A.1. (contd)

Species And Run	Hatchery Or Wild	Pre-Hydrosystem Conditions	Arrival Time And Travel Time	Fish Size	Fish Physiology And Health

Snake R. Fall Chinook	H		Connor et al. 2002, Smith et al. 2003, Connor et al. 2004, Connor et al. 2005, Tiffan et al. 2009	Connor et al. 2004, Connor et al. 2005, Connor 2007, Marsh et al. 2010a, b	Budy et al. 2002, Connor et al. 2004
	W	Connor et al. 2002	Connor et al. 2002, Connor et al. 2005, Tiffan et al. 2009	Connor et al. 2002, Connor 2007	Budy et al. 2002
Snake R. Steelhead	H		Plumb et al. 2006, Kennedy et al. 2007, Marsh et al. 2007	Zabel et al. 2005, Kennedy et al. 2007, Marsh et al. 2007, Marsh et al. 2008b, Marsh et al. 2010c	Zabel et al. 2005, Kennedy et al. 2007
	W		Plumb et al. 2006, Kennedy et al. 2007, Marsh et al. 2007, Zabel et al. 2008a, b	Marsh et al. 2004, Plumb et al. 2006, Kennedy et al. 2007, Marsh et al. 2008b, Zabel et al. 2008a, b, Marsh et al. 2010c	Congleton et al. 2000, Budy et al. 2002, Kennedy et al. 2007
	NA		Pearcy 1992	Scheuerell et al. 2009	Matthews et al. 1986
Other		Muir and Coley 1996, Levin et al. 2002, Wilson 2003, Harvey and Kareiva 2005, Scheuerell et al. 2005, Luce and Holden 2009, Sanderson et al. 2009, Macneale et al. 2010	Kemp et al. 2005, Sykes et al. 2009	Arendt 1997, Beamish and Mahnken 2001, Welch 2007, Porter et al. 2009 a, b, Porter et al. 2010 a, b	Brett 1979, Maule et al. 1987, Mesa 1994, Mesa et al. 1998, Railsback and Rose 1999, Kelsey et al. 2002, Mesa et al. 2002, Price and Schreck 2003, Welker and Congleton 2003, Biro et al. 2004, Finstad et al. 2004, Wagner et al. 2004, Schreck et al. 2005, Trudel et al. 2005, Collier et al. 2006, Congleton and Wagner 2006, Liebert and Schreck 2006, Naesje et al. 2006, Schreck et al. 2006, Angilletta et al. 2008, Mather et al. 2008, Mesa et al. 2008, Bellgraph et al. 2010

Table A.1. (contd)

Species And Run	Hatchery Or Wild	Disease	Dam Operations	Barging Conditions

Snake R. Spring/ summer Chinook	H	Arkoosh et al. 2006, Dietrich et al. 2007, Dietrich et al. 2008, Marsh et al. 2008b, Eder et al. 2009a, b, Dietrich et al. 2010, Marsh et al. 2010c, Dietrich et al. 2011, Van Gaest et al. 2011	Zabel et al. 1998, Ferguson et al. 2005, Popper 2006, Schaller et al. 2007a, Eder et al. 2009a, ISAB 2008b, 2009, DeHart 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	Congleton et al. 2000, Congleton 2003, Wagner et al. 2004, Congleton et al. 2005, Buchanan et al. 2006, Normendeau 2006, Ryan et al. 2007, Marsh et al. 2008b, Halvorsen et al. 2009, ICF Jones & Stokes 2009, Dietrich et al. 2010, Marsh et al. 2010c, d
	W	Marsh et al. 2008b, Marsh et al. 2010c	Pearcy 1992, Zabel et al. 1998, Ferguson et al. 2005, Schaller et al. 2007a, ISAB 2008b, Zabel et al. 2008a, b, ISAB 2009, DeHart 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	Pearcy 1992, Zabel et al. 1998, Ferguson et al. 2005, ISAB 2008b, Marsh et al. 2008b, Zabel et al. 2008a, b, ICF Jones & Stokes 2009, ISAB 2009, DeHart 2010, Marsh et al. 2010c
	NA	Elliott et al. 1997, Schreck et al. 2005, Schreck et al. 2006	Pearcy 1992, Zabel et al. 1998, Ferguson et al. 2005, ISAB 2008b, Zabel et al. 2008a, b, ISAB 2008b, ISAB 2009, DeHart 2010	
Snake R. Fall Chinook	H		Smith et al. 2003, Tiffan et al. 2009	ICF Jones & Stokes 2009
	W		Connor et al. 2003, Tiffan et al. 2009	ICF Jones & Stokes 2009
	NA		Ferguson et al. 2005, ISAB 2008b	
Snake R. Steelhead	H	Marsh et al. 2008b, Marsh et al. 2010c	Ferguson et al. 2005, Plumb et al. 2006, Schaller et al. 2007a, ISAB 2008b, 2009, DeHart 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	Congleton et al. 2000, Congleton 2003, Ryan et al. 2007, Marsh et al. 2008b, ICF Jones & Stokes 2009, Marsh et al. 2010c, d
	W	Marsh et al. 2008b, Marsh et al. 2010c	Ferguson et al. 2005, Plumb et al. 2006, Schaller et al. 2007a, ISAB 2008b, Zabel et al. 2008a, b, ISAB 2008b, ISAB 2009, DeHart 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	Congleton et al. 2000, Congleton 2003, Ryan et al. 2007, Marsh et al. 2008b, ICF Jones & Stokes 2009, Marsh et al. 2010c
	NA		Pearcy 1992, Sandford and Smith 2002, Sandford et al. 2012	Wagner et al. 2004, McMichael et al. 2006
Other		Maule et al. 1987, Pascho et al. 1993, Elliott et al. 1997, Mesa et al. 1998, Elliott and Pascho 2001	Wilson 2003, Ferguson et al. 2005, Ferguson et al. 2006, Schaller and Petrosky 2007, ISAB 2008b, 2009, NOAA 2010, ISAB 2010	ICF Jones & Stokes 2009, Marsh et al. 2010d

Table A.1. (contd)

Species And Run	Hatchery Or Wild	Lower River Conditions And Fish Predation	Estuary Conditions And Avian Predation	Ocean Conditions	Straying, Fallback And Other Behaviors During Adult Migration
Snake R. Spring/ summer Chinook	H	Muir et al. 2006, Ledgerwood et al. 2007, Mesa et al. 2008, Clemens et al. 2009	Ledgerwood et al. 2007, Hockersmith et al. 2008, Eder et al. 2009a, Eder et al. 2009b	Muir et al. 2006, Welch 2007, Porter et al. 2009a, b, Rechisky et al. 2009, Porter et al. 2010 a, b, Rechisky 2010	Boggs et al. 2004, Keefer et al. 2004, Keefer et al. 2006b, Keefer et al. 2006c, Keefer et al. 2008a, Keefer et al. 2008b
	W	Muir et al. 2006, Ledgerwood et al. 2007	Ledgerwood et al. 2007	Pearcy 1992, Muir et al. 2006	Boggs et al. 2004, Keefer et al. 2004, Keefer et al. 2006b, Keefer et al. 2006c, Keefer et al. 2008a, Keefer et al. 2008b
	NA	Schreck et al. 2005, Schreck et al. 2006	Schreck et al. 2005, Schaller and Petrosky 2007	Scheuerell and Williams 2005, Schreck et al. 2006, Schaller and Petrosky 2007, Scheuerell et al. 2009	Keefer et al. 2006a
Snake R. Fall Chinook	H				Boggs et al. 2004, Marsh et al. 2010b
	W				Boggs et al. 2004
	NA	Ledgerwood et al. 2007, Clemens et al. 2009	Burrows 1969, Ledgerwood et al. 2007		Goniea et al. 2006
Snake R. Steelhead	H	Ledgerwood et al. 2007, Clemens et al. 2009	Kennedy et al. 2007, Ledgerwood et al. 2007		Boggs et al. 2004, Keefer et al. 2006b, Marsh et al. 2007, Keefer et al. 2008a
	W	Ledgerwood et al. 2007	Kennedy et al. 2007, Ledgerwood et al. 2007		Boggs et al. 2004, Keefer et al. 2006b, Keefer et al. 2008a
	NA			Pearcy 1992, Scheuerell et al. 2009	Keefer et al. 2008c

Table A.1. (contd)

Species and run	Hatchery or Wild	Lower River conditions and fish predation	Estuary conditions and avian predation	Ocean conditions	Straying, fallback and other behaviors during adult migration
Other		Mesa and Olson 1993, Mesa et al. 1998, Mesa et al. 2002, Enstipp et al. 2007, Mesa et al. 2008, Porter 2008, Carter 2009	Collis et al. 2001, Collis et al. 2002, Roby et al. 2003, Ryan et al. 2003, Anderson et al. 2004, Antolos et al. 2004, Suryan et al. 2004, Antolos et al. 2005, Bottom et al. 2005, Lyons et al. 2005, Schreck et al. 2005, Emmett and Sampson 2007, Lyons et al. 2007, McComas et al. 2007, Schaller and Petrosky 2007, ISAB 2008c, McComas et al. 2008, Roby et al. 2008, Wiese et al. 2008, Roby et al. 2011a, b	Burrows 1969, Nickelson 1986, Brodeur and Ware 1992, Pearcy 1992, Gargett 1997, Beamish and Mahnken 2001, De Robertis et al. 2005, Emmett et al. 2006, Schreck et al. 2006, Schaller and Petrosky 2007, Welch 2007, Emmett and Krutzikowsky 2008, Parnel et al. 2008, Buhle et al. 2009, Porter et al. 2009a, b, Rechisky et al. 2009, Porter et al. 2010 a, b, Welch et al. 2009, Rechisky 2010	Burrows 1969, Wertheimer and Evans 2005, Goniea et al. 2006, Keefer et al. 2006a, Naughton et al. 2006, Keefer et al. 2008c, Ruzycki and Carmichael 2010

Table A.1. (contd)

Species And Run	Hatchery Or Wild	Tagging	SAR, T:I, *D* And Other Survival Estimates In The Field	Comprehensive Reviews And Comments
Snake R. Spring/ summer Chinook	H	Hockersmith et al. 2003, Hockersmith et al. 2008, Rechisky and Welch 2010	Zabel and Williams 2002, Congleton 2003, Anderson et al. 2005, Buchanan et al. 2005, Zabel et al. 2005, Buchanan et al. 2007, Schaller et al. 2007a, Welch 2007, Dietrich et al. 2008, Eder et al. 2009a, Eder et al. 2009b, Porter et al. 2009 a, b, Rechisky et al. 2009, NOAA 2010, Porter et al. 2010 a, b, Rechisky 2010, Tuomikoski et al. 2010, Buchanan et al. 2011, Porter et al. 2011	Giorgi et al. 2002, Marmorek et al. 2004, Williams et al. 2005, ISAB 2007b, ISAB and ISRP 2007, ISAB 2008a, Williams 2008
	W		Kareiva et al. 2000, Zabel and Williams 2002, Congleton 2003, Anderson et al. 2005, Zabel et al. 2005, Schaller et al. 2007a, Marsh et al. 2008a, Hinrichsen and Fisher 2009, NOAA 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	
	NA		Sandford and Smith 2002	
Snake R. Fall Chinook	H	Anglea et al. 2004	Marsh et al. 2010a, b	
	W			
	NA	Brown et al. 2006, Brown et al. 2010		
Snake R. Steelhead	H		Anderson et al. 2005, Zabel et al. 2005, Schaller et al. 2007a, NOAA 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	
	W		Marsh et al. 2004, Anderson et al. 2005, Zabel et al. 2005, Marsh et al. 2007, Schaller et al. 2007a, NOAA 2010, Tuomikoski et al. 2010, Buchanan et al. 2011	
	NA		Sandford and Smith 2002	
Other		Burrows 1969, Elliott and Pascho 2001, Brown et al. 2006, Goniea et al. 2006, Parken et al. 2008, Chittenden et al. 2009, ISAB 2009, Knudsen et al. 2009, Rub et al. 2009, Rechisky and Welch 2010	Dauble and Mueller 2000, Deriso et al. 2001, Hinrichsen and Fisher 2009, Porter et al. 2009 a, b, Rechisky et al. 2009, Porter et al. 2010 a, b, Rechisky 2010	ISAB 2007a

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Please click on hyperlinks to see abstracts and summaries.

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A.3 Abstracts and Executive Summaries

Achord, S, PS Levin, and RW Zabel. 2003. "Density-dependent mortality in Pacific salmon: The ghost of impacts past?" *Ecology Letters* 6(4):335-342.

Conservation biologists often ignore density dependence because at-risk populations are typically small relative to historical levels. However, if populations are reduced as a result of impacts that lower carrying capacity, then density-dependent mortality may exist at low population abundances. Here, we explore this issue in threatened populations of juvenile chinook salmon (*Oncorhynchus tshawytscha*). We followed the fate of more than 50 000 juvenile chinook in the Snake River Basin, USA to test the hypothesis that their survival was inversely associated with juvenile density. We also tested the hypotheses that non-indigenous brook trout and habitat quality affect the presence or strength of density dependence. Our results indicate that juvenile chinook suffer density-dependent mortality and the strength of density dependence was greater in streams in which brook trout were absent. We were unable to detect an effect of habitat quality on the strength of density dependence. Historical impacts of humans have greatly reduced population sizes of salmon, and the density dependence we report may stem from a shortage of nutrients normally derived from decomposing salmon carcasses. Cohorts of juvenile salmon may experience density-dependent mortality at population sizes far below historical levels and recovery of imperiled populations may be much slower than currently expected.

Achord S, RW Zabel, and BP Sandford. 2007. "Migration Timing, Growth, and Estimated Parr-to-Smolt Survival Rates of Wild Snake River Spring-Summer Chinook Salmon From the Salmon River Basin, Idaho, to the Lower Snake River." *Transactions of the American Fisheries Society* 136(1):142-154.

Survival, growth, and juvenile migration timing are key life history traits for at-risk salmon populations. To estimate these traits in threatened wild Snake River spring-summer Chinook salmon (*Oncorhynchus tshawytscha*), we tagged fish as parr in 3-17 natal streams per year from 1991 to 2003. We injected passive integrated transponder tags into part collected from streams within the Salmon River basin in Idaho. Each spring, after the previous summer's tagging, fish were detected as smolts in the juvenile fish bypass systems of lower Snake River darns. Estimated parr-to-smolt survival to Lower Granite Dam (excluding migration year 1992) ranged from 3% to 48% for individual populations and from 8% to 25% (yearly average = 16%) for all streams combined. From 1998 to 2004, estimated parr-to-smolt survival declined from 25% to 8%, in part because of part density-dependent effects. Overall annual average growth rates from tagging to detection at Little Goose Dam ranged from 39.7 to 43.3 mm during 2001-2004, and significant differences in growth were observed among sites and years. Growth of individuals was positively related to elapsed time between tagging and recapture and negatively related to fork length at tagging. Annual migration timing distributions for fish populations from the different streams varied highly within and between years. Timing of the 10th to 90th percentile passing Lower Granite Dam ranged from 20 to 45 d for the combined wild populations (average = 38 d). Median passage date was negatively related to autumn temperature, spring temperature, and March river flow, and was positively related to elevation of the tagging site. Baseline data generated by this project provide a foundation for understanding the biocomplexity of these populations, which is critical to effective recovery efforts for these threatened wild fish stocks.

Anderson, CD, DD Roby, and K Collis. 2004. "Foraging patterns of male and female Double-crested Cormorants nesting in the Columbia River estuary." *Canadian Journal of Zoology-Revue Canadienne De Zoologie* 82(4):541-554.

The nesting colony of Double-crested Cormorants, Phalacrocorax auritus (Lesson, 1831), on East Sand Island in the Columbia River estuary is currently the largest for this species on the Pacific Coast of North America. We used radiotelemetry to investigate the spatial and temporal foraging patterns of nesting cormorants to better understand how this colony of piscivores meets its resource needs. We determined that nesting adults tended to forage >5 km from the colony and foraging distribution was distinctly different between the sexes. On average, males commuted nearly twice the distance to forage compared with females. Females typically foraged in the estuarine mixing zone, reportedly the region of the estuary with the greatest densities of schooling fishes, while males tended to commute more than 15 km to forage in the freshwater zone. Foraging intensity of both sexes varied by time of day, tide stage, and tide series; foraging generally intensified during ebb tides. These gender differences in foraging patterns, combined with the ability to forage at considerable distance from the colony on a wide variety of prey, may allow this large and growing colony to remain productive while potentially competing for food with many thousands of other piscivorous waterbirds that use East Sand Island.

Anderson JJ. 2000. “A vitality-based model relating stressors and environmental properties to organism survival.” *Ecological Monographs* 70:445-470.

A survivorship curve is shaped by the differential survivability of the organisms within the population, and a change in a survivorship curve with a stressor reflects the differential response of the organisms to the stressor. Quantifying this linkage in a simple, rigorous way is valuable for characterizing the response of populations to stressors and ultimately for understanding the evolutionary selection of individuals exposed to stressors. To quantify this stressor-individual-population linkage with as few parameters as possible. I present a simple mechanistic model describing organism survival in terms of age-dependent and age-independent mortality rates. The age-independent rate is represented by a Poisson process. For the age-dependent rate, a concept of vitality is defined, and mortality occurs when an organism's vitality is exhausted. The loss of vitality over age is represented by a continuous Brownian-motion process, the Weiner process; vitality-related mortality occurs when the random process reaches the boundary of zero vitality. The age at which vitality-related mortality occurs is represented by the Weiner-process probability distribution for first-arrival time. The basic model has three rate parameters: the rate of accidental mortality, the mean rate of vitality loss, and the variability in the rate of vitality loss. These rates are related to body mass, environmental conditions, and xenobiotic stressors, resulting in a model that characterizes intrinsic and extrinsic factors that control a population's survival and the distribution of vitality of its individuals. The model assumes that these factors contribute to the rate parameters additively and linearly. The model is evaluated with case studies across a range of species exposed to natural and xenobiotic stressors. The mean rate of vitality loss generally is the dominant factor in determining the shape of survival curves under optimal conditions. Xenobiotic stressors add to the mean rate in proportion to the strength of the stressor. The base, or intrinsic, vitality loss rate is proportional to the - 1/3 power of adult body mass across a range of iteroparous species. The increase in vitality loss rate with a xenobiotic stressor can be a function of body mass according to the allometric relationship of the organism structures affected by the stressor. The model's applicability to dose-response studies is illustrated with case studies including natural stressors (temperature, feeding interval, and population density) and xenobiotic stressors (organic and inorganic toxicants). The model provides a way to extrapolate the impact of stressors measured in one environment to another environment; by characterizing how stressors alter the vitality probability distribution, it can quantify the degree to which a stressor differentiates members of a population.

Anderson JJ, MC Gildea, DW Williams, and T Li. 2008. "Linking growth, survival, and heterogeneity through vitality." *American Naturalist* 171:E20-E43.

We model the cross-stage effect of juvenile growth on future cohort survival with vitality, a single stochastic measure of an organism's survival capacity that results in death when it reaches 0. In this construct, the distribution of vitality at the end of a growth treatment stage, which is a measure of survival capacity heterogeneity, determines a cohort's susceptibility to starvation in a subsequent challenge stage. The model predicts that the treatment-stage duration and mass gain determine the mean and variance of the initial vitality distribution of the challenge stage, which in turn determine the effect of a challenge-stage stressor on survival. Studies linking the effect of juvenile growth on time to starvation for chinook salmon and yellow perch are compared to model predictions. The feasibility of predicting survival and heterogeneity in overwintering fish populations from first-year growth is considered. Some limitations and potential extensions of the model to other scenarios are discussed.

Anderson JJ, RA Hinrichsen, C Van Holmes, and KD Ham. 2005. Historical Analysis of PIT Tag Data for Transportation of Fish at Lower Granite, Little Goose, Lower Monumental and McNary Dams - Task 1: Analysis of In-River Environmental Conditions. PNWD-3514, prepared by Battelle–Pacific Northwest Division Richland, Washington, for U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Biological Services Contract no. DACW68-02-D-0001, Task Order 0009.

The U.S. Army Corps of Engineers (Corps) intercepts migratory juvenile salmonids at up to four dams and transports them downstream in an attempt to increase their survival rate to the ocean. Previous studies have shown that transport does not always increase smolt to adult returns (SAR). Therefore, it is important to understand if, and when, the transportation of fish is likely to improve survivals. The purpose of this study was to examine the available information to identify factors that influence the survival of juvenile salmonids migrating out of the Snake River and how these factors affect the performance of the transportation system. PIT tag data regarding transportation and bypass processes and their effects on juvenile salmonids, have been collected since 1995 in the Lower Snake River. In addition, environmental data have been collected throughout the basin, including water temperature, total dissolved gas, river discharge, and spill proportion. These data were analyzed to identify:

1. Year-to-year variation in SAR
2. Within-year statistical correlations among specific transportation operations and SAR
3. Environmental factors that would allow prediction of when the SAR of transported fish exceed the SAR of in-river passing fish (T:I > 1)

Results indicated that SAR varied widely among years for all passage history types and for all stocks. An increasing trend in SAR began about 1998 for spring/summer Chinook salmon and steelhead. SARs increased after 1998 for fish tagged above Lower Granite (LGR) Dam and for those tagged at LGR Dam. For fall Chinook salmon, SAR varied among years, but no clear trend was evident from 1995 to 2000.

In spite of large variation in SAR among years, regression analyses revealed consistent trends among groups with differing passage histories. Our analysis of passage routes, using yearly averaged SARs across years, indicated that hatchery spring/summer Chinook salmon transported from LGR and Little Goose (LGS) Dams had higher SARs than from all other passage history types. Transported hatchery spring/summer Chinook salmon returned at rates 30% higher than nondetected fish and at nearly twice the rate of once-detected fish and fish transported from Lower Monumental (LMN) and McNary (MCN) Dams. Wild spring/summer Chinook salmon transported from LGR returned at higher rates than those returned to migrate in the river, but LGR/LGS transported fish returned at rates equal to only 80% of the in-river fish detected only once. Wild and hatchery steelhead transportation at LGR and LGS appeared to be beneficial or at least not deleterious relative to nondetected and once-detected fish passage. For fall Chinook salmon, the limited evidence suggests that nondetected fish return at higher rates than transported fish, but there were too few fish to make the more important comparisons of transported versus detected. For all fish, in-river passage SAR was higher for nondetected fish than detected fish; multiple-detected fish had the lowest SARs among groups.

A number of environmental covariates were examined for correlations with SAR. Two independent methods, covariate analysis and running averages, showed that SAR was strongly correlated with LGR passage day, temperature and, to a lesser extent, flow. In particular, for spring/summer Chinook salmon and steelhead the SAR of fish that passed in river decreased with increasing temperature and LGR passage day. These two covariates were highly correlated so the significance of each could not be separated. Additionally, transported fish SARs did not vary significantly with flow, temperature or LGR passage day. Estimates of the impact of temperature on smolt passage survival from relationships proposed in other studies was sufficient to explain half the decline of in-river fish SARs. Furthermore, indirect evidence from challenge experiments conducted by NOAA in 2002 indicated it was possible that higher migration temperature could have weakened the in-river migrants ability to survive as they entered the ocean.

From the exponential relationships of SAR and covariates it was possible to obtain equations relating for T:I to temperature, and T:I to LGR passage day. The T:I ratio increased with both temperature and passage day. However, our analysis of the impacts of temperature on in-river fish suggested an increasing T:I ratio resulted from degrading conditions for in-river passing fish, not improved survival of transported fish.

When all stocks were taken together, the resulting equations predicted that when day > 112 or temperature > 9.3°C, transported fish would return at higher rates than in-river fish. Flow was also correlated with T:I in some years, but the seasonal dynamics of flow made it a poor predictor of SAR. A retrospective analysis on spring/summer Chinook salmon indicated that temperature may be the better predictor of optimal transportation conditions.

Angilletta MJ, EA Steel, KK Bartz, JG Kingsolver, MD Scheuerell, BR Beckman, and LG Crozier. 2008. "Big dams and salmon evolution: Changes in thermal regimes and their potential evolutionary consequences." *Evolutionary Applications* 1(2):286-299.

Dams designed for hydropower and other purposes alter the environments of many economically important fishes, including Chinook salmon (*Oncorhynchus tshawytscha*). We estimated that dams on the Rogue River, the Willamette River, the Cowlitz River, and Fall Creek decreased water temperatures during summer and increased water temperatures during fall and winter. These thermal changes undoubtedly impact the behavior, physiology, and life histories of Chinook salmon. For example, relatively high temperatures during the fall and winter should speed growth and development, leading to early emergence of fry. Evolutionary theory provides tools to predict selective pressures and genetic responses caused by this environmental warming. Here, we illustrate this point by conducting a sensitivity analysis of the fitness consequences of thermal changes caused by dams, mediated by the thermal sensitivity of embryonic development. Based on our model, we predict Chinook salmon likely suffered a decrease in mean fitness after the construction of a dam in the Rogue River. Nevertheless, these demographic impacts might have resulted in strong selection for compensatory strategies, such as delayed spawning by adults or slowed development by embryos. Because the thermal effects of dams vary throughout the year, we predict dams impacted late spawners more than early spawners. Similar analyses could shed light on the evolutionary consequences of other environmental perturbations and their interactions.

Anglea SM, DR Geist, RS Brown, KA Deters, and RD McDonald. 2004. “Effects of Acoustic Transmitters on Swimming Performance and Predator Avoidance of Juvenile Chinook Salmon.” *North American Journal of Fisheries Management* 24(1):162-170.

The objective of this study was to determine whether juvenile Chinook salmon (*Oncorhynchus tshawytscha*) are negatively influenced by the intraperitoneal implantation of acoustic transmitters. We evaluated swimming performance and predator avoidance of juvenile salmonids implanted with acoustic transmitters that weighed up to 6.7% of the fish's body weight in air. Critical swimming speeds (U-crit) of tagged, sham-tagged (surgery but no tag), and control fish were measured in a respirometer to determine tag effects on swimming performance. Swimming performance was similar among treatment groups at 1-d and 21-d postsurgery intervals. Predator avoidance of fish implanted with active tags was evaluated to determine whether tagged fish were impaired by the operation of the tags or predators were attracted to the signals emitted from the tags. Predator avoidance was evaluated by comparing the proportion of each treatment group consumed (active tag, inactive tag, sham, and control) during exposure to piscivorous adult rainbow trout (*O. mykiss*). Surgical implantation of acoustic tags in-juvenile fall Chinook salmon did not significantly affect swimming performance. Implantation of acoustic transmitters (active and inactive) did not result in greater predation susceptibility in tagged fish than in untagged fish.

Antolos M, DD Roby, and K Collis. 2004. "Breeding ecology of Caspian terns at colonies on the Columbia plateau." *Northwest Science* 78(4):303-312.

We investigated the breeding ecology and diet of Caspian terns on the Columbia Plateau in southeastern Washington and northeastern Oregon. We examined trends in colony size and area during 1996-2001, and estimated number of breeding pairs, nesting density, fledging success, and diet composition at selected colony sites in 2000 and 2001. We found six tern colonies totaling similar to1.000 breeding pairs, ranging in size from < 50 to nearly 700 pairs. Predation by mink caused complete abandonment of one of these colonies in 2000 and 2001. The relocation of similar to9,000 Caspian tern breeding pairs from Rice Island to East Sand Island in the Columbia River estuary did not result in an obvious increase in the number of tern breeding pairs on the Columbia Plateau during the study period. The majority of Caspian tern prey items at colonies on the mid-Columbia River consisted of juvenile salmonids. At a colony in Potholes Reservoir, Washington, Caspian terns commuted over 100 km round-trip to the Columbia River to forage on juvenile salmonids, suggesting that locally abundant food may be limiting. High nesting densities at other mid-Columbia River colonies suggest that availability of breeding habitat may limit colony size. The small size of Caspian tern colonies on the Columbia Plateau, and possible constraints on availability of suitable nesting habitat within the study area, suggest that the level of predation on ESA-listed juvenile salmonids in this region will likely remain well below that currently observed in the Columbia River estuary.

Arendt JD. 1997. "Adaptive Intrinsic Growth Rates: An Integration Across Taxa." *Quarterly Review of Biology* 72(2):149-177.

The evolution of intrinsic growth rate has received,ed less attention than other life history traits, and has been Studied differently in plants, homoiotherms, and poikilotherms. The benefits of rapid growth an obvious, so the problem is to explain the costs and tradeoffs that cause organisms to grow below their physiological maximum. Four prevailing themes emerge from the literature: (1) slow growth is adaptive for dealing with nutrient stress, (2) the tradeoff between growth rate and development limits growth in species that require mature function early in life, (3) rapid growth evolves when a minimum size must be reached quickly, such as for sexual maturation or over wintering and (4) rapid growth may evolve to compensate for slowed growth owing to environmental conditions. Evidence for each of these themes is detailed for plants, homoiotherms, and poikilotherms. In addition, empirical evidence is reviewed costs of rapid gr growth, including increased fluctuating asymmetry, reduced immune capacity, and reduced ability to respond to environmental stress.

Arkoosh MR, AN Kagley, BF Anulacion, DA Boylen, BP Sandford, FJ Loge, LL Johnson, and TK Collier. 2006. "Disease Susceptibility of Hatchery Snake River Spring-Summer Chinook Salmon with Different Juvenile Migration Histories in the Columbia River." *Journal of Aquatic Animal Health* 18(4):223-231.

Various methods have been developed to mitigate the effects of dams on juvenile Pacific salmon *Oncorhynchus* spp. migrating to the Pacific Ocean through the Columbia River basin. In this study, we examined the health of hatchery Snake River spring and summer Chinook salmon relative to two mitigating strategies: dam bypass and transportation (e.g., barging). The health of out-migrants was assessed in terms of the difference in the incidence of mortality among fish, categorically grouped into no-bypass, bypass, and transportation life histories, in response to challenge with the marine pathogen Listonella anguillarum during seawater holding. These three life histories were defined as follows: (1) fish that were not detected at any of the juvenile bypass systems above Bonneville Dam were classified as having a no-bypass life history; (2) fish that were detected at one or more juvenile bypass systems above Bonneville Dam were classified as having a bypass life history; and (3) fish that were barged were classified as having the transportation life history. Barged fish were found to be less susceptible to L. anguillarum than in-river fish-whether bypassed or not-which suggests that transportation may help mitigate the adverse health effects of the hydropower system of the Columbia River basin on Snake River spring-summer Chinook salmon. The findings of this study are not necessarily transferable to other out-migrant stocks in the Columbia River basin, given that only one evolutionarily significant unit, that is, Snake River spring-summer Chinook salmon, was used in this study.

Arkoosh MR, S Strickland, A Van Gaest, GM Ylitalo, L Johnson, GK Yanagid, TK Collier, and JP Dietrich. In press. “Trends in Organic Pollutants and Lipids in Juvenile Snake River Spring Chinook Salmon with Different Outmigrating Histories through the Lower Snake and Middle Columbia Rivers.” Science of the Total Environment.

A three-year field study was conducted from 2006 to 2008 to monitor the spatial and temporal trends of organic pollutants in migrating juvenile Snake River spring Chinook salmon (*Oncorhynchus tshawytscha*) sampled from the Lower Snake and Middle Columbia River Basins. Specifically, hatchery-reared juvenile salmon were monitored as they navigated the Federal Columbia River Power System (FCRPS) by either transport barge (Barged) or remained in the river (In-River) from Lower Granite Dam to a terminal collection dam, either John Day Dam or Bonneville Dam. Levels of polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and organochlorine (OC) pesticides were detected in the bodies of both In-River and Barged salmon during the 2006, 2007 and 2008 outmigrating season. At the terminal dam, In-River fish had greater concentrations of persistent organic pollutants POPs than Barged salmon. Of the POPs detected, dichlorodiphenyltrichloroethanes (DDTs) were found at the greatest concentrations in the salmon bodies. These elevated lipid-normalized concentrations in the In-River fish were due to lipid depletion in all years as well as increased exposure to POPs in some years as indicated by an increase in wet weight contaminant concentrations. Salmon were also exposed to polycyclic aromatic hydrocarbons (PAHs) as indicated by the phenanthrene (PHN) signal for biliary fluorescent aromatic compounds (FACs) at the hatcheries or prior to Lower Granite Dam. There were detectable levels of biliary FACs as fish migrated downstream or were barged to the terminal dam. Therefore, the potential exists for these organic pollutants and lipid levels to cause adverse effects and should be included as one of the variables to consider when examining the effects of the FCRPS on threatened and endangered juvenile salmon.

Badil S, DG Elliott, T Kurobe, K Clemens, M Blair, and MK Purcell. 2011. “Comparative evaluation of molecular diagnostic tests for *Nucleospora salmonis* and prevalence in migrating juvenile salmonids from the Snake River, USA.” *Journal of Aquatic Animal Health* 23:19-29.

Nucleospora salmonis is an intranuclear microsporidian that primarily infects lymphoblast cells and contributes to chronic lymphoblastosis and a leukemia-like condition in a range of salmonid species. The primary goal of this study was to evaluate the prevalence of *N. salmonis* in out-migrating juvenile hatchery and wild Chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss* from the Snake River in the U.S. Pacific Northwest. To achieve this goal, we first addressed the following concerns about current molecular diagnostic tests for *N. salmonis*: (1) nonspecific amplification patterns by the published nested polymerase chain reaction (nPCR) test, (2) incomplete validation of the published quantitative PCR (qPCR) test, and (3) whether N. salmonis can be detected reliably from nonlethal samples. Here, we present an optimized nPCR protocol that eliminates nonspecific amplification. During validation of the published qPCR test, our laboratory developed a second qPCR test that targeted a different gene sequence and used different probe chemistry for comparison purposes. We simultaneously evaluated the two different qPCR tests for *N. salmonis* and foundthat both assays were highly specific, sensitive, and repeatable. The nPCR and qPCR tests had good overall concordance when DNA samples derived from both apparently healthy and clinically diseased hatchery rainbow trout were tested. Finally, we demonstrated that gill snips were a suitable tissue for nonlethal detection of N. salmonis DNA in juvenile salmonids. Monitoring of juvenile salmonid fish in the Snake River over a 3-year period revealed low prevalence of *N. salmonis* in hatchery and wild Chinook salmon and wild steelhead but significantly higher prevalence in hatchery-derived steelhead. Routine monitoring of *N. salmonis* is not performed for all hatchery steelhead populations. At present, the possible contribution of this pathogen to delayed mortality of steelhead has not been determined.

Bellgraph BJ, GA McMichael, RP Mueller, and JL Monroe. 2010. "Behavioural response of juvenile Chinook salmon *Oncorhynchus tshawytscha* during a sudden temperature increase and implications for survival." *Journal of Thermal Biology* 35(1):6-10.

- Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) survival and behaviour were evaluated during a temperature increase from 8.8 to 23.2 °C.
- Relatively little mortality (12%) occurred, which was unexpected.
- The percent of fish with an active swimming behaviour increased from 26% to 93% and opercular beat rates increased from 76 to 159 beats per minute.
- Although sublethal in the laboratory, thermal stress was likely incurred by juvenile salmon in this study and the associated behavioural changes may increase predation potential in the wild.

Biro PA, AE Morton, JR Post, and EA Parkinson. 2004. "Over-winter lipid depletion and mortality of age-0 rainbow trout (*Oncorhynchus mykiss*)." *Canadian Journal of Fisheries & Aquatic Sciences* 61(8):1513-1519.

In this study we identify the size-dependent risk of winter starvation mortality as a strong selective pressure on age-0 rainbow trout (*Oncorhynchus mykiss*) that could promote the risk-taking behaviour and allocation of energy to lipids previously observed in young trout cohorts. Age-0 trout subjected to simulated winter starvation conditions gradually depleted lipid reserves to a critical minimum lipid content below which death occurred. Small fish with lower lipid content exhausted lipid reserves earlier, and experienced high mortality rates sooner, than larger fish with greater lipid content. Consequently, winter starvation endurance was dependent upon size-dependent lipid reserves and winter duration. To validate the laboratory findings in the field, we stocked several size classes of hatchery-raised trout with known lipid content at the start of winter into two experimental lakes, and estimated survival and lipid depletion at winter's end. Larger age-0 trout had greater initial lipid reserves than smaller trout. Individuals depleted most of their lipid reserves over the winter, and experienced mortality that ranged from just under 60% for the largest individuals to just over 90% of the smallest individuals. Many survivors had lipid contents near, but none were below, the minimum lipid content determined in the laboratory.)

Boggs CT, ML Keefer, CA Peery, TC Bjornn, and LC Stuehrenberg. 2004. "Fallback, Reascension, and Adjusted Fishway Escapement Estimates for Adult Chinook Salmon and Steelhead at Columbia and Snake River Dams." *Transactions of the American Fisheries Society* 133(4):932-949.

During their upstream spawning migration in the Columbia River basin, some adult salmonids *Oncorhynchus* spp. ascend and then fall back over main-stem hydroelectric dams. Fall-back can result in fish injury or death, migration delays, and biases in fishway counts, the primary index for escapement and the basis for production estimates and harvest quotas. We used radiotelemetry to calculate fallback percentages and rates, reascension percentages, biases in fishway escapement estimates due to fallback, and occurrence of behaviorally motivated fallback (correcting overshoot of natal sites) by spring-summer and fall Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*). The study area included eight Columbia River and Snake River dams evaluated from 1996 to 2001. For all years combined, about 22% of spring-summer Chinook salmon, 15% of fall Chinook salmon, and 21% of steelhead fell back at least once at a dam. Fallback percentages for spring-summer Chinook salmon were generally highest at Bonneville and the Dalles dams and decreased at progressively upstream dams. Fallback rates for spring-summer Chinook salmon were positively correlated with river discharge. Fallback percentages for steelhead and fall Chinook salmon were less variable between years but were more variable between dams than those of spring-summer Chinook salmon. Reascension percentages at dams ranged widely between runs and sites and were negatively related to the number of fish that entered tributaries downstream from the fallback location. Fall Chinook salmon were the most likely to enter a downstream tributary after falling back, though this behavior was also observed in spring-summer Chinook salmon and steelhead. For all years and at all dams, fallback produced positive fishway count biases ranging from 1% to 16% for spring-summer Chinook salmon, 1% to 38% for fall Chinook salmon, and 1% to 12% for steelhead.

Bottom DL, CA Simenstad, J Burke, AM Baptista, DA Jay, KK Jones, E Casillas, and MH Schiewe. 2005. "Salmon at river's end: The role of the estuary in the decline and recovery of Columbia River salmon." U.S. Department of Commerce NOAA Technical Memorandum NMFS-NWFSC-68, Northwest Fisheries Center, National Marine Fisheries Service, National Oceanic Atmospheric Administration, Seattle, Washington.

The continued decline of Columbia River salmon (*Oncorhynchus* spp.) populations has long focused concerns on habitat changes upriver, particularly the effects of large hydroelectric dams. Increasing evidence that ocean conditions strongly influence salmon production, however, has raised questions about the importance of the estuarine environment to salmon and whether the hydropower system has affected estuarine-rearing habitats. In response to Northwest Power Planning Council recommendations, we initiated a review of what is known about the effects of the hydroelectric system on the hydrology, habitats, and ecology of the Columbia River estuary. Our goal was to develop recommendations for improving estuarine conditions or to identify research that may be needed before appropriate salmon-management changes can be defined. Our review and analyses addressed four major questions:

1. What habitats and processes support native salmon populations during the estuarine phase of their life cycle?
2. Have changes to the estuary had a significant role in salmon decline?
3. What have been the impacts of flow regulation on the hydrology, habitat, and biological interactions in the estuarine ecosystem?
4. What estuarine conditions are necessary to maintain salmonid diversity in the Columbia River basin?

Brodeur RD and DM Ware. 1992. "Long-term variability in zooplankton biomass in the subartic Pacific Ocean." *Fisheries Oceanography* 1:32-38.

Zooplankton collections from the subarctic Pacific were analyzed from two periods (1956–1962 and 1980–1989). In this report, we document: 1) a positive correlation between the intensity of winter winds and subsequent summer zooplankton biomass in the subarctic gyre within these periods; and 2) a doubling of zooplankton biomass and a similar increase in pelagic fish and squid abundance between these two periods of time. Some possible explanations for these changes are considered.

Brown RS, DR Geist, KA Deters, and A Grassell. 2006. "Effects of surgically implanted acoustic transmitters > 2% of body mass on the swimming performance, survival and growth of juvenile sockeye and Chinook salmon." *Journal of Fish Biology* 69(6):1626-1638.

The influence of surgical implantation of an acoustic transmitter on the swimming performance, growth and survival of juvenile sockeye salmon (*Oncorhynchus nerka*) and Chinook salmon (*Oncorhynchus tshawytscha*) was examined. The transmitter had a mass of 0.7 g in air while sockeye salmon had a mass of 7.0-16.0 g and Chinook salmon had a mass of 6.7-23.1 g (a transmitter burden of 4.5-10.3% for sockeye salmon and 3.1-10.7% for Chinook salmon). Mean critical swimming speeds (U-crit) for Chinook salmon ranged from 47.5 to 51.2 cm s(-1) [4.34-4.69 body lengths (fork length, L-F) s(-1)] and did not differ among tagged, untagged and sham-tagged groups. Tagged sockeye salmon, however, did have lower U-crit than control or sham fish. The mean U-crit for tagged sockeye salmon was 46.1 cm s(-1) (4.1 L-F s(-1)), which was c. 5% less than the mean U-crit for control and sham fish (both groups were 48.6 cm s(-1) or 4.3 L-F s(-1)). A laboratory evaluation determined that there was no difference in L-F or mass among treatments (control, sham or tag) either at the start or at the end of the test period, suggesting that implantation did not negatively influence the growth of either species. None of the sockeye salmon held under laboratory conditions died from the influence of surgical implantation of transmitters. In contrast, this study found that the 21 day survival differed between tagged and control groups of Chinook salmon, although this result may have been confounded by the poor health of Chinook salmon treatment groups. (c) 2006 Battelle Memorial Institute.

Brown RS, RA Harnish, KM Carter, JW Boyd, KA Deters, and MB Eppard. 2010. "An Evaluation of the Maximum Tag Burden for Implantation of Acoustic Transmitters in Juvenile Chinook Salmon." *North American Journal of Fisheries Management* 30(2):499-505.

A substantial percentage of the Pacific salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*) smolts that emigrate to the ocean each year are smaller than 110 mm (fork length). However, relatively few researchers have implanted acoustic transmitters in fish of this size, and none have reported minimum fish lengths below 110 mm for which the tag burden did not negatively influence growth or survival. The influence of a surgically implanted acoustic microtransmitter and a passive integrated transponder (PIT) tag on the growth and survival of hatchery-reared juvenile Chinook salmon was examined over a period of 30 d. Growth and survival were compared between treatment (tagged) and control (untagged) fish within three sizegroups (80–89, 90–99, and 100–109 mm). The acoustic microtransmitter and PIT tag implanted in our study had a combined weight of 0.74 g; the combined tag burden for implanted fish ranged from 4.5% to 15.7%. The results indicated that growth and survival among implanted juvenile Chinook salmon were size dependent. Significant differences in growth rate and survival were observed between treatment and control fish in the 80–89-mm group. The survival of implanted fish smaller than 11.1 g (tag burden, >6.7%) and the growth of fish smaller than 9.0 g (tag burden, >8.2%) were negatively affected by the implantation or presence of an acoustic microtransmitter and PIT tag. The results of this study will aid researchers in determining the minimum fish size suitable for use in acoustic telemetry studies that estimate the short-term (30-d) survival and growth of juvenile salmonids.

Buchanan RA, JR Skalski, and SG Smith. 2006. "Estimating the Effects of Smolt Transportation from Different Vantage Points and Management Perspectives." *North American Journal of Fisheries Management* 26(2):460-472.

Smolt transportation is a major mitigation strategy in the Columbia River hydrosystem, yet measures of its effects on adult return rates are often unclear. Managers use a variety of transportation effect measures that need to be clearly defined and easy to understand. We develop eight alternative transportation effect measures based on a release-recapture model of juvenile and adult passive integrated transponder tag data and relate the measures to different management perspectives. The performance measures include site-specific transport-in-river ratios (T/Is) that view the effect of transportation operations at a site either separate from ("isolated") or in the context of ("contextual") the rest of the transportation system. Both relative and absolute systemwide measures of transportation effects are developed, as well as measures for fish in the release group had they been untagged. All performance measures are calculated by the program ROSTER. Transportation effect measures for summer Chinook salmon (*Oncorhynchus tshawytscha*) from the McCall and Pahsimeroi hatcheries released in the Snake River in 1999 range from the isolated site-specific relative value at Lower Granite Dam of 2.015 (SE = 0.152) to a systemwide relative value of 1.232 (SE = 0.036). This paper explains how these two estimates and the others are correct depending on perspective and management intent.

Buchanan RA, JR Skalski, and K Broms. 2008. Survival and Transportation Effects for Migrating Snake River Wild Chinook Salmon and Steelhead: Historical Estimates From 1996-2004 and Comparison to Hatchery Results. DRAFT. Monitoring and Evaluation of Smolt Migration in the Columbia Basin, Volume XVIII. Prepared by the School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington, for the Bonneville Power Administration, Portland, Oregon. Project no. 199105100 and contract no. 35477.

The combined juvenile and adult detection histories of PIT-tagged wild salmonids migrating through the Federal Columbia River Power System (FCRPS) were analyzed using the ROSTER (River-Ocean Survival and Transportation Effects Routine) statistical release-recapture model. This model, implemented by software Program ROSTER, was used to estimate survival on large temporal and spatial scales for PIT-tagged wild spring and summer Chinook salmon and steelhead released in the Snake River Basin upstream of Lower Granite Dam from 1996 to 2004. In addition, annual results from wild salmonids were compared with results from hatchery salmonids, which were presented in a previous report in this series (Buchanan, R. A., Skalski, J. R., Lady, J. L., Westhagen, P., Griswold, J., and Smith, S. 2007, "Survival and Transportation Effects for Migrating Snake River Hatchery Chinook Salmon and Steelhead: Historical Estimates from 1996 - 2003," Technical report, Bonneville Power Administration, Project #1991-051-00). These results are reported here. Annual estimates of the smolt-to-adult return ratio (SAR), juvenile inriver survival from Lower Granite to Bonneville, the ocean return probability from Bonneville to Bonneville, and adult upriver survival from Bonneville to Lower Granite are reported. Annual estimates of transport-inriver (T/I) ratios and differential post-Bonneville mortality (*D*) are reported on a dam-specific basis for release years with sufficient numbers of wild PIT-tagged smolts transported. Transportation effects are estimated only for dams where at least 1,000 tagged wild smolts were transported from a given upstream release group. Because few wild Chinook salmon and steelhead tagged upstream of Lower Granite Dam were transported before the 2003 release year, T/I and *D* were estimated only for the 2003 and 2004 release years. Performance measures include age-1-ocean adult returns for steelhead, but not for Chinook salmon. Spring and summer Chinook salmon release groups were pooled across the entire Snake River Basin upstream of Lower Granite Dam for this report.

Annual estimates of SAR from Lower Granite back to Lower Granite averaged 0.92% with an estimated standard error (SE) of 0.25% for wild spring and summer Chinook salmon for tagged groups released from 1996 through 2004, omitting age-1-ocean (jack) returns. Only for the 1999 and 2000 release years did the wild Chinook SAR approach the target value of 2%, identified by the NPCC as the minimum SAR necessary for recovery. Annual estimates of SAR for wild steelhead from the Snake River Basin averaged 0.63% (SE = 0.15%), including age-1-ocean returns, for release years 1996 through 2004. For release years when the ocean return probability from Bonneville back to Bonneville could be estimated (i.e., 1999 through 2004), it was estimated that on average approximately 83% of the total integrated mortality for nontransported, tagged wild spring and summer Chinook, and 78% for steelhead (omitting the 2001 release year), occurred during the ocean life stage (i.e., from Bonneville to Bonneville). This suggests that additional monitoring and research efforts should include the ocean and estuary environment.

Annual estimates of the dam-specific T/I for Lower Granite Dam were available for the 2003 and 2004 release years for both wild Chinook salmon and wild steelhead. The estimated T/I for Lower Granite was significantly > 1.0 for Chinook in 2004 ($P < 0.0001$) and for steelhead in both 2003 ($P < 0.0001$) and 2004 ($P < 0.0001$), indicating that for these release years, wild fish transported at Lower Granite returned there in higher proportions than fish that were returned to the river at Lower Granite, or that passed Lower Granite without detection as juveniles. Annual estimates of the dam-specific T/I for Little Goose Dam were available for wild Chinook salmon for both 2003 and 2004. The estimated T/I for Little Goose was significantly > 1.0 for wild Chinook in 2004 ($P = 0.0024$), but not in 2003 ($P = 0.1554$).

Differential post-Bonneville mortality (*D*) is the ratio of post-Bonneville survival to Lower Granite Dam of transported fish to that of nontransported ("inriver") fish. Estimates of *D* were available for transportation from Lower Granite and Little Goose dams in 2003 and 2004 for wild Chinook, and from Lower Granite Dam in 2003 and 2004 for wild steelhead. Point estimates ranged from 0.74 (SE = 0.29) for transportation of wild Chinook salmon from Lower Granite Dam in 2003 to 1.91 (SE = 0.61) for transportation of wild steelhead from Lower Granite Dam in 2003. Small transport groups resulted in high uncertainty on the point estimates, and only for 2003 steelhead transported from Lower Granite Dam did transported fish have significantly greater post-Bonneville survival than nontransported fish ($P = 0.0213$).

The trends observed in survival and mortality estimates for wild Snake River spring and summer Chinook and steelhead agree well with the trends observed for hatchery Chinook and steelhead presented in Buchanan et al. (2007). In general, wild and hatchery estimates track each other well, with high correlations between wild and hatchery estimates for SAR ($r = 0.9517$), juvenile inriver survival ($r = 0.7916$), and ocean return probability ($r = 0.9879$) for Chinook, and for SAR ($r = 0.8654$), ocean return probability ($r = 0.9943$), and adult upriver survival ($r = 0.9637$) for steelhead. For steelhead, the estimated SAR for wild fish was often greater than the estimated SAR for hatchery fish, suggesting that the hatchery SAR may be a reasonable surrogate, providing a minimum estimate of SAR for wild fish. A similar pattern is seen for SAR and ocean return probability estimates between wild Chinook and hatchery spring Chinook, juvenile inriver survival for steelhead, and for adult upriver survival for both Chinook and steelhead.

Buchanan RA, JR Skalski, JL Lady, P Westhagen, J Griswold, and SG Smith. 2007. Survival and Transportation Effects for Migrating Snake River Hatchery Chinook Salmon and Steelhead: Historical Estimates From 1996-2003. Monitoring and Evaluation of Smolt Migration in the Columbia Basin, Volume XVI. Prepared by the School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the Bonneville Power Administration, Portland, Oregon. Project no. 91-051-00, for Contract no. 29676, under Contract 35477.

In 2005, the University of Washington developed a new statistical model to analyze the combined juvenile and adult detection histories of PIT-tagged salmon migrating through the Federal Columbia River Power System (FCRPS). This model, implemented by software Program ROSTER (River-Ocean Survival and Transportation Effects Routine), has been used to estimate survival and transportation effects on large temporal and spatial scales for PIT-tagged hatchery spring and summer Chinook salmon and steelhead released in the Snake River Basin from 1996 to 2003. Those results are reported here. Annual estimates of the smolt-to-adult return ratio (SAR), juvenile inriver survival from Lower Granite to Bonneville, the ocean return probability from Bonneville to Bonneville, and adult upriver survival from Bonneville to Lower Granite are reported. Annual estimates of transport-inriver (T/I) ratios and differential post-Bonneville mortality (*D*) are reported on both a systemwide basis, incorporating all transport dams analyzed, and a dam-specific basis. Transportation effects are estimated only for dams where at least 5,000 tagged smolts were transported from a given upstream release group. Because few tagged hatchery steelhead were transported in these years, no transportation effects are estimated for steelhead. Performance measures include age-1-ocean adult returns for steelhead, but not for Chinook salmon. Additional results are available online at http://www.cbr.washington.edu/trends/roster/php.

Annual estimates of SAR from Lower Granite back to Lower Granite averaged 0.71% with a standard error (SE) of 0.18% for spring Chinook salmon from the Snake River Basin for tagged groups released from 1996 through 2003, omitting age-1-ocean (jack) returns. For summer Chinook salmon from the Snake River Basin, the estimates of annual SAR averaged 1.15% (SE=0.31%). Only for the release years 1999 and 2000 did the Chinook SAR approach the target value of 2%, identified by the NPCC as the minimum SAR necessary for recovery. Annual estimates of SAR for hatchery steelhead from the Snake River Basin averaged 0.45% (SE=0.11%), including age-1-ocean returns, for release years 1996 through 2003. For release years when the ocean return probability from Bonneville back to Bonneville could be estimated (i.e., 1999 through 2003), it was estimated that on average approximately 86% of the total integrated mortality for nontransported, tagged hatchery spring and summer Chinook, and 74% for steelhead, occurred during the ocean life stage (i.e., from Bonneville to Bonneville). This suggests that additional monitoring and research efforts should include the ocean and estuary environment. Annual estimates of the systemwide T/I are weighted averages of the dam-specific T/I ratios for each transport dam (with ≥ 5,000 tagged fish transported), weighted by the probabilities of being transported at each dam. The systemwide T/I compares the observed SAR under the existing transportation system with the expected SAR if the transportation system had not been operated. Estimates of 1.0 indicate that the systemwide transportation program has no effect on SAR, while estimates > 1.0 indicate that the transportation program increases SAR. Excluding the 2001 release group, the geometric mean of the systemwide T/I estimates for hatchery spring Chinook salmon from the Snake River Basin was 1.15 (SE=0.03) for release years 1997 through 2003. The geometric mean of the systemwide T/I estimates for hatchery summer Chinook salmon from the Snake River Basin was 1.28 (SE=0.13) for release years 1997 through 2000 and 2003. Estimates were much higher for the 2001 release groups. These estimates reflect transportation from Lower Granite and/or Little Goose for most release years, depending on the number of tagged smolts actually transported at each dam during each release year. Differential post-Bonneville mortality (*D*) is the ratio of post-Bonneville survival to Lower Granite Dam of transported fish to that of nontransported ("inriver") fish. Excluding the 2001 release year, the geometric mean of the *D* estimates for hatchery spring Chinook salmon from the Snake River Basin was 1.00 (SE=0.09) for release years 1997 through 2003. For hatchery summer Chinook salmon from the Snake River Basin, the geometric mean of the i estimates was 1.32 (SE=0.27) for release years 1997 through 2000 and 2003. These estimates reflect transportation from Lower Granite and/or Little Goose, depending on the number of tagged smolts actually transported at each dam during each release year. Approximately half the point estimates of *D* for both spring and summer Chinook salmon were 1.0 or greater, indicating that for those release groups, transported fish did not have lower ocean and adult survival than nontransported fish. For those years with estimates of $D < 1.0$, the systemwide T/I estimates were always ≥ 1.0, indicating that despite lower ocean and adult survival of transported fish, transportation did not lower SAR overall.

Buchanan RA, JR Skalski, RL Townsend and KH Ham. 2011. *The Effect of Bypass Passage and Adult Returns of Salmon and Steelhead: An Analysis of PIT-Tag Data Using the Program ROSTER*. Draft Final Report. Prepared by the University of Washington, Seattle, Washington and Battelle, Pacific Northwest Division, Richland, Washington, for the U.S. Army Corps of Engineers, Walla Walla District under contract W912EF-08-D-0004 DO4. PNWD-4241.

To evaluate the influence of passage through bypass systems on juvenile salmonids, this study compared adult return rates among groups of fish with differing passage histories through the dams of the Federal Columbia River Power System (FCRPS). The analysis relied on passive integrated transponder (PIT)-tag detections to assign fish to passage through a bypass system and, in some cases, through a particular bypass route. Each individual's passage history comprised a series of dams where it was detected or not, and that history culminated with adult detection in the adult ladder at Lower Granite Dam, denoting adult return. By comparing the adult return rates of groups of fish with different bypass passage histories, it was possible to identify patterns of bypass locations and configurations associated with low adult return rates relative to other passage histories. Bypass systems that are consistently associated with reduced adult return rates may be worthy of further study to identify the mechanisms behind the differences.

This juvenile/adult PIT-tag meta-analysis using Program ROSTER (River-Ocean Survival and Transportation Effects Routine) found strong evidence that bypass events are associated with reduced adult return rates of Chinook salmon and steelhead smolts. In general, fish that migrated through the hydrosystem without detection in any bypass system had higher adult return rates than fish that were bypassed at least once. Based on the observational data available, we could not distinguish between mechanistic effects of passing through the bypass system and selectivity of the system among fish passing the dam. Thus, we use the term "perceived bypass effect" to describe the relative difference in adult return rate between bypassed and non-bypassed fish.

For yearling Chinook salmon, smolts with one or more bypass events tended to have lower adult return rates than non-bypassed smolts. With multiple bypass events, the adult return rate of yearling Chinook salmon declined further. Steelhead smolts that were bypassed at only a single dam exhibited no noticeable decrease in adult returns. However, two or more bypass events for steelhead smolts reduced the rate of adult returns. In addition to simple perceived effects of bypass at individual dams, some pairs of dams appeared to have synergistic effects, where the effect on adult returns from joint detection at the two dams was more than the sum of the perceived effects of bypass at the two dams separately.

The PIT-tag analyses found little evidence that spring or summer Chinook salmon bypassed at Lower Granite Dam returned at lower rates than other inriver fish, even if they were also bypassed at other dams downstream. For steelhead, however, bypass at Lower Granite combined with bypass at downstream dams was associated with reduced adult return rates compared to other inriver steelhead. Spring/summer Chinook salmon that were bypassed at Lower Granite and then transported from Little Goose Dam tended to return as adults at lower than expected rates. Lower than expected adult returns for summer Chinook salmon and steelhead detected in the bypass systems at both Lower Granite and McNary dams suggest a negative synergistic effect of that combination of bypass systems, that is, fewer adult returns than would have been expected from the perceived effects of bypass at those two dams singly. This suggests that there may be a weak effect of bypass at Lower Granite Dam that is exhibited only if bypassed fish experience other bypass or stressful experiences downstream. There was no compelling evidence that smaller fish were more likely to enter the bypass system at Lower Granite Dam than larger fish.

Bypass at Little Goose Dam was consistently associated with a reduced adult return rate compared to other inriver smolts for both spring and summer Chinook salmon, regardless of whether they were detected elsewhere downstream. On average, between 27% and 33% fewer adults than expected were detected from the groups of PIT-tagged Chinook smolts that were bypassed at Little Goose Dam over the 11 years of the study. Lower than expected adult returns for summer Chinook salmon detected in the bypass systems at both Little Goose and Bonneville dams suggest a negative synergistic effect of that combination of bypass systems, indicative of a possible latent effect of bypass at Little Goose. Steelhead bypassed at Little Goose demonstrated no obvious reduction in adult returns compared to other inriver fish. The bypass system at Little Goose underwent an operational change in 2002, when wider conveyance pipes and a new three-way diversion-by-code gate were installed. Perceived bypass effects did not appear to diminish significantly after these modifications.

Bypass at Lower Monumental Dam appeared to be associated with reduced adult return rates for both spring Chinook and steelhead, with a slightly less obvious effect on summer Chinook. Spring Chinook salmon that were detected at Lower Monumental produced from 2% to 36% fewer adults than expected on average, while summer Chinook detected at Lower Monumental produced an average of 2% to 28% fewer adults than expected from other inriver fish, depending on where else the smolts were detected downstream. Steelhead detected at Lower Monumental produced from 11% to 41% fewer adults than expected.

Ice Harbor Dam had juvenile PIT-tag detections beginning in 2005. With only 2 years of data available, there was low power to detect any possible effect of bypass at Ice Harbor on adult returns for both Chinook and steelhead. Furthermore, because nearly all fish that were bypassed at Ice Harbor passed through primary (“full-flow”) bypass, it was not possible to compare primary and facility bypass.

Fish that were bypassed at McNary Dam tended to return as adults at lower than expected rates, but only if they were also detected at another dam. In particular, bypass at McNary combined with bypass at either Lower Monumental or John Day consistently produced fewer returning adults than expected, for all three stocks. Bypass at McNary alone did not appear to reduce the number of returning adults. Lower than expected adult returns for spring Chinook salmon detected in the bypass routes at both McNary and Bonneville dams, and for steelhead detected in the bypass routes at both McNary and John Day dams, indicate a negative synergistic effect of those combinations of bypass systems. This suggests that there may be a possible latent effect of bypass at McNary that requires other potentially stressful experiences in order to be exhibited. The return-to-river lines at the McNary bypass system were replaced in 2002, but did not appear to result in increased adult returns. It was also not clear that fish length was related to the probability of being bypassed at McNary. Primary bypass became available at McNary Dam in 2003, but there was no evidence that fish using the primary bypass had higher adult return rates than fish that used facility bypass. Only one year of data was available to compare adult returns of fish that passed through the sort-by-code holding tank with those that passed through facility bypass directly, and there was no significant difference in adult returns between these two routes.

Bypass at John Day Dam appeared to be associated with reduced adult return rates for both spring and summer Chinook salmon, in particular if the fish had been bypassed previously at an upriver dam. Steelhead did not appear to return at lower rates after passing John Day through the bypass. However, because John Day is relatively far downriver from the release sites and tends to have low detection probability (<0.20 over all release groups), few fish were detected at John Day over the duration of the study, and so the power to detect a bypass effect was relatively low compared to the dams further upriver. Chinook that were detected at John Day produced from 10% to 42% fewer adults than expected, depending on where else the fish were detected.

There was little evidence from the PIT-tag data of a bypass effect at Bonneville Dam for any stock. Chinook that were detected both at Bonneville and another upstream dam (i.e., Little Goose, Lower Monumental, or McNary) tended to return in fewer numbers than expected. However, it should be noted that with relatively low detection numbers at Bonneville and the resulting low expected numbers of adults, there was low statistical power to detect an effect on adult returns at Bonneville, especially for steelhead. The bypass system operations at Bonneville changed radically in 2000, when the bypass system at the first powerhouse was discontinued, and operational priority was switched to the second powerhouse. There was no evidence of improved adult return rates after that change, although once again there was low power to detect an effect. In 2006, PIT-tag detection became available in both the primary bypass and the Corner Collector. Based on this single year of juvenile detection data, there was no significant difference in adult return rates between fish that passed via the Corner Collector and those that passed via facility bypass.

Analysis of hatchery releases of spring Chinook salmon found no consistent evidence that bypass systems were size-selective for smaller fish. Although meta-analyses at Little Goose, Lower Monumental, McNary, and John Day dams found that smaller fish were on average more likely to be detected or bypassed ($P<0.0001$), individual tests were equivocal. A total of 50 tests found smaller fish had a significantly lower probability of being bypassed while another 36 tests found smaller fish had a significantly higher probability of being bypassed ($\alpha = 0.05$). While size-selectivity may play some role in the perceived bypass effects, its exact role remains unclear. The long lag time between fish being PIT-tagged at the hatchery and subsequent detection events reduces the ability of any analysis to assess size-related bypass effects using the data available at this time.

The statistical power of the tests performed to assess perceived bypass effects on adult returns increases with more years of data, larger numbers of expected adult returns, and larger reductions in the adult return rate (i.e., larger effects). Reasonable statistical power ($1-\beta \geq 0.70$) was attainable for effect sizes ≥30% and expected number of adults ≥7 ($\alpha=0.05$, 1-tailed). While expected adult returns of ≥7 were commonplace for spring Chinook salmon and for capture histories with detections at upper river dams, this threshold was not as often attained for steelhead or summer Chinook salmon, capture histories with multiple dam detections, or bypass events at Bonneville. Low statistical power may explain why certain tests were nonsignificant, as well as why comparisons of adult return rates between operational eras or alternative bypass routes were generally nonsignificant.

Some gaps in the analysis remain. Certain bypass routes are either unmonitored by PIT-tag detectors or only recently monitored, with incomplete adult return data available at the time of analysis. Primary bypass is one such route. In addition, more information is needed on the condition of migrating smolts as they approach the dam, in order to separate true bypass effects from selectivity of the bypass system. One glaring omission is the ability to compare bypassed fish with those passing through turbines. While the bypass system at some dams may not be benign compared to the spillway, it is likely to be superior to the alternative of turbine passage. However, PIT-tag data are incapable of distinguishing whether fish passed via turbine or spillway. The biological and managerial consequences of mortality associated with bypass must be interpreted in the context of hydroproject operations that include spillway, bypass, and turbine passage mortality. The best measurement of this integrated response is the overall smolt-to-adult ratio that takes all passage options and their relative proportions into account.

Budy P and H Schaller. 2007. "Evaluating tributary restoration potential for pacific salmon recovery." *Ecological Applications* 17(4):1068-1086.

Although habitat restoration can play a key role in the conservation of imperiled species, for animals that demonstrate long migrations and complex life histories, reliance on physical restoration of isolated habitat patches comes with considerable uncertainty. Nevertheless, within freshwater ecosystems, stream restoration has become a major conservation focus, with millions of dollars spent annually on efforts aimed at recovering degraded habitat and imperiled riverine species. Within this context, we addressed fundamental uncertainties of the focus on tributary restoration for recovery of salmon: (1) Is there potential for improving habitat in tributaries? (2) What magnitude of early survival improvement can be expected based on stream restoration? and (3) Will incremental increases in early survival be sufficient to ensure viability overall? We combined simple mechanistic habitat models, population viability measures, and categorical filters to quantify "restoration potential," expressed as increased total life-cycle survival in response to restored tributary condition, across 32 populations composing five major population groups (MPG). A wide gap remains between how much survival improvement is needed versus what is likely to occur; restoration potential meets the necessary minimum increase needed for only four populations within one MPG. The remaining populations (84%, 4 MPG) still fall far below the survival increase needed for future viability. In addition, across all populations and groups, a 171% increase (on average) in total life-cycle survival is needed; only similar to 106% appears possible. A recovery strategy for these salmon that relies largely on tributary restoration to mitigate for known mortality imposed at other life stages (e. g., migration through hydropower dams) is risky with a low probability of success. We demonstrate an approach for completing an a priori evaluation of restoration potential linked to population viability, such that habitat restoration efforts can be biologically prioritized and scarce resources can be allocated to efforts with the greatest potential and the least amount of risk, in terms of meeting conservation and recovery goals.

Budy P, GP Thiede, N Bouwes, CE Petrosky, and H Schaller. 2002. "Evidence Linking Delayed Mortality of Snake River Salmon to their Earlier Hydrosystem Experience." *North American Journal of Fisheries Management* 22(1):35-51.

The numbers of Snake River salmon and steelhead (*Oncorhynchus* spp.) have substantially declined since the completion of the Columbia River hydrosystem. We used analytical approaches, to identify management options for halting the decline of these stocks, such as removal of Snake River darns and improvements to the existing hydrosystem. The benefits these actions are predicted to have in terms of salmon recovery hinge on whether the mortality that takes place in the estuary and early in their ocean residence is related to earlier hydrosystem experience during downstream migration. Evidence from the literature demonstrates numerous mechanisms that would explain this delayed mortality in relation to a fish's experience passing through: the hydrosystem. Spatial and temporal comparisons of stock performance provide indirect evidence of delayed mortality and evidence that delayed mortality is linked to hydrosystem experience. Recent mark-recapture data also provide evidence of differences in delayed mortality by route of passage through the hydrosystem. The different types of evidence discussed here suggest that the delayed mortality of Snake River fish is related to the hydrosystem.

Burrows RE. 1969. "The Influence of Fingerling Quality on Adult Salmon Survivals." Transactions of the American Fisheries Society 98(4):777-784.

The Salmon-Cultural Laboratory of the Bureau of Sport Fisheries and Wildlife in cooperation with the Bureau of Commercial Fisheries is conducting investigation to determine the effect of fingerling quality on adult salmon survival. Three approaches are being employed. In the first, differences in a single characteristic are imposed on two lots of marked fish. In the second, the fortuitous differences in characteristics imposed by twelve hatchery regimens over four brood years are measured. In the third, the differences in characteristics between hatcheries and between prerelease samples and those recovered in the estuary are compared. In all three methods, differences in adult survivals determine the significance of differences in fingerling characteristics. Results to date indicate that to increase survival the average fall chinook fingerling at time of release should have higher stamina, larger size, ncreased protein and energy reserves, and a lower disease incidence.

Carter JA, GA McMichael, ID Welch, RA Harnish, and BJ Bellgraph. 2009. *Seasonal Juvenile Salmonid Presence and Migratory Behavior in the Lower Columbia River*. PNNL-18246, prepared by the Pacific Northwest National Laboratory, Richland, Washington, for the U.S. Army Corps of Engineers, Portland, Oregon. Contract no. DE-AC05-76RL01830.

The U.S. Army Corps of Engineers conducts construction and dredging activities in the lower Columbia River and estuary to maintain navigation routes. This area is used by several species of Pacific salmon protected under the Endangered Species Act of 1973. To facilitate planning of proposed channel maintenance projects, the Portland District of the U.S. Army Corps of Engineers contracted the Pacific Northwest National Laboratory to summarize information regarding juvenile anadromous salmonid distribution and behavior in the lower Columbia River and estuary, including existing published information as well as data from 5 years (2004–2008) of acoustic telemetry studies conducted in the Columbia River estuary using the Juvenile Salmon Acoustic Telemetry System.

Juvenile anadromous Pacific salmon rear in and migrate through the Columbia River and estuary between Bonneville Dam and the Pacific Ocean. A large quantity of information has been published on seasonal presence, habitat use, and migratory behavior of Chinook salmon. Some information is available on steelhead. Information on use of the Columbia River estuary by the less abundant anadromous salmonid species (cutthroat and bull trout) and or those species having life histories with limited freshwater rearing and migration (pink and chum salmon) is limited. This is not to say that estuary

habitats are not important to the life cycle of these species; instead, it is simply a statement that specific information is lacking or the existing information indicates these species are not known to widely utilize these estuary habitats for extended periods.

Little information exists on use of the Columbia River estuary by pink salmon. Based on published information on this species from other areas, it is likely that pink salmon use of the Columbia River estuary is very limited. Chum salmon are present in the Columbia River estuary following emergence as early as mid-January through mid July, with the peak in abundance between mid April and mid May as they migrate seaward. Hatchery and wild coho salmon use the Columbia River estuary as a migratory route to the Pacific Ocean and also for rearing in some cases. Rearing coho salmon may be in the Columbia River estuary throughout the year, with peak abundance of smolts migrating between April and June. Similar to coho salmon, juvenile Chinook salmon may be found rearing in the Columbia River estuary any time of the year. Stream-type Chinook salmon, which typically rear in higher elevation tributaries for 1 year prior to migrating to sea, are most abundant in the Columbia River estuary between early April and early June. Large numbers of pre-smolt Chinook salmon rear in the Columbia River estuary, and it is likely that many of these are fall Chinook salmon. The fall Chinook salmon migration through the Columbia River estuary typically peaks between May and July. However, there is typically a pulse of subyearling Chinook salmon entering the estuary in March from hatchery releases from Spring Creek National Fish Hatchery upstream of Bonneville Dam. Sockeye salmon typically rear in freshwater lakes for 1 to 3 years prior to migrating to the ocean and primarily use the Columbia River estuary as a migration corridor. The limited information available indicates that sockeye salmon are most abundant in the Columbia River estuary in May. Cutthroat trout may use the Columbia River estuary for seasonal rearing and as a migration corridor, with peak abundance of migratory juveniles between March and May. Steelhead typically rear in freshwater tributary habitats for one to several years prior to seaward migration, although juvenile steelhead may use the estuary for limited rearing. Juvenile steelhead abundance in the Columbia River estuary peaks between late May and mid-June.

Most anadromous salmonid smolts migrate rapidly through the Columbia River estuary. Migration rates are influenced by river discharge, fish species/run type, distance from the ocean, date, and fish size. In general, smolts pass through the Columbia River estuary more quickly during periods of high discharge and later in their migration season. Larger smolts tend to move more rapidly than their smaller cohorts. Migrating smolts tend to move faster as they approach the ocean, slowing just prior to ocean entry. Smolts that migrate downstream past Bonneville Dam in-river travel more rapidly through the Columbia River estuary than fish that are transported in barges and released downstream of Bonneville Dam. Acoustic telemetry data collected in the Columbia River estuary between 2004 and 2008 indicate that yearling Chinook salmon typically migrated at a rate of about 80 km/day between Bonneville Dam and Vancouver, Washington. Yearling Chinook salmon migrated slower (~60 km/day) through the section of the Columbia River between Vancouver and the mouth of the Columbia River. Once yearling Chinook salmon committed to leaving the Columbia River, typically during an ebb tide, they migrated rather quickly at rates between 100 and 150 km/day between RKM 8.3 and 2.8. Data collected on arrays of acoustic receivers placed throughout the Columbia River estuary beginning in 2007 indicate that yearling and subyearling Chinook salmon and steelhead travel more slowly in the final 50 km of the Columbia River than in the previous 200 km, before substantially increasing their travel rates as they exit the river and enter the Pacific Ocean.

When most smolts reached the lower 8 km of the Columbia River, they exited the river and entered the plume on an ebb tide. Between 76% and 91% of the acoustic-tagged yearling Chinook salmon were first detected at RKM 8.3 during an ebb tide. Subyearling Chinook salmon also were more likely to pass RKM 8.3 on an ebb tide, with 84% to 94% of those fish passing during ebb tides. Relationships between steelhead passage and tide stage were similar to that of Chinook salmon smolts, with 89% to 91% of the acoustic-tagged steelhead passing RKM 8.3 during ebb tide conditions.

Acoustic-tagged salmonid smolts were present in the Columbia River estuary throughout all times of day during their migration seasons, with no clear patterns in diel presence at most acoustic arrays. The one exception may be that more yearling Chinook salmon appeared to pass the Columbia River Bar (RKM 2.8) just after sunrise than at other times of the day.

Most anadromous salmonid smolts appear to migrate seaward in or near the navigation channel. However, information in published reports and from recent acoustic telemetry studies shows that small proportions of the tagged fish were detected using off-channel migration routes. Main channel use in the Bonneville Dam tailrace was pronounced for all tagged species and run types, with a maximum of 3% of detections in side channels near Reed and Lady islands. Between Vancouver, Washington, and the mouth of the river, side channel use was more common for all groups, with larger proportions of the acoustictagged smolts detected in side channels south of the islands near Cathlamet, Washington, and in Grays Bay.

Most acoustic-tagged yearling and subyearling Chinook salmon passed the acoustic receiver array near East Sand Island (RKM 8.3) on the north (Washington) side of the navigation channel. This was especially pronounced for subyearling Chinook salmon, most of which tended to pass this array close to East Sand Island. With only 2 years of data (2005 and 2008), no clear pattern in cross-channel distribution was observed for acoustic-tagged steelhead on the array near East Sand Island. Migration distribution across the array on the Columbia River Bar (RKM 2.8) tended to be nearer, or in, the navigation channel than it was at RKM 8.3 for yearling and subyearling Chinook salmon and steelhead. Limited data on the depth distribution of acoustic-tagged salmonid smolts migrating through the Columbia River estuary in 2007 showed that depth use was highly variable but appeared to be deeper for subyearling Chinook salmon than for yearling Chinook salmon.

Published accounts of the use of plume areas by juvenile salmonids suggest that the Columbia River plume is a food-rich habitat where juvenile salmonids have the opportunity for significant growth as they adjust their physiology to the more saline ocean environment. All species of Pacific salmon that emigrate from the Columbia River estuary utilize the plume to some extent. Several authors have concluded that the structure and conditions within the Columbia River plume may have a pronounced effect on the distribution, growth, and survival of salmon smolts leaving the Columbia River.

Chittenden C, K Butterworth, K Cubitt, M Jacobs, A Ladouceur, D Welch, and R McKinley. 2009. "Maximum tag to body size ratios for an endangered coho salmon (O-kisutch) stock based on physiology and performance." *Environmental Biology of Fishes* 84(1):129-140.

Many coho salmon stocks (*Oncorhynchus kisutch*) have been in decline during the past three decades. Canada's most endangered salmon stock, the Thompson River coho salmon, is being studied extensively as managers attempt to reverse these population declines. Investigators are using acoustic telemetry to track the migratory behaviour and survival of the Thompson River (and other) coho salmon stocks. Coho salmon pre-smolts are relatively small compared with salmonid species that are typically studied using acoustic telemetry; therefore the identification of the appropriate sizes of fish and tags to use is critical.

This study tested the effects of surgically implanting the three smallest sizes of acoustic tags currently available on the growth, survival, tag retention, swimming performance and physical condition of coho salmon pre-smolts for 300 days post-surgery. Maximum tag size to body size ratios ranged from 15-17% by fork length and 7-8% by mass for the three tag sizes (11 cm fork length for a 6 x 19 mm tag, 12.5 cm for a 7 x 19 mm tag, and 14 cm for a 9 x 21 mm tag). Based on our results, it is unlikely that coho salmon pre-smolts implanted with acoustic transmitters following these size guidelines would have poor survival in studies of freshwater migratory behaviour as a result of the surgery or the tag.

Clemens BJ, SP Clements, MD Karnowski, DB Jepsen, AI Gitelman, and CB Schreck. 2009. "Effects of Transportation and Other Factors on Survival Estimates of Juvenile Salmonids in the Unimpounded Lower Columbia River." *Transactions of the American Fisheries Society* 138(1):169-188.

We estimated the survival of juvenile salmonids out-migrating through the lower Columbia River to the Pacific Ocean. We tested the null hypotheses that no association exists between survival and transportation type (including barge transportation and in-river migration with no transportation), release date, river flow. mean body weight, and tag type. During 2002-2004. spring-summer (SS) and fall Chinook salmon (*Oncorhynchus tshawytscha)* and steelhead (*O. mykiss*) were implanted with uniquely coded radio or acoustic transmitter Lags and released during the early, middle. and late out-migration periods. A series of receiver lines were used to detect these fish and estimate survival. Estimated survival varied considerably with transportation type and release date for fall Chinook salmon and steelhead. but the results were dependent upon year. Estimated survival between the lowermost dam (Bonneville Dam) and the upper estuary (river kilometer 46) was relatively high for SS Chinook salmon and steelhead. whereas estimates for fall Chinook salmon were comparatively low. This order of high to low survival for SS Chinook salmon-steelhead, and fall Chinook salmon corresponds with the chronology of out-migration timing and waning rivet flows. After accounting for it number of factors. estimated survival between Bonneville Dam and the tipper-estuary site did not differ significantly between steelhead that were barged and those that migrated in-river during 2002 and 2003. Conversely, estimated survival to the upper-estuary site was quite low for barged fall Chinook salmon in comparison with fish migrating in-river during the middle and late release dates in 2003. Hypotheses for the low survival of barged fall Chinook salmon are presented and discussed.

Collier TK, MR Arkoosh, LL Johnson, TR Ginn, and FJ Loge. 2006. "The influence of chemical contaminants on disease ecology in Columbia River Chinook salmon." *Marine Environmental Research* 62:S370-S370.

Rebuilding populations of Pacific salmon listed under the Endangered Species Act is a complex scientific, social, and policy issue. Many factors (loss of habitat, harvest and hatchery practices, dams) are generally acknowledged to have led to precipitous declines, but factors that limit recovery likely include those as well as other anthropogenic and environmental stresses. We have investigated the effects of one class of stress, chemical contaminant exposure, on immune function and disease resistance of juvenile Chinook salmon for several years. Recently we expanded these studies to an additional stress, namely passage around or through hydropower infrastructure (designated as 'in river' stresses). A dynamic population model was developed and populated with laboratory and field data, and used to compare the relative effects of chemical contaminants and in-river stresses on disease resistance and associated mortality. The results showed that infectious disease in Chinook salmon is strongly modulated by both chemical contaminants and in-river stresses via effects on host-susceptibility. Whereas in-river stress increased the mean force of infection by a factor of 1.6, chemical stress increased the mean force of infection by 2.2. Cumulative disease-induced mortalities were also calculated for estuary residence times of 30–120 days, and ranged from 6% to 18%. This study provides a novel and quantitative illustration of a method to compare different types of stress on an ecologically relevant endpoint. It further suggests that chemical contaminant stress is comparable in magnitude to other factors generally acknowledged to be important in rebuilding salmonid populations.

Collis K, DD Roby, DP Craig, S Adamany, JY Adkins, and DE Lyons. 2002. "Colony Size and Diet Composition of Piscivorous Waterbirds on the Lower Columbia River: Implications for Losses of Juvenile Salmonids to Avian Predation." *Transactions of the American Fisheries Society* 131(3):537-550.

We investigated colony size and diet composition of piscivorous waterbirds (gulls, terns, and cormorants) nesting on the lower Columbia River from the mouth (river kin 0) to the head of McNary Pool (river kin 553) in 1997 and 1998. The study was prompted by concern that avian predation might constitute a significant source of mortality to juvenile salmonids *Oncorhynchus* spp. during out-migration. The diet of California gulls Larus californicus and ring-billed gulls L. delawarensis nesting in colonies above The Dalles Dam (river km 308) included few fish and very few juvenile salmonids. The sole exception was a small colony of California gulls in which salmonids accounted for 15% (by mass) of the diet. Juvenile salmonids were, however, an important component of the diet of colonial waterbirds nesting in the Columbia River estuary. On Rice Island (river km 34), salmonids accounted for 74%, (by mass) of the diet of Caspian terns Sterna. caspia, 46% for double-crested cormorants Phalacrocorax auritus, and 11% for glaucous-winged-western gulls L glaucescens X L occidentalis. Juvenile salmonids were especially prevalent in the diets of colonial waterbirds on Rice Island during April and May. By comparison, juvenile salmonids were significantly less prevalent in the diet of cormorants and gulls nesting lower in the estuary on East Sand Island (river kin 8), presumably due to the greater availability of marine forage fishes. Our results indicate that avian predation on juvenile salmonids in the lower Columbia River is more prevalent in the estuary than near the large upriver gull colonies. Furthermore, the high incidence of salmonids in the diets of Caspian terns, cormorants, and gulls nesting on Rice Island suggests that the impact of avian predation on survival of smolts may be reduced by discouraging piscivorous birds from nesting there, while encouraging nesting on East Sand Island and other sites nearer to marine foraging areas.

Collis K, DD Roby, DP Craig, BA Ryan, and RD Ledgerwood. 2001. "Colonial Waterbird Predation on Juvenile Salmonids Tagged With Passive Integrated Transponders in the Columbia River Estuary: Vulnerability of Different Salmonid Species, Stocks, and Rearing Types." *Transactions of the American Fisheries Society* 130(3):385-396.

Passive integrated transponder (PIT) tags implanted in Columbia River basin juvenile salmonids Oncorhyncus spp. were recovered from breeding. colonies of Caspian terns Sterna caspia and double-crested cormorants Phalacrocorax auritus on Rice Island, a dredge spoil island in the Columbia River estuary. Tags were recovered to assess the relative vulnerability of different salmonid species, stocks, and rearing types to avian predators. We detected 50,221 PIT tags at the two bird colonies, mostly from juvenile chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) raised in hatcheries; 72% of the total tags were from the tern colony and 28% from the cormorant colony. Tagged steelhead smolts were more vulnerable to predation by both bird species than were yearling chinook salmon. More than 15% of PIT tags from steelhead smolts that were available in the estuary in 1998 were detected at the bird colonies compared with 2% of PIT tags from yearling chinook salmon. The greater vulnerability of steelhead may reflect size-dependent selection by avian predators. Salmonids listed under the Endangered Species Act and unlisted salmonids were equally vulnerable to predation by both terns and cormorants. Hatchery-raised yearling chinook salmon were more vulnerable than their wild counterparts to predation by terns, a surface-feeding species; however, hatchery-raised and wild yearling chinook salmon were equally vulnerable to predation by cormorants, a diving species. These results suggest that hatchery-raised yearling chinook salmon, and hatchery-raised steelhead in some years, are more vulnerable to tern predation than wild fish because they have a greater tendency to reside near the water surface where terns forage.

Congleton J, T Wagner, J Evavold, and B Sun. 2003. Evaluation of the Effects of Physiological Condition on Comparative Survival of Transported Juvenile Salmon (DACW.68-00-C-0030) Annual Report, 2001. Prepared by Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Recent studies have shown that smolt-to-adult return rates (SARs) of barge-transported juvenile chinook salmon vary within the migration season, and may trend upward or downward over periods of a few days. Indices of physiological stress and of smoltification also vary intraseasonally in transported chinook salmon. Elevated stress indices in mid-season are believed due to behavioral interactions with larger, more aggressive juvenile steelhead during collection and transportation. Stress can adversely affect physiological functions and performance capabilities, and progression of the parr-smolt transformation is essential for acclimation to seawater. For these reasons, observations of intraseasonal changes in stress, smoltification, and other indices of nutritional condition and health may help to explain intraseasonal changes in SARs of barged fish. Therefore, the objectives of the present study were to: (l) collect data on intraseasonal changes in physiological indices for transported wild and hatchery chinook salmon that can be, when adult returns are complete, compared with intraseasonal changes or trends in SARs, (2) to compare physiological indices of wild and hatchery chinook salmon between upriver (Lower Granite Dam) and downriver sample sites and between rearing types, (3) to compare stress indices (plasma cortisol and glucose) in wild and hatchery chinook salmon cotransported with low, medium, and high densities of steel head, and (4) to use available data from previous years to test for negative correlations between steelhead loading densities in barges and SARs for transported chinook salmon. Demonstration of a negative correlation would support the hypothesis that transportation-related stress results in delayed mortality of chinook salmon.

Few between-date differences were observed in size, condition factor, lipid and protein content, or blood-chemistry indices for transported wild and hatchery chinook salmon. Plasma triglycerides trended downward over time for wild and hatchery chinook salmon, while plasma lipase activities increased over time. This concurrent decrease in plasma triglycerides and increase in plasma lipase activity suggests decreasing lipid metabolism over time, which is consistent with the metabolic demands of the parr-smolt transformation, and with intraseasonal declines in body lipid content.

On two occasions, wild and hatchery chinook salmon were sampled from transportation barges at Lower Granite Dam and again downriver, approximately 1 day later, while the barge was in tow between John Day Dam and Bonneville Dam. Sampling at both Lower Granite Dam and at a downriver location, allowed us to compare blood-chemistry indices between sites. Rearing typexsite and timexsite interactions made interpreting between-site differences for many blood-chemistry indices difficult. Plasma cortisol levels, however, were significantly higher in fish collected at Lower Granite Dam compared to fish collected downriver. Elevated plasma cortisol at Lower Granite Dam was likely in response to the barge loading process, which has been shown previously to be an acute stressor on transported fish.

There were significant differences in blood-chemistry indices between wild and hatchery chinook salmon. Hatchery chinook salmon had significantly higher levels ofplasma cholesterol and triglycerides compared to wild fish, possibly reflecting differences in rearing diets and rate offood intake. Wild fish had significantly higher levels of plasma glucose, lipase, and marginally significant higher levels ofplasma cortisol. The higher levels of plasma cortisol and glucose in wild chinook salmon suggests that wild fish are more stressed than hatchery fish during the transportation process, or are in a more advanced state ofparr-smoltification transformation, or both.

Wild chinook salmon transported with high densities of cotransported steel head had significantly higher levels ofplasma cortisol than wild fish transported under medium steelhead densities (there was an insufficient sample size to compare wild chinook salmon transported under low steelhead densities). Plasma glucose levels were also elevated in wild chinook salmon transported in high density barge holds compared to medium density holds; however, this difference was not significant ($P = 0.16$). There were no significant differences in plasma cortisol or glucose for hatchery chinook salmon cotransported in low, medium, or high steelhead densities. These data suggest that wild fish maybe more stressed when cotransported with higher densities of steelhead than hatchery fish.

Gill Na+, K+-ATPase activities (an indicator of the parr-smolt transformation) differed significantly over time, with lower gill Na+, K+-ATPase activities early in the emigration season, and remaining at relatively constant levels during later sampling dates. This contrasts with 2000, when a significant downward trend in gill Na+, K+-ATPase activities was observed for wild chinook salmon sampled on transport barges, with highest values measured in late April and early May. Mean gill Na+, K+-ATPase activities for wild chinook salmon were lower in 2001 than in 2000 (6.8 to 8.5 mmol Pilh/mg protein versus 8.3 to 13.5 mmol Pilh/mg protein). Mean gill Na+, K+-ATPase activities were significantly higher in wild chinook salmon compared to hatchery fish in 2001. This is consistent with the other physiological indices that change during smoltification (i.e., plasma cortisol), indicating that wild fish were more physiologically prepared to enter seawater.

Our retrospective analysis fa iled to demonstrate negative correlations between daily steelhead loading densities and daily SARs of chinook salmon transported in 1995, 1998, or 1999. In each year, daily SARs for transported chinook salmon increased to seasonal maximums during the last week of April or the first week of May, during a period when steelhead densities in the barges were also increasing. This suggests that other factors, such as seasonal increases in estuarine or marine productivity, may have influenced post-release survival. Nevertheless, our analysis may have failed to reject the null hypothesis (no relationship between steel head densities and chinook salmon SARs) because: (1) the power of our tests was low, (2) the effect of transportation-related stress on survival is of importance in some years but was small or absent in the years for which data are currently available, or (3) the effect of transportationrelated stress on survival is small or absent in all years.

Congleton JL, J Evavold, D Jones, M Santora, B Sun, and T Wagner. 2005. Evaluation of Physiological Condition of Transported and Inriver Migrating Juvenile Salmonids and Effects on Survival (DACW68-00-C-0030): Annual Report, 2003. Prepared by the Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. University of Idaho, Moscow, Idaho.

In 2003, as in previous study years (1998-2002), yearling spring/summer Chinook salmon (*Oncorhynchus tshawytscha*) PIT-tagged1 at three hatcheries in the Snake River Basin (Dworshak, Rapid River, and McCall) were sampled at three locations: prior to release, from the bypass system at Lower Granite Dam (LGR; the first dam on the Snake River encountered by down-stream migrants), and from the bypass system at Bonneville Dam (BON; the last dam on the Columbia River, 461 km downstream from Lower Granite Dam). In addition, migrating wild yearling Chinook salmon, PIT-tagged2 at LGR, were sampled at BON. Body water, lipid, protein, and ash masses were determined so that the rate of use of energy reserves could be estimated as the fish migrated to, and then through, the hydropower system. Plasma concentrations of triglyceride, cholesterol, and total protein and activities of alkaline phosphatase were measured as indices of nutritional status. Analyses of variance and covariance were performed to determine the effects of sampling site, travel time, and bypass exposure on body composition and nutritional indices for hatchery (H) and wild (W) fish.

An experiment was performed in 2003 to determine the effect of barge loading density on stress indices and other physiological indices in barged W Chinook salmon. Paired barge compartments were loaded at high density (nominal >30 g fish/L water, or about 0.25 lb/gallon) and at low density (< 10 g/L) on seven occasions. Subsamples (16 fish) were taken from each of the compartments as the barges were towed between John Day Dam and The Dalles Dam on the lower Columbia River, 32 to 35 h after departing LGR. Mean values of stress indices (plasma cortisol and glucose) determined for fish sampled from high-density and low-density compartments (the experimental unit) were compared by paired t-tests (n = 7).

Flow Conditions and Travel Times:

1. In 2003, April and May flows in the Snake River were similar to 2002, also an average-flow year. Mean travel times were similar to other study years (with the exception of 2001, a low-flow year) for Rapid River and McCall fish, but were several weeks longer than in other study years (with the exception of 2001) for Dworshak fish.

Changes in Condition of Migrating Hatchery Fish[1]:

1. Mean lengths of H Chinook salmon increased by 5.5 to 6.8 mm as the fish migrated through the hydropower system, but wet and dry masses did not increase significantly. As in previous study years, the fish were in negative energy balance throughout the downstream migration. With fish length controlled (i.e., as a covariate), body lipid mass and protein mass decreased from LGR to BON (P < 0.0001), and decreased with increasing travel time (P < 0.0001) from release sites to the dams. The composite mean length-controlled (to 135 mm) protein content of H fish arriving at BON was 2889 mg in mg in 2003, and the LGR-to-BON decrease was –15%. By comparison, LGR-to-BON decreases in length-controlled protein content for 2000, 2001, and 2002 were –14, –21, and –19%.
2. Blood-chemistry indices of nutritional condition decreased as the fish migrated downstream. Over the past four years, nutritional indices were higher in 2000 and 2002, indicating relatively favorable foraging conditions in those years, than in 2001 or 2003.
3. Migrating Dworshak, Rapid River, and McCall fish were similar in length and weight in 2003. Length-controlled lipid mass was and nutritional indices were higher for McCall fish than for Dworshak fish (with Rapid River fish intermediate). On the other hand, length-controlled protein

[1] Hatchery fish were tagged for the Fish Passage Center's Comparative Survival Study.

mass was higher for Dworshak than for Rapid River fish (with McCall fish intermediate). Overall, Dworshak fish were in better condition than in previous years.

4. Of the H fish sampled at BON, 31% had experienced two or more bypasses at upstream dams. Exposure to dam bypass systems was negatively correlated with the quantity of lipid and protein reserves (as percentages of body mass and as length-controlled masses), as were also the nutritional blood-chemistry indices total protein, cholesterol, and alkaline phosphatase. These results support the hypothesis that multiple bypass exposures result in decreases in nutritional condition, or, alternatively, that the probability of bypass passage is higher for fish with lower nutritional condition.
5. A significant correlation was found between bypass exposure and fish length, indicating that smaller fish had a higher probability of bypass than larger fish. This relationship was not, however, responsible for the negative correlation between bypass exposure and fish condition reported above.

Changes in Condition of Migrating Wild Fish[1]:

1. Growth (increase in length) of W fish was positively correlated with travel time from LGR to BON. The overall mean LGR-to-BON increase was 6.3 mm (in comparison, the mean LGR-to-BON increase for W fish in 2002 was 7.8 mm), but wet and dry masses did not increase significantly. Length-controlled lipid and protein mass of W fish decreased from LGR to BON ($P < 0.0001$, $P < 0.0001$). The decrease in length-controlled protein content was –18%, compared with –15% in hatchery fish. Despite the slightly greater loss of protein in W fish between LGR and BON, length-controlled protein mass was significantly higher for W fish than for H fish at both sites. Similarly, mean condition factors of W fish sampled at LGR and at BON (1.02, 0.89) were significantly higher than those of H fish (0.95, 0.86).
2. The use of energy reserves during hydrosystem passage did not differ greatly between W and H fish in 2003. As reported above, the LGR-to-BON decrease in length-controlled protein mass was larger for W fish than for H fish. Alkaline phosphatase activities, which vary with ration size, decreased in both W and H fish as they migrated from LGR to BON. These findings differ from findings for 2002, when the LGR-to-BON decrease in length-controlled protein mass of migrating W fish was smaller (–11%) for W fish than for H fish (–19%), and AP activities increased rather than decreased in W fish.
3. Of the W fish sampled at BON, 30% had experienced two or more bypasses at upstream dams. Neither percentage lipid, percentage protein, length-controlled lipid content, length-controlled protein content, nor blood-chemistry indices were correlated with bypass exposure. No relationship was found between bypass exposure and body length. These findings contrast with the significant correlations between bypass exposure and condition of H fish reported above.

Barge Loading Density Experiment:

1. Comparison of blood-chemistry means for fish sampled from high-density and low-density barge compartments indicated significantly higher ($P = 0.05$) mean plasma glucose concentrations for fish transported at higher densities. The difference (86 ± 3.3, 77 ± 3.3 mg/dL) was, however, small, and no significant difference was found for plasma cortisol, a primary stress-response indicator. Interpreted in the light of earlier studies, these results confirm that juvenile chinook salmon are stressed by co-transport with steelhead. Steelhead densities in "high-density" compartments in this experiment (mean 27 g/L) were, however, below the range (40 to 60 g/L) previously observed to be

[1] Wild fish were tagged by NOAA Fisheries personnel for survival studies.

associated with sustained stress responses in transported Chinook salmon. Steelhead densities of 35 g/L (0.3 lbs/gallon) or below appear to elicit minimal stress responses in Chinook salmon during barge transportation.

Congleton JL, WJ LaVoie, D Fryer, J Evavold, and B Sun. 2001. Evaluation of Procedures for Collection, Transportation, and Downstream Passage of Outmigrating Salmonids (MPE-W-95-3): Annual Report, 1998. Prepared by Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife Resources, University of Idaho, Moscow, Idaho, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

In 1998, PIT-tagged spring/summer chinook salmon (*Oncorhynchus tshawytscha*) reared at three hatcheries in the Snake River Basin (Dworshak, Rapid River, and McCall) were sampled prior to release and from bypass systems at selected hydroelectric dams on the Snake and Columbia Rivers. Carcass and gut water, lipid, protein, and ash concentrations and total quantities were detennined so that the use of energy reserves could be determined as the fish migrated downstream to, and then through, the hydropower system. Plasma triglyceride, cholesterol, and total protein concentrations and alkaline phosphatase activity were measured as indices of nutritional status. Plasma activities of the enzymes alanine aminotransferase, aspartate aminotransferase, lactate dehydrogenase, and creatine kinase were measured as indices of metabolic status. Data were analyzed by analysis of variance (ANOV A) or by analysis of covariance (ANCOVA); only significant ($P < 0.05$) differences are reported in this summary.

1. Juvenile chinook salmon were in negative energy balance throughout the downstream migration. Mean lengths, wet weights, and dry weights increased little or not at all as the fish migrated from the Snake River dams to the lower Columbia River dams, 288 to 461 km downstream. Lipid content (% body weight) decreased to one-half prerelease values in fish sampled at Lower Granite Dam and to one-third to one-fourth of prerelease values in fish sampled at dams on the lower Columbia River, averaging 1.9% body weight at John Day Dam and 1.6% at Bonneville Dam. Protein content declined from 16.0% body weight in fish sampled before release to 14.5% in fish sampled at John Day Dam. Mean lipid and protein values were smaller for Dworshak fish than for Rapid River and McCall fish, both on a percentage body weight basis (ANOVA) and when total quantities of lipid and protein were compared for fish of the same length (ANCOVA).

2. Log total lipid increased with increasing fish size, decreased from upstream to downstream sites, and decreased with increasing travel time (ANCOV A). These results suggest that lipid usage increased with distance traveled as well as with time, and that migrating fish are not simply displaced downstream by river currents, but also expend energy for swimming. The model predicts that a 20-d increase in travel time to John Day Dam would decrease the lipid reserves of McCall Hatchery fish by an additional 37%.

3. Blood chemistry indices known to decline in fasting fish-plasma triglyceride, cholesterol, and total protein concentrations and alkaline phosphatase activities-decreased as the fish migrated to Lower Granite Dam, and decreased further as the fish continued nrigrating to John Day Dam. The energetic deficit in migrating fish is likely due in part to a restricted rate of food intake.

4. Plasma activities of the gluconeogenic enzymes ALT and AST increased as the fish migrated from release points to Lower Granite Dam and to Little Goose Dam, but subsequently declined (-67%, -48%) as the fish continued migrating to John Day Dam. Activities of creatine kinase and lactate dehydrogenase also declined (-90%,-33%) as the fish migrated from Lower Granite Dam to John Day Dam. Decreases in enzyme activity may result from a general, energetic deficit-induced breakdown of

body proteins. Lowered enzyme activities may reduce the performance capabilities of migrating fish for swimming, osmoregulation, and other vital functions.

5. The body composition and blood chemistry of wild spring/summer chinook salmon juveniles were similar to hatchery fish of similar size sampled at Lower Granite Dam. No data are available on physiological changes in wild fish during migration through the hydropower system.
6. If depletion of lipid reserves, loss of body protein, and decreased tissue enzyme activities adversely affect the viability of smolts migrating through the Snake/Columbia River hydropower system, adverse effects would be most evident in years of low flow, when travel times from the Snake River Basin to the estuary would be 3 to 4 weeks longer than those observed in 1998.

Congleton JL, WJ LaVoie, CB Schreck, and LE Davis. 2000. "Stress Indices in Migrating Juvenile Chinook Salmon and Steelhead of Wild and Hatchery Origin Before and After Barge Transportation." *Transactions of the American Fisheries Society* 129(4):946-961.

Migrating wild (W) and hatchery-reared (H) chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) juveniles were sampled after loading into fish-transport barges at Lower Granite Dam on the Snake River, Washington, and after barge transportation downstream to Bonneville Dam on the Columbia River. Stress indices (increased plasma cortisol and glucose concentrations and decreased plasma chloride concentrations) were higher ($P < 0.001$) for chinook salmon sampled during midseason (early to mid-May), when fish loading densities in barges were at seasonal maximums, than were stress indices for those sampled earlier or later. Cortisol concentrations in chinook salmon were correlated with steelhead densities after loading of barges ($P < 0.0001$, R-2 = 0.41) and after arrival of barges at Bonneville Dam ($P < 0.0001$, R-2 = 0.65). Cortisol concentrations were not correlated with gill Na+, K+-adenosine triphosphatase activities, which were higher in W than in H fish of both species. Cortisol concentrations were higher ($P < 0.0001$ in 1994, $P = 0.02$ in 1995) in W than in H chinook salmon, and concentrations declined in both groups during barge transportation early and late in the migration season but not during midseason. In contrast, cortisol concentrations were lower ($P < 0.001$) in W than in H steelhead, were not correlated with steelhead loading densities, and declined in both W and H fish during barge transportation on all sampling dates. Electrolyte disturbances were greater in chinook salmon than in steelhead, but disturbances were similar for W and H fish of both species. Stress-related water gain was, however, greater (or was compensated more slowly) in W than in H fish. These results indicate that chinook salmon are more stressed by barge transportation than are steelhead. If the viability of juvenile chinook salmon is reduced by adverse physiological, immunological, or behavioral responses to transportation stress, reductions in survival rates should be largest for fish transported during midseason, when densities of juvenile steelhead in the fish-transport barges are highest.

Congleton JL and T Wagner. 2006. "Blood-chemistry indicators of nutritional status in juvenile salmonids." *Journal of Fish Biology* 69(2):473-490.

Three experiments were performed to determine the effects of food deprivation (21-35 days at 10-12 degrees C) on selected blood-chemistry variables in juvenile salmonids. The experimental groups were laboratory-reared rainbow trout (*Oncorhynchus mykiss*) (RBT), laboratory-reared Chinook salmon (*Oncorhynchus tshawytscha*) (LCS) and hatchery-reared, actively migrating Chinook salmon (MCS). After fasting, RBT and LCS were refed for 10 days. In fasted fishes, plasma alkaline phosphatase (ALP) activities decreased relatively rapidly, differing significantly ($P <= 0.05$) from activities in fed control fishes after 1 2 weeks. Total protein (for all groups) and total cholesterol (for RBT and MCS) decreased

relative to fed controls after 2-3 weeks, and total calcium (for RBT and MCS) after 3-4 weeks. Plasma ALP activities recovered after 10 days refeeding, but total protein, cholesterol and calcium concentrations did not. Triglyceride concentrations were highly variable and responded significantly to fasting only in the trial with RBT. Concentrations of some variables decreased (glucose and phosphorus) or increased (total magnesium) relative to control values during the initial days or weeks of fasting and then stabilized at new levels. Activities of four metabolic enzymes of intracellular origin (alanine aminotransferase, aspartate ammotransferase, lactate dehydrogenase and creatine kinase) did not differ significantly in the plasma of fed and fasted fishes. (c) 2006 The Fisheries Society of the British Isles (No claim to original US government works).

Connor WP, BD Arnsberg, SG Smith, DM Marsh, and WD Muir. 2007. *Postrelease Performance of Natural and Hatchery Subyearling Fall Chinook Salmon in the Snake and Clearwater Rivers*. Prepared by the Idaho Fisheries Resource Office, United States Fish and Wildlife Service, Ahsahka, Idaho, the Nez Perce Tribe Department of Fisheries Resources Management, Orofino, Idaho, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

In 2005, we initiated a multi-year study to compare smolt-to-adult return rate (SAR) ratios between two groups of Snake River Basin fall Chinook salmon (*Oncorhynchus tshawytscha*) that reached the sea through a combination of either (1) transportation and inriver migration or (2) bypass and inriver migration. We captured natural subyearlings rearing along the Snake and Clearwater rivers and implanted them with passive integrated transponder (PIT) tags, but knew in advance that sample sizes of natural fish would not be large enough for precision comparisons of SAR ratios. To increase sample sizes, we also cultured Lyons Ferry Hatchery subyearlings under a surrogate rearing strategy, implanted them with PIT tags, and released them into the Snake and Clearwater rivers to migrate seaward. The surrogate rearing strategy involved slowing growth at Dworshak National Fish Hatchery to match natural subyearlings in size as closely as possible, while insuring that all of the surrogate subyearlings were large enough for tagging (i.e., 60-mm fork length). Surrogate subyearlings were released during the peak rearing periods of natural subyearlings from late May to early July 2005. Some hatchery subyearlings reared under a production rearing strategy were also PIT tagged and released into the Snake and Clearwater rivers in 2005 as part of ongoing research. Releasing large numbers of hatchery subyearlings cultured under the production rearing strategy was a possible alternative for increasing the precision of SAR ratio comparisons if surrogate fish were not available. The production rearing strategy involved accelerating growth at Lyons Ferry Hatchery sometimes accompanied by several weeks of acclimation at sites along Snake and Clearwater rivers prior to release from April to June. Here we compared the postrelease performance of natural subyearlings to the postrelease performance of surrogate and production subyearlings. We made this comparison to help the fisheries community determine which of the two hatchery rearing strategies produced fish that were the most similar to natural subyearlings. Attributes of postrelease performance compared were (1) passage timing at select dams, (2) level of exposure to summer spill, (3) travel time, (4) size during seaward migration, and (5) joint probability of active migration and survival. Based on quantitative similarity indices, we conclude that these attributes were more similar between natural and surrogate subyearlings than between natural and production subyearlings. We discuss options for improving the surrogate rearing strategy.

Connor WP, HL Burge, R Waitt, and TC Bjornn. 2002. "Juvenile Life History of Wild Fall Chinook Salmon in the Snake and Clearwater Rivers." *North American Journal of Fisheries Management* 22(3):703-712.

Dam construction in the 1950s and 1960s blocked passage to the historical spawning area of Snake River fall chinook salmon (*Oncorhynchus tshawytscha*). We obtained water temperature data and collected juvenile fall chinook salmon in three present-day spawning areas from 1992 to 2000 to investigate the relation between water temperature and juvenile life history events. We used historical water temperatures and the literature to depict juvenile life history in the historical spawning area. Water temperatures in the three present-day spawning areas differed significantly from winter to spring, when eggs were incubating (P less than or equal to 0.0001), as well as during spring, when juveniles were rearing and starting seaward migration (P less than or equal to 0.0001). When water temperatures were warmer, the timing of most life stages was generally earlier. The life stages included fry emergence (r(2) = 0.85, N = 14, P < 0.0001), growth to parr size (r(2) = 0.94, N = 15, P < 0.0001), and smolt emigration (r(2) = 0.93, N = 14, P < 0.0001). The percentage of parr that overwintered in freshwater and migrated seaward the next spring increased when spring water temperatures decreased (r(2) = 0.40, N = 12, P = 0.02). As the historical spawning area was warmer than present-day spawning areas, fall chinook salmon juvenile life history progressed on an earlier time schedule. We conclude that dam construction changed juvenile fall chinook salmon life history in the Snake River basin by shifting production to areas with relatively cool water temperatures and comparatively lower growth opportunity.

Connor WP, SG Smith, T Andersen, SM Bradbury, DC Burum, EE Hockersmith, ML Schuck, GW Mendel, and RM Bugert. 2004. "Post-release Performance of Hatchery Yearling and Subyearling Fall Chinook Salmon Released into the Snake River." *North American Journal of Fisheries Management* 24(2):545-560.

Two rearing treatments are used at Lyons Ferry Hatchery to produce yearling (age-1) and subyearling (age-0) fall Chinook salmon (*Oncorhynchus tshawytscha*) for supplementing production of wild fish in the Snake River. We compared four indicators of yearling and subyearling postrelease performance, namely, seaward movement, condition factor, growth rate, and survival. A standard rearing treatment was used to grow yearlings slowly for 14 months to sizes of 152-162 mm (mean fork length). A second standard rearing treatment was used to grow medium subyearlings at a moderate rate for 5 months to 84-89 nm. Two modified rearing treatments were used to produce large subyearlings that were grown rapidly to 90-103 mm and small subyearlings that were grown slowly to 70-76 mm. We released yearlings in April and subyearlings in June on the typical supplementation schedule. Seaward movement, condition factor, growth, and survival varied among rearing treatments. Yearlings moved seaward fastest for reasons related to their large size. Yearlings had the lowest postrelease condition factors and growth rates because they were released when temperatures were cool and they moved seaward quickly, spending little time to feed. Yearlings had the highest survival because they were released when the water was cool, they moved seaward quickly, and their large size reduced susceptibility to predation. Small subyearlings moved seaward the slowest because of their small size and slow growth before release. Small subyearlings had the highest postrelease condition factors and highest growth rates because they lingered and were exposed to relatively high temperatures that were favorable for growth. Small subyearlings had the lowest survival because they lingered and were exposed to low flow and warm water for long durations and their small size increased susceptibility to predation. We conclude that fall Chinook salmon performance after release from Lyons Ferry Hatchery is influenced by release date and by rearing treatment effects on size, prerelease growth rate, and postrelease behavior.

Connor WP, JG Sneva, KF Tiffan, RK Steinhorst, and D Ross. 2005. "Two Alternative Juvenile Life History Types for Fall Chinook Salmon in the Snake River Sasin." *Transactions of the American Fisheries Society* 134(2):291-304.

Fall Chinook salmon (*Oncorhynchus tshawytscha*) in the Snake River basin were listed under the Endangered Species Act in 1992. At the time of listing, it was assumed that fall Chinook salmon juveniles in the Snake River basin adhered strictly to an ocean-type life history characterized by saltwater entry at age 0 and first-year wintering in the ocean. Research showed, however, that some fall Chinook salmon juveniles in the Snake River basin spent their first winter in a reservoir and resumed seaward movement the following spring at age 1 (hereafter, reservoir-type juveniles). We collected wild and hatchery ocean-type fall Chinook salmon juveniles in 1997 and wild and hatchery reservoir-type juveniles in 1998 to assess the condition of the reservoir-type juveniles at the onset of seaward movement. The ocean-type juveniles averaged 112-139 mm fork length, and the reservoir-type juveniles averaged 222-224 mm fork length. The large size of the reservoir-type juveniles suggested a high potential for survival to salt water and subsequent return to freshwater. Scale pattern analyses of the fall Chinook salmon spawners we collected during 19982003 supported this point. Of the spawners sampled, an overall average of 41% of the wild fish and 51% of the hatchery fish had been reservoir-type juveniles. Males that had been reservoir-type juveniles often returned as small "minijacks" (wild, 16% of total; hatchery, 40% of total), but 84% of the wild males, 60% of the hatchery males, and 100% of the wild and hatchery females that had been reservoir-type juveniles returned at ages and fork lengths commonly observed in populations of Chinook salmon. We conclude that fall Chinook salmon in the Snake River basin exhibit two alternative juvenile life histories, namely ocean-type and reservoir-type.

Crozier LG, AP Hendry, PW Lawson, TP Quinn, NJ Mantua, J Battin, RG Shaw, and RB Huey. 2008. "Potential responses to climate change in organisms with complex life histories: Evolution and plasticity in Pacific salmon." *Evolutionary Applications* 1(2):252-270.

Salmon life histories are finely tuned to local environmental conditions, which are intimately linked to climate. We summarize the likely impacts of climate change on the physical environment of salmon in the Pacific Northwest and discuss the potential evolutionary consequences of these changes, with particular reference to Columbia River Basin spring/summer Chinook (*Oncorhynchus tshawytscha*) and sockeye (*Oncorhynchus nerka*) salmon. We discuss the possible evolutionary responses in migration and spawning date egg and juvenile growth and development rates, thermal tolerance, and disease resistance. We know little about ocean migration pathways, so cannot confidently suggest the potential changes in this life stage. Climate change might produce conflicting selection pressures in different life stages, which will interact with plastic (i. e. nongenetic) changes in various ways. To clarify these interactions, we present a conceptual model of how changing environmental conditions shift phenotypic optima and, through plastic responses, phenotype distributions, affecting the force of selection. Our predictions are tentative because we lack data on the strength of selection, heritability, and ecological and genetic linkages among many of the traits discussed here. Despite the challenges involved in experimental manipulation of species with complex life histories, such research is essential for full appreciation of the biological effects of climate change.

Crozier L and RW Zabel. 2006. "Climate impacts at multiple scales: evidence for differential population responses in juvenile Chinook salmon." *Journal of Animal Ecology* 75(5): 100-1109.

1. We explored differential population responses to climate in 18 populations of threatened spring-summer Chinook salmon Onchorynchus tshawytscha in the Salmon River basin, Idaho. 2. Using data from a long-term mark-release-recapture study of juvenile survival, we found that fall stream flow is the best predictor of average survival across all populations. 3. To determine whether all populations responded similarly to climate, we used a cluster analysis to group populations that had similar annual

fluctuations in survival. The populations grouped into four clusters, and different environmental factors were important for different clusters. 4. Survival in two of the clusters was negatively correlated with summer temperature, and survival in the other two clusters was positively correlated with minimum fall stream flow, which in turn depends on snow pack from the previous winter. 5. Using classification and regression tree analysis, we identified stream width and stream temperature as key habitat factors that shape the responses of individual populations to climate. 6. Climate change will likely have different impacts on different populations within this metapopulation, and recognizing this diversity is important for accurately assessing risks.

Crozier LG, RW Zabel, EE Hockersmith, and S Achord. 2010. "Interacting effects of density and temperature on body size in multiple populations of Chinook salmon." *Journal of Animal Ecology* 79(2):342-349.

1. The size individuals attain reflects complex interactions between food availability and quality, environmental conditions and ecological interactions. A statistical interaction between temperature and the density of conspecifics is expected to arise from various ecological dynamics, including bioenergetic constraints, if population density affects mean consumption rate or activity level. Density effects on behaviour or size-selective predation could also generate this pattern. This interaction plays an important role in bioenergetic models, in particular, and yet has not been documented in natural populations.
2. The lengths of 131 286 juvenile wild Chinook salmon (*Oncorhynchus tshawytscha*) across 13 populations spread throughout the Salmon River Basin, Idaho, USA over 15 years were compared to test whether juvenile density alters the relationship between body size and temperature.
3. Strong evidence for a negative interaction between mean summer temperature and density emerged, despite the relatively cool temperatures in this high elevation habitat. Growth correlated positively with temperature at lower densities, but the correlation was negative at the highest densities.
4. This is the first study to document this interaction at such a large spatial and temporal scale, and suggests that warmer temperatures might intensify some density-dependent processes. How climate change will affect individual growth rates in these populations will depend intimately on ecological conditions, particularly food availability and population dynamics. More broadly, the conditions that led to the interactions observed in our study - limited food availability and temperatures that ranged above those optimal for growth - likely exist for many other natural populations, and warrant broader exploration.

Dauble DD and RP Mueller. 2000. "Difficulties in Estimating Survival for Adult Chinook Salmon in the Columbia and Snake Rivers." *Fisheries* 25(8):24-34.

We reviewed current methods used to estimate survival of adult chinook salmon (*Oncorhynchus tshawytscha*) as they migrate upstream past hydroelectric projects in the Columbia and Snake rivers, evaluated known and unaccounted-for loss factors, and assessed how adult survival estimates could be improved. Dam counts and associated passage conversion rates do not always provide accurate estimates of adult survival between hydroelectric projects. Expansion techniques for reconstructing run size and harvest rates also contribute to variability in estimates of run size and potential loss between hydroelectric projects. Use of passage conversion rates to estimate in-river survival of adult spring chinook salmon had less uncertainty than for estimates of other runs. Fixed-run cui off dates for migration timing result in a high uncertainty for monitoring relative numbers of summer chinook salmon. We also found it difficult to reconstruct run size to spawning areas or to estimate interdam survival for fall chinook in lower Snake River darns because of straying and high incidence (e.g., up to 40% at some projects) of fallback behavior. In-river survival estimates of adult chinook salmon would be improved by factoring adult fallback percentages into passage estimates, combining spring and summer runs for accounting purposes, methods.

Deriso RB, DR Marmorek, and IJ Parnell. 2001. "Retrospective patterns of differential mortality and common year-effects experienced by spring and summer chinook salmon (*Oncorhynchus tshawytscha*) of the Columbia River." *Canadian Journal of Fisheries and Aquatic Sciences* 58(12):2419-2430.

We used spawner-recruit data to estimate the instantaneous differential mortality (mu) experienced by seven Snake River spring and summer chinook (*Oncorhynchus tshawytscha*) stocks relative to six lower Columbia River stocks. We applied 37 Ricker stock-recruit models to these data, incorporating different assumptions about measurement error, transport survival, intrinsic productivity, methods of estimating mu, and common year-effects that affect the survival of all stocks. Estimates of mean mu for the 12 best models ranged from 0.55 to 1.90 (mean of 1.09), implying that passage from Lower Granite Dam to John Day Dam reduced recruitment of 1970-1990 Snake River broods by an average of 42-85% (mean of 66%). Differential mortality was cyclical and moderately high in the 1970s brood years, low for 1980-1983, near average in 1984-1989, and high in 1990. Our empirical estimates of mu showed low bias and were between those produced by two mechanistic passage models. The best empirical models included common year-effects, which shifted from generally positive effects on 1952-1968 brood years to generally negative effects on 1970-1990 broods. Year-effects were not significantly correlated with two climate indices or with water travel time (the time that water takes to travel down the Columbia River).

De Robertis A, CA Morgan, RA Schabetsberger, RW Zabel, RD Brodeur, RL Emmett, CM Knight, GK Krutzikowsky, and E Casillas. 2005. “Columbia River plume fronts. II. Distribution, abundance, and feeding ecology of juvenile salmon.” *Marine Ecology-Progress Series* 299:33-44.

Well-defined fronts develop at the seaward edge of riverine plumes where suspended materials and planktonic organisms are concentrated by convergent water flows. Riverine plume fronts have been hypothesized to be favorable fish habitats because they can lead to localized prey aggregations. We examined the spatial distribution of juvenile Pacific salmonids *Oncorhynchus* spp. in and around plankton-rich frontal regions of the Columbia River plume to test the hypothesis that juvenile salmonids aggregate at riverine plume fronts to feed. Juvenile salmonids tended to be abundant in the frontal and plume regions compared to the more marine shelf waters, but this pattern differed among specie's and was not consistent across the 2 study years. Stomach fullness tended to be higher in the more marine shelf waters than either the front or plume areas, which does not support the hypothesis that salmonids consistently ingest more prey at frontal regions. Many prey organisms were disproportionately abundant at these fronts, but salmon stomach-content analysis did not reveal higher stomach contents at fronts or identify prey groups indicative of feeding in the frontal areas. Although our results indicate that the Columbia River plume influences the distributions of juvenile salmon, our observations do not support the hypothesis that juvenile salmonids congregate to feed at fronts at the leading edge of the Columbia River plume. The short persistence time of these fronts may prevent juvenile salmon from exploiting these food-rich, but ephemeral, features.

Dietrich J, D Boylen, B Fleenor, J Groff, G Hutchinson, J Osborn, S Strickland, D Thompson, A Van Gaest, T Collier, M Arkoosh, and F Loge. 2008. *Estimate of Hydrosystem Delayed Mortality Associated with*

Barged and In-River Outmigration Life-History Strategies of Snake River Spring/Summer Chinook Salmon. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Code BPS-00-10.

Various methods have been developed to mitigate the effects of Federal Columbia River Power System (FCRPS) on juvenile salmon migrating to the Pacific Ocean through the Columbia River Basin. We conducted an Anadromous Fish Evaluation Program-funded study in FY02 to examine the health of hatchery-reared Snake River spring/summer Chinook salmon relative to bypass history and barging. The health of outmigrants was assessed in terms of the difference in the incidence of mortality among fish, categorically grouped into no-bypass, bypass, and barging life-histories, in response to challenge with the pathogenic marine bacterium Listonella anguillarum during seawater holding. In this study (FY06) we repeated the FY02 study utilizing Snake River spring/summer Chinook salmon reared in two distinct hatcheries. In replicate disease challenges in both study years, the cumulative mortality associated with barged fish was statistically less than fish with in-river life-histories. In this study, juvenile salmon were also collected at Lower Granite Dam to serve as a baseline control for FCRPS stress exposure. The juvenile salmon with in-river life histories were also found to be more susceptible to infectious disease than fish collected at Lower Granite Dam, while barged salmon were not. Collectively, these results suggest that the FCRPS does impose a level of stress that adversely impacts the health of outmigrants, and barging alleviates that stress. The disease challenge experiments completed in this study replicated trends in the FY02 AFEP-funded study, as well as revealed differences in disease susceptibility based on the hatchery of origin. Barged outmigrants from Dworshak Hatchery were more susceptible to disease than outmigrants from Rapid River Hatchery. Although this difference in disease susceptibility was not observed in In-River fish, we hypothesize that the less fit fish were already culled from the In-River population by the time they reached Bonneville Dam, thereby eliminating potential differences in disease susceptibility in fish from the two hatcheries at the point of entry into the estuary. In addition to results from the disease challenge, selected physical, chemical, and biological characteristics of the smolts and/or their environment were evaluated to provide an ecological context within which to evaluate underlying mechanisms associated with differing disease susceptibility. Several of these factors were shown to support the differential disease susceptibility between hatcheries and experimental cohorts identified in the disease challenges. In contrast to the increased fitness showed in the barged and Lower Granite cohorts of fish during the laboratory pathogen exposures, barged and Lower Granite cohorts of fish were observed to have high incidences of natural infections resulting in mortality within the first few weeks of laboratory holding. Mortalities observed in experimental cohorts during laboratory holding did not affect disease challenge results, as indicated by laboratory controls. The source of the natural infections, as well as the contribution of the FCRPS to disease transmission in barges and bypass structures are unknown and require a separate study design. The collective results suggest that barging may help mitigate adverse health effects of the Federal Columbia River Power System on Snake River spring/summer Chinook salmon, but the fate of the barged fish in the estuary and ocean may depend on their health status prior to barging and their hatchery of origin.

Dietrich J, D Boylen, D Spangenberg, C Bravo, D Thompson, E Loboschefsky, M Arkoosh, T Collier, and F Loge. 2007. Disease Susceptibility of Hatchery-Reared Yearling Snake River Spring/Summer Chinook Salmon with Different Migration Histories in the Columbia River. Prepared by the University of California, Davis, California, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric

Administration, Newport, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Code BPS-00-10.

The Federal Columbia River Power System (FCRPS) has critically affected salmon migration and populations, with some of the Columbia River Basin threatened or endangered evolutionarily significant units of salmon species migrating past as many as 8 dams. Barging fish through the FCRPS is one effort that has been implemented to mitigate the impact of the FCRPS on juvenile fish outmigration. However, estimates of differential delayed mortality, *D*, for hatchery-reared Snake River spring/summer Chinook salmon have implied that transporting fish around the dams increases their delayed mortality relative to fish with an In-River life-history. In replicate Anadromous Fish Evaluation Program-funded studies (2002 and 2006), we have shown that fish with In-River life-histories are more susceptible to disease during planned laboratory challenge with an infectious agent (e.g., Listonella anguillarum) than fish with Barged life-histories, implying that barging may help mitigate adverse health effects of the FCRPS. To address the difference in outcomes of our previous studies and *D* values for hatchery-reared Snake River spring/summer Chinook salmon, we conducted the present study to determine the extent of delayed mortality in the estuary and to identify the likely factors that contribute to differences in delayed mortality in the estuary of Barged and In-River hatchery-reared Snake River spring/summer Chinook salmon. To determine the magnitude of delayed mortality in the estuary, hatchery-reared Snake River spring/summer Chinook salmon with Barged and In-River life-histories were held in net pens at two locations and their survival was monitored daily. We found that the magnitude of net pen mortality was directly impacted by the duration that fish were held and their outmigration life-history. Fish with Barged life-histories that were held for less than 10 days had greater net pen mortality than fish with In-River life-histories that were held for the same period. However, fish with In-River life-histories that were held for the total 28 days had greater net pen mortality than fish with Barged life-histories that were held for the same period. The maximum differential mortality between the two life-histories was 3.4% (on day 6) for short holding times and 27.1% (on day 28) for long holding times. During short periods of holding, outmigration life-history factors primarily contributed to the greater mortality in Barged fish relative to In-River fish. Immune function and hematology assays indicated that fish from both life-histories were stressed and responding to infections immediately prior to net pen holding. Clinical diseases were found by histopathology and attributed to the cause of mortality observed in both groups, but the rapid onset of mycotic and BKD-associated mortality in fish from the Barged treatment group suggests that the diseases were contracted prior to arrival. The pathogen prevalence survey provided further evidence that transmission of these two diseases occurred in the barge holds. As the duration of holding increased, the environmental conditions (i.e., pathogen exposure, contaminant exposure, and increasing water temperature) surrounding the net pens became the greatest stressor impacting the mortality of both Barged and In-River fish. The magnitude of net pen mortality and the susceptibility of fish to stressors did vary by hatchery, site, and passage cohort, based on the strengths and weaknesses of fish and stressors. Hence, the primary conclusions of this study were:

1. Mortalities in the net pens are primarily associated with infectious diseases;
2. Conditions on the barge exacerbate disease;
3. Environmental conditions in the estuary exacerbate disease; and
4. Stress associated with In-River outmigration through the FCRPS exacerbate disease.

Dietrich J, J Osborn, D Boylen, G Hutchinson, S Strickland, A Van Gaest, T Collier, and M Arkoosh. 2010. *Disease transmission among Snake River spring/summer Chinook salmon under laboratory controlled*

transportation conditions. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, the University of California, Davis, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla,Washington. Study Codes BPS-W-00-10 and TPE-W-04-1.

In this AFEP-funded study, we investigate the likelihood of transmission of infectious disease in yearling Snake River Chinook salmon under controlled laboratory conditions intended to mimic transportation through the Federal Columbia River Power System (FCRPS). In previous AFEP studies, we detected salmonid pathogens by polymerase chain reaction (PCR) in barge hold water at Lower Granite Dam immediately after loading, as well as upon completion of the barge trip at Bonneville Dam. Similarly, we found an increase in the number of fish containing these pathogens after the barge trips relative to fish sampled prior to barging, suggesting pathogen transmission can occur during transport operations. To identify transport conditions that could minimize disease transmission, we conducted a laboratory investigation to evaluate the transmission of Renibacterium salmoninarum, the causative agent of Bacterial Kidney Disease (BKD), from infected 'Donor' juvenile salmon to healthy 'Susceptible' juvenile salmon. The fish cohabitated under three different holding densities (0.05, 0.18, and 0.50 lb/gal), and two different tank exchange rates (2.0 and 5.7 exchanges/hour) that represented a range of conditions found during FCRPS transport. Susceptible and Donor fish were held under simulated transport conditions for 60 hours in order to mimic the period of raceway collection and holding (24 hours), as well as downriver transport by barge (36 hours). After the 60-hour cohabitation, the Susceptible fish were removed from the Donor fish and monitored for 100 days. Gill and kidney tissue were collected and analyzed by nested and quantitative PCR for the presence of R. salmoninarum. In the current study, we have demonstrated transmission of *R. salmoninarum* from infected fish to the gills of most Susceptible fish (>90%). This transmission occurred during cohabitation with a range of infected fish prevalence (7-40%) and a time period comparable to transportation from Lower Granite Dam. We have also demonstrated transmission of *R. salmoninarum* from infected fish to the gills of the majority of Susceptible fish during cohabitation under a range of water exchange rates and fish holding densities that can occur during transport operations from Lower Granite Dam. The initial transmission of *R. salmoninarum* to interior tissues (kidneys) and corresponding progression of infection was affected by exposure conditions. PCR detections and multivariate linear regression indicated that initial transmission to Susceptible fish kidneys was dependent on fish density and independent of exchange rate. Sampling 100 days later indicated that both fish density and water exchange rate significantly affect *R. salmoninarum* prevalence and copy number in Susceptible fish kidneys. Infection was greatest in treatments with the lowest fish density and exchange rate, as well as the highest fish density and exchange rate. The collective results from this study indicate that *R. salmoninarum* transmission within barge holds can be reduced by altering current transportation operating conditions that increase barge hold exchange rates with increasing fish loading densities. The regression model predicted minimal transmission at high exchange rate and low fish densities. The rates of cell replication and pathogenesis are not equivalent for all salmonid pathogens and laboratory conditions are not equivalent to a mixed species barging environment. The variable transmission of *R. salmoninarum* under different fish densities and exchange rates observed in this study should provide USACE and stakeholders with primary information regarding the influence of these basic transport variables on disease transmission, as well as suggesting operating conditions that may reduce disease transmission.

Dietrich JP, DA Boylen, DE Thompson, EJ Loboschefsky, CF Bravo, DK Spangenberg, GM Ylitalo, TK Collier, DS Fryer, MR Arkoosh, and FJ Loge. 2011. "An Evaluation of the Influence of Stock Origin and Out-migration History on the Disease Susceptibility and Survival of Juvenile Chinook Salmon." Journal of Aquatic Animal Health 23(1):35-47.

Various methods have been developed to mitigate the adverse effects of the Federal Columbia River Power System on juvenile Pacific salmon out-migrating through the Columbia River basin. In this study, we found that hatchery-reared spring Chinook salmon Oncorhynchus tshawytscha in the river are in varying degrees of health, which may affect delayed mortality and the assessment of the effectiveness of management actions to recover listed stocks (e. g., barging fish downstream versus leaving fish in the river). A laboratory disease challenge with Listonella anguillarum was completed on fish from Rapid River Hatchery and Dworshak National Fish Hatchery (NFH) with different out-migration histories: (1) transported by barge, (2) removed from the river before barging, or (3) left to travel in-river. Barged fish from Rapid River Hatchery experienced less mortality than fish from Dworshak NFH. No statistical differences were found between the hatcheries with fish that had in-river out-migration histories. We suggest that the stressors and low survival associated with out-migration through the hydropower system eliminated any differences that could have been present. However, 18-25% of the fish that were barged or collected before barging died in the laboratory before the disease challenge, compared with less than 2% of those that traveled in-river. Owing to disproportionate prechallenge mortality, the disease-challenged populations may have been biased; thus, they were also considered together with the prechallenge mortalities. The synthesis of prechallenge and disease-challenged mortalities and health characteristics evaluated during out-migration indicated that the benefit of barging was not consistent between the hatcheries. This finding agrees with adult survival and delayed mortality estimates for the individual hatcheries determined fromadult returns. The results suggest that the health status of fish and their history before entering the hydropower system (hatchery of origin and out-migration path) are critical variables affecting the conclusions drawn from studies that evaluate mitigation strategies.

Eder K, D Thompson, R Buchanan, J Heublein, J Groff, J Dietrich, J Skalski, C Peery, M Arkoosh, T Collier, and F Loge. 2009a. *Survival and travel times of in-river and transported yearling Chinook salmon in the lower Columbia River and estuary with investigation into causes of differential mortality*. Prepared by the University of California, Davis, California, the University of Washington, Seattle Washington, the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, the University of Idaho, Moscow, Idaho, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Codes BPS-00-10 and SPE-06-2.

In this study, differential mortality of transported and in-river yearling Chinook salmon in the lower Columbia River and estuary (LRE) was estimated using Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic tags and concomitant detection arrays. The extent of differential mortality was assessed in terms of the Barge to In-River Survival Ratio (BI ratio) in the LRE, with values greater than 1 indicative of a higher survival of barged fish relative to inriver fish, and values less than 1 indicative of a higher survival of in-river fish relative to barged fish. The value of the BI ratio over the course of the entire outmigration season was 0.84 (SE = 0.03) for fish transiting RKM 202 to 8.3. Values of the BI ratio were 0.77 (SE = 0.05), 0.81 (SE = 0.05), and 0.94 (SE = 0.05) for fish transiting RKM 202 to 8.3 during the early, middle, and late periods of the outmigration season, respectively. The BI ratios of 0.84 and 0.77 were statistically different than a ratio of 1. The values of the BI ratios suggest differential mortality in the LRE, with a higher incidence of mortality in barged fish than in-river fish. The lowest survival for both barged and in-river fish in the LRE occurred between RKM 35.6 and 8.3, a location representing both the furthest point of saltwater intrusion into the estuary and the nesting location of avian predators. Mean travel times of in-river fish between RKM 202 and 8.3 were consistently around 2.3 (SE = 0.01) days for the entire outmigration season, whereas for barged fish the values decreased from 7.9 (SE = 0.19) to 3.1 (SE = 0.03) days over the course of the outmigration season. The longer residence times of barged fish may have increased the risk of avian predation: bird predation estimates below Bonneville Dam were considerably higher in barged study fish (5%) than in-river study fish (3%).

In this study, the health of barged and in-river outmigrant yearling Chinook salmon was assessed by characterizing the extent and putative causes of mortality of fish held in net pens located at Tongue Point (fresh water site) and Sand Island (saline site) in the LRE. The magnitude of cumulative net pen mortality of all groups of fish held at both net pen locations was strongly impacted by net pen location. All groups of fish held at both net pen locations experienced significantly greater mortality during holding at Tongue Point relative to Sand Island, thus suggesting that both barged and in-river fish arrive at Bonneville Dam in a compromised condition that decreases their probability of survival during extended freshwater residence time. Additionally, fish barged early in the outmigration season had a higher incidence of mortality in the net pens than fish barged later in the season. Overall, mycotic infection and metabolic disease were the main causes of mortality in barged fish held in the freshwater net pen site (Tongue Point); ceratomyxosis was the main cause of mortality in net pen fish with an in-river outmigration history. Net pen findings in this study were consistent with past AFEP-funded studies. Given that the residence time in the LRE of barged fish is greater than in-river fish (data based on actively migrating JSATS-tagged barged and in-river fish in the LRE), one might hypothesize that fish health is contributing to the observed differences in differential mortality observed in actively migrating JSATS-tagged barged and in-river fish in the LRE. However, specific statistically significant linkages between measures of fish health and survival of actively migrating barged and in-river fish in the LRE were not established in this study because of logistical difficulties in study implementation.

Eder K, D Thompson, J Dietrich, D Boylen, A Van Gaest, S Strickland, J Groff, M Arkoosh, and F Loge. 2009b. *Hydrosystem Delayed Mortality Associated with Barge and In-River Outmigration Histories of Snake River Spring/Summer Chinook Salmon with Investigation into Possible Causes of Differential Mortality – DRAFT*. Prepared by the University of California, Davis, California, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Code BPS-W-00-10.

In this study, the extent and possible causes of differential delayed mortality of transported and in-river hatchery-reared spring/summer Chinook salmon were assessed (i) in estuary net pens in the lower Columbia River and estuary (LRE) and (ii) with observations of treatment groups collected from the river system during outmigration. Based on the prevalence of either pathogens, analyzed by Polymerase Chain Reaction (PCR), or clinical signs of disease, analyzed by pathology, in fish destructively sampled, the population of Snake River spring/summer Chinook salmon originating from Rapid River or Clearwater Hatchery were healthier prior to release than after completing their outmigration in 2008. Both barging and in-river outmigrations adversely impacted the health of the outmigrant population. Once arriving in the LRE, environmental conditions further impacted the health of the outmigrating population of Snake River spring/summer Chinook salmon. Compromised health increased the incidence of mortality during freshwater net pen holding in the LRE. For fish held in a saline-influenced site, the factors contributing to the incidence of mortality at the freshwater site, including outmigration history and health status, diminished, and the incidence of mortality of both barged and in-river fish was negligible. Extended LRE transit times of barged fish, particularly early in the season, may be contributing to elevated differential mortality of actively migrating barged fish relative to actively migrating fish with an in-river outmigration history in the LRE. The various pathology, pathogen prevalence, smoltification, and condition factor metrics analyzed in this study would further suggest that the health of the outmigrant population may be playing a contributing role in differential mortality in the LRE.

Elliott DG, RJ Pascho, and LM Jackson, GM Matthews, and JR Harmon. 1997. "*Renibaeterium salmoninarum* in Spring-Summer Chinook Salmon Smolts at Dams on the Columbia and Snake Rivers." *Journal of Aquatic Animal Health* 9:114-126.

We evaluated Renibaeterium salmoninarum infection in smolts of hatchery and wild spring-summer Chinook salmon (*Oncorhynchus tshawytscha*) sampled during most of the outmigration at Little Goose (1988) and Lower Granite dams (1988-1991) on the Snake River and at Priest Rapids and McNary dams on the Columbia River (1988-1990). We sampled 860-2,178 fish per dam each year. Homogenates of kidney-spleen tissue from all fish were tested for the presence of R. salmoninarum antigens by the enzyme-linked immunosorbent assay (ELISA), and homogenates from 10% of the fish were examined by the fluorescent antibody technique (FAT). Although only 1-11% of fish sampled at a given dam during any l year exhibited lesions characteristic of bacterial kidney disease, 86-100% of the fish tested positive for R. salmoninarum antigen by ELISA, whereas 4-17% of the fish tested positive by the FAT. During most years, a majority (68-87%) of fish testing positive by the ELISA had low R. salmoninarum antigen levels, but in 1989, 53% of positive fish from Lower Granite Dam and 52% from McNary Dam showed medium-to-high antigen levels. For most years, the highest mean antigen levels were measured in fish sampled after 75% of the total out-migrants had passed a given dam. When the largest numbers of fish were being collected for bypass or downriver transportation, mean antigen levels were relatively low.

Elliott DG, RJ Pascho, and AN Palmisano. 1995. "Brood stock segregation for the control of brood stock segregation for the control of bacterial kidney disease can affect mortality of progeny Chinook salmon (*Oncorhynchus tshawytscha*) in seawater." *Aquaculture* 132:133-144.

Segregation of spring chinook salmon (Oncorhynchus tshawytscha) brood stock based on the measurement of maternal Renibacterium salmoninarum infection levels by the enzyme-linked immunosorbent assay (ELISA) and the fluorescent antibody technique (FAT) was previously shown to affect the prevalence and levels of bacterial kidney disease (BKD) in progeny fish during hatchery rearing. Smolts from that study were subjected to standardized fish health and condition evaluation procedures 2 weeks before the conclusion of hatchery rearing and release of the fish for migration to the Pacific Ocean. The results suggested that the general health of the smolts in the progeny group from parents that had low R. salmoninarum infection levels or tested negative for R. salmoninarum (low-BKD group) was better than that of the smolts in the progeny group from female parents with high R. salmoninarum infection levels (high-BKD group). Testing by the ELISA showed that the overall severity of R. salmoninarum infection also was lower in the smolts from the low-BKD group. Subgroups of smolts from the study were acclimated to tanks of seawater for extended holding. After a 22-day acclimation period and 98 days in full-strength (29 ppt salinity) seawater, total mortality was 12% in the low-BKD group and 44% in the high-BKD group. All of the mortality in the low-BKD group and 85% of the mortality in the high-BKD group occurred after the fish were transferred to full-strength seawater. Testing of kidney tissues from all dead fish by the FAT revealed that 85% of the fish that died in the high-BKD group had high R. salmoninarum numbers, indicating that BKD was te cause of death. In contrast, none of the fish that died in the low-BKD group had detectable numbers of R. salmoninarum. We concluded that

brood stock segregation by use of the ELISA and the FAT can affect mortality and the R. salmoninarum status of progeny chinook salmon for as long as 21 months after hatching, even after the fish have been transferred to seawater.

Emmett RL and GK Krutzikowsky. 2008. “Nocturnal Feeding of Pacific Hake and Jack Mackerel Off the Mouth of the Columbia River, 1998-2004: Implications for Juvenile Salmon Predation.” *Transactions of the American Fisheries Society* 137(3):657-676.

Predation by piscivorous marine fishes has been hypothesized to be a primary source of marine mortality for Pacific Northwest juvenile salmon. During the springs and summers of 1998-2004, we collected predator and prey fishes (forage and juvenile salmonids) at the surface at night off the mouth of the Columbia River. Pacific hake Merluccius productus had relatively low percentages of empty stomachs during cool-ocean years (2000 through 2002) and high percentages during 1998, a warm-ocean year. Euphausiids and fishes were the most commonly eaten prey for both species. Pacific hake and jack mackerel Trachurus symmetricus appeared to show some diet selectivity, eating some fish, including salmonids, in a higher proportion than found in the environment. Both Pacific hake and jack mackerel ate juvenile salmonids, but at very low amounts. After considering population sizes in the study area, these two predators do not appear to be responsible for the death of large numbers of Columbia River juvenile salmon smolts. However, we may have underestimated the number of salmonids eaten by hake and mackerel due to the limitations of our study. More work needs to be done to identify and quantify predation of juvenile salmon off the Pacific Northwest.

Emmett, RL, GK Krutzikowsky, and P Bentley. 2006. "Abundance and distribution of pelagic piscivorous fishes in the Columbia River plume during spring/early summer 1998-2003: Relationship to oceanographic conditions, forage fishes, and juvenile salmonids." *Progress in Oceanography* 68(1):1-26.

From 1998 to 2003, we observed large fluctuations in the abundance and distribution of four pelagic predatory (piscivorous) fishes off northern Oregon and southern Washington, USA. Fluctuations in predatory fish species composition and abundance were strongly linked to the date of the spring transition and to ocean temperatures. Predatory fishes, forage fishes, and juvenile salmonids had distinct spatial distributions, with predators distributed primarily offshore and forage fish and salmonids onshore, but this varied depending on ocean conditions. We suggest that predatory and forage fish distributions respond to ocean temperatures, predator/prey interactions, and possibly turbidity. A shift in ocean conditions in 1999 decreased overall predator fish abundance in the Columbia River plume, particularly for Pacific hake. Marine survival of juvenile salmon started to increase in 1999, and forage fish densities increased in 2000, lagging by one year. (c) 2005 Elsevier Ltd. All rights reserved.

Emmett, RL and DB Sampson. 2007. "The relationships between predatory fish, forage fishes, and juvenile salmonid marine survival off the Columbia River: A simple trophic model analysis." *California Cooperative Oceanic Fisheries Investigations Reports* 48:92-105.

A trophic model that simulates interactions between a predatory fish (Pacific. hake, Merluccius productus), forage fish, and juvenile salmon off the Columbia River was constructed to identify if trophic interactions could account for marine mortality of Columbia River juvenile salmon. The model estimates the number of juvenile salmon that are eaten annually by Pacific hake off the Columbia River for a given hake and forage fish population. Model results indicate that the presence of high numbers of Pacific hake could account for high mortallty of some juvenile salmonid species/stocks leaving the Columbia River,

and that this mortality would be much reduced when fora-e fish are abundant. Estimates of hake and forage fish abundance, based on field data collected from 1998-2005, were used in the model to derive annual estimates of the number of salmon possibly eaten by hake. A multiple regression analysis using the output from the trophic model and average May/June Columbia River flows accounted for much of the annual variation in Columbia River fall Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon marine survival ($p < 0.05$, R-2 > 60%), but not spring or summer Chinook salmon. For these two stocks, average May/June sea-surface temperature was the best predictor of marine survival. Results support the hypothesis that for some Columbia River salmon species/stocks, marine survival is predation-driven and affected by the interaction between the abundance of Pacific hake, forage fish, Columbia River flows, and possibly ocean turbidity. Future modeling work should include predation estimates of other large fishes, marine mammals, and sea birds.

Enstipp, MR, D Gremillet, and DR Jones. 2007. "Investigating the functional link between prey abundance and seabird predatory performance." *Marine Ecology-Progress Series* 331:267-279.

Investigating the relationships that link marine top predators and their prey is crucial for an understanding of the mechanisms that operate within marine food chains. Many seabird species capture their prey underwater, where direct and continuous observation is difficult. However, in a captive setting, predator-prey interactions can be studied under controlled conditions and in great detail. Using an underwater video-array, we investigated the prey-capture behaviour of a foot-propelled pursuit diver, the double-crested cormorant Phalacrocorax auritus, targeting juvenile rainbow trout (*Oncorhynchus mykiss*). We tested the effects of prey density, prey size, light conditions and prey behaviour (schooling versus solitary trout) on the foraging performance of 9 cormorants. As predicted, prey density exerted the strongest influence on cormorant foraging success. While we found an apparently linear relationship between prey density and prey capture rate, a density below the threshold of about 2 g m(-3) resulted in disproportionately lower catch per unit effort (CPUE) values. If such a threshold density exists in a natural setting, it could have important implications for birds confronted with a decline in food abundance, when density levels will be reduced. We also demonstrate the marked impact of fish behaviour on the predatory performance of cormorants. Capture success of cormorants was significantly lower and pursuit duration significantly higher when birds attacked schooling rather than solitary trout. By contrast, prey size and light conditions did not have a measurable effect on cormorant prey-capture performance. Our study is an experimental investigation into the prey-capture performance of an avian pursuit diver within a captive setting. We provide input values that should be incorporated into ecological models, which might help to understand predator requirements in a changing environment.

Ferguson JW, RF Absolon, TJ Carlson, and BP Sandford. 2006. "Evidence of Delayed Mortality on Juvenile Pacific Salmon Passing Through Turbines at Columbia River Dams." *Transactions of the American Fisheries Society* 135(1): 139-150.

We evaluated the survival of juvenile salmon through turbines in Columbia River dams and found no differences between two operations but strong evidence of delayed mortality from turbine passage. After tagging with a passive integrated transponder (PIT) tag and a radio tag, yearling Chinook salmon (*Oncorhynchus tshawytscha*) were released at McNary Dam on the Columbia River through a turbine operating both within 1% of peak efficiency (a discharge rate of 317 m(3)/s) and outside the 1% range at the maximum blade angle (464 m(3)/s). Estimated relative survival to a detection array 15 km downstream was 0.871 at 317 m(3)/s and 0.856 at 464 m(3)/s and 0.858 and 0.814, respectively, to an array 46 km downstream. The highest point estimates of survival occurred under the lower discharge, suggesting that operating turbines within 1% of peak efficiency is a useful guideline for fish protection at McNary Dam. In a concurrent evaluation using balloon tags, estimated mean direct survival ranged from 0.930 to 0.946. Radio tag estimates were significantly lower than balloon tag estimates under both operations. Based on these differences, we estimated that delayed mortality comprised from 46% to 70% of total estimated mortality. We reviewed the literature and concluded that delayed mortality was caused by sublethal impacts to fish sensory systems, which increased vulnerability to predation in the tailrace. We recommend that future research to improve turbine designs and operations for fish passage focus on this major component of mortality.

Ferguson JW, GM Matthews, RL McComas, RF Absolon, DA Brege, MH Gessel, and LG Gilbreath. 2005. *Passage of Adult and Juvenile Salmonids Through Federal Columbia River Power System Dams*. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-NWFSC-64, National Marine Fisheries Service, Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington.

Over the past 60 years, a large amount of information has been amassed from studies conducted on the behavior and survival of juvenile and adult Pacific salmon (*Oncorhynchus* spp.) during passage through eight hydroelectric dams operated by the U.S. Army Corps of Engineers on the lower Snake and Columbia rivers. The eight dams are Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams on the lower Snake River, and McNary, John Day, The Dalles, and Bonneville Dams on the lower Columbia River. These dams and their reservoirs are the mainstem component of the Federal Columbia River Power System (FCRPS).

This technical memorandum focuses primarily on passage data associated with the dams as they have been configured recently, and not on effects on salmon that might accrue from major changes such as dam removal. The effects of the FCRPS on evolutionarily significant units of salmon listed under the Endangered Species Act and potential benefits to these populations from actions undertaken in the hydropower system are being addressed elsewhere, such as through deliberations of the Technical Recovery Teams, which establish biologically based recovery goals, and Biological Opinions. Here we present a synthesis of the most recent and current information and summary conclusions on the following topics: 1) juvenile salmonid passage through spillways, 2) juvenile passage through mechanical screen bypass systems, 3) juvenile passage through turbines, 4) juvenile passage through sluiceways and surface bypass systems, 5) juvenile diel passage and timing past dams, and 6) adult salmonid passage past dams and through the eight-dam reach.

Spill increases fish passage efficiency (proportion of juvenile fish passing through nonturbine routes) and reduces migration time through forebays and tailraces. In general, when daytime spill is provided, spillway passage of juvenile salmonids occurs at a fairly constant diel rate, and migration timing may be delayed if spill is managed based on passage patterns at the powerhouse. Spill has the potential to reduce the exposure of juvenile salmonids to predation, high water temperatures, and disease. Tailrace residence time for juvenile salmonids passing through spillways is influenced by spill volume and pattern. Generally, spillway passage results in more rapid tailrace egress than bypass system passage. Because piscine predators prefer hydraulic conditions provided in eddies and backwaters, spill patterns that facilitate the egress of juvenile salmonids from the spillway stilling basin and through the tailrace likely increase survival.

Fish survival through spillways can be very high (near 1.00) and is often higher than turbine or bypass system survival when spill passage conditions are optimal. However, survival through spillways with deflectors or shallow stilling basins can be negatively influenced by stilling basin depth and turbulence, hydraulic patterns in the basin, spillbay location within the spillway relative to the spill pattern being used, deflector elevation relative to tailwater elevation and thus total river flow, gate opening, and fish location when passing through the spillbay and under the control gate. Survival through spillways with deflectors or shallow basins can be considerably less than 0.98, a value typically used in hydropower system modeling exercises. Observations and lessons learned from spillway survival studies at The Dalles, Ice Harbor, and Lower Monumental Dams should be applied to other spillways with deflectors to ensure that safe spillway passage conditions are being provided at these locations.

Estimates of spill efficiency (the proportion of fish approaching a project that pass via the spillway) and spill effectiveness (spill efficiency divided by the proportion of total river flow passing over the spillway) for juvenile salmonids vary by dam, the percentage of river flow spilled, spill pattern, time of day, species/run, and dam configuration. Spill effectiveness is generally between 1.0 and 2.0, but can range considerably higher at certain dams. There is a strong indication that above a certain spill level there is no gain and very likely a reduction in spill effectiveness, although spill efficiency will continue to increase with the percentage of total river flow spilled.

Relatively few studies have been conducted on subyearling Chinook salmon (*Oncorhynchus tshawytscha*) survival through spillways during the summer migration period under contemporary conditions. Estimates of mean spillway passage survival at Ice Harbor and The Dalles Dams since 1997 using traditional spill patterns ranged from 0.75 to 1.00. However, due to problems associated with stilling basin conditions at these dams, this wide range in spillway survival estimates may not be representative of other Snake and Columbia River dams. For example, estimated mean survival through the spillway for John Day Dam in 2002 and 2003 ranged from 0.96 to greater than 1.00 when 30% of river flow was spilled throughout a 24-hour period. In addition, estimated mean survival through the Ice Harbor Dam spillway was 0.96 in 2003 under a "bulk" spill pattern, where higher flow was concentrated in fewer spillbays.

Results of gas bubble disease (GBD) monitoring and research on juvenile salmonids indicate that incidents of high prevalence and severity of GBD signs and probable related mortality are associated with exceptionally high river flows or unusual dam operation problems where powerhouse flows are limited. Under total dissolved gas cap conditions of 115% (forebay) and 120% (tailrace), signs of GBD are minimal or nonexistent, with no apparent GBDrelated mortality.

Estimates of how many fish are guided into mechanical screen bypass systems at dams vary by location (dam, turbine), time (season, day, time of day), species/run, and method used (physical netting, hydroacoustics, radiotelemetry, and estimates based on detection of fish tagged with passive integrated transponder [PIT] tags). These variables make it difficult to confidently develop accurate and precise point estimates of fish guidance efficiency. Even so, we present our best estimates by dam. Extended-length screens appear to guide higher percentages of smolts without concomitant increases in descaling and injury rates, but only when appropriately designed vertical barrier screens are installed that can manage increased flows into turbine gatewells. Once fish have been guided into gatewells, estimates of passage efficiency into the bypass system have generally exceeded 70%, the regionally acceptable value, and estimates are higher for extended-length than for standard-length fish guidance screens. Contemporary mechanical screen bypass systems are vastly improved compared to the original systems that operated during the 1970s and early 1980s, based on recent low rates of descaling, injury, and system mortality. However, outfall location and configuration are important considerations for maximizing the survival of juvenile salmonids that are bypassed back to the river below dams. Mechanical screen systems have the potential to be selective for species/run, life history types, and other attributes such as size. Operations that provide multiple routes to pass fish around dams presumably minimize the risk of reducing biodiversity associated with mechanical screen bypass systems.

Smolt-to-adult return rates for PIT-tagged in-river migrants are related to bypass history. Smolts detected at dams other than Lower Granite Dam often return as adults at lower rates than fish not detected at any dams. For hatchery (but not wild) smolts, detection frequency is inversely related to return rates. A confounding factor is that smaller smolts with lower return rates tend to be more easily guided into bypass systems than larger smolts with higher return rates.

Passage through components of mechanical screen bypass systems induces physiological changes related to the general adaptation syndrome, or stress, in juvenile anadromous salmonids. However, the physiological effects of passage through fish bypass facilities are nominal for juvenile Chinook salmon and steelhead (*O. mykiss*), as measured by blood plasma stress indices, and follow a typical sequence for fish subjected to an acute stressor followed by acclimation to or removal of the stressor. Unless exhaustion or physical injury are involved, the majority of bypassed fish are probably minimally affected by a single, and possibly several, stressful experiences. There is some evidence that multiple stress experiences can cumulatively diminish survivability, and post-stress survival likely depends on a combination of the type of stressor involved and each fish's overall condition and health, and thus, sensitivity to that stressor at the time.

At bypass facilities all fish sizes and species are mixed and small yearling Chinook salmon smolts can become stressed when in the presence of larger steelhead smolts. Separation will be necessary to reduce extended holding of small fish with larger fish, especially in the context of transportation. Prototype high-velocity separators separate in excess of 80% of small from large fish and could potentially be used in future mechanical screen bypass systems.

During summer, juvenile anadromous salmonids migrating through the Columbia and Snake rivers encounter water temperatures that often exceed the 20°C (68°F) threshold mandated in the Washington State Clean Water Act. Temperatures exceeding 25°C (77°F), the upper incipient lethal limit for salmonids, have also been documented during the summer juvenile migration period. High summer water temperatures caused a catastrophic mortality within the juvenile collection facility at McNary Dam in summer 1994, which was thought to have resulted from operating turbine units at the south end of the powerhouse that draw in warmer water. Modifications to powerhouse operations and improved temperature monitoring have prevented a recurrence, because average mortality rates during the most recent five summers ranged from 0.6 to 1.0%.

Passage timing for each route of dam passage varies with dam configuration, flow volume through the route, species, run, and life history type. Most studies were not designed to evaluate 24-hour passage behaviors for each species and life history type, making it difficult to precisely describe passage timing for each dam under varying conditions. In general, juvenile migrants that arrive during daytime tend to not pass through powerhouse routes (turbines and bypass) on arrival but will readily pass through surface-oriented outlets and daytime spill if provided. For juvenile migrants that arrive at night, passage is more equally distributed amongst available routes.

Results from studies of the Lower Granite Dam removable spillway weir and Wells Dam deep-slot surface bypass systems demonstrate that surface bypass is a viable concept that can produce high rates of nonturbine fish passage with a relatively small percentage of project discharge. Surface bypass systems operated 24 hours per day reduce forebay residence times of juvenile salmon and exposure to predators relative to the existing program of 12-hour spill at night. Optimum surface bypass performance is attained when the entrance is at a location known to attract large numbers of fish. Marginal results from other locations indicate that site conditions may limit performance at some locations. Weir entrances have proven more successful at passing juvenile salmon and steelhead migrants than deep-slot entrances, especially when flow velocity through the weir increases gradually. Discharge through the entrance should be sufficient to create a strong velocity flow-field upstream, but high discharge alone will not overcome a marginal entrance location. Additional passage facilities such as a floating forebay curtain or turbine intake occlusion can help improve fish guidance through surface bypass systems. To achieve high passage efficiency and survival, successful surface bypass designs need to address guidance into the entrance, passage through the collector, discharge into the tailrace, and egress through the immediate tailrace. Recent data indicate that impact velocities up to 15.2 ms-1 (50 fts-1) are safe for juvenile salmonids for discharges greater than 1,000 cfs.

Estimates of juvenile fish survival through turbines ranged from 0.81 to 0.92 for studies conducted from 1939 through 1968. Studies conducted under contemporary conditions using radiotelemetry and PIT-tag methodologies suggest mean survival through turbines generally remains in this range. Therefore, turbines continue to represent a significant source of mortality for juvenile salmon migrating through the FCRPS. Indirect mortality can be a significant component of total estimated turbine mortality, which future efforts to improve survival through turbines must address.

While a statistically significant relationship between juvenile salmonid survival and peak turbine efficiency has not been demonstrated, operation of units within 1% of peak efficiency most often encompassed the operation that produced the maximum estimated survival. Therefore, continued operation within 1% of peak turbine efficiency is a reasonable operating guideline to follow until more detailed information on the relationship between unit operations and maximum fish survival for each family of turbines is developed. Development of more refined guidelines appears warranted because maximum survival can be as much as 3.2% higher than survival measured at peak efficiency, and this potential improvement in survival is large compared to that for other FCRPS configuration modifications.

Recent radiotelemetry estimates of adult salmonid survival from Ice Harbor Dam to Lower Granite Dam on the Snake River have generally exceeded 90%, and PIT-tag estimates of survival from Bonneville Dam on the lower Columbia River to Lower Granite Dam have been over 80% for spring/summer Chinook salmon and 70–80% for steelhead. For adult salmonids that do not fall back at dams, estimates of survival range from 3% to 5% higher than for those that do fall back. Adult survival above the hydrosystem to hatcheries or spawning grounds is variable and estimates from Ice Harbor Dam using radiotelemetry range from 54% to 77%. The effects of passage through the hydrosystem on reproductive success are unknown.

Overall travel times and migration rates of radio- and PIT-tagged adult salmonids from Bonneville Dam to upriver Columbia or Snake River sites vary by species/run, time of year, and environmental conditions. Recent estimates of travel times and migration rates are similar to times and rates observed during the early development of the FCRPS, when there were fewer dams and the Snake River was unimpounded. Delays in dam passage for upstream migrating adult salmonids are associated with high levels of spill (≥40 kcfs), highly fluctuating spill, and high turbidity. In addition, elevated river water temperatures (>20EC) increase travel times between dams and through fishways at dams. Fishway entrance preferences are for deep/wide openings with significant attraction flow. The transition areas between collection channels and ladders are the fishway segments where adult Chinook salmon and steelhead are most likely to turn around and exit the fishway. Rates of fallback through a dam vary by species/run, environmental conditions, and dam. Higher rates are associated with high river flows, spill, and with adult fishway exit locations in close proximity to spillways. Fallback results in an overestimation of adult counts in fish ladders.

Estimates of repeat spawning rates for steelhead kelts that migrate downstream through the Snake and Columbia rivers are low (≈2%). While potentially negative effects of the hydrosystem on iteroparity rates have been recognized, the magnitude of the effects on survival and reproductive success are not clearly understood. Higher flows and spill significantly reduce travel and passage times for downstream-migrating kelts.

Relative to salmonids, upstream passage at Columbia and Snake River dams is poor for adult Pacific lamprey (Lampetra tridentata) and white sturgeon (Acipenser transmontanus). American shad (Alosa sapidissima) have thrived in the FCRPS habitat, but their overall ecological impacts on anadromous salmonids have not been studied.

Friedland KD, LP Hansen, DA Dunkley, and JC MacLean. 2000. "Linkage between ocean climate, post-smolt growth, and survival of Atlantic salmon (*Salmo salar* L.) in the North Sea area." Ices Journal of Marine Science 57(2):419-429.

We examined two long-term tagging studies with wild salmon stocks in the North Sea area. The salmon stocks, the Figgjo in southern Norway and the North Esk in eastern Scotland, reside in relatively un-impacted rivers that continue to sustain healthy runs of salmon. The return rates for one seawinter fish (1SW), the predominant age at maturity for both stocks, were highly correlated. An analysis of sea surface temperature distributions for periods of high versus low return rate showed that when low sea surface temperatures dominate the North Sea and southern coast of Norway during May, salmon survival has been poor. Conversely, when high sea surface temperatures extend northward along the Norwegian coast during May, survival has been good. Ocean conditions can be further related to the recruitment process through growth studies for the North Esk stock. Post-smolt growth increments for returning 1SW fish showed that enhanced growth was associated with years during which temperature conditions were favorable, which in turn resulted in higher survival rates. The implicit linkage between growth and survival suggests that growth-mediated predation is the dominant source of recruitment variability. Mechanisms by which ocean climate may affect post-smolt growth are discussed.

Finstad A G, O Ugedal, T Forseth, and TF Næsje. 2004. "Energy-related juvenile winter mortality in a northern population of Atlantic salmon (*Salmo salar)*." *Canadian Journal of Fisheries and Aquatic Sciences* 61(12):2358-2368.

By comparing the population frequency distributions for specific somatic energy between samplings using quantile–quantile (QQ) plots, we tested for energy-related mortality of juvenile (2- and 3-year-old) Atlantic salmon (*Salmo salar*) sampled at monthly intervals throughout three consecutive winters in a Norwegian river located at 70°N. Between several of the sampling periods, changes in the distributions of specific energy were observed corresponding to removal of low-energy individuals. By using energetic

modelling we demonstrated that metabolic processes or feeding could not be responsible for the shifts in the shape of the energy distributions and that negative-energy-dependent mortality was the most likely explanation for the observations. No changes in mean size of the fish or in the shape of the size distributions were observed between successive sampling periods, indicating that mortality was linked to levels of storage energy rather than to body size per se. Our study indicated a critical body energy level for survival of juvenile salmon at approximately 4400–4800 J·g–1, corresponding to a depletion of storage lipids.

Fryer DS. 2008. "Swimming Performance of Hatchery-Reared Yearling Chinook Salmon *Oncorhynchus tshawytscha* Before and After Passage Through the Snake-Columbia River Hydropower System." Thesis, University of Idaho, Moscow, Idaho.

We investigated the sprint swimming performance of migrating hatchery-reared Chinook salmon (*Oncorhynchus tshawytscha*) smolts collected at Lower Granite Dam (LGR), the first dam encountered by smolts migrating from the Snake River Basin (Idaho and Oregon, USA), and at Bonneville (BON) Dam, the lowermost dam on the Columbia River. In 2001 and 2002, fish from each of three Idaho hatcheries (identified by intraperitoneal passive integrated transponder tags) were diverted from juvenile-fish bypass systems at the two dams (two dates at each dam in 2001 and three dates in 2002) and transported to the wet laboratory at the University of Idaho. After a recovery period, the fish (three replicated groups of ten fish per hatchery) were swum to fatigue at a constant velocity of 7 to 8 body lengths/s. This test was repeated for four consecutive days. Mean time-to-fatigue was significantly longer for fish collected at LGR than for fish collected at BON in both years. Mean time-to-fatigue differed significantly among fish from different hatcheries and, in both years, was longest for McCall Hatchery fish, intermediate for Rapid River Hatchery fish, and shortest for Dworshak Hatchery fish. During the 4-d testing period, the performance of Rapid River and McCall hatchery fish collected at LGR sometimes improved (learning effect), but the performance of fish collected at BON did not. Chinook salmon smolts fed either a high daily ration (2.0 % body weight/d) or reduced daily ration (0.5 % body weight/d) for 30 d following collection at BON improved sprint endurance over 4-day trials. We conclude that sprint swimming performance declined as smolts migrated 461 km from LGR to BON, and swimming capabilities differed between fish produced at different hatcheries.

Gargett AE. 1997. "The optimal stability 'window': a mechanism underlying decadal fluctuations in North Pacific salmon stocks?" *Fisheries Oceanography* 6(2):109-117.

While recent evidence suggests that North Pacific salmon stocks are influenced by decadal variability in atmospheric forcing of the ocean, the actual combination of physical and biological processes that determines this linkage has not been identified. This paper describes a possible scenario in which water column stability is the primary factor by which the physical environment influences phytoplankton production, the basis for production at higher trophic levels. Variation in the strength of the wintertime Aleutian Low pressure area affects water column stabilities, hence primary production, along the entire eastern boundary of the North Pacific. The 'optimal stability window' explains the qualitative relationship between fish stocks and the strength of the winter Aleutian Low, as well as the observed out-of-phase variation between northern and southern salmon stocks.

Ginn TR and FJ Loge. 2007. "Dose-structured population dynamics." Mathematical Biosciences 208:325-343.

Applied population dynamics modeling is relied upon with increasing frequency to quantify how human activities affect human and non-human populations. Current techniques include variously the population's spatial transport, age, size, and physiology, but typically not the life-histories of exposure to other important things occurring in the ambient environment, such as chemicals, heat, or radiation. Consequently, the effects of such 'abiotic' aspects of an ecosystem on populations are only currently addressed through individual-based modeling approaches that despite broad utility are limited in their applicability to realistic ecosystems [V. Grimm, Ten years of individual-based modeling in ecology: what have we learned and what could we learn in the future? Ecol. Model. 115 (1999) 129-148][1]. We describe a new category of population dynamics modeling, wherein population dynamical states of the biotic phases are structured on dose, and apply this framework to demonstrate how chemical species or other ambient aspects can be included in population dynamics in three separate examples involving growth suppression in fish, inactivation of microorganisms with ultraviolet irradiation, and metabolic lag in population growth. Dose-structuring is based on a kinematic approach that is a simple generalization of age-structuring, views the ecosystem as a multicomponent mixture with reacting biotic/abiotic components. The resulting model framework accommodates (a) different memories of exposure as in recovery from toxic ambient conditions, (b) differentiation between exogenous and endogenous sources of variation in population response, and (c) quantification of acute or sub-acute effects on populations arising from life-history exposures to abiotic species. Classical models do not easily address the very important fact that organisms differ and have different experiences over their life cycle. The dose structuring is one approach to incorporate some of these elements into the existing structures of the classical models, while retaining many of the features (and other limitations) of classical models.

Giorgi A, M Miller, and J Stevenson. 2002. *Mainstem Passage Strategies In the Columbia River System: Transportation, Spill, and Flow Augmentation*. Prepared by BioAnalysts, Inc., Redmond, Washington, for the Northwest Power Planning Council, Portland, Oregon.

The National Marine Fisheries Service 2000 Biological Opinion (BO) for the Federal Columbia River Power System (FCRPS) prescribes guidelines for smolt transportation, spill and flow augmentation to improve survival of salmonid stocks listed under the ESA (Appendix A). With respect to these strategies the NPPC is concerned about the following issues:

1. What does the scientific literature inform us regarding the benefits, shortcomings, or risks associated with each passage strategy, and as compared to other passage options?
2. Which aspects of the scientific information are in dispute?
3. What are the critical uncertainties attending each strategy?
4. What is being, or could be done to reduce uncertainty and disputes?

In terms of scope, the NPPC seeks information for both ESA-listed and unlisted salmonid populations across a range of water years. The Council seeks clear, concise and succinct treatment of these issues. Our approach is to review key research and analyses that have appeared in the literature, then distill out the key findings and synthesize the results. The focus is on evaluations conducted under contemporary river operations, which were initiated in the early 1990s and formalized as guidelines in the 1995 and 2000 Federal Columbia River Power System Biological Opinions. Additionally, we identify key uncertainties and gaps in the information base, and identify research that is in place or planned to fill those gaps.

Smolt Transportation

Using general, annual indices of performance, both NMFS and CBFWA analyses showed that the majority of the time, fish transported from Lower Granite and Little Goose dams produced TIRs higher than or equal to corresponding inriver control groups. Bouwes et al. (2001) concluded modest transportation benefits were evident for hatchery Chinook, and slight to negligible benefits for wild fish. Sandford and Smith (in press) state that, "once a juvenile fish is entrained in a bypass system at a "collector dam", transporting the fish maximizes the probability of its eventual return as an adult." Based on assessments by those two investigations, it appears that there is a survival advantage associated with transporting Snake River hatchery spring/summer Chinook and steelhead, particularly from the upper two dams, Lower Granite and Little Goose dams. However, the rationale for transporting smolts from Lower Monumental and McNary dams is less clear. The benefits of transporting Snake River hatchery fish from those dams are equivocal.

In some years, small sample sizes have resulted in poor or undefined precision for key estimates. This can limit the ability to make statistically defensible conclusions. Authors examining recent estimates do not confidently state that transported fish survive at significantly higher rates than inriver counterparts. Neither Sandford and Smith (in press), nor Bouwes et al. (2001) explicitly tested key hypotheses such as; $D > Vc$, or TIR > 1.0. Presumably future analyses by these two research groups will do so. In recent times the resurgence in adult returns offers improved precision and opportunities for meaningful statistical tests.

Whether or not wild fish respond favorably to transportation is difficult to ascertain at this juncture. Even though the limited numbers of evaluations indicate higher return rates for transported smolts, the estimates are based on such small sample sizes that the precision for wild fish is particularly poor. Thus, reliance on the point estimate as a representative value is questionable.

Survival from smolt to returning adult (SAR) for hatchery and wild spring summer Chinook has increased substantially since 1993, and has been increasing steadily from 1997-1999, reaching SAR levels in 1999 that approach and in some cases exceed the 2% minimum recovery threshold for wild stocks as identified in PATH (Figures 1.5 and 1.6). This suggests that neither transport nor inriver migration conditions may be a bottleneck to recovery, when marine-based survival is at some adequate level.

No mass transportation study has been conducted that targets Snake River fall Chinook. Such evaluations are warranted, and planned for initiation in 2002.

There is evidence to suggest that homing fidelity may be impaired for some species of transported fish, including fall Chinook, sockeye, and steelhead. Studies that target spring/summer Chinook and steelhead require emphasis. Straying may in part contribute to delayed effects associated with transporting smolts. It may be advantageous to ascertain the extent of straying associated with transport of all species to address certain ESA concerns. Excessive straying may result in increased hatchery fish intermingling among wild adults on the spawning grounds. This may not be desirable. Ongoing telemetry/PIT tag-based studies of adult passage should offer additional insight on this matter.

Delayed differential effects relative to inriver migrants are consistently evident for transported fish. However, by-and- large adult return rates to Lower Granite Dam exceed those of inriver migrants designated as controls. In such cases, there would still be a survival advantage to transport Snake River fish from Lower Granite and likely Little Goose dams.

Spill

Apart from the Snake River stocks, which can largely be transported, the majority of smolts emanating from the rest of the basin continue to migrate in-river to below Bonneville Dam. Optimizing smolt survival during downstream migration has been a longstanding goal of fisheries managers.

We focus on contemporary passage survival estimates and estimation techniques (balloon-, radio-, and PIT-tag methods) developed during the 1990's that continue to be applied this decade.

The collective information indicates that spillways appear to be the safest passage routes available at dams, even more benign than many smolt bypass systems, particularly those involving the screening of turbine intakes. The magnitude of smolt survival through spillways varies across dams and species. This is particularly evident when total effects are reflected in the empirically obtained estimates. This suggests that species- and dam-specific estimates should be updated for each dam and applied in any future passage modeling analyses. Spillway flow deflectors (gas abatement devices) appear to increase smolt mortality relative to a standard spillbay, by 1-3 percentage points. Even so, survival will typically still exceed the turbine route at most dams. The potential for increased smolt losses at the concrete needs to be balanced against gains associated with gas abatement. It is not clear that passage models currently provide an accurate assessment of this tradeoff.

Studies assessing the direct and total effects associated with spillway passage indicate that survival is related to discharge at some sites, with mortality increasing at excessive discharge volumes. The difference in survival across discharges can range from negligible to nearly 7 percentage points, depending on the dam and species.

In passage modeling analyses, values for model parameters should be periodically updated for each dam and species. The set of empirical estimates that characterize smolt passage survival through spillways, as well as spill efficiency, are being continually expanded. However, that collective information is not being systematically compiled and synthesized on a regular basis for the hydrosystem at large. Notable exceptions include papers by Muir et al. (2001a), Ploskey et al. (2001) and Anglea et al. (2001) for selected sites.

Passage modeling may afford the only practical means to evaluate the relative benefits of various spill scenarios, at the level of the overall smolt population. The other approach requires obtaining reliable empirical survival estimates linked specifically to spill conditions. This requires a well-designed experimental protocol that will likely be very difficult to implement in this complex system of competing uses.

The NMFS Total Dissolved Gas standard of a maximum 120% saturation in the tailrace of Columbia River dams is generally achievable by following the dam-specific gas caps identified in the Biological Opinion, and implementing the spill program currently in place in the Mid- Columbia. The exception occurs in higher flow years when spill volumes cannot be effectively controlled due to flows exceeding the hydraulic capacities at the various dams. The standard appears satisfactory for protecting salmonid species within the hydro-system, but it exceeds water quality guidelines established by the Environmental Protection Agency.

The full biological impacts of a spill program have not been evaluated in their entirety. Smolt survival receives emphasis. Model analyses try to predict changes in smolt survival to below Bonneville Dam. Quantitative system analyses have not formally addressed the potential for impacts on adult mortality.

Empirical evaluations conducted in situ, have limitations as well. For example those recently conducted by Zabel et al. (in press) and FPC (2001) observed changes over small segments (projects), thus cumulative effects through the system are not evident. Furthermore, results from empirical evaluations are equivocal, because spill effects have not been clearly isolated from other factors.

The effects of spill operations and levels on adult passage behavior as linked to long-term survival are not well understood. Some of the recent adult passage research suggests that higher spill volumes may exacerbate migration delay and fallback. But, convincing quantitative relationships have not been developed. Adult passage studies are continuing and may provide insight on these matters.

Flow Augmentation

Flow augmentation (FA) is the intentional release of water from storage reservoirs for the purpose of increasing flows to enhance migratory conditions for juvenile and adult life stages of salmonids in the Snake and Columbia rivers. Flow augmentation provided to the upper Columbia River (downstream from Chief Joseph Dam) comes from large storage reservoirs such as Grand Coulee Dam and a complex of storage reservoirs that drain into it from Canada and Montana. In the Snake River flow augmentation is provided from Dworshak Dam and through the Hells Canyon Complex in Idaho (Figure 3.1). The foundation for prescribing such actions is based on two premises:

1. Increased water velocity ◊ increases migration speed of smolts ◊ increases survival.
2. Lowering water temperature (summer) ◊ improves migratory and rearing conditions for both juvenile and adult salmonids ◊ results in improved survival.

Information obtained or reported since the early 1990's is the focus of this report, but a brief historical backdrop is provided where needed. Both river operations and the mark-recapture tools and associated analytical procedures have changed markedly from previous decades. Thus, the contemporary information is most applicable today.

Flow effects on smolt migration speed: For most spring- migrating species the evidence indicates that increased flow (water velocity) contributes to swifter migration speed. Information regarding fall Chinook is equivocal.

- River discharge appears to be the most influential variable affecting migration speed of steelhead and sockeye salmon in the Snake and mid-Columbia rivers.
- Two factors, flow and the degree of smolt physiological development, explain the observed variation in the migration rate of yearling Chinook salmon (except in the mid-Columbia where only smolt development has been identified as a predictor variable).
- At least four variables have been implicated as influencing the migration speed of subyearling (fall or summer/fall) Chinook; flow, water temperature, turbidity and fish size. However, strong correlations among these predictor variables confound the ability to identify causative agents.

Flow effects on smolt survival: PIT tag based smolt survival estimates acquired since 1993 provide the most relevant data set for characterizing smolt survival dynamics through the impounded mainstem Snake and Columbia rivers.

- Based on recent PIT tagged based estimates there is little evidence supporting a flow survival relationship across the water years experienced from 1993-2000, for yearling Chinook or steelhead.
- However, in 2001 under the extreme low flow conditions, steelhead survival decreased dramatically to about 63% per project (typically it is near 90%). Slow migration speed and rapidly increasing water temperatures are implicated as causative factors affecting residualization and mortality.
- A complex of factors is implicated as influencing Snake River fall Chinook survival including, flow, water temperature and turbidity. These environmental variables are strongly correlated during the summer migration, confounding the ability to identify the most influential one. Knowing if water velocity or temperature is the most influential could be important when the decision is to use Dworshak or Hell's Canyon for flow augmentation, since the temperature of those water sources differs greatly.

The premise for reducing summer water temperature, particularly in the Snake River, to improve rearing and migratory conditions for juvenile fall Chinook and adult salmonids appears sound.

- The literature indicates that maintaining river temperatures at or below 20°C is advantageous to both life stages of fall Chinook, and adult steelhead, all of which are in the river in August and early September.

However, it is not clear that releasing cool water from Dworshak effectively alters the thermal structure of most of the Lower Snake River. The major effect is localized at two upper reservoirs (LGR, LGS) according to results reported by Bennett et al. (1997).

- When cool water enters the reservoirs it sinks to the bottom. This can provide cool refugia in deeper waters, but not uniform cooling of reservoirs.
- The greatest change in temperature attributable to FA releases from Dworshak is evident at LGR, where water temperatures under FA are predicted to be as much as 4-8°F below base conditions at certain times. At Ice Harbor the difference is on the order of 1-2 °F.

Flow Augmentation Evaluations are generally lacking. Only a handful of studies have attempted to:

- Quantify the volume and shape of water provided specifically as FA.
- Translate that incremental increase in flows to changes in water velocity and temperature.
- Predict the change in smolt travel time and survival attributable to those increases
- Identify whether populations of interest (e.g., ESA stocks) have encountered FA events.

The last such evaluation treated information through the 1995 water year, and only for the Snake River. Given the community's sensitivity to this controversial management action, a holistic comprehensive updated evaluation seems prudent, and long overdue. The scope of future evaluations need to more fully address the balance of benefits and risks between anadromous and resident fish resources.

Goniea TM, ML Keefer, TC Bjornn, CA Peery, DH Bennett, and LC Stuehrenberg. 2006. "Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures." *Transactions of the American Fisheries Society* 135(2):408-419.

The relationships between lower Columbia River water temperatures and migration rates, temporary tributary use, and run timing of adult fall Chinook salmon (*Oncorhynchus tshawytscha*) were studied using historical counts at dams and recently collected radiotelemetry data. The results from more than 2,100 upriver bright fall Chinook salmon radio-tagged over 6 years (1998, 2000-2004) showed that mean and median migration rates through the lower Columbia River slowed significantly when water temperatures were above about 20 degrees C. Slowed migration was strongly associated with temporary use of tributaries, which averaged 2-7 degrees C cooler than the main stem. The proportion of radio-tagged salmon using tributaries increased exponentially as Columbia River temperatures rose within the year, and use was highest in the warmest years. The historical passage data showed significant shifts in fall Chinook salmon run timing distributions concomitant with Columbia River warming and consistent with increasing use of thermal refugia. Collectively, these observations suggest that Columbia River fall Chinook salmon predictably alter their migration behaviors in response to elevated temperatures. Coolwater tributaries appear to represent critical habitat areas in warm years, and we recommend that both main-stem thermal characteristics and areas of refuge be considered when establishing regulations to protect summer and fall migrants.

Greene CM and TJ Beechie. 2004. "Consequences of potential density-dependent mechanisms on recovery of ocean-type Chinook salmon (*Oncorhynchus tshawytscha*)." *Canadian Journal of Fisheries and Aquatic Sciences* 61(4):590-602.

Restoring salmon populations depends on our ability to predict the consequences of improving aquatic habitats used by salmon. Using a Leslie matrix model for Chinook salmon (*Oncorhynchus tshawytscha*) that specifies transitions among spawning nests (redds), streams, tidal deltas, nearshore habitats, and the ocean, we compared the relative importance of different habitats under three density-dependent scenarios: juvenile density independence, density-dependent mortality within streams, delta, and nearshore, and density-dependent migration among streams, delta, and nearshore. Each scenario assumed density dependence during spawning. We examined how these scenarios influenced priorities for habitat restoration using a set of hypothetical watersheds whose habitat areas could be systematically varied, as well as the Duwamish and Skagit rivers. In all watersheds, the three scenarios shared high sensitivity to changes in in nearshore and ocean mortality and produced similar responses to changes in other parameters controlling mortality (i.e., habitat quality). However, the three scenarios exhibited striking variation in population response to changes in habitat area (i.e., capacity). These findings indicate that nearshore habitat relationships may play significant roles for salmon populations and that the relative importance of restoring habitat area will depend on the mechanism of density dependence influencing salmon stocks.

Greene CH, BA Block, DW Welch, G Jackson, GL Lawson, and EL Rechisky. 2009. "Advances in Conservation Oceanography." *Oceanography* 22:210-223.

Overexploitation of living resources and climate change are among the most obvious global-scale impacts of human society on marine ecosystems. In an age of such large-scale anthropogenic impacts, marine scientists, resource managers, and policymakers must rethink their approaches to protecting and managing marine populations and ecosystems. Conservation oceanography is an emerging field of science that incorporates the latest advances in ocean science and technology to provide resource managers and policymakers with the information they need to ensure the sustainability of the marine environment and its living resources. Here, we discuss the historical context of conservation oceanography as it applies to marine fisheries management. We then describe two projects, one focused on Atlantic bluefin tuna and the other on Pacific salmon, that illustrate the potential of new tagging and tracking technologies for transforming the science underlying fisheries management.

Hall JE, J Chamberlin, AN Kagley, C Greene, and KL Fresh. 2009. "Effects of Gastric and Surgical Insertions of Dummy Ultrasonic Transmitters on Juvenile Chinook Salmon in Seawater." *Transactions of the American Fisheries Society* 138(1):52-57.

The objective of this study was to develop guidance for tagging methods for juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in their first ocean year by evaluating the effects of tagging during this critical life stage. We compared survival over 42 d among juvenile hatchery Chinook salmon receiving surgically implanted dummy ultrasonic transmitters (equivalent to VEMCO V7-1 L tags) ranging from 2.6% to 8.8% of body mass with that of fish receiving gastrically implanted tags. Survival was significantly lower in fish receiving gastrically implanted transmitters (21%) than for the gastric-sham (66%), surgery (61%), surgery-sham (58%), and control treatments (90%). Survival was also significantly higher in the control treatment than in all other treatments. The results of this study indicate that surgical insertion into the peritoneal cavity is the preferred method of transmitter implantation in juvenile Chinook salmon in their first ocean year and that the transmitters should be less than 5.8% of the fish's body mass to reduce transmitter-related mortality.

Halsing DL and MR Moore. 2009. "Cost-Effective Management of Snake River Chinook Salmon: Response to Wilson et al." *Conservation Biology* 23(2):479-481.

Management decisions related to recovery of Snake River spring- and summer-run (SRSS) Chinook salmon should be informed by sound science. The Comment by Wilson et al. (2009 [this issue]) has the apparent purpose of discrediting the quality of our analysis in Halsing and Moore (2008), such that the results would not be used to inform decisions. But we agree on use of our results: although our methodology is sound, the results should not directly guide such decision making. We state this at important points in our paper: in the abstract,

> Application of our results to salmon management is limited by data availability and model assumptions, but these limitations can help guide research that addresses critical uncertainties and information (p. 338);

in the final paragraph of the introduction,

> Direct application of the results to salmon management, however, is limited by data availability and model assumptions (p. 340);

and, in the final paragraph of the paper,

> This approach can be utilized by resource managers with responsibility for salmon recovery as new evidence becomes available on the biological effectiveness and economic cost of additional management measures (p. 349).

Our stated purpose was to develop and demonstrate a methodology for linking biological and economic models to address SRSS Chinook salmon management. Perhaps Wilson et al. did not understand our intentions or believed they needed to reinforce the above points based on concern that managers would apply our results. We believe, however, that the Wilson et al. comment is very

misleading and quite strained in its effort to depict our analysis as inappropriate for a purpose for which it was never intended.

Halvorsen MB, LE Wysocki, CM Stehr, DH Baldwin, DR Chicoine, NL Scholz, and AN Popper. 2009. "Barging Effects on Sensory Systems of Chinook Salmon Smolts." *Transactions of the American Fisheries Society* 138(4):777-789.

To avoid mortality caused by passage through dam turbines and spillways, juvenile Chinook salmon (*Oncorhynchus tshawytscha*) are annually transported downstream by barge through the federal hydropower system on the Snake and Columbia rivers. Survival of transported fish is higher than that of in-river migrants; however, transported fish experience higher rates of postrelease mortality. Increased mortality could result from a decrease in the ability to detect or avoid predators due to stressors associated with the barge environment. This study examined the effects of barging on juvenile Chinook salmon olfaction and auditory function, two sensory systems involved in predator detection. We focused on dissolved metals known to be toxic to the salmon olfactory system and on the level of noise from the barge, which could impair the auditory system. Experimental groups included animals collected (1) before barge loading (control group), (2) at the Bonneville Dam bypass system (migrant fish), (3) immediately after barge transport, and (4) within 7 d postbarging and at or after 7 d postbarging. Measured concentrations of dissolved metals from the water within the barge were below established water quality criteria for the protection of aquatic life. Moreover, ultrastructural examination of the olfactory epithelium surface showed no evidence of injury to olfactory sensory neurons. Noise in the barge holding tanks had levels up to 136 dB referenced to 1 μPa (root mean square) with primary energy below 400 Hz. Auditory sensitivity was measured using the auditory-evoked potentials (AEP) technique. We found a small but statistically significant threshold shift for fish collected within 7 d postbarging, while in the 7-d-and-later postbarging group the AEP thresholds were similar to the control. Our findings indicate that the olfactory systems of transported Chinook salmon are intact and probably functional, while the auditory sensitivities are compromised with probable recovery.

Harvey CJ and PM Kareiva. 2005. "Community context and the influence of non-indigenous species on juvenile salmon survival in a Columbia River reservoir." *Biological Invasions* 7(4):651-663.

Non-indigenous species (NIS) have been called biological pollutants, which implies that reducing their numbers should reduce negative impacts. To test this hypothesis, we used food web models, parameterized with data from field studies, to ask how reducing the number of NIS co-occurring with endangered salmon would affect salmon mortality. Our analyses indicate that predation on Upper Columbia River spring Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) juveniles was affected very little by NIS reduction. The effects of removing NIS were partly or totally offset by indirect food web interactions, and were subtle compared to effects of native predator management. We predict that the most effective way of reducing predation on salmon smolts will involve managing native predators and targeted removals of specific NIS. Minimizing impact of established NIS thus entails not only reducing NIS prevalence, but also considering background management practices and community context.

Hinrichsen RA and TR Fisher. 2009. "Inferences on the Latent Mortality of Snake River Spring–Summer-Run Chinook Salmon Using Spawner–Recruit Models." *Transactions of the American Fisheries Society* 138(6):1232-1239.

The rapid decline of the Snake River spring–summer-run Chinook salmon (*Oncorhynchus tshawytscha*) evolutionarily significant unit (ESU) in the 1990s led a group of scientists to develop the Plan for Analyzing and Testing Hypotheses (PATH). Under this plan, researchers used spawner–recruit (SR) data to estimate the survival of out-migrating smolts through eight dams of the Federal Columbia River Power System (FCRPS). Direct measurements of survival during out-migration, known as passage survival, were not available, so the PATH scientists estimated survival for index populations using trends from Ricker-type SR models. This modeling framework had the advantage of estimating both the direct and indirect (or latent) effects (FCRPS-related mortalities that do not occur until the smolts have passed the FCRPS dams) on the life cycle survival of the populations. We evaluated the SR model used by the PATH scientists by examining how changes in model structure affected important inferences. We calculated condition indexes as measures of the sensitivity of the model results to perturbations in the SR data and model structure, finding that the results were highly sensitive to certain assumptions. In particular, we found that changing the Ricker a term from a population-specific parameter to a parameter common to all of the populations in the ESU changed total passage survival from 9% to 56% and latent mortality from one-half the total passage mortality to a value that is not significantly different from zero. Therefore, the condition indexes revealed high potential sensitivities of the SR model results to perturbations in data and model structure. Although information criteria indicated that the population-specific model had a poorer fit than lower-parameter models, it was impossible to resolve the question as to whether there was latent mortality.

Hockersmith EE, RS Brown, and TL Liedtke. 2008. *Comparative Performance of Acoustic-Tagged and Passive Integrated Transponder-Tagged Juvenile Salmonids*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, the Pacific Northwest National Laboratory, Richland, Washington, and the U.S. Geological Survey, Cook, Washington, for the Environmental Resources Branch, Planning and Engineering Division, Portland District, U.S. Army Corps of Engineers, Portland, Oregon. Contract no. W66QKZ60441152.

The goal of this study was to determine whether fish tagged with the Juvenile Salmonid Acoustic Telemetry System (JSATS) tag could provide unbiased estimates of passage behavior and survival within the performance life of the tag. We conducted field studies to assess tag effects using hatchery reared Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*). Tag effects were also evaluated in cooperative laboratory studies by the Pacific Northwest National Laboratory and the U.S. Geological Survey. For the field evaluation, we released a total of 996 acoustic-tagged fish in conjunction with 21,026 PIT-tagged fish into the tailrace of Lower Granite Dam on 6 and 13 May 2006. The acoustic tags were 16.9 mm in length, 5.5 mm in diameter, and weighed 0.66 g in air (an average of 2.7% of the fish weight). A PIT tag was inserted along with the acoustic tag at the time of tagging. Travel times, detection probabilities, and survival were estimated from PIT-tag detections of individual fish at Little Goose, Lower Monumental, McNary, John Day, and Bonneville Dams. Migration rates, detection probabilities, survival, and avian predation rates were compared between fish tagged with both a JSATS and PIT tag and those tagged with only a PIT tag.

Travel times between release and downstream dams were not significantly different between acoustic-tagged and PIT-tagged fish for the majority of reaches evaluated. For fish released on 6 May, we observed some significant differences in travel times; however, these differences were generally 1 d or less and may have been related to sample sizes of acoustic-tagged fish. PIT-tag detection probabilities for acoustic- and PIT-tagged fish were similar, and differences were 2% or less. Estimated survival was not statistically different among tag types between the tailrace of Lower Granite Dam and downstream sites

except in the first reach (Lower Granite Dam tailrace to Little Goose Dam tailrace) where acoustic-tagged fish had higher survival than PIT-tagged fish. Avian predation rates were similar between acoustic-tagged and PIT-tagged fish.

Holecek DE, KJ Cromwell, and BP Kennedy. 2009. "Juvenile Chinook Salmon Summer Microhabitat Availability, Use, and Selection in a Central Idaho Wilderness Stream." *Transactions of the American Fisheries Society* 138(3):633-644.

We measured summer microhabitat use, availability, and selection by age-0 Chinook salmon (*Oncorhynchus tshawystscha*) in the Big Creck drainage, Idaho. Age-0 fish selected for low-velocity (0-25 cm/s), moderate-depth (40-80 cm) habitats that were located within 80 cm of cover. Pools (52%) and runs (38.5%) were the most commonly used habitat types. while pebbles (33.7%) and sand (234) were the most Often Used substrates. Cover type use was predominated by woody debt is (54.8%) and rock outcrops (23.7%). Run (38.5%) and riffle (32.9%) were the most available habitats in Big Creek, while pebble (38.4%) and cobble (28.2%) were the most available substrates. Mean water velocity (47 cm/s) availability and distance to cover (108 cm) availability were greater than those selected by age-0 Chinook salmon. while mean total water depth (30 cm) availability was lower than that selected by the Fish. Linear. regression was used to show that all increase in Juvenile Chinook Salmon total length was significantly ($P < 0.05$) related to increased total water depth ($r(2) = 0.08$). local water depth ($r(2) = 0.73$). and focal water velocity ($r(2)=0.49$) use. The relationship of habitat use and fish total lengths indicate that even within it short temporal period. juvenile Chinook salmon will select for different habitats its they grow. Upper and lower Big Creek microhabitat availability characteristics differed significantly ($P < 0.05$). Upper Big Creek had more fish per unit of preferred rearing habitat than lower Big Creek, Which suggests that either summer microhabitat availability or redd density partially explain the density differences observed in Big Creek. Microhabitat use and availability were useful for identifying habitat selection of age-0 Chinook salmon in Big Creck. The data from this study can be Used for future identification, quantification, and restoration of suitable Chinook salmon rearing habitat in other Pacific Northwest streams.

Hurst TP. 2007. "Causes and consequences of winter mortality in fishes." *Journal of Fish Biology* 71(2):315-345.

Winter mortality has been documented in a large number of freshwater fish populations, and a smaller, but increasing, number of marine and estuarine fishes. The impacted populations include a number of important North American and European resource species, yet the sources of winter mortality remain unidentified in most populations where it has been documented. Among the potential sources, thermal stress and starvation have received the most research attention. Other sources including predation and pathogens have significant impacts but have received insufficient attention to date. Designs of more recent laboratory experiments have reflected recognition of the potential for interactions among these co-occurring stressors. Geographic patterns in winter mortality are, in some cases, linked to latitudinal clines in winter severity and variability. However, for many freshwater species in particular, the effects of local community structure (predators and prey) may overwhelm latitudinal patterns. Marine (and estuarine) systems differ from freshwater systems in several aspects important to overwintering fishes, the most important being the lack of isolating barriers in the ocean. While open population boundaries allow fish to adopt migration strategies minimizing exposure to thermal stresses, they may retard rates of evolution to local environments. Geographic patterns in the occurrence and causes of winter mortality are ultimately determined by the interaction of regional and local factors. Winter mortality impacts population dynamics through episodic depressions in stock size and regulation of annual cohort strength. While the former tends to act in a density-independent manner, the latter can be density dependent, as most sources of mortality tend to select against the smallest members of the cohort and population. Most stock assessment and management regimes have yet to explicitly incorporate the variability in winter mortality. Potential management responses include postponement of cohort evaluation (to after first winter of life), harvest restrictions following mortality events and habitat enhancement. Future research should place more emphasis on the ecological aspects of winter mortality including the influences of food-web structure on starvation and predation. Beyond illuminating an understudied life-history phase, studies of overwintering ecology are integral to contemporary issues in fisheries ecology including ecosystem management, habitat evaluation, and impacts of climate change. (c) 2007 The Author Journal compilation (C) 2007 The Fisheries Society of the British Isles.

ICF Jones & Stokes (ICF J&S). 2009. Evaluation of Effects of Extended Transport on Survival of Salmonid Smolts: Impacts of Fish Predation in the Lower Columbia River. Final Report ICF J&S 00776.08, prepared by ICF J&S, Vashon, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Transporting juvenile fish from the Lower Snake River collection projects provides a mechanism for moving migrating smolts downstream, and thereby avoiding further direct dam and reservoir effects experienced by in-river migrants. In recent years, strategies to fine tune the transportation program have been initiated. The strategies have been largely driven by the actions and needs identified in Biological Opinions to assist the recovery of Endangered Species Act (ESA) listed fish. In 2005, a pilot study was initiated to investigate the adult return rate effect on transported smolts from releasing them near the mouth of the Columbia River as compared to the standard release site just downstream from Bonneville Dam. This project utilized recommendations from previous AFEP program studies suggesting that releasing fish nearer to the saltwater environment could increase adult return rates of transportedjuveniles. In 2006-2007, tagged experimental groups of smolts have been released on an outgoing tide, during nighttime hours to determine if survival to adult return for these fish noticeably improved over the standard release site.

This investigation was initiated to address concerns raised by regional fishery managers that unexpected consequences might occur with this strategy to both listed and unlisted in-river migrating fish from both the Snake and Columbia rivers.

Our evaluation of the potential effect of alternative transport release points on smolt survival through the lower Columbia River (Bonneville Dam to Rkm 0) of non-transported hatchery and wild salmonids originating from above and below Bonneville Dam was based on a predictive model that incorporates available information and data, and, as necessary, professional judgment.

The reader should not interpret the results of this analysis as predictions applicable to any particular year or as a stochastic inference capable of being bounded by confidence intervals. There are far too many unknowns surrounding smolt predation in the lower Columbia River and estuary to characterize any a priori evaluation of extended transportation as a prediction of this type. Rather, our exercise should be considered primarily as the logical implications of a plausible model of predator-prey relationships. This non-stochastic model posits a relationship between the proportion of each prey type in a predator's diet and the proportion of that prey type in the environment. Within this general predator-prey relationship, our model adds the reasonable qualifications that predation on a particular prey species should increase

with greater exposure to predator populations and the degree of overlap between periods of peak prey outmigration and maximum energy need in the predator population.

The components of the model were: (A) Transportation scenarios, (B) In-river smolt abundance, (C) Predator-prey dynamics, and (D) Survival response on in-river migrants. Predators included in the model were northern pikeminnow (Ptychocheilus oregonensis), Caspian terns (Hydroprogne caspia, formerly Sterna caspia) and double-crested cormorants (Phalacrocorax auritus). Predation intensity was computed via bioenergetics models. Predation rates on key smolt types (subyearling Chinook, yearling Chinook, coho and steelhead) was computed using Ivlev's Electivity Index (E):

$$E = (r - p) / (r + p)$$

where r is the proportion of prey of a specific type in the diet and p is the proportion of the prey type in the environment.

Model predictions of predation show that extended transportation provides a substantial benefit to the survival of transported fish through the lower Columbia. The ratio of extended transport survival to survival under status quo transport was 1.1 to1.4, depending on smolt type, with subyearling Chinook predicted to benefit most. Extended transport was estimated to have a small effect (survival ratio of 0.97 to 0.99) on the survival of non-transported smolts, whether they originate upstream or downstream of Bonneville Dam.

We also computed the effect of extended transportation on the survival of a combined population of transported and non-transported smolts. Survival of subyearling Chinook was predicted to increase by about 10% when averaged over both migration types. Comparable results for yearling Chinook and steelhead were 7% and 6%, respectively. Coho survival was predicted to decline by 2%.

The model predicted benefit of extended transportation to survival of transported fish to ocean entry was generally consistent with experimental observations. Ryan et al. (2007) determined that avian predation rates on PIT-tagged yearling Chinook released at Astoria were one seventh the rates of yearlings released at Skamania Landing. The same study estimated an eight-fold reduction in avian mortality for steelhead released at Astoria compared to steelhead released at Skamania Landing. Relative to fish released at Skamania Landing, our model predicted seven-fold and five-fold reductions in avian mortality for Astoria releases of yearling Chinook and steelhead, respectively. Explicitly, our model estimated that the mortality attributable to cormorant and tern predation from the East Sand Island nesting colonies were 12% and 2% for yearling Chinook released at Skamania and Astoria, respectively, and 17% and 3% for steelhead released at Skamania and Astoria. Model predictions of survival under extended transport are strongly influenced by assumed travel time through the estuary and especially by the proportion of a release assumed to have moved beyond the foraging radius of East Sand Island birds by dawn.

Because our results only examined the effects of predation to the point of ocean entry, we cannot claim that these results imply higher adult returns. Ryan et al. (2007) noted that extended transport fish may be unprepared to make an immediate transition to saltwater, and when forced to do so may incur a delayed mortality because of physiological stresses. The ultimate test must therefore compare adult recoveries from paired releases of fish under both kinds of transportation.

The significance of output from our model should be gauged by the congruity between its assessment of current predation rates and observed predation rates, as well as the conditions under which it predicts qualitatively different outcomes. Its primary use is to provide a quantitative perspective from which qualitative insights might be gained with respect to the complex predator-prey relationships occurring in the lower Columbia River and to help identify critical uncertainties, needed research and key elements of a monitoring plan to be conducted if extended transportation is implemented on a large scale.

Independent Scientific Advisory Board (ISAB). 2007a. *Climate Change Impacts on Columbia River Basin Fish and Wildlife*. Report no. 2007-2, Portland, Oregon.

Warming of the global climate is unequivocal. Evidence includes increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. Eleven of the last twelve years (1995 -2006) rank among the 12 warmest years in the instrumental record of global surface temperature (since 1850). The linear warming trend over the last 50 years (0.13 +/- 0.03°C per decade) is nearly twice that for the last 100 years. The total global average temperature increase from 1850 – 1899 to 2001 – 2005 is 0.76 +/- 0.19°C.

Climate records show that the Pacific Northwest has warmed about 1.0 ºC since 1900, or about 50% more than the global average warming over the same period. The warming rate for the Pacific Northwest over the next century is projected to be in the range of 0.1-0.6° C/decade. Projected precipitation changes for the region are relatively modest and unlikely to be distinguishable from natural variability until late in the 21st century. Most models project long-term increases in winter precipitation and decreases in summer precipitation. The changes in temperature and precipitation will alter the snow pack, stream flow, and water quality in the Columbia Basin:

- Warmer temperatures will result in more precipitation falling as rain rather than snow
- Snow pack will diminish, and stream flow timing will be altered
- Peak river flows will likely increase
- Water temperatures will continue to rise

These changes will have a variety of impacts on aquatic and terrestrial habitats in the Columbia Basin.

Independent Scientific Advisory Board (ISAB). 2007b. Latent Mortality Report – Review of Hypotheses and Causative Factors Contributing to Latent Mortality and Their Likely Relevance to the "Below Bonneville"; Component of the COMPASS Model. Report no. ISAB 2007-1, Portland, Oregon.

On November 27, 2006, NOAA Fisheries requested that the ISAB review a number of hypotheses about the causative factors that contribute to latent mortality. Additionally, the Columbia River Inter-Tribal Fish Commission urged the ISAB to agree on a method for assigning weights to the submitted hypotheses. These hypotheses are intended for incorporation in the Comprehensive Passage (COMPASS) model, specifically to affect the "below Bonneville" component of the model. In an effort to provide the modeling team with some initial input, the ISAB offers the following recommendations and conclusions:

- The ISAB recommends that the various components of latent mortality be merged into a single model. A merged data set should be used to evaluate this model with a statistical analysis that aids in selecting among hypotheses. The ISAB recommends this investigation as the most scientifically rigorous approach to reducing the number of alternative hypotheses based on all available data.

- The ISAB concludes that the hydrosystem causes some fish to experience latent mortality, but strongly advises against continuing to try to measure absolute latent mortality. Latent mortality relative to a damless reference is not measurable. Instead, the focus should be on the total mortality of in-river migrants and transported fish, which is the critical issue for recovery of listed salmonids. Efforts would be better expended on estimation of processes, such as in-river versus transport mortality that can be measured directly.
- Estimates based on limited time series have a high degree of uncertainty, and ocean conditions that affect survival will vary on several time/space scales. Thus there will be considerable uncertainty in estimates of post-BON survival, and the ISAB recommends that this uncertainty be accounted for as efforts to reduce it continue. Estimates of the uncertainty should be bounded and incorporated in simulation models and annual management planning processes.
- Future monitoring and research is needed to further quantify biological factors that contribute to variability in estimated post-BON mortality. In particular, the ISAB recommends that acoustic tags continue to be developed and used to assess and partition mortality in the lower river, the estuary, and the Pacific Ocean shelf. In addition, the ISAB recommends the continuation of PIT tagging with a monitoring and evaluation program designed to reduce the current levels of uncertainty.
- The ISAB also recommends that a logit modeling approach be investigated as a potential alternative framework for future modeling of post-BON mortality.

Independent Scientific Advisory Board (ISAB). 2008a. *Snake River Spill-Transport Review*. Report no. ISAB 2008-5, Portland, Oregon.

At NOAA Fisheries' March 28, 2008 request, the ISAB conducted this scientific review of seasonal variation in the benefit of transportation of smolts from four Snake River Evolutionary Significant Units (spring/summer Chinook, steelhead, sockeye, and fall Chinook). NOAA Fisheries' request included several questions, and in April 2008 the Columbia River Inter-Tribal Fish Commission (CRITFC) and the Oregon Department of Fish and Wildlife (ODFW) raised some additional questions. The three sets of questions had substantial overlap, and some questions were more related to policy and hence not appropriate for scientific review. Accordingly, the ISAB combined and condensed the three sets of questions into the five general questions presented below.

Structural and operational changes to the hydrosystem in 2006 and 2007 are not yet fully reflected in the data available for review in this report. Moreover, very few data are available to assess the impact of alternative spill-transport operations on species such as sockeye, coho salmon, and Pacific lamprey. Even the more plentiful data for Snake River spring/summer Chinook and steelhead do not yield unequivocal results about seasonal variation in the effectiveness of smolt transport. Given the magnitude of uncertainty imposed by the nature and extent of available information, the ISAB continues to see merit in a strategy of "spreading the risk" to balance the possible risks against the perceived benefits of juvenile salmonid transportation.

Independent Scientific Advisory Board (ISAB). 2008b. *Review of the Comprehensive Passage (COMPASS) Model – Version 1.1*. Report no. ISAB 2008-3, Portland, Oregon.

This report is the fourth in a series of ISAB reports pertaining to the development of the Comprehensive Passage Model (COMPASS) created by NOAA Fisheries along with federal, state, and tribal agencies and the University of Washington. COMPASS is intended to predict the effects of alternative hydropower operations on salmon survival rates and provide ongoing evaluation for the new Federal Columbia River Power System Biological Opinion (BiOp). COMPASS is a welcome addition to the analytical tools available to both scientists and managers. These periodic ISAB critiques have been explicitly intended to provide constructive suggestions to facilitate continuing development of a valuable modeling tool. The specific questions for this round of review, and our responses, are the following:

- Does the model successfully perform the desired capabilities, as listed below?
  - realistically portray the hydro-system and variable river conditions
    - The fit to available in-river and hydro-system data is quite good. With a few exceptions, the model has captured the impact of the variables considered. The question of how well the model will work for river conditions encountered in future years must await later data.
  - allow for the simulation of the effects of management actions
    - COMPASS will permit evaluation of a reasonable range of management options, though the passage data are still insufficient to fine-tune the management choices. Full-blown management simulation is (mostly) a future challenge for COMPASS, but the possibilities are promising.
  - characterize uncertainty in prediction
    - This version provides improved treatment of uncertainty, allowing for the correlation of estimates from sequential projects. The uncertainty is separated into components for stochastic sampling and for differences among time periods. How well that treatment serves the simulation effort must await a fully simulation-capable version.
  - represent hydro-system-related effects that occur outside the hydro-system
    - The Bonneville Dam (BON) → Ocean → BON survival component of the model is still poorly characterized, in the absence of reliable data from below Bonneville Dam. The ISAB's sense is that continuing to elaborate latent mortality is somewhat pointless, given the lack of comparable data from the pre-hydro-system period. The ISAB also concluded that it is time to separate the detailed survival experience of fish transported from each collection point (Lower Granite (DAM), Little Goose Dam (LGS), Lower Monumental Dam (LMO), and McNary Dam (MCN) separately, because those seem to be different, and it is not possible to model the transportation alternatives if transported fish from all four projects are treated as a single cohort.
- Is the model too complex or too simple?
  - The ISAB's sense is that the model is now of about the complexity that will be useful, and it is manageable.
- Does the model realistically represent the data and its variability?
  - The model allows for variability in prediction, based on variability in the input parameters. And, at least where the requisite empirical data exist, the model does a credible job of reflecting a

dynamic reality. The requisite data are sometimes in short supply, however, and both the COMPASS team and the ISAB recommend that more data of the necessary types be gathered.

- Are the statistical methods sound?
  - The COMPASS team's statistical methodology is generally sound, but questions remain about several of the methodology's finer points (the Akaike Information Criterion (AIC), log-linear versus logit-linear regression and prediction, multinomial versus normal error structures, and the inclusion or exclusion of a grand intercept term in the model). The effort is moving along nicely, but statistical methods are still evolving in this arena, and it is premature to view the methods embedded in COMPASS as firmly set.
- Is the documentation adequate?
  - The documentation is good, as far as it goes, though we offer some suggestions for additional improvements. The COMPASS team has decided to delay preparation of the User's Guide for a later effort. The ISAB's view is that deployment region-wide cannot realistically occur without that Guide. Strategic and management decisions are already being considered, and the BiOp is now reality, all of which argue for early availability.

In response to the ISAB's third-round critique of the COMPASS document, the COMPASS team provided a variety of responses. The ISAB has used this opportunity to provide additional feedback on those responses, by way of iterating the conversation.

Finally, we provide a detailed critique on each section of the current version of COMPASS 1.1. This critique is offered in the spirit of constructive suggestion to the COMPASS team, and we trust that our critique will be useful in continuing efforts to develop this valuable modeling tool for the region.

Independent Scientific Advisory Board (ISAB). 2008c. *Review of the Estuary Recovery Module*. Report no. ISAB 2008-2, Portland, Oregon.

Assignment Background

On November 27, 2007, the ISAB received an assignment from NOAA's Science and Research Director Dr. Usha Varanasi to provide a scientific review of the Columbia River Estuary ESA Recovery Plan Module for Salmon and Steelhead. The module was prepared under contract for NOAA's Northwest Regional Office to provide consistent treatment of the factors in the estuary that affect all listed salmon and steelhead in the Columbia River Basin. To inform the ISAB's review, Phil Trask (P.C Trask and Associates), the consultant that prepared the estuary module, gave a presentation to the ISAB in Portland on January 25 2008 and verbal responses to comments posed by ISAB members in their preliminary review.

The estuary module is intended to complement all Columbia River Basin salmon and steelhead recovery plans. Specifically, the purpose of the module is to identify and prioritize habitat-related management actions, that, if implemented, would reduce threats to salmon and steelhead in the Columbia River estuary and plume. The estuary module was prepared to link with the upstream recovery plans of the Federal Columbia River Power System (FCRPS) Biological Opinion as the estuary is a common area for all stocks in the Columbia River Basin.

In the context of the lower Columbia River management plans, the estuary module is said to be consistent with information in the Council's "Mainstem Lower Columbia River and Columbia River Estuary Subbasin Plan (NPCC, 2004), the Lower Columbia River Estuary Partnership's Comprehensive Conservation and Management Plan, and the Columbia River Estuary Study Taskforce's Columbia River Estuary Data Development Program. In addition, other ongoing planning processes will be using information from the estuary module to various degrees. These include the FCRPS Biological Opinion remand collaborative process and activities of the Lower Columbia Fish Recovery Board and Lower Columbia Stakeholders Group.

The importance of the Columbia River estuary habitats for juvenile and adult salmonids and our lack of scientific data from these areas have been recognized in several recent reviews by the ISAB and/or ISRP. These include a report on how estuary management fits into the Columbia River Basin Fish and Wildlife Program (ISAB 2000-5) and the subbasin plans review (ISRP/ISAB 2004-13). The estuary also featured prominently recently in the ISAB report on human population impacts on Columbia River Basin Fish and Wildlife because of the concentrations of urban development in the lower river and estuary (ISAB 2007-3). The need for additional research, monitoring, and evaluation of estuarine restoration projects has been noted in recent ISRP Retrospective Reports (e.g., ISRP 2005-14).

To provide a focused review of the estuary module, NOAA proposed six questions, as per below. The ISAB responded to each in depth, as time allowed, and also provided a detailed Appendix providing specific comments on the document.

Independent Scientific Advisory Board (ISAB). 2009. Tagging Report – A Comprehensive Review of Columbia River Basin Fish Tagging Technologies and Programs. Report no. ISAB 2009-1, Portland, Oregon.

Review Origins: In 2006, the Independent Scientific Review Panel (ISRP) reviewed 112 tagging-related proposals. All were submitted in response to the Northwest Power and Conservation Council's solicitation for Fiscal Years 2007-2009 implementation of the Columbia River Basin Fish and Wildlife Program (ISRP 2006a). Based on its examination of those proposals, the ISRP recommended, as it has several times since 1998, that the Fish and Wildlife Program would benefit from a comprehensive review of fish tagging projects funded by the program (ISRP 2006b).

Over several review cycles and in numerous reports, the ISRP raised issues about:

- identifying potential impacts on coded wire tag programs from regulations requiring mass marking of hatchery fish with adipose fin clips and mark-selective fisheries (ISRP 2005),
- finding long-term solutions to mathematical and statistical problems in the estimation of smolt-to-adult return rates from tagging data (ISRP 2002),
- developing coordinated annual operations plan for the application of PIT tags in support of long-term monitoring and evaluation of out-migration survival of juvenile salmon and return rates of adults (ISRP 2005),
- establishing a comprehensive design for tag data collection for the Basin (ISRP 2000), and
- implementing forward-looking monitoring/tagging programs designed to address questions that may arise in the future (ISRP 2000).

The ISRP suggested a review addressing the complex interactions between projects and, at the same time, recommended inclusion of projects involving smolts, Passive Integrated Transponder (PIT) tags, radio tags, coded wire tags (CWT), and acoustic tags.

Independent Scientific Advisory Board (ISAB). 2010. *Review of NOAA Fisheries' 2010 Low Flow Fish Transport Operations Proposal*. Report no. ISAB 2010-2, Portland, Oregon.

On February 25, 2010, NOAA Fisheries requested ISAB assistance with a question related to a low flow transportation proposal for the spring 2010 juvenile salmon outmigration. Current river forecasts predict a low flow year for 2010, prompting NOAA Fisheries to propose maximizing the transport of Snake River juvenile steelhead and spring/summer Chinook in the month of May. NOAA's specific charge to ISAB was: "Taking into account the ISAB's 2008 recommendation "whenever river conditions allow during the late April- May period, a strategy allowing for concurrent transportation and spill is prudent," NOAA (in looking at the data from the 2007 low-flow year), determined that if flow conditions in 2010 were similar to those in 2007 (i.e., < 65 kcfs), it would not be "prudent" to continue spilling water in May at the three collector projects as in 2007. The question for the ISAB was whether NOAA Fisheries had correctly interpreted the ISAB's recommendation. If not, NOAA requested further explanation of ISAB's reasoning in the 2008 recommendation."

Other parties have contributed data and analyses on this same issue, have raised additional questions, and/or have expressed their opinions on the proper course of action relative to spring spill for 2010. The NOAA Fisheries request asks for a review by early April 2010 to allow the ISAB findings to be considered in final operational decisions for this spring. In the interest of a timely decision on spring spill, we have concentrated on meeting the initial charge, but have commented on the ancillary issues as time has allowed.

The question of whether "river conditions allow" must necessarily involve a wide variety of other considerations. Among these considerations are projected power requirements and water demands, which are beyond the legitimate purview of the ISAB. From the standpoint of protecting the region's biotic resources, however, the ISAB's assessment of scientific data, references, and analyses that were reviewed leads us to the same conclusion as expressed in our previous review (ISAB 2008-5), specifically that spill should be viewed as a default condition and that a mixed strategy of transportation and spill, as implemented in recent years, is once again the strategy most in accord with the available scientific information.

As indicated in our previous review (ISAB 2008-5), "other analyses … indicate that as spill increases, in-river survival increases and the relative benefit of transportation decreases." The new data on steelhead and spring/summer Chinook are in accord with and reinforce the conclusions from that earlier report, to the effect that there are survival benefits to be gained from increased spill. However, available evidence indicates that there are overall benefits of transportation for steelhead and spring/summer Chinook under most environmental conditions. In reviewing additional information available since the 2008 ISAB review, smolt to adult return ratios (SARs) for transported fish (T), relative to those for in-river migrants (M), produce T:M ratios that may be summarized as:

- Steelhead, T:M (hatchery stocks) > T:M (wild stocks)
- Spring/Summer Chinook, T:M (hatchery stocks) > T:M (wild stocks)

- T:M (steelhead) >> T:M (spring/summer Chinook) > 1
- T:M ratios increase from early April through the end of May
- Increasing spill reduces the transportation SAR, relative to the in-river migrant SAR, but T:M ratios generally remain > 1.

There are, however, other species-specific and ecological considerations that require examination. The earlier data on sockeye were preliminary and inconclusive, and more and better data are available from the new reports. These new data indicate that the 2007 survival of sockeye was much better than that from 2005. A notable difference in hydrosystem management was court-ordered spill in 2007. Sockeye returns in 2007 were strong in both mid-Columbia and Snake River populations and it appears that favorable oceanic conditions may have been partly responsible for the increased survival of both stocks from the 2007 cohort. It appears that in-river Snake River stocks benefited more than did mid-Columbia stocks. A clear interpretation of the effect of a mixed transportation and spill strategy on Snake River sockeye survival is not yet available. The proposed NOAA Operations Proposal would result in transport of a major proportion of migrating juvenile sockeye from the Snake River.

Straying of Snake River steelhead into Lower Columbia River tributaries (e.g., John Day River) appears to be elevated for transported fish, relative to those that migrate in-river. Some straying is to be expected, under natural conditions, but the rates from transported fish are increased. A detailed assessment of the adaptive consequences of genetic introgression of Snake River stocks into the local gene pools lies mostly in the future, but early results are reason for concern for the Middle Columbia stocks, some of which are listed under the Endangered Species Act (ESA).

There are other species in the Columbia River and its tributary watersheds that require attention, among them Pacific lamprey. Data are too limited at this time to clearly evaluate the likely effects of NOAA's proposed transport operations on Pacific lamprey. In summary, there are a number of competing considerations that must be weighed in the decision on spring spill, some of which favor transportation, some of which favor spill. Snake River steelhead and spring/summer Chinook are not the only species of interest, as important as they are. Snake River sockeye and Middle Columbia steelhead are also major factors, and lamprey though still poorly understood warrant consideration. There will be other species that will become matters of concern in the future, none of which had transportation as their normal travel vector. Further, a low flow year, such as is projected for 2010, allows proactive evaluation of the utility of spill under conditions likely to be faced in the future.

The new data buttress and extend the earlier data, but uncertainties remain. Thus, the ISAB conclusion is the same now as it was in 2008. From a scientific standpoint, a mixed strategy for spill and transport is best supported by the available science. Ecological and evolutionary considerations provide an important framework in support of this strategy.

Independent Scientific Advisory Board (ISAB) and Independent Scientific Review Panel (ISRP). 2007. *Review of the Comparative Survival Study's (CSS) Ten-Year Retrospective Summary Report*. Report no. ISAB 2007-6, Portland, Oregon.

This report is the most recent in a series of ISAB and ISRP reviews of the Comparative Survival Study. The Northwest Power and Conservation Council (the Council) requested this current ISAB and ISRP review of the CSS Ten-Year Retrospective Summary Report to inform the funding decision for the CSS proposal for Fiscal Years 2008 and 2009. This review follows on an earlier review by the ISAB of the CSS 2005 Annual Report, also requested by the Council, in which two questions were posed. These two questions were given provisional answers in the ISAB review, and a number of specific concerns were identified that made the Annual Report an inadequate source of information to answer those questions more thoroughly. The ISAB review of the CSS 2005 Annual Report (ISAB 2006-32) included a recommendation that the CSS team prepare a summary and retrospective synthesis of the first 10 years of the project, because such a synthetic review of information and interpretation was needed to provide clear answers to the questions posed by the Council, as well as to support other management applications and scientific interpretations of the CSS results. This current review is of the resultant CSS 10-Year Retrospective Report, which has been completed in response to the ISAB 2006-3 recommendations and directive from the Council. This ISAB and ISRP review was requested by the Council, which also asked that the ISAB and ISRP evaluate the responsiveness of the Retrospective to comments in ISAB 2006-3 and again provide answers to the Council's two questions.

The ISAB and ISRP find that the ten-year summary report is clear, thorough, responsive to past ISAB comments, and was completed in a retrospective style, a major accomplishment for which we commend the CSS investigators. The ISAB/ISRP provide their detailed evaluation in four parts: the ISRP recommendation for the CSS FY 2007-09 proposal, the ISAB/ISRP response to the two questions posed by the Council in their 2005 request for review of the CSS, an evaluation of the effectiveness of the CSS Retrospective in answering the concerns that were posed by the ISAB's review of the 2005 Annual Report, and chapter by chapter specific comments for the CSS team.

The ISRP finds that the CSS FY 2007-09 proposal Meets Scientific Review Criteria (In Part). Specifically, the ISRP finds that the first three biological objectives of the CSS proposal (Estimate Smolt to Adult Survival Rates [SARs], SAR Hydro Goal, and Transport to Control [T/C] Ratios) meet scientific review criteria. The ISRP finds that the fourth objective (Upriver/Downriver Comparisons) does not meet scientific review criteria, because of inevitable confounding from other factors in establishing cause(s) of upriver/downriver differences that may be detected, regardless of sample size and detection power that could be achieved.

Overall, the CSS Ten-Year Retrospective was effective in answering the concerns posed by the ISAB's review of the CSS 2005 Annual Report (ISAB 2006-3). The Retrospective provided improved clarity in the presentation and explanation of the sophisticated methodologies used in analyses of CSS data. The scope of CSS investigations resulted in an extensive report, containing many detailed summaries of past and present work, and the report presents key data and data summaries in support of their major conclusions. The CSS team has responded very well in a short time frame to the difficult challenge of including enough details to allow scientific review, while avoiding obfuscation by sheer volume of material.

Kareiva P, M Marvier, and M McClure. 2000b. "Recovery and Management Options for Spring/Summer Chinook Salmon in the Columbia River Basin." *Science* 290(5493):977-979.

Construction of four dams on the lower Snake River (in northwestern United States) between 1961 and 1975 altered salmon spawning habitat, elevated smolt and adult migration mortality, and contributed to severe declines of Snake River salmon populations. By applying a matrix model to long-term population data, we found that (i) dam passage improvements have dramatically mitigated direct mortality associated with dams; (ii) even if main stem survival were elevated to 100%, Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*) would probably continue to decline toward extinction; and

(iii) modest reductions in first-year mortality or estuarine mortality would reverse current population declines.

Keefer, ML, CC Caudill, CA Peery, and TC Bjornn. 2006a. "Route selection in a large river during the homing migration of Chinook salmon (*Oncorhynchus tshawytscha*)." *Canadian Journal of Fisheries and Aquatic Sciences* 63(8):1752-1762.

Upstream-migrating adult salmon must make a series of correct navigation and route-selection decisions to successfully locate natal streams. In this field study, we examined factors influencing migration route selections early in the migration of 4361 radio-tagged adult Chinook salmon (*Oncorhynchus tshawytscha*) as they moved upstream past dams in the large (similar to 1 km wide) Columbia River. Substantial behavioral differences were observed among 11 conspecific populations, despite largely concurrent migrations. At dams, Chinook salmon generally preferred ladder passage routes adjacent to the shoreline where their natal tributaries entered, and the degree of preference increased as salmon proximity to natal tributaries increased. Columbia River discharge also influenced route choices, explaining some route selection variability. We suggest that salmon detect lateral gradients in orientation cues across the Columbia River channel that are entrained within tributary plumes and that these gradients in cues can persist downstream for tens to hundreds of kilometres. Detection of tributary plumes in large river systems, using olfactory or other navigation cues, may facilitate efficient route selection and optimize energy conservation by long-distance migrants.

Keefer ML, CC Caudill, CA Peery, and SR Lee. 2008a. "Transporting juvenile salmonids around dams impairs adult migration." *Ecological Applications* 18(8):1888-1900.

Mitigation and ecosystem-restoration efforts may have unintended consequences on both target and nontarget populations. Important effects can be displaced in space and time, making them difficult to detect without monitoring at appropriate scales. Here, we examined the effects of a mitigation program for juvenile salmonids on subsequent adult migration behaviors and survival. Juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) were collected and uniquely tagged with passive integrated transponder (PIT) tags at Lower Granite Dam (Washington State, USA) on the Snake River and were then either transported downstream in barges in an effort to reduce out-migration mortality or returned to the river as a control group. Returning adults were collected and radio-tagged at Bonneville Dam (Washington-Oregon, USA) on the Columbia River 1-3 years later and then monitored during; 460 km of their homing migrations. The proportion of adults successfully homing was significantly lower, and unaccounted loss and permanent straying into non-natal rivers was higher, for barged fish of both species. On average, barged fish homed to Lower Granite Dam at rates about 10% lower than for in-river migrants. Barged fish were also 1.7-3.4 times more likely than in-river fish to fall back downstream past dams as adults, a behavior strongly associated with lower survival. These results suggest that juvenile transport impaired adult orientation or homing abilities, perhaps by disrupting sequential imprinting processes during juvenile out-migration. While juvenile transportation has clear short-term juvenilesurvival benefits, the delayed effects that manifest in adult stages illustrate the need to assess mitigation success throughout the life cycle of target organisms, i.e., the use of fitness-based measures. In the case of Snake River salmonids listed under the Endangered Species Act, the increased straying and potential associated genetic and demographic effects may represent significant risks to successful recovery for both target and nontarget populations.

Keefer ML, CC Caudill, CA Peery, SR Lee, BJ Burke, and ML Moser. 2006b. *Effects of transport during juvenile migration on behavior and fate of returning adult Chinook salmon and steelhead in the Columbia-Snake hydrosystem, 2000-2003*. Prepared by the U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, Idaho, and the Northwest Fisheries Science Center, National Ocean and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Portland and Walla Walla Districts, Portland and Walla Walla, Washington. Study code ADS-00-4.

We used radiotelemetry to examine the effects of juvenile transportation on adult fate and migration behaviors of 1,184 Snake River spring–summer Chinook salmon and steelhead. All study fish were collected and tagged with passive integrated transponder (PIT) tags as juveniles at Lower Granite Dam on the Snake River from 1998-2002 and returned as adults during 2000-2003. Approximately 60% of the adults radio-tagged in this study were transported in barges as juveniles from Snake River dams to release sites downstream from Bonneville Dam on the Columbia River. Juveniles that were not transported migrated downstream in-river.

Adult homing was significantly lower and unaccounted loss and permanent straying into non-natal basins was higher for both spring–summer Chinook salmon and steelhead that were barged as juveniles. On average, adult fish barged as juveniles homed to Lower Granite Dam at rates about 10% lower than fish that had migrated in-river. Homing to Lower Granite Dam differed between juvenile release years for both species, reflecting differences in treatments and river environment during both juvenile and adult migrations. The presence of fin clips (certain hatchery origin) was not significantly associated with Chinook salmon homing, while unclipped steelhead returned to Lower Granite Dam at significantly lower rates than fin-clipped fish. Straying rates in both species were higher among groups barged as juveniles. When compared to in-river migrants, barged Chinook salmon were 1.9 times more likely and barged steelhead were 1.3 times more likely to fall back at dams as adults. Among fish that fell back, a significantly greater proportion of barged fish also experienced multiple fallback events than in-river migrants.

Decreased homing, increased fallback, and increased straying rates by transported fish were inter-related and linked to hatchery origin in some cases. The results were consistent between species and years, strongly suggesting that juvenile transport impaired adult orientation of both hatchery and wild fish during return migration. Streams-of-origin and hatcheries-of-origin were unknown for most fish and differences among sub-basin stocks may have influenced results. However, there were clear associations between adult behavior and transport history, despite the potential presence of underlying sub-basin variation. Future studies are needed to isolate the effects migration timing, of origin, and of in-stream residence times upstream from Lower Granite Dam from those of transport history for Snake River salmon and steelhead. Overall, the results suggest that the benefits of barging juveniles may be reduced due to negative effects on returning adults. These effects are typically difficult to quantify and may include both adult losses and significant changes to population genetic structure caused by increased straying of barged fish.

Keefer ML, CA Peery, and CC Caudill. 2006c. "Long-distance downstream movements by homing adult chinook salmon." *Journal of Fish Biology* 68(3):944-950.

Unusually long downstream movements totalling several hundred kilometres to > 1100 km were observed during upstream homing migrations of radio-tagged spring Chinook salmon *Oncorhynchus*

tshawytscha in the Columbia and Snake Rivers, U.S.A. Downstream migrants, identified by their repeated ascension and fallback over a series of large hydroelectric dams within the migration corridor, were primarily hatchery-origin males. (c) 2006 The Fisheries Society of the British Isles.

Keefer ML, CA Peery CA, and CC Caudill. 2008b. "Migration timing of Columbia River Spring Chinook Salmon: Effects of Temperature, River Discharge, Anti Ocean Environment." *Transactions of the American Fisheries Society* 137(4):1120-1133.

In an effort to improve run timing forecasts for Columbia River spring Chinook salmon (*Oncorhynchus tshawytscha*), we examined relationships among regional ocean climate indices, in-river environmental conditions, and full run and stock-specific migration timing metrics. Results consistently indicated that adult Chinook salmon arrived earliest in years with low river discharge or warm water temperatures and arrived latest in years of cold water temperatures and high flows. As single predictors, in-river conditions generally explained more interannual variability in salmon return timing than did air temperature, the Pacific Decadal Oscillation, or the North Pacific Index. However, best-fit multiple-regression models included a combination of in-river and climate predictors. While spatial and temporal scales of the analyses were relatively coarse (i.e., monthly values were used for all predictors), clear patterns emerged that can be used to improve pre- and in-season run timing forecasting models for Columbia River spring Chinook salmon. We recommend continued refinement of climate-based and environmental predictive tools to help manage anadromous fish stocks, including the threatened and endangered populations of the Columbia River basin.

Keefer, ML, CA Peery, MA Jepson, KR Tolotti, TC Bjornn, and LC Stuehrenberg. 2004. "Stock-specific migration timing of adult spring-summer Chinook salmon in the Columbia River basin." *North American Journal of Fisheries Management* 24(4):1145-1162.

An understanding of the migration timing patterns of Pacific salmon (*Oncorhynchus* spp.) and steelhead (*O. mykiss*) is important for managing complex mixed-stock fisheries and preserving genetic and life history diversity. We examined adult return timing for 3,3 17 radio-tagged fish from 38 stocks of Columbia River basin spring-smumer Chinook salmon (*O. tshawytscha*) over 5 years. Stock composition varied widely within and between years depending on the strength of influential populations. Most individual stocks migrated at similar times each year relative to overall runs, supporting the hypotheses that run timing is predictable, is at least partially due to genetic adaptation, and can be used to differentiate between some conspecific populations. Arrival timing of both aggregated radio-tagged stocks and annual runs was strongly correlated with river discharge; stocks arrived earlier at Bonneville Dam and at upstream dams in years with low discharge. Migration timing analyses identified many between-stock and between-year differences in anadromous salmonid return behavior and should aid managers interested in protection and recovery of evolutionarily significant populations.

Keefer, ML, RH Wertheimer, AF Evans, CT Boggs, and CA Peery. 2008c. "Iteroparity in Columbia River summer-run steelhead (*Oncorhynchus mykiss*): implications for conservation." *Canadian Journal of Fisheries and Aquatic Sciences* 65(12):2592-2605.

We used ultrasound imaging and passive integrated transponder (PIT)-tagging programs to assess maturation status and iteroparity patterns in summer-run steelhead (anadromous rainbow trout, *Oncorhynchus mykiss*) of the interior Columbia River Basin (Pacific Northwest, USA). Postspawn kelts examined in downstream fish bypass systems at Columbia River and Snake River dams were disproportionately female (> 80%) and majorities were of wild origin, unlike prespawn steelhead at these sites. Annual repeat migration estimates varied from 2.9% to 9.0% for kelts tagged at lower Columbia River dams (n = 2542) and from 0.5% to 1.2% for Snake River kelts (n = 3762). Among-site differences reflected greater outmigration distance and additional dam passage hazards for Snake River kelts. There was also strong evidence for condition-dependent mortality, with returns an order of magnitude higher for good-versus poor-condition kelts. Disproportionately more females and wild fish also returned, providing potentially valuable genetic and demographic benefits for the Columbia River's threatened steelhead populations. Results overall provide baseline data for evaluating kelt mortality mitigation efforts and basic life history information for steelhead conservation planning.

Kemp PS, MH Gessel, and JG Williams. 2005. "Seaward migrating subyearling Chinook salmon avoid overhead cover." *Journal of Fish Biology* 67(5):1381-1391.

Approximately three-quarters of migrating autumn (fall) Chinook salmon (*Oncorhynchus tshawtscha*) smolts avoided a covered channel and selected an uncovered channel when presented with a choice in an experimental flume. Rejection of overhead cover occurred prior to, but was rare post-channel entrance. Smolts may selectively reject riparian cover as an adaptive behavioural response to minimize predation risk and enhance rates of migration. The findings have implications for fish bypass design and riparian habitat and culvert restoration.

Kennedy, B. M., W. L. Gale, and KG Ostrand. 2007. "Relationship between smolt gill Na+, K+ ATPase activity and migration timing to avian predation risk of steelhead trout (*Oncorhynchus mykiss*) in a large estuary." *Canadian Journal of Fisheries and Aquatic Sciences* 64(11):1506-1516.

We examined avian predation risk of juvenile steelhead trout (*Oncorhynchus mykiss*) migrating through the Columbia River Estuary in relation to their osmoregulatory physiology, body length, rearing conditions (hatchery or wild), migration timing, and migration year. From 2003 to 2006, mean gill Na+, K+ ATPase activity of migrating wild steelhead was greater than hatchery steelhead. Hatchery steelhead were always longer than wild steelhead. Wild steelhead never had higher plasma [Na+] or osmolality levels than hatchery fish after seawater challenge trials conducted in 2004, 2005, and 2006. More passive integrated transponder (PIT) tags from hatchery fish (19%; 126 of 678 fish) were detected on East Sand Island among bird nesting colonies than PIT tags of wild fish (14%; 70 of 509 fish), presumably consumed by birds. As gill Na+, K+ ATPase activity and migration date within a year increased, the probability of an individual fish being eaten by an avian predator decreased. Length, rear type, and year were not related to predation risk. These results show that physiology and migration timing of juvenile steelhead play an important role in a migrant's risk to avian predation within an estuary.

Knudsen CM, MV Johnston, SL Schroder, WJ Bosch, DE Fast, and CR Strom. 2009. "Effects of Passive Integrated Transponder Tags on Smolt-to-Adult Recruit Survival, Growth, and Behavior of Hatchery Spring Chinook Salmon." *North American Journal of Fisheries Management* 29(3):658-669.

We tagged juvenile upper Yakima River hatchery spring Chinook salmon (*Oncorhynchus tshawytscha*) with passive integrated transponder (PIT) and coded wire snout tags in a double-tag study 10 test the assumptions that tags are not lost and do not affect postrelease survival, behavior, or growth. The average loss of PIT tags was 2.0% (95% confidence interval [CI] = 0.7-3.2%) ill juveniles before release and 18.4%, in recaptures returning 6 months to 4 years after release (95%, CI = 17.2-19.5%). Adult tag losses were not significantly correlated with age of return (analysis of covariance. P = 0.40),

indicating that the majority of PIT tag loss had occurred within the first 6 months after release. Smolt-to-adult recruit survival (SARS) of PIT-tagged fish was significantly lower ($P < 0.05$) than that of non-PIT-tagged (NPT) fish because of tag loss and reduced survival, resulting in an average underestimate of SARS of 25.0%. After correcting for tag loss, we estimated PIT tag-induced mortality to be as great as 33.3% with a mean of 10.3% over all brood years, ($P < 0.05$). Mean lengths and weights of PIT-tagged adults were less than those of NPT adults in all age comparisons. However, only age-4 PIT-tagged adults were significantly smaller than NPT fish of the same age (mean length difference = 1.1 cm; mean body weight difference = 0.1 kg: analysis of variance, $P < 0.05$). There was no significant difference between migration timing of PIT-lagged and NPT adults within the upper Yakima River (Mann-Whitney test, $P > 0.09$). Given the widespread and increasing use of PIT tags. and their use in calculating critical estimators related to salmonid life history of Endangered Species Act Populations. the effects Of using PIT tags must be quantitatively considered under actual study conditions and. if necessary. be accounted for.

Ledgerwood RD, AS Cameron, BP Sandford, LB Way, and GM Matthews. 2007. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary Using Pair-Trawls. Prepared by Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington. Contract no. 56ABNF100030.

In 2005, we continued a study to detect juvenile anadromous salmonids (*Oncorhynchus* spp. implanted with passive integrated transponder (PIT) tags using a large surface pair-trawl fitted with a PIT-tag detection antenna. We sampled in the Columbia River upper estuary between river kilometers (rkm) 61 and 83 for 909 h between 20 April and 5 August and detected 14,101 PIT-tagged juvenile salmonids of various species, runs, and rearing types. Not all stocks and rearing types were equally represented in the annual detection totals. For example, of the total detections, 18% were wild fish and 79% were hatchery-reared; 64% were Chinook salmon, 32% were steelhead, and the remaining 4% were other salmonid species.

During the spring migration period, the principal target fish (yearling migrants) were the roughly 740,000 PIT-tagged spring/summer Chinook salmon and 770,000 PIT-tagged steelhead released into the Columbia River Basin. Some of these fish migrated in the river to the estuary; others were diverted to transportation barges at Lower Granite Dam or at other downstream collector dams. Transported fish were then released into the Columbia River about 9 km downstream from Bonneville Dam. As in 2002, we extended sampling into the summer migration period, targeting the more than 279,000 PIT-tagged subyearling fall Chinook salmon. These fish were released into the Snake and upper Columbia Rivers for NMFS transportation studies. These fish either migrated in the river or were transported from collection facilities at Lower Granite; Little Goose, and Lower Monumental Dams on the Snake River and McNary Dam on the Columbia River.

In this study, we used the antenna that was developed in 2001 and the trawl that was developed in 2003. The antenna weighed about 200 kg in air, with a fish passage tunnel measuring 86 cm in diameter. Two Whit-Patten transceivers were housed inside a separate data-collecting vessel (electronics barge) and recorded PIT-tag detections, electronic status reports, and global-positioning-system (GPS) locations. The barge floated directly above, and was also used to deploy, the antenna. The antenna was attached to a trawl, which we had altered in 2003 to include an extended net floor measuring 9 m. The trawl was towed using a pair of 12.5-m long vessels. Under tow we maintained a distance of 91.5 m between the wings, which resulted in an effective sample depth of 5 to 6 m (measured at the center of the floor). Hand-written logs, including land marks and events, were also maintained. A camera mounted inside the antenna provided nearly constant video surveillance (during daytime hours) which aided in monitoring fish passage and debris accumulation.

Sampling effort was commensurate with arrival in the estuary of inriver migrating yearling Chinook salmon and steelhead from the Snake River transportation study releases. A single daily crew began sampling on 20 April and the effort was increased from single to double daily crews on 27 April. This double-crew effort continued until 17 June, when we returned to a single-daily crew. During this time period, we averaged 13 h/d of detector on-time and detected 2.8% of all Chinook salmon and 3.5% of all steelhead previously detected at Bonneville Dam. These rates were a rough measure of sampling efficiency with the large trawl.

Of the fish detected, 27% had been transported and released downstream from Bonneville Dam. Another 5% had previously been detected in the bypass system at Bonneville Dam. This proportion was lower than in previous years due to the lack of detection capability associated with a new corner collector at the dam. The remaining 68% had not been transported or detected at Bonneville Dam. These percentages were similar to the migration history proportions of fish detected in previous years, except where noted. A total of 59% of our detections had been released in the Snake River, 34% in the upper Columbia River, and 7% downstream from McNary Dam. Only 25 non-transported PIT-tagged fish detected in the estuary had been released from sites downstream from Bonneville Dam; another 36 had been released from Bonneville Dam and 21 from Bonneville Hatchery (rkm 233).

During the peak of the spring migration period, we sampled nearly continuously. However, high winds and swift currents often hindered sampling between 1300 and 1800 PDT, forcing us to shut down. Sample sizes of yearling Chinook salmon and steelhead were sufficient in most instances to conclude that diel trends among wild and hatchery rearing types were similar; thus, we presented the analyses and summaries from the pooled data. During the two-crew sampling period, we averaged 4 and 10 yearling Chinook salmon detections per hour of daylight and darkness, respectively, for hatchery and wild rear-types combined ($P = 0.005$). We also averaged three steelhead detections per hour of daylight and four per hour of darkness ($P = 0.748$).

Travel speed from Bonneville Dam to Jones Beach was significantly higher for inriver migrant yearling Chinook salmon (median 90 km d-1) than for those released from barges (median 68 km d-1; $P = 0.000$). However, there was no significant difference in travel speed between barged and inriver-migrant steelhead (80 versus 78 km d-1, respectively; $P = 0.684$).

Since 2001, we have continued development of a PIT-tag detection trawl for use in salt or brackish water. Periodic electronic and net modifications have been required. The goal was to deploy a smaller surface pair-trawl system in lower, more inaccessible areas of the estuary, in hopes of detecting fish previously detected in the upper estuary. A small, rapidly deployable, mobile PIT-tag detection system may also prove useful in smaller rivers, high-volume bypass channels, and other areas of the Columbia River or Pacific Ocean.

In 2005, we deployed a smaller trawl in the lower estuary, primarily between rkm 8 and 16. In this smaller trawl, the trawl body was larger than that used in previous years, and was 4.9 m square at its entrance and 8.5 m in length. A floor of 1.8-cm stretch-measure webbing extended forward 6-m between the wings. A 20-m section of 1.8-cm mesh followed by a 15-m section of 33-cm mesh made up the trawl wings, which were also larger than in previous years. Fish exited the trawl through a single PIT-tag detection antenna coil positioned 1.8 m beneath the surface. We used a new antenna with a circular shape measuring 107 cm in diameter.

The trawl was towed using a pair of 7.5-m long vessels. Under tow, we maintained a distance of about 34 m between the wings of the small trawl. We had an effective sample depth of about 4 to 5 m (measured at the center of the floor). The antenna weighed about 136 kg in air, including ballast. A PIT-tag transceiver (Destron/Fearing model FS-1001A) was mounted on a pontoon barge towed at the rear of the trawl. Cables led from the underwater antenna to the barge, where a wireless modem transmitted PIT-tag detections and electronic status reports from the transceiver to a recording computer in the cabin of a tow vessel.

The small-trawl system was deployed in the lower estuary between 16 May and 8 June during the two-crew sampling period of the large trawl. A total of 38 PIT-tagged fish were recorded during 73 h of sampling along the north and south side of the ship channel during both daylight and darkness hours. No major problems with entanglements of bait fish or salmonids were encountered in the lower estuary. One steelhead detected in brackish water had been previously detected in the large trawl upstream at Jones Beach. Travel time between the two detection sites (mean 35 h) was correlated to the number of flood tides encountered during the journey, similar to years previous. Since 2002, we have detected 10 fish in both trawls, with travel times ranging from 16 to 40 h, corresponding to encounters of 1-3 flood tides during passage from the upper to the lower estuary.

In order to evaluate the ability to guide smolts through an antenna system, we occasionally deployed a passive PIT-tag sampling device along the shoreline at Jones Beach as well. Following the small trawl sample period, we adapted the same Hobe Cat and Pelican box systems for the shoreline sampler, which was equipped with wireless video and data transmission capabilities (Destron-Fearing transceiver). This enabled us to view, record, and potentially quantify fish passage, while capturing detection data, all from the shore. We used a night design that was slightly modified from that used in 2004; the cod end was altered to attach an antenna made up of 3-in diameter PVC pipe. We sampled for about 20 h over a 6-d period with no detections.

Levin PS, S Achord, BE Feist, and RW Zabel. 2002. "Non-indigenous brook trout and the demise of Pacific salmon: a forgotten threat?" *Proceedings of the Royal Society B-Biological Sciences* 269(1501):1663-1670.

Non-indigenous species may be the most severe environmental threat the world now faces. Fishes, in particular, have been intentionally introduced worldwide and have commonly caused the local extinction of native fish. Despite their importance, the impact of introduced fishes on threatened populations of Pacific salmon has never been systemically examined. Here, we take advantage of several unique datasets from the Columbia River Basin to address the impact of non-indigenous brook trout, Salvelinus fontinalis, on threatened spring/summer-run Chinook salmon, *Oncorhynchus tshawytscha*. More than 41 000 juvenile Chinook were individually marked, and their survival in streams without brook trout was nearly double the survival in streams with brook trout. Furthermore, when brook trout were absent, habitat quality was positively associated with Chinook survival, but when brook trout were present no relationship between Chinook survival and habitat quality was evident. The difference in juvenile Chinook survival between sites with, and without, brook trout would increase population growth rate (lambda) by ca. 2.5%. This increase in A would be sufficient to reverse the negative population growth observed in many Chinook populations. Because many of the populations we investigated occur in wilderness areas, their habitat has been considered pristine; however, our results emphasize that non-indigenous species are present and may have a dramatic impact, even in remote regions that otherwise appear pristine.

Levin PS, Zabel RW, and Williams JG. 2001. "The road to extinction is paved with good intentions: negative association of fish hatcheries with threatened salmon." *Proceedings of the Royal Society of London Series B-Biological Sciences* 268:1153-1158.

Hatchery programmes for supplementing depleted populations of fish are undergoing a worldwide expansion and have provoked concern about their ramifications for populations of wild fish. In particular, Pacific salmon are artificially propagated in enormous numbers in order to compensate for numerous human insults to their populations, yet the ecological impacts of this massive hatchery effort are poorly understood. Here we test the hypothesis that massive numbers of hatchery-raised Chinook salmon reduce the marine survival of wild Snake River spring Chinook, a threatened species in the USA. Based on a unique 25-year time-series, we demonstrated a strong, negative relationship between the survival of Chinook salmon and the number of hatchery fish released, particularly during years of poor ocean conditions. Our results suggest that hatchery programmes that produce increasingly higher numbers of fish may hinder the recovery of depleted wild populations.

Li T and JJ Anderson. 2009. "The vitality model: A way to understand population survival and demographic heterogeneity." *Theoretical Population Biology* 76:118-131.

A four-parameter model describing mortality as the first passage of an abstract measure of survival capacity, vitality, is developed and used to explore four classic problems in demography: (1) medfly demographic paradox, (2) effect of diet restriction on longevity, (3) cross-life stage effects on survival curves and (4) mortality plateaus. The model quantifies the sources of mortality in these classical problems into vitality-dependent and independent parts, and characterizes the vitality-dependent part in terms of initial and evolving heterogeneities. Three temporal scales express the balance of these factors: a time scale of death from senescence, a time scale of accidental mortality and a crossover time between evolving versus initial heterogeneity. The examples demonstrate how the first-passage approach provides a unique and informative perspective into the processes that shape the survival curves of populations.

Liebert AM and CB Schreck. 2006. "Effects of acute stress on osmoregulation, feed intake, IGF-1, and cortisol in yearling steelhead trout (*Oncorhynchus mykiss*) during seawater adaptation." *General and Comparative Endocrinology* 148(2):195-202.

Juvenile steelhead (*Oncorhynchus mykiss*) acclimated to freshwater (FW) were subjected for 3 It to confinement stress in FW, and subsequently saltwater (SW, 25 ppt) was introduced to all tanks. Fish were sampled immediately after the stress treatment, and 1, 7, and 14 days after introduction of SW. Electrolytes, cortisol, glucose, and lactate showed the typical stress response expected after stress treatment in FW. Fish regained osmotic balance within 24 It. Glucose concentrations were increasing throughout the experiment and lactate levels stayed elevated during the time spent in SW. Insulin-like growth factor-1 (IGF-1) did not show an immediate response to stress but after transfer to SW we detected significantly higher concentrations for control fish at days 1 and 14. The differences in IGF-1 levels between stressed and control fish are not reflected in SW adaptability but positive correlations between IGF-1 and electrolyte levels in control fish may indicate its role for osmoregulation.

Confinement stress did not impair feed intake subsequently in SW, but our results suggest that feed intake was suppressed by the change of the media from FW to SW. (c) 2006 Elsevier Inc. All rights reserved.

Luce CH and ZA Holden. 2009. "Declining annual streamflow distributions in the Pacific Northwest United States, 1948-2006." *Geophysical Research Letters* 36.

Much of the discussion on climate change and water in the western United States centers on decreased snowpack and earlier spring runoff. Although increasing variability in annual flows has been noted, the nature of those changes is largely unexplored. We tested for trends in the distribution of annual runoff using quantile regression at 43 gages in the Pacific Northwest. Seventy-two percent of the stations showed significant (alpha = 0.10) declines in the 25th percentile annual flow, with half of the stations exceeding a 29% decline and a maximum decline of 47% between 1948 and 2006. Fewer stations showed statistically significant declines in either median or mean annual flow, and only five had a significant change in the 75th percentile, demonstrating that increases in variance result primarily from a trend of increasing dryness in dry years. The asymmetric trends in streamflow distributions have implications for water management and ecology well beyond those of shifted timing alone, affect both rain and snow-dominated watersheds, and contribute to earlier timing trends in high-elevation watersheds.

Lyons DE, DD Roby, and K Collis. 2005. "Foraging Ecology of Caspian Terns in the Columbia River Estuary, USA." *Waterbirds* 28(3):280-291.

Comparisons were made of the foraging ecology of Caspian Terns (Sterna caspia) nesting on two islands in the Columbia River estuary using radio telemetry and observations of prey fed to chicks and mates at each colony. Early in the chick-rearing period, radio-tagged terns nesting at Rice Island (river km 34) foraged mostly in the freshwater zone of the estuary close to the colony, while terns nesting on East Sand Island (river km 8) foraged in the marine or estuarine mixing zones close to that colony. Late in the chick-rearing period, Rice Island terns moved more of their foraging to the two zones lower in the estuary, while East Sand Island terns continued to forage in these areas. Tern diets at each colony corresponded to the primary foraging zone (freshwater versus marine/mixing) of radio-tagged individuals: Early in chick-rearing, Rice Island terns relied heavily on juvenile salmonids (*Oncorhynchus* spp., 71% of identified prey), but this declined late in chick-rearing (46%). East Sand Island terns relied less on salmonids (42% and 16%, early and late in chick-rearing), and instead utilized marine fishes such as Anchovy (Engraulis mordax) and Herring (Clupea pallasi). Throughout chick-rearing, Rice Island terns foraged farther from their colony (median distance: 12.3 km during early chick-rearing and 16.9 km during late chick-rearing) than did East Sand Island terns (9.6 and 7.7 km, respectively). The study leads to the conclusion that Caspian Terns are generalist foragers and make use of the most proximate available forage fish resources when raising young.

Lyons DE, DD Roby, and K Collis. 2007. "Foraging patterns of Caspian terns and double-crested cormorants in the Columbia River estuary." *Northwest Science* 81(2):91-103.

We examined spatial and temporal foraging patterns of Caspian terns and double-crested cormorants nesting in the Columbia River estuary, to potentially identify circumstances where juvenile salmonids listed under the U.S. Endangered Species Act might be more vulnerable to predation by these avian piscivores. Data were collected during the 1998 and 1999 breeding seasons, using point count surveys of foraging birds at 40 sites along the river's banks, and using aerial strip transect counts throughout the estuary for terns. In 1998, terns selected tidal flats and sites with roosting beaches nearby for foraging,

making greater use of the marine/mixing zone of the estuary later in the season, particularly areas near the ocean jetties. In 1999, cormorants selected foraging sites in freshwater along the main channel with pile dikes present, particularly early in the season. Foraging trends in the other year for each species were generally similar to the above but usually not significant. During aerial surveys we observed 50% of foraging and commuting terns within 8 km of the Rice Island colony, and <= 5 % of activity occurred >= 27 km from this colony in both years. Disproportionately greater cormorant foraging activity at pile dikes may indicate greater vulnerability of salmonids to predation at those features. Colony relocations to sites at sufficient distance from areas of relatively high salmonid abundance may be a straightforward means of reducing impacts of avian predation on salmonids than habitat alterations within the Columbia River estuary, at least for terns.

Macneale KH, BL Sanderson, JYP Courbois, and PM Kiffney. 2010. "Effects of non-native brook trout (*Salvelinus fontinalis*) on threatened juvenile Chinook salmon (*Oncorhynchus tshawytscha*) in an Idaho stream." *Ecology of Freshwater Fish* 19:139-152.

Non-native fishes have been implicated in the decline of native species, yet the mechanisms responsible are rarely apparent. To examine how non-native brook trout may affect threatened juvenile Chinook salmon, we compared feeding behaviours and aggressive encounters between these sympatric fish in Summit Creek, Idaho. Snorkelers observed 278 focal fish and examined diets from 27 fish in late summer 2003. Differences in feeding behaviours and diets suggest that there was minimal current competition for prey, although individual Chinook feeding activity declined as their encounter rate with other fish increased. While difference in size between fish generally determined the outcome of encounters (larger fish 'winning'), it was surprising that in some interspecific encounters aggressive Chinook displaced slightly larger brook trout (< 20 mm longer). We suggest that in late summer, frequent intraspecific interactions may be more important than interspecific interactions in potentially limiting Chinook growth in Summit Creek and perhaps in other oligotrophic streams where they co-occur.

Marmorek DR, M Porter, IJ Parnell, and C Peters, eds. 2004. *Comparative Survival Study Workshop, February 11–13, 2004; Bonneville Hot Springs Resort*. Compiled and edited by ESSA Technologies Ltd., Vancouver, British Columbia, for the Fish Passage Center, Portland Oregon, and the U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office, Vancouver, Washington.

The Comparative Survival Study (CSS) Oversight Committee convened a workshop in February 2004 on the effects of hydrosystem configuration and operation on salmon and steelhead survival. The workshop was attended by 17 scientists who have studied hydrosystem effects at a wide range of spatial/temporal scales and levels of organization.

Specific objectives of this workshop were to:

1. synthesize the results of Comparative Survival Study Oversight Committee (2002) and other research studies;
2. document and assess evidence relating to various factors that can affect survival rates over different life history stages, including hydrosystem passage, delayed mortality, time of ocean entry, and travel time;
3. produce a report synthesizing and assessing the evidence for and against hypothesized mechanisms for differential survival (hatchery-wild; upstream-downstream) and smolt to adult returns; and

4. provide the foundation for a series of publications in peer-reviewed journals.

The organizing structure for the workshop took the form of a series of hierarchical *impact hypothesis diagrams* designed to represent an increasingly more detailed set of hypotheses about possible mechanisms for differential survival. This provided a clear framework within which workshop participants were asked to evaluate varied hypotheses relating to delayed mortality, and to evaluate the strength of evidence for and against these hypotheses. Workshop participants were separated into 2 groups (Subgroup A and Subgroup B).

Subgroup A was charged with evaluating evidence for the overall hypothesis that passage through or around the hydrosystem causes **indirect** mortality to smolts that may not be expressed until the estuary/ocean life stage (Hypothesis 2). Subgroup A was also charged with analyzing and evaluating recent evidence for five of the six suggested mechanisms for delayed mortality (i.e., hydrologic changes, timing of estuary entry, changes in developmental state, fixed mortality/day, effects of smolt bypass structures).

Subgroup B was charged with evaluating existing evidence relating specifically to the hypothesis that smolt passage routes through or around the hydrosystem cause various types of **stress** on smolts that increase vulnerability to mortality factors. In addition to evaluating the more general evidence relating stress to indirect mortality, Subgroup B assessed the value of evidence linking four specific stress-induced mechanisms hypothesized as causing delayed mortality: 1) increased vulnerability to horizontal transmission of pathogens; 2) reduced growth rates or condition of smolts; 3) increased vulnerability to predation; and 4) reversal of, or incomplete smoltification.

The evidence available to the two subgroups differed, and therefore there are also differences in the summaries of their work in this report. Subgroup A conducted several new analyses directly focused on key uncertainties. Subgroup B reviewed and evaluated existing studies, both published and unpublished, for their relevance and support of specific stress mechanisms. Much of the behavioral and physiological evidence reviewed by subgroup B is focused on studies of the responses of individual fish on relatively short time scales and restricted spatial scales. By contrast, Subgroup A examined survival information on seasonal to multi-year time scales for widely separated fish stocks. One of the major challenges of the workshop was to begin to synthesize research results across such diverse scales. This effort needs to continue, with further analyses required that attempt to correlate physiological/behavioral indices with survival rate estimates.

The specific hypotheses evaluated by each workshop subgroup, the evidence examined, and their conclusions/recommendations in regard to each hypothesis are presented below.

Subgroup A

Subgroup A participants focused their initial efforts at more clearly documenting the patterns that suggest delayed mortality is occurring. This included developing new assessments of the observed differences in SARs between different stock groups (i.e., hatchery versus wild, transported versus inriver, upstream versus downstream). Secondly the subgroup directed their efforts at evaluating many of the hypothesized causal mechanisms for such differences, and pursued some new analyses in this regard. These analyses are preliminary, and have not been published previously.

Hypothesis 2: Passage through or around the hydrosystem causes indirect mortality to smolts that may not be expressed until the estuary/ocean life stage. Indirect effects may be expressed differently for hatchery and wild fish.

Evidence:

Spatial and temporal comparisons of stock performance provide indirect evidence of delayed mortality and that delayed mortality is linked to hydrosystem experience.

Recent mark-recapture data also provide evidence of differences in delayed mortality by route of passage through the hydrosystem.

- Different agencies have used somewhat different SAR metrics and drawn different conclusions about recent changes. Progress was made to determine why the results and conclusions were so dramatically different between agency analyses, however resolution of the “best” method to estimate SARs for the run-at-large has not been finalized.
- Updated estimates for the time series of λn (post-Bonneville survival factor for in-river fish) employing the Delta model (Deriso et al. 2001) indicate that λn has stayed low in recent brood years. These results are contrary to the interpretation of SAR information by NOAA Fisheries that in recent years there may be very little delayed mortality of in-river fish.

Overall conclusions/recommendations:

- Results from updated model runs suggest that delayed mortality for Snake River spring/summer Chinook populations has remained high in recent years.
- The various management agencies responsible for the Columbia Basin should endeavor to work more cooperatively to evaluate common datasets, and agree on assumptions used in future shared analyses.

Hypothesis 2.1: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by causing changes in hydrologic conditions in the estuary*.

Evidence:

- Little directed work has been done to date that would allow clear evaluation of this hypothesis. There is a general lack of science-based information concerning attributes of tidal freshwater and oligohaline transition zones needed to support juvenile salmon, particularly in the Columbia River estuary.
- However, recent evidence supports the concern that flow in the Columbia River significantly affects the availability of estuarine habitats and that flow is much reduced compared to historic levels. Annual spring freshet flows through the Columbia River estuary are ~50% of the traditional levels that flushed the estuary and carried smolts to sea, and total sediment discharge is ~1/3 of 19th Century levels.
- Effects of flow regulation on habitat opportunities for subyearling salmon remain equivocal due to uncertainties in available bathymetric data.

Overall conclusions/recommendations:

- Analyses to date indicate that habitat and food-web changes within the estuary and other factors affecting salmon population structure and life histories have likely altered the capacity of the Columbia estuary to support juvenile salmon, though it isn't clear how the effects differ for transported versus in-river, or hatchery versus wild groups of fish.
- Further work is required to revise historical bathymetric data and acquire new data on present day, shallow water bathymetry and circulation. Simulations should be pursued that include three dimensional modeling of salinity intrusion and stratification as a third environmental variable important in determining juvenile salmon distribution and residence time.

Hypothesis 2.2a: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by delaying (in-river) or accelerating (transport) arrival of smolts in the estuary*.

Evidence:

- Spring/summer Chinook transported from LGR and LGS arrive below BONN 2 to 3 weeks earlier than fish that migrate in-river. Transported fish arriving below BONN in early April have lower SARs than later groups and take longer to travel from BONN to lower Columbia River.
- The Snake and Columbia River dams and reservoirs have doubled to tripled the travel time of inriver spring/summer Chinook and steelhead through these rivers, delaying ocean entry time.
- SARs for transported hatchery smolts appear correlated with the total number of salmonid smolts passing BONN. In 1999 the early April transport groups had fewer co-migrants and alternative prey for predators. Increased vulnerability to predators and immature smolt development stage might explain the lower SARs of early transport groups.
- The start of the optimal "window" of ocean entry appears to be around April 30th for both in-river and transported fish, based on CSS PIT-tag data for 1998-2000. The end of the optimal "window" of ocean entry appears to be around June 18th for in-river fish, and (with adequate flows) June 30th for transported fish.
- Post-Bonneville survival of in-river Snake River spring/summer Chinook (λn) has remained at low levels in brood years 1991–1996, levels consistent with brood years 1985–1990, though lower than brood year 1986.
- SARs could, in theory, be affected by Water Travel Time (WTT) only through changes to direct mortality (e.g., greater predation rates in reservoirs). However, post-Bonneville survival (λn) also appears to be negatively correlated with WTT, suggesting that higher WTT is associated with higher levels of both direct and indirect mortality.

Overall conclusions/recommendations:

- The number of alternative prey available to smolt predators in the Columbia River plume and nearshore ocean likely plays a key role in determining smolt survival (i.e., probability of avoiding predation). Presence of alternative prey will (to some extent) be dictated by smolt entry time to the estuary.
- Differences observed in post-Bonneville Dam survival rates between transported and in-river migrating smolts may be influenced by duration of time the smolts spend in the lower Columbia

River before actually entering the ocean. Early transported wild Chinook smolts may be migrating below Bonneville Dam at very slow speeds and therefore may be more vulnerable to predators.

- Delayed arrival of in-river fish in the Columbia estuary related to WTT likely continues to cause post-BONN delayed mortality of in-river fish.

Hypothesis 2.2b: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by changing and delaying the smolt development processes, through both altered timing of entry and stress*.

Evidence:

- Fish appear to smolt as they migrate.
- Fish that are given insufficient time to complete smoltification will likely experience high energetic costs in attempting to osmoregulate in salt water, resulting in decreased resistance to pathogens and increased susceptibility to predators.
- Smolt indices such as gill ATPase suggest that early-run fish are less smolted than later run fish.
- Barged early-run spring Chinook may have less opportunity to migrate a sufficient distance in freshwater, necessary in some fish to stimulate smolt development.
- In-river fish that are stressed may have delayed or reversed smolt development.

Overall conclusions/recommendations:

Causes of variation in *D* and SARs relating to timing of entry are most likely a combination of different factors. These include:

1. Developmental stage of smolts; both a lack of readiness for saltwater entry of early transport groups, and possible stress-induced changes in development for in-river fish.
2. The number of outmigrating smolts of various species (i.e., variation in schooling protection that can potentially swamp predators).
3. Year to year and seasonal variation in the condition of the estuary and availability of alternative prey.
4. Water Travel Time, which is negatively correlated with λn, the post_BONN survival of in-river fish.
5. Immature smolt developmental stage and increased estuarine predation are probably more important than stress in explaining low spring Chinook *D*'s for early season runs, but stress is likely a factor in consistently depressing SARs and λn for in-river fish.

Hypothesis 2.4: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) by shifting the timing of mortality of transported fish to post-Bonneville Dam, based on the hypothesis that fish experience a fixed rate of mortality*.

This hypothesis asserts that fish migrating in-river experience an inherent mortality rate per day that will be expressed in the SARs. Transported fish collected at the uppermost dam don't have the opportunity to be culled from the population. Therefore, the transport fish SARs include unfit fish that were destined to die anyway, but because of the short duration of transport were not exposed to the challenges of inriver migration (i.e., transported fish have experienced only 1.5 days of mortality pre-

Bonneville, whereas inriver fish have had 12–22 days of pre-Bonneville mortality). The analyses to explore this hypothesis looked at upstream-downstream and between year differences in *D*.

- ***Upstream-downstream differences in D***: If continual "culling" were the primary cause for the in-river mortality experience through the hydrosystem, then the *D* values for smolts Lower Monumental Dam should be higher than for smolts transported from Lower Granite (due to some culling between LGR and LMO).
- ***Between year differences in D:*** If continual "culling" is occurring the entire time that smolts are migrating in-river throughout the hydro system, then in-river smolts migrating in low flow years should have lower pre-Bonneville Dam and higher post-Bonneville Dam survival than do smolts migrating in high flow years. This scenario would lead to lower Ds in low flow years and higher Ds in high flow years.

Evidence:

- ***Upstream-downstream differences in D***: Data presented by NMFS made no case for continual "culling" of hatchery Chinook and only a weak case for continual "culling" of wild Chinook. But there were too few PIT tagged wild Chinook smolts transported from Little Goose Dam (and even fewer from Lower Monumental Dam) to obtain enough adult returns to properly conduct this type of analysis with the available data on PIT tagged wild Chinook.
- ***Between year differences in D***: The analysis compared the high flow year of 1999 with the low flow year of 2001. Post-Bonneville Dam survival rates between the two years were compared using a modified *D** value computed using fish from study Category C1. Contrary to the hypothesis, the *D** values were much higher in the low flow year, which reflects the extreme difference in survival in the estuary between these two years rather than a continuous "culling" mechanism. The SAR for Lower Granite Dam transported Chinook was 3 to 4 times higher in the high flow year than in the low flow year.

Overall conclusions/recommendations:

Overall, both upstream-downstream and among year patterns did not appear to support the culling hypothesis. Analyses on other years' data would be worthwhile.

Hypothesis 2.5: *The hydrosystem indirectly affects smolt-to-adult survival (SARs) through size selectivity and annual variation in bypass survival.*

Zabel et al. (2003) suggested that fish size (length) is an important factor in both survival through Columbia dam bypasses and detection at these bypasses, although the overall analysis indicated size selection at the bypass detection systems is relatively weak. A reanalysis of existing PIT tag data from 1998 to 2000 was conducted to assess whether biologically meaningful size-selectivity at the bypass systems was occurring. Other potential sources of bias in SARs estimates were explored in supplementary analyses.

Assessment of size selection at Columbia bypass systems (Section 3.9.1, T. Berggren)

Evidence:

- Reanalysis of data for wild Chinook collected at Lower Granite Dam and PIT tagged for transportation studies by NMFS in 1998 to 2000 showed a weak trend in size selectivity at Little Goose Dam with the largest sized fish generally showing the lowest collection efficiency.

Overall conclusions/recommendations

- There does not appear to be any strong size-selectivity trends apparent in the PIT tag data from the Lower Granite Dam transportation studies.
- The weak pattern of observed size-selectivity could be associated with this particular study design. Further investigation utilizing PIT tagged smolts that have had a longer duration between tagging and detection at downstream dams is needed. However, this duration cannot be too long as to allow smolt growth to confound differences between size at tagging and size when the PIT tagged fish are being detected in the bypass systems at the dams.

Effects of varied bypass operations/systems on past differences in survival of C0 and C1 fish (Section 3.9.2, T. Berggren)

Evidence:

There are elements of dam operations and detection protocols that have varied over the years, and could also contribute to confounding of perceived patterns in SARs and D, as well as compiling any analyses of the changing pattern in the ratio of C0:C1 survival.

- **Changes in Spill**: The change in the pattern of SARs for PIT tagged wild spring/summer Chinook in study categories C0 and C1 since 1998 may be influenced by recent changes in hydro project operations.
- **Sample sizes**: There were extremely small PIT tag sample sizes for the 1994 to 1997 adult returns.
- **Changes in PIT detection ability**: The full bypass detection history through all six dams equipped with PIT tag has only been available since 1998.
- **Overall patterns of detection rates and spill**: Changes in the makeup of the C0 group appeared related to higher spill volumes in recent years, but small sample sizes prevent further analysis. Increased spill would also have decreased the number of bypasses experienced by the C1 group as the probability that they passed in spill increased.

Overall conclusions/recommendations:

- Although some inferences can be made from the data as to why C0 and C1 detections may have changed over the years, the CSS study was not structured to specifically address the question of the effects of bypass passage on SARs. Furthermore, retrospective analysis of this question is difficult due to small sample sizes for the early years and because the full 6-dam detection history was not available until 1998. Within these limitations inferences can be made from trends in the data as to why there may have been a change over the years in the pattern of SARs between smolts in categories C0 and C1, though no strong conclusions can be made.

- An alternate way to address the question might be to conduct an analysis of data from 1998 and beyond, and group all of the juvenile data by the number of bypass detections. This would lead to groups with from one to six detections, and the adult returns from these data could be compared. This would be a cleaner analysis.

Subgroup B – Stress (Hypothesis 2.3)

Subgroup B discussions focused on links between stress related to hydrosystem passage and increased risk or susceptibility to hypothesized mortality factors, not on the links between those mortality factors and patterns in overall survival.

Discussion and review of the papers established that the general link between hydrosystem stress increased vulnerability to mortality factors is likely and that there are at least two likely pathways (based on the current strength of evidence available) through which this can occur: disease and predation. However, discussions and review did not establish the specific underlying mechanisms by which these effects would occur, or the magnitude of such effects.

Similarly, the subgroup discussions did not explore how these pathways could result in differential rates of delayed mortality between smolts with different life history experiences, or the spatial and temporal onset of delayed mortality. The pathway and mechanisms by which delayed mortality occurs may be different for smolts with different passage histories (e.g., transported versus hydrosystem), different origins (e.g., wild versus hatchery), or emigrating from different geographic regions (e.g., upriver versus downriver).

Hypothesis 2.3.1: *Smolt passage routes through or around the hydrosystem cause various types of stress on smolts that increase vulnerability to mortality factors (2.3.1.1 – 2.3.1.4).*

Evidence: Workshop discussions and eleven papers reviewed during and after the workshop.

Overall conclusions: The hypothesis is **likely**.

Recommendations: There is a need to undertake greater synthesis of current work and design/undertake controlled lab/field experiments to link stress responses in the field to subsequent stress-related mortality outside of the hydrosystem.

Hypothesis 2.3.1.1: *Amount or extent of passage through or around the hydrosystem increases vulnerability to horizontal transmission of pathogens.*

Evidence: Workshop discussions and 7 papers reviewed during and after the workshop.

Overall conclusions: The hypothesis is **likely but uncertain**. Conceptually and based on supporting literature, Subgroup B considered this the highest ranked stress hypothesis in terms of explaining delayed mortality. However, the evidence in support of this hypothesis is generally based on laboratory studies on many animals that show increased disease susceptibility as a result of stress. There is no direct support showing that migrating smolts succumb to disease more readily after stress events.

Recommendations: There is still a need for properly designed field experiments to define the relationship between the level of stress experienced by smolts during hydrosystem passage and the degree of increased vulnerability to pathogens.

Hypothesis 2.3.1.2: *Passage through or around the hydrosystem reduces growth rates or condition of smolts.*

Evidence: Workshop discussions and 3 papers and presentations reviewed during and after the workshop Overall conclusions: At this time, the hypothesis is considered **impossible to evaluate**. Evidence relating to this hypothesis is very weak as only two published papers were found and they provided only indirect evidence. Jim Congleton's presentation at the workshop provided much stronger evidence in direct support, but this work is not yet peer reviewed and published. Although suggestive, further work in this regard is required before an assessment can be made.

Recommendations: 1) Extend literature review to determine if any additional supporting information currently exists for this hypothesis; 2) continue and extend current studies examining the affect of stressors during hydrosystem passage on smolt condition and growth; 3) PIT tag smolts to assess smolt condition, growth rate and survival as groups with different transport histories move through the hydrosystem and beyond; 4) design specific field/lab experiments to identify stressor events and their impact on overall condition and subsequent survival.

Hypothesis 2.3.1.3: *Passage through or around the hydrosystem increases vulnerability to predation*.

Evidence: Workshop discussions and 23 papers reviewed during and after the workshop Overall conclusions: The hypothesis is **likely but uncertain**. There is a strong body of evidence in the literature showing increased predator susceptibility of fish as a result of stress. However this evidence is derived principally from laboratory studies: field predation studies have not been designed to test the link to stress.

Recommendations: 1) Use PIT tag data to examine differential predation rates of smolts by avian predators based on transport history; and 2) Design field experiments to test the hypothesis of differential stress-mediated predation.

Hypothesis 2.3.1.4: *Passage through or around the hydrosystem results in reversal of, or incomplete smoltification*.

Evidence: Workshop discussions and 5 papers reviewed during and after the workshop.

Overall conclusions: The hypothesis is **unlikely, but uncertain**. There is at present only limited evidence from the literature for this hypothesis. However, the number of studies available for review was limited, and only two represent field-based assessments of actively migrating smolts. Additionally, there are other factors (beyond stress) that need to be more clearly accounted for in studies of smoltification.

Recommendations: 1) Improve monitoring of smoltification indices (e.g., ATPase) during hydrosystem passage. For example, use PIT tagging to allow sampling of distinct fish groups for examination of ATPase activity at different points in the hydrosystem for fish undergoing different passage routes. 2) Design field experiments to better identify if stressor events can affect smoltification with subsequent consequences for survival.

Marsh DM, PS Benjamin, GM Matthews, and WD Muir. 2007. Research Related to Transportation of Juvenile Salmonids on the Columbia River, 2005: Final report for the 2003 Hatchery Steelhead Juvenile Migration. Prepared by Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Delivery Order E86960099.

Since 1999, the National Marine Fisheries Service has conducted annual studies to evaluate transportation of Snake River steelhead smolts. In 2003, we began annual studies to evaluate transportation of upper Columbia River hatchery steelhead smolts. Here we report complete adult recovery data from Columbia River hatchery steelhead smolts marked with passive integrated transponder (PIT) tags and released in 2003. From June 2005 through May 2006, we recovered age-2-ocean steelhead adults, completing adult returns from the 2003 study year. As smolts, these fish were tagged and released from Wells (246,056), Winthrop (49,241), Chelan (33,147), Eastbank (61,981), and Ringold (95,161) Hatcheries. At McNary Dam, PIT-tagged smolts that entered the juvenile bypass system were collected, and on alternate days, either diverted to transportation holding raceways or returned to the river through the full-flow bypass system. Transported fish were released below Bonneville Dam, while bypassed fish completed their juvenile migration in the river, along with study fish that did not enter the juvenile collection system at McNary Dam (inriver migrants).

From 2005 to 2006 we detected 198 age-2-ocean transported fish, 221 age-2-ocean full-flow bypassed fish, and 2,461 age-2-ocean inriver migrants from the 2003 releases. Based on all 2003 returns combined, smolt-to-adult return rates (SARs) were 2.34 for transported fish, 1.94 for full-flow bypass fish, and 2.45 for inriver migrants. These SARs resulted in a transport-to-inriver migrant ratio (T/I) of 0.96 (95% CI 0.86-1.07), a bypass-to-inriver migrant ratio (B/I) of 0.79 (95% CI 0.71-0.88), and a transport-to-bypass ratio of 1.21 (95% CI 1.04-1.40). Annual differential delayed mortality, *D*, was estimated at 0.97.

Of adults detected at Bonneville Dam, 71% of transported fish, 70% of full-flow bypass fish, and 71% of inriver migrant fish successfully migrated to McNary Dam (not adjusted for any take in the Zone 6 fishery). For age-1-ocean adults, median travel time from Bonneville Dam to McNary Dam was 19.0 d for transported fish, 16.5 for bypassed fish, and 17 d inriver migrants. For age-2-ocean adults, median travel times were faster, at 13.0 d for transported fish, 11.0 for bypassed fish, and 12.0 d for inriver migrants.

Marsh DM, JR Harmon, NN Paasch, KL Thomas, KW McIntyre, WD Muir, and WP Connor. 2010a. *A Study to Understand the Early Life History of Snake River Fall Chinook Salmon, 2006.* Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, and the Idaho Fishery Resource Office, U.S. Fish and Wildlife Service, Ahsahka, Idaho, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Delivery Order W68SBV60237302.

We began a study in 2005 to document the downstream passage histories of returning adult PIT-tagged Snake River fall Chinook salmon *Oncorhynchus tshawytscha*. The study was undertaken in part to further understand the juvenile life history strategies of passive integrated transponder (PIT) tagged fish that were never detected during their juvenile migration. We analyzed data from adults recaptured at Lower Granite Dam from September to November 1998-2006. Scale samples were read to determine age at ocean entry (subyearling or yearling). Downstream passage histories were determined to the extent possible based on juvenile PIT-tag detections and age at ocean entry. The effects of age at ocean entry on time spent in seawater and fork length at return were also evaluated.

We analyzed data on a total of 134 returning fall Chinook salmon recaptured at Lower Granite Dam during 1998-2006. All fish had been tagged as subyearlings and released to migrate inriver during 1994-1998 and 2000-2004, when summer spill was limited at Snake River dams. Of the 134 adults, only 32 (24%) had entered the ocean as subyearlings, and only 6 of these 32 fish had never been detected as juveniles. Of the 134 adults, 102 had entered the ocean as yearlings. Of these 102 yearling ocean entrants, 31 were known to have spent their first winter in reservoirs and the remaining 71 in unknown freshwater/estuarine locations. We deduced that many of the 71 yearling ocean entrants likely wintered in reservoirs upstream from Bonneville Dam.

Recaptured fall Chinook salmon adults that migrated inriver during 1994-2004 provided baseline data for years with limited summer spill, whereas recaptured fall Chinook salmon jacks and mini-jacks that migrated inriver during 2005 provided the first baseline data for a year with summer spill (additional age classes yet to return).

Based on preliminary adult returns of inriver migrants, three trends were apparent indicating differences between spill and non-spill years for both Snake and Clearwater River fall Chinook salmon. For adults from the Snake River, the first trend was that the percentage of yearling ocean entrants decreased from 76% for the 1998-2004 releases to 13% for the 2005 releases. Second, the minimum percentage of fish that had been reservoir-type juveniles decreased from 22% for the 1998-2004 releases to 0% for the 2005 releases. Third, fewer subyearling ocean entrants passed downstream undetected during years when summer spill was limited (1998-2004) than when summer spill was fully implemented (2005).

For adult inriver migrants from the Clearwater River, the first trend was that the percentage of yearling ocean entrants varied little between fish released during 1998-2004 (82%) and those released in 2005 (88%). Second, there was little variation in the percentage of adults that had been reservoir-type juveniles between the 1998-2004 releases (36% or more) and 2005 releases (31% or more). Third, similar to results from the Snake River, fewer subyearling ocean entrants from the Clearwater River passed downstream undetected during 1998-2004 than in 2005. These trends should be followed as more data become available.

We recaptured 34 adult fall Chinook salmon at Lower Granite Dam that had been tagged as subyearlings, transported during summer, and released below Bonneville Dam. Of these transported fish, 76% had entered the ocean as subyearlings and 24% as yearlings after wintering in fresh or estuarine water. We recaptured an additional 15 fish that had been tagged as subyearlings and transported during fall. Of these, only 7% had entered the ocean as subyearlings, while 93% had wintered in fresh or estuarine water and entered the ocean as yearlings.

In addition to the subyearlings tagged and released above Lower Granite Dam, river-run subyearlings were tagged at Lower Granite Dam in September and October 2002-2005 and transported by truck to a release site below Bonneville Dam. During 2005 and 2006, we recaptured 80 returning fall Chinook salmon from this group. Thirty-six percent of these fish had entered the ocean as subyearlings, with the remaining 64% having entered as yearlings.

We found that subyearling ocean entrants were less likely than yearling ocean entrants to return after spending 1 year or less at sea (subyearlings produced fewer jacks and no mini-jacks). However, after omitting jacks and mini-jacks from consideration, yearling ocean entrants still comprised over half of the full-term adults. Full-term adults that had been yearling ocean entrants were usually similar in size or larger than full-term adults that entered the ocean as subyearlings.

We conclude that Snake River fall Chinook salmon juveniles employ diverse downstream passage and life history strategies to reach the sea. This diversity should be considered when planning recovery measures, designing dam-passage studies, and attempting to calculate smolt-to-adult return rates for release groups with different passage histories, particularly when undetected passage is prevalent.

Marsh DM, JR Harmon, NN Paasch, KL Thomas, KW McIntyre, BP Sandford, and GM Matthews. 2004. Transportation of Juvenile Salmonids on the Columbia and Snake Rivers, 2003: Final report for 2000 and 2001 Steelhead Juveniles. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Delivery Order E86960099.

Since 1999, the National Marine Fisheries Service has evaluated transportation of Snake River steelhead smolts. Beginning in 2003, transportation from McNary Dam was also evaluated for steelhead PIT-tagged at upper Columbia River hatcheries. In 2001, subyearling fall Chinook salmon studies began in the Snake River and at McNary Dam.

Steelhead Tagged as Juveniles in 2000

From 1 July 2003 to 30 June 2004, we recovered age-3-ocean steelhead adults from smolts tagged in 2000, completing adult returns from that study year. In 2000, we tagged only wild fish and released them into the Lower Granite Dam tailrace. For analysis, the transport group included only fish collected and transported from Little Goose Dam and the “inriver” comparison group excluded any fish detected at Little Goose and Lower Monumental Dams. During this period we detected no new wild age-3-ocean adults from the 2000 tagging at Lower Granite Dam; the only age-3-ocean adult detected was a returning kelt that had been counted when it returned as an age-2-ocean adult. Based on all 2000 returns combined (age-1-ocean through age-3-ocean fish), the smolt-to-adult return rates (SARs) of transported and inriver fish were 3.98 and 1.85, respectively, resulting in a transport-to-inriver (T/I) ratio of 2.15 (95% CI, 1.99-2.40).

As in 1999, SARs varied with the seasonal timing of juvenile migration, but had a different pattern. While SARs from the 1999 study year were generally higher for fish migrating later in the season, SARs from fish marked in 2000 were higher for earlier migrants, with few adult returns of fish marked after early May. Overall differential delayed mortality (*D*) was 0.95.

Of adults detected at Bonneville Dam, 71% of transported and 81% of inriver groups migrated successfully to Lower Granite Dam (not adjusted for harvest in the Zone 6 fishery). Respective median travel times for transported and inriver age-1-ocean adults from Bonneville Dam to Lower Granite Dam were 48 and 58 d. Age-2-ocean fish were approximately 40-50% faster, averaging 30 and 31 d for transported and inriver fish, respectively.

Steelhead Tagged as Juveniles in 2001

From 1 July 2003 to 30 June 2004, we recovered age-2-ocean steelhead adults from smolts tagged in 2001, virtually completing adult returns from that study year. In 2001, we tagged only wild fish, and because of record low flows, released all fish into barges at Lower Granite Dam; thus there was no "inriver" comparison group for the 2001 juvenile migration. During the adult recovery period, we detected 156 wild age-2-ocean adults tagged as juveniles in 2001 at Lower Granite Dam.

Because no age-3-ocean adults have returned since tagging began in 1999, we expected few, if any, detections of age-3-ocean adults from the 2001 tagging. Therefore we calculated the final smolt-to-adult return rate (SAR) for 2001 based on returns of age-1 and age-2-ocean fish in 2002 and 2003. For fish transported in 2001, the SAR was 2.33 (95% CI, 2.11-2.55).

For fish from the 2001 juvenile migration year, SARs again varied depending on the seasonal timing of their migration as juveniles. The pattern of variation was similar to that seen in 2000, with SARs generally higher for fish that migrated early in the season and few returns of fish marked after early May.

Of adults detected at Bonneville Dam, 68% migrated successfully to Lower Granite Dam (not adjusted for any take in the Zone 6 fishery). Median travel time from Bonneville to Lower Granite Dam was 54 d for age-1-ocean adults and 43 d for age-2-ocean adults.

Marsh DM, JR Harmon, NN Paasch, KL Thomas, KW McIntyre, BP Sandford, GM Matthews, and WD Muir. 2008a. Transportation of Juvenile Salmonids on the Snake River, 2006: Final Report for the 2003 Wild Spring/Summer Chinook Salmon Juvenile Migration. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Delivery Order E86960099.

The National Marine Fisheries Service began annual studies in 1995 to evaluate the efficacy of transporting Snake River spring/summer Chinook salmon *Oncorhynchus tshawytscha* smolts from Lower Snake River hydropower projects. From March to August 2006, we recovered 24 age-3-ocean spring/summer Chinook salmon adults, completing adult returns from smolts tagged during the 2003 study year.

In 2003, we tagged only wild fish and either released them into the Lower Granite Dam tailrace or loaded them into a barge at Lower Granite Dam. For analysis, the inriver migrant group was compared with two transport groups: one tagged and transported from Lower Granite Dam (LGR) and a second collected and transported from Little Goose Dam (LGS). The inriver migrant group excluded any fish detected at a Snake River dam after collection and tagging at LGR. During 2003, inriver migrants experienced higher-than-average flows, particularly late in the migration season. Spill during 2003 was provided at Snake and Columbia River dams as prescribed by the National Marine Fisheries Biological Opinion.

Based on all 2003 returns combined (jacks through age-3-ocean fish), the smolt-to-adult return rates (SARs) were 0.34 for fish transported from Lower Granite Dam, 0.20 for those transported from Little Goose Dam, and 0.13 for fish released to migrate in the river. For comparison, we also estimated the SAR of fish collected and returned to the river (bypassed) at one or more collector dams below Lower Granite Dam. The SAR for these bypassed fish was 0.10 (95% CI, 0.05-0.15).

For our study fish, these results produced transport-to-in-river migrant ratios (T/Is) of 2.64 (95% CI, 1.88-4.27) for fish transported from Lower Granite Dam and 1.60 (95% CI, 0.96-2.77) for fish transported from Little Goose Dam. We also observed a ratio of 1.65 for Lower Granite Dam to Little Goose Dam transport groups. As in previous years, SARs varied with timing of the juvenile migration. The estimate of annual differential delayed mortality, *D*, was 0.99.

While annual estimates of SAR and *D* are a main objective of transportation studies, the most useful information in recent years has been the discovery of temporal patterns in these indices. As in previous years, transport SARs in 2006 varied according to timing of the juvenile migration: there was a slight rise in SARs for fish that migrated early in the 2003 season, followed by a drop, and then a strong surge upward in mid-May. In a pattern similar to that observed in recent years, SARs for inriver migrants were highest for fish that migrated as juveniles early in the season and gradually decreased for later-migrating juveniles. Because delayed mortality, *D*, is driven by the transport SAR pattern, peaks in *D* occurred at the same time as peaks in transport SARs, with the highest peak occurring at the end of May.

In transportation studies from 1995 to 2001, we collected and tagged a relatively constant proportion of the population arriving at Lower Granite Dam. Thus a majority of study fish were collected during the peak of the juvenile migration, with far fewer being tagged early or late in the season. After observing the marked differences in SARs related to juvenile migration timing, we redesigned the study to tag more fish in the early and late segments of the migration season. This tagging design provided more accurate data with which to examine relationships between SARs and juvenile migration timing.

However, as a result of this tagging plan, the passage distribution of the general population of migrating wild spring/summer Chinook salmon at Lower Granite Dam was slightly different from that of our tagged sample. When we weighted the results according to passage distribution of the general population, the SAR for fish transported from Lower Granite Dam dropped from 0.34 to 0.25, while the SAR for inriver migrants remained at 0.13. Thus, the T/I for fish transported from Lower Granite Dam dropped from 2.64 to 1.96. Weighting also decreased the estimate of annual differential delayed mortality, *D*, from 0.99 to 0.90.

Among wild spring/summer Chinook transported from Lower Granite Dam in 2003, fish tagged at the dam for NMFS transportation studies produced higher T/I ratios (2.64) than fish tagged above the dam for other studies (0.62). Also, for wild spring/summer Chinook salmon transported from Little Goose Dam, fish tagged at Lower Granite for NMFS transportation evaluations produced a higher T/I ratio (1.60) than fish tagged above Lower Granite Dam for other research (0.77).

Conversion rates (the percentage of adults that successfully migrated from Bonneville Dam to Lower Granite Dam) varied widely among the three groups, perhaps in part due to the low number of adults. Respective overall conversion rates were 80.0 for groups transported from Lower Granite, 87.5 for those transported from Little Goose, and 96.0 % for inriver migrants (numbers were not adjusted for take in the Zone 6 fishery). Age-2-ocean adults had higher conversion rates, in general, than age-3-ocean adults. Median travel times of age-2-ocean adults ranged from 17 to 109% shorter than those of age-3-ocean adults.

Marsh DM, KW McIntyre, BP Sandford, SG Smith, WD Muir, and GM Matthews. 2010b. *Transportation of Snake River Fall Chinook Salmon 2008: Final Report for the 2004 Juvenile Migration*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington. Delivery Order E86960099.

The National Marine Fisheries Service began annual studies in 2001 to evaluate the efficacy of transporting Snake River fall Chinook salmon (*Oncorhynchus tshawytscha*) smolts from Lower Snake River hydropower projects. From 2001 through 2003, we tagged hatchery subyearling fall Chinook salmon at Lyons Ferry Hatchery and released them 81 km above Lower Granite Dam at Snake River kilometer 254. In 2004, this tagging routine was interrupted due to a lack of available subyearling fall Chinook salmon at Lyons Ferry Hatchery. Instead, we tagged river-run fish at Lower Granite Dam in 2004. During September and October 2004, we also tagged a fall transport index group of subyearling Chinook salmon (no fish were released to migrate inriver) for the third year at Lower Granite Dam. Final adult returns from tagging in both summer and fall 2004 are reported here. Results from 2001-2003 have been reported and are summarized and cited here in Appendix B.

Our original study was designed to compare smolt-to-adult return rates (SARs) of fish transported as juveniles from Lower Granite Dam with those of fish released to migrate inriver and not detected at any collector dam. However, recent data has shown the model used to estimate numbers of nondetected fish in studies using spring Chinook salmon cannot be used for Snake River fall Chinook salmon. This model relies on the assumption of equal probabilities of detection for fish from each cohort. However we now know that some fall Chinook delay their downstream migration for several months, passing dams during the winter when bypass systems are dewatered. Thus, since there is no way to reliably estimate numbers of nondetected fish, we report only the SARs of fish with known passage histories from the fish initially released.

Known passage histories of subyearling Chinook include those of transported fish, fish detected and bypassed as subyearlings in 2004, and fish detected migrating the year following release (holdover fish). From August to November 2008, we detected four age-4-ocean adults that had been transported from Lower Granite Dam in 2004, one adult that had been detected during spring 2005 (holdover), and five age-4-ocean adults from the transport index group marked in September-October 2004. The adults returning in 2008 complete adult returns from smolts tagged during the 2004 study year. Total adult returns from the summer marking at Lower Granite Dam in 2004 were very poor; only 20 adults returned to Lower Granite Dam for the 3 test groups.

For the combined age classes of subyearling fish tagged during summer 2004 (jacks through age-4-ocean fish), SARs were 0.14% (95% CI, 0.02-0.26%) for transported fish, 0.10% (0.04-0.17%) for bypassed fish, and 2.22% (0.04-4.40%) for holdovers. The SAR for the fall transport index group was 1.89% (1.35-2.42%).

For the combined year-classes of fish tagged as juveniles in June and July 2004, adult conversion rates between Bonneville and Lower Granite Dam were 83.3 (5 of 6 fish) for transported fish, 45.0 (9 of 20 fish) for bypassed fish, and 57.1% (4 of 7 fish) for holdover fish (rates not adjusted for harvest). For the fall transport index group, the overall conversion rate was 54.0% (47 of 87 fish), and of the fish not arriving at Lower Granite, up to 23% did not convert from McNary to Lower Granite Dam, while the loss between Bonneville and McNary Dams ranged from 17 to 45%. The lower river stretch has the Zone 6

Native American fishery. Too few adults returned to make meaningful comparisons of conversion rates among treatment groups.

Median travel times of adults from transport, bypass, and holdover groups ranged from 12 to 14 d, while the fall transport index group had a median travel time of 15 d.

Results from the small number of returning adults from 2004 transportation study releases did not provide definitive information change the conclusion of Williams et al. (2005) (based on earlier study years) that "transportation appeared to neither greatly harm nor help" Snake River fall Chinook salmon. The transported group had slightly higher SARs than the bypassed group in 2004. The highest SARs were seen in fish that delayed migration until fall or held over and migrated the following year as yearlings.

Marsh DM, WD Muir, D Elliott, T Murray, L Applegate, C McKibben, and S Mosterd. 2008b. *Alternative Barging Strategies to Improve Survival of Transported Juvenile Salmonids, 2007*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, and the U.S. Geological Survey, Seattle, Washington, for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington. Contract no. W68SBV60307671 and W68SBV60418618.

During spring 2007, we conducted a study to test the hypothesis that releasing transported juvenile salmonids *Oncorhynchus*. spp to the lower Columbia River estuary at river kilometer (rkm) 10 would produce higher smolt-to-adult return rates (SARs) than releasing them just below Bonneville Dam at rkm 225. We speculated that releasing transported fish an additional 215 km downstream from the location presently used could decrease smolt mortality due to predation by piscivorous fish and birds. Adults returning over the next several years will provide data to test this hypothesis.

In addition to evaluating a release location for transported fish, we used new, non-lethal techniques to collect fish pathogen data. We determined pathogen loads in study fish to evaluate whether pathogens in individual fish affect vulnerability to avian predators as well as SARs.

On five consecutive Sundays, starting in late April 2007 and running through May, run-of-the-river yearling Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) were collected and tagged with passive integrated transponder (PIT) tags at the Lower Granite Dam juvenile fish facility. Following tagging, fish were transferred to raceways and held until the following day, when they were loaded on barges for transport. A total of 9,494 hatchery and 1,891 wild yearling Chinook salmon were tagged and released downstream from Astoria at rkm 10, while 14,390 hatchery and 2,991 wild yearling Chinook salmon were tagged and released at Skamania Landing (rkm 225). In total, we released 20,206 hatchery and 2,553 wild steelhead at rkm 10 and 26,692 hatchery and 4,490 wild steelhead at rkm 225. Fewer fish were tagged than planned, particularly Chinook salmon, because permission to begin the study was delayed for a week; thus we missed the opportunity to tag on an earlier Sunday in April.

All Astoria releases were made after dark on an outgoing tide to reduce avian predation by Caspian terns Hydroprogne caspia and double-crested cormorants Phalacrocorax auritas from the nearby nesting colonies on East Sand Island. In fall 2007, abandoned bird colonies were scanned to detect PIT tags from fish released from this and other studies, and these data were used to estimate the number of fish from each release group preyed upon by piscivorous birds.

During each tagging day, about 300 non-lethal gill clip samples were collected for pathogen analyses (*Renibacterium salmoninarum* and *Nucleospora salmonis*), for a total of 1,449 samples over the season. These data allowed us to determine whether infection with *R. salmoninarum*, *N. salmonis*, or both pathogens was correlated with predation vulnerability. There was no evidence from the 2006 or 2007 study that infection of fish with one or both pathogens influenced rates of predation, but *R. salmoninarum* infection levels in the majority of tested fish were low, especially in the 2007 sample. Current methodologies for assaying *N. salmonis* can only provide numbers of fish infected, not infection levels, although a quantitative test should be in place for the 2008 study.

We will need to wait several years for complete adult returns to determine the efficacy of releasing transported salmonids at rkm 10 instead of the traditional release site at rkm 225. Based on preliminary returns from 2006 releases, transporting smolts to the estuary appeared to provide a modest improvement in SARs for steelhead, but not for yearling Chinook salmon. For steelhead, based on returns through 18 November 2008, 504 adults returned from the Skamania Landing releases with an estimated SAR of 1.21, while 445 adults returned from the Astoria releases with an estimated SAR of 1.52, resulting in a TA/TS of 1.26. For yearling Chinook salmon, with jacks and 2-ocean adult returns, the total thus far from the Skamania Landing releases is 124 with estimated SARs of 0.51, and from the Astoria releases, 49 with an estimated SAR of 0.30, resulting in a TA/TS of 0.59.

After two years of releases at the two sites, we do know that the new release location affected vulnerability to avian predators: mean avian predation rates (minimum estimates as not all tags are detected) in 2007 were 1.9% for yearling Chinook salmon released at Skamania Landing, but only 0.6% for those released near Astoria. Avian predation rates were 12.8% for steelhead released at Skamania Landing, but only 1.7% for their cohort released at Astoria. These results are nearly identical to those from 2006 releases. These results show that releasing fish farther downstream, at night, and on an outgoing tide will reduce avian predation substantially, particularly for steelhead, the species most vulnerable to avian predation. This finding is relevant for management actions related to recovery of juvenile salmonids that pass the world's largest Caspian tern and double-crested cormorant colonies during their downstream migration.

Marsh DM, WD Muir, BP Sandford, D Elliott, L Applegate, C McKibben, S Mosterd, S Badil, and J Woodson. 2010c. *Alternative Barging Strategies to Improve Survival of Transported Juvenile Salmonids, 2008 DRAFT*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, and the U.S. Geological Survye, Seattle, Washington, for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington. Contract no. W68SBV60307671 and W68SBV60418618.

In spring 2008, we continued a multi-year study to test the hypothesis that release of transported fish in the lower Columbia River estuary near Astoria (river kilometer 10) would produce higher adult returns than release at Skamania Landing, the established location just below Bonneville Dam (rkm 225). To evaluate this hypothesis, we released transported groups of juvenile Pacific salmon (*Oncorhynchus* spp.) to both sites for comparison of smolt-to-adult return rates (SARs) from each group. We speculated that moving the release site 215 km downstream could decrease smolt mortality due to predation by piscivorous fish and birds. Releases in 2008 made up the third and final consecutive year of juvenile releases for this study. Adults returning over the next several years will provide data to test this hypothesis.

In addition to evaluating a release location for transported fish, we used new, non-lethal techniques to collect fish pathogen data. We determined pathogen loads in study fish to evaluate whether pathogens in individual fish affect vulnerability to avian predators as well as SARs.

On six consecutive Sundays, from mid April to May 2008, we collected river-run yearling Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) at the Lower Granite Dam juvenile fish facility. All study fish were tagged with passive integrated transponder (PIT) tags. After tagging, fish were transferred to raceways and held until the following day, when they were loaded on barges for transport. Fewer yearling Chinook salmon were collected than planned; total releases of yearling Chinook were 19,555 at Astoria (16,519 hatchery and 3,036 wild) and 28,237 at Skamania Landing (23,717 hatchery and 4,520 wild). More steelhead were collected than planned, with total releases of 31,039 at Astoria (rkm 10; 25,353 hatchery and 5,686 wild) and 40,546at Skamania Landing (rkm 225; 32,920 hatchery and 7,626 wild).

All releases at rkm 10 were made after dark on an outgoing tide to reduce avian predation by Caspian terns Hydroprogne caspia and double-crested cormorants Phalacrocorax auritas from nearby nesting colonies on East Sand Island. After the nesting season, abandoned bird colonies were scanned to detect PIT tags from fish released from this and other studies, and these data were used to estimate the minimum numbers of fish from each release group preyed upon by piscivorous birds (only minimum predation rates can be estimated, as not all tags are detected).

During each tagging day, about 300 non-lethal gill clip samples were collected for pathogen analyses (*Renibacterium salmoninarum* and *Nucleospora salmonis*), for a total of about 1,800 samples over the season. These data allowed us to determine whether infection with R. salmoninarum, N. salmonis, or both was correlated with predation vulnerability. There was no conclusive evidence from studies in 2006, 2007, or 2008 that infection of fish with one or both pathogens influenced rates of predation, but infection levels of *R. salmoninarum* were low in the majority of test fish during all 3 years.

In 2008, the first year that N. salmonis levels in gill samples could be quantified, the majority of N. salmonis-infected fish were determined to have low infection levels. However, PIT tags from two of the six fish (hatchery steelhead) with the highest recorded N. salmonis levels (>1,000 DNA copies per reaction) were recovered from the East Sand Island Caspian tern colony in 2008. In addition, the PIT tag from one of the two fish (hatchery steelhead) with the highest recorded *R. salmoninarum* levels (>1,000 bacteria per mg tissue) was recovered from the tern colony in 2007. These data suggested increased vulnerability to avian predation of steelhead with high infection levels of either pathogen. Because of the lower avian predation rates on juvenile Chinook salmon than on juvenile steelhead, relatively few PIT tags from pathogen-tested Chinook salmon were detected on East Sand Island (7 to 33 tags) in comparison to PIT tags from pathogen-tested steelhead (98 to 139 tags) during the three years of pathogen testing.

After three years of releases at the two sites, we have clear evidence that the new release location affected vulnerability to avian predators. Mean minimum avian predation rates in 2008 were 3.9% for yearling Chinook salmon released at rkm 225, but only 0.9% for those released at rkm 10. Minimum avian predation rates were 14.9% for steelhead released at rkm 225 but only 4.4% for their cohorts released at rkm 10. These results were nearly identical to those from releases in 2006 and 2007, and show that releasing fish farther downstream, at night, and on an outgoing tide will reduce avian predation substantially, particularly for steelhead, the species most vulnerable to avian predation. This finding is relevant for management actions related to recovery of juvenile salmonids that pass the world's largest Caspian tern and double-crested cormorant colonies during their downstream migration.

We will need to wait several years for complete adult returns from all three release years to determine the efficacy of releasing transported salmonids at Astoria versus Skamania Landing. Based on complete adult returns from 2006 releases, the release site at Astoria (rkm 10) provided a modest improvement in SARs for steelhead but was detrimental for yearling Chinook salmon. For wild and hatchery steelhead combined, 551 adults returned from releases at Skamania for a SAR of 1.32, while 509 adults returned from releases at Astoria for a SAR of 1.75. This resulted in a SARs ratio of 1.20 (95% CI, 1.01-1.41) for Skamania:Astoria. For wild and hatchery yearling Chinook salmon combined, 139 adults returned from releases at rkm 225 for a SAR of 0.57, while 53 returned from releases at rkm 10 for a SAR of 0.33: thus the Skamania-to-Astoria ratio was only 0.49 (95% CI, 0.18-1.31). These results may vary by release year. However, based on 2006 releases, transporting steelhead smolts to the estuary increased the rate of straying and lowered conversion rates between Bonneville Dam and Lower Granite Dam, likely due to greater impairment of homing ability.

Marsh DM, BP Sandford, SG Smith, GM Matthews, and WD Muir. 2010d. Transportation of Columbia River Salmonids from McNary Dam: Final Adult Returns from the 2002-2004 Hatchery Spring Chinook and 2003-2005 Hatchery Steelhead Juvenile Migrations–DRAFT report. Prepared by Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers Walla Walla District, Walla Walla, Washington. Delivery Order E86960099.

In 2002, the National Marine Fisheries Service began multi-year studies to evaluate transport of upper Columbia River hatchery spring Chinook salmon smolts from McNary Dam. In 2003, NMFS began similar studies for upper Columbia hatchery steelhead. Smolts of each species were marked each year with passive integrated transponder (PIT) tags and released to migrate in the river or transported and released below Bonneville Dam. Here we report complete results from adult returns of Columbia River hatchery yearling spring Chinook salmon marked in 2002-2004 and steelhead smolts marked in 2003-2005.

At McNary Dam, the PIT-tag detection system in the full-flow bypass pipe was available only on a limited basis during the 2002 study. Therefore, all fish collected at the dam that year were sent over the separator. At the A and B Raceway Diversion gates, the Separation by Code system was set to divert 80% of Chinook study fish to transport. The remaining 20% were returned to the river via the juvenile facility bypass. From 2003 to 2005, transportation of our study fish from McNary Dam was conducted on alternate days. On the day study fish were collected for transportation, all fish entered the juvenile collection system where fish tagged for this study were diverted to transport holding raceways while the remaining (non-targeted fish) were returned to the river through the facility bypass system.

Hatchery Yearling Chinook. Juvenile yearling Chinook were collected and tagged at hatcheries in the Columbia River Basin upstream from McNary Dam. All fish were released directly from the hatchery at which they were tagged. As shown below, the number and proportion of the total release was similar at each hatchery among years. The exception was at Leavenworth, where the number varied from 216,698 to 267,533 (66.6 to 77.1%).

	Winthrop	Methow	Entiat	Leavenworth
2002	5.8%	n/a	17.1%	77.1%
2003	5.9%	10.2%	17.3%	66.6%
2004	5.9%	10.2%	17.3%	66.6%

In all study years, transported fish were barged and released below Bonneville Dam, bypassed fish completed their juvenile migration in the river, and inriver migrants were only those fish that passed via spillways or turbines at McNary Dam (i.e., without being detected).

For Chinook salmon, smolt-to-adult ratios (SARs) were poor for all 3 years, ranging from 0.19 to 0.43%. Ratios of SARs are shown below (with 95% CIs). Bypass SARs were for the juvenile facility bypass in 2002 and full-flow bypass in 2003 and 2004.

	Transport/Inriver	Bypass/Inriver	Transport/Bypass
2002	0.95 (0.78-1.13)	1.02 (0.79-1.28)	0.93 (0.71-1.24)
2003	0.74 (0.60-0.91)	0.62 (0.50-0.75)	1.20 (0.90-1.58)
2004	0.82 (0.62-1.03)	0.52 (0.37-0.68)	1.57 (1.09-2.27)

Patterns in the relationship between juvenile migration timing of Chinook salmon and SARs were different among all 3 study years. Even though the patterns were different, study years 2002 and 2003 were similar in that there were multiple peaks in both bypass and transport relative to juvenile timing, while study year 2004 had only one peak related to juvenile timing for both bypass and transport SARs.

The conversion rates of returning Chinook salmon adults (the percentage of adults detected at Bonneville Dam and subsequently detected at McNary Dam; not adjusted for any take in the Zone 6 fishery) ranged from 81% for study year 2004 to 86% for study year 2002. Differences between the transport and migrant groups varied between years, with the largest difference (three percentage points) occurring in 2003 (transport was the lower group).

Based on overall study results, Columbia River hatchery Chinook salmon that passed McNary Dam via the spillway/turbine route had higher SARs than fish collected and transported (geomean of 0.83 with 95% CI, 0.72-0.93). However, if a hatchery Chinook was guided into the juvenile collection system, transport provided a benefit over returning the fish to the river via the full-flow bypass pipe (geomean of 1.39 with 95% CI, 1.04-2.14).

Hatchery Steelhead. From 2003 to 2005, juvenile steelhead used in this study were tagged in the following proportions at the five hatcheries listed below:

	Wells	Winthrop	Chelan	Eastbank	Ringold
2003-2005	50.2%	10.3%	6.8%	12.8%	19.9%

Fish from Wells Hatchery were outplanted to the Methow and Okanogan Rivers; fish from Winthrop were released to the Methow River; and fish from Chelan and Eastbank Hatcheries were outplanted to the Wenatchee River. Fish from Ringold Hatchery were released to the Columbia River.

Numbers of fish tagged and proportions of the juvenile migration tagged were similar in all 3 years. However, fewer Ringold Hatchery fish were used in the 2005 study. Detections of Ringold Hatchery study fish in the adult ladder at McNary Dam in February 2005 (two months prior to the planned release date) led to the discovery of a hole in the tail screen of the holding pond. After repairing the screen, a PIT-tag detector was installed on the outflow from the pond so study fish could be detected when they were released in April. Only those Ringold Hatchery fish detected leaving the pond (64.3% of the steelhead tagged) were used in the 2005 study.

In adult returns from all three release years, SARs of steelhead were higher than those of Chinook salmon, ranging from 1.51 to 2.44%. Ratios of SARs are shown below for the three study groups (with 95% CIs).

	Transport/Inriver	Bypass/Inriver	Transport/Bypass
2003	0.96 (0.86-1.06)	0.80 (0.72-0.89)	1.20 (1.04-1.38)
2004	1.28 (1.11-1.45)	0.96 (0.84-1.09)	1.33 (1.11-1.57)
2005	1.09 (0.99-1.22)	1.01 (0.91-1.12)	1.08 (0.95-1.24)

Patterns of steelhead SARs in relation to juvenile migration timing were similar for transport groups from 2003 and 2004 and for full-flow bypass groups from 2003 to 2005. Steelhead that migrated as juveniles early in the season (mid-April) had the highest SARS. A decline in SARs was observed for steelhead that migrated after mid-April, with a second, smaller peak occurring after this 2- to 3-week decline. Finally, SARs declined to zero for fish that migrated as juveniles from the end of May to early June. The 2005 transport group was different in that there was only one peak, which occurred for fish migrating the first week of May.

Conversion rates of returning steelhead adults ranged from 65% in 2003 to 76% in 2005 and showed little difference between the groups within a year. Differences between the transport and inriver groups varied between years, with the largest difference (four percentage points) occurring in 2004 (transport was the lower group). In both 2003 and 2005, transported steelhead converted at slightly higher rates than inriver migrants, but the difference was less than 0.5% in both years. The loss between McNary and Bonneville Dam was due to some combination of straying, harvest, and mortality, but we have no data to determine percentages of loss from these three sources, or whether they differed between the study groups.

In contrast to results for spring Chinook salmon, overall results from studies of Columbia River hatchery steelhead transported from McNary Dam showed that transportation provided a benefit over fish that passed the dam through the spillway/turbine route (geomean of 1.10 with 95% CI, 1.02-1.18). Also, for fish that had already been guided into the juvenile collection system at a dam, transport provided a benefit over returning to the river, regardless of whether the river return route was through the full-flow bypass pipe (geomean of 1.20 with 95% CI, 1.10-1.31) or the facility bypass pipes (geomean of 1.39 with 95% CI, 1.15-1.72).

Thus, different results were obtained for the two species evaluated, with hatchery steelhead showing greater benefit from transport at McNary Dam and hatchery spring Chinook salmon showing greater benefit from inriver migration. For both species, if a fish was collected, it was better to transport the fish than return it to the river via the full-flow bypass pipe. The response to transport of wild Chinook salmon, wild steelhead, sockeye salmon, or any other species, was not evaluated during this study.

Mather ME, DL Parrish, CA Campbell, JR McMenemy, and JM Smith. 2008. "Summer temperature variation and implications for juvenile Atlantic salmon." *Hydrobiologia* 603:183-196.

Temperature is important to fish in determining their geographic distribution. For cool- and cold-water fish, thermal regimes are especially critical at the southern end of a species' range. Although temperature is an easy variable to measure, biological interpretation is difficult. Thus, how to determine what temperatures are meaningful to fish in the field is a challenge. Herein, we used the Connecticut River as a model system and Atlantic salmon (*Salmo salar*) as a model species with which to assess the effects of summer temperatures on the density of age 0 parr. Specifically, we asked: (1) What are the spatial and temporal temperature patterns in the Connecticut River during summer? (2) What metrics might detect effects of high temperatures? and (3) How is temperature variability related to density of Atlantic salmon during their first summer? Although the most southern site was the warmest, some northern sites were also warm, and some southern sites were moderately cool. This suggests localized, within basin variation in temperature. Daily and hourly means showed extreme values not apparent in the seasonal means. We observed significant relationships between age 0 parr density and days at potentially stressful, warm temperatures (>= 23 degrees C). Based on these results, we propose that useful field reference points need to incorporate the synergistic effect of other stressors that fish encounter in the field as well as the complexity associated with cycling temperatures and thermal refuges. Understanding the effects of temperature may aid conservation efforts for Atlantic salmon in the Connecticut River and other North Atlantic systems.

Matthews GM, DL Park, S Achord, and TE Ruehle. 1986. "Static Seawater Challenge Test to Measure Relative Stress Levels in Spring Chinook Salmon Smolts." *Transactions of the American Fisheries Society* 115(2):236-244.

A static seawater challenge test was successfully developed and used to establish a profile of the relative stress levels of spring Chinook salmon smolts *Oncorhynchus tshawytscha* within the smolt collection and transport system at Lower Granite Dam on the Snake River. A major feature of the test was the development of water-to-water transfer techniques designed to assure minimal stress interference associated with sampling and transferring test fish from the freshwater sample sites to the seawater test chambers. The test was used to isolate stresses associated with movement of smolts through the system, with handling and marking procedures, and with holding spring Chinook salmon smolts in the presence of predominately hatchery-reared steelhead Salmo gairdneri smolts. The test results clearly indicated a pattern of increasing stress levels as smolts moved through the system. The bypass system, the fish and debris separator complex, and transport by truck were areas where stress levels i ncreased. Dipnetting smolts with a standard dip net was implicated as the major contributor to the overall stress associated with our handling and marking procedures. The stress level of spring Chinook salmon smolts appeared to be influenced by the presence of high populations of hatchery-reared steelhead smolts. Procedures used in the test provided reliable but somewhat variable results. Changes recommended for reducing the variability include a shorter test time and a different method of replication.

Maule AG, CB Schreck, and SL Kaattari. 1987. “Changes in the Immune System of Coho Salmon (*Oncorhynchus kisutch*) during the Parr-to-Smolt Transformation and after Implantation of Cortisol.” *Canadian Journal of Fisheries & Aquatic Sciences* 44(1):161-166.

The primary immune response of coho salmon (*Oncorhynchus kisutch*), as assessed by the production of splenic antibody-secreting cells (plaque-forming cells, PFC) after an injection of Vibrio anguillarum O-antigen, decreased during smoltification. This period was marked by increases in gill Na^{+}-K^{+}-adenosine triphosphatase (ATPase) activity and plasma thyroxine and cortisol titers. Numbers of leucocytes relative to erythrocytes in peripheral blood and splenic lymphocytes relative to fish body weight were also reduced. Fish reared at normal hatchery density (approximately 2 fish*L^{-1}) appeared to have reduced rates of development and higher numbers of PFC than fish reared at one-third normal density. Moreover, in fish changed from normal density to low density 2 wk before sampling, ATPase activity and plasma thyroxine levels were equal to those in fish reared continuously at normal density, but plasma cortisol levels and PFC were equal to those in fish reared at low density. Fish with cortisol implants had higher plasma cortisol titers, reduced numbers of splenic PFC, splenic lymphocytes, and circulating leucocytes, and greater mortality when fish were exposed to V. anguillarum.

McClure MM, EE Holmes, BL Sanderson, and CE Jordan. 2003. “A large-scale, multispecies status, assessment: Anadromous salmonids in the Columbia River Basin.” *Ecological Applications* 13(4):964-989.

Twelve salmonid evolutionarily significant units (ESUs) throughout the Columbia River Basin are currently listed as threatened or endangered under the Endangered Species Act; these ESUs are affected differentially by a variety of human activities. We present a standardized quantitative status and risk assessment for 152 listed salmonid stocks in these ESUs and 24 nonlisted stocks. Using data from 1980-2000, which represents a time of stable conditions in the Columbia River hydropower system and a period of ocean conditions generally regarded as poor for Columbia Basin salmonids, we estimated the status. of these-stocks under two different assumptions: that hatchery-reared spawners were not reproducing during the period of the censuses, or that hatchery-reared spawners were reproducing and thus that reproduction from hatchery inputs was masking population,trends. We repeated the analyses using a longer time period containing both "good" and "bad". ocean conditions (1965-2000) as a first step toward determining whether recent apparent declines are a result of sampling a period of poor ocean conditions. All the listed ESUs except Columbia River chum showed declining trends with estimated long-term population growth rates (X's) ranging from 0.85 to 1.0, under the, assumption that hatchery fish were not reproducing and not masking the true X. If hatchery fish were reproducing, the estimated X's fanged from 0.62 to 0.89, indicating extremely low natural reproduction and survival. For most ESUs, there was no significant decline in population growth rates calculated for. the 1980-2000 Versus 1965-2000 time periods, suggesting that the current population status for most ESUs is not solely. a result of changes in ocean conditions, and that without other changes, risks will persist even during upturns in ocean conditions. However, estimated population growth rates for the Snake River spring-summer Chinook salmon and steelhead ESUs were significantly lower during the longer time period. This difference may be due to a period of dam building on the Snake River during the 1960s and 1970s. For 33 stocks and seven ESUs, the probability of extinction could be estimated. The estimates were generally low for all ESUs with the exception of Upper Columbia River spring Chinook and Upper Willamette River steelhead. The probability of 90% decline could be estimated for all stocks. The mean probability of 90% decline in 50 years was highest for Upper Columbia River spring Chinook (95% mean probability across all stocks within the ESU) and Lower Columbia River steelhead (80% mean probability). We estimated the effects of two different management actions on long-term growth rates for the ESUs. Harvest reductions offer a

means to mitigate risks for ESUs that bear substantial harvest pressure, but they are unlikely to increase population growth rates enough to produce stable or increasing trends for all ESUs. Similarly, anticipated improvements to passage survival through the Snake and mainstem Columbia hydropower systems may be important, but additional actions are likely to be necessary to recover affected ESUs.

McComas RL, LG Gilbreath, SG Smith, GM Matthews, JW Ferguson, GA McMichael, JA Vucelick, and T Carlson. 2007. *A Study to Estimate Salmonid Survival through the Columbia River Estuary using Acoustic Tags, 2005*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, and Pacific Northwest National Laboratory, Portland, Oregon, for the U.S. Army Corps of Engineers Portland District, Portland, Oregon. Delivery Order E86910060.

In 2005, NOAA Fisheries, with Battelle Pacific Northwest National Laboratory and the U.S. Army Corps of Engineers, initiated the second phase of a multi-year project to estimate juvenile salmonid survival through the lower Columbia River and estuary. A total of 870 yearling and 1,217 subyearling run-of-the-river Chinook salmon Oncohrhynchus tshawytscha tagged with surgically implanted acoustic transmitters and passive integrated transponder (PIT) tags were released through the Bonneville Dam juvenile bypass facility outfall into the Columbia River. Yearling Chinook salmon were released 4 May–1 June (4 releases); subyearling fish were released 18 June–16 July (5 releases). Mean survival, assessed using the single-release estimation model, ranged from 0.564 (SE = 0.0683) to 0.873 (SE = 0.0545) for yearling release groups, and from 0.150 (SE = 0.245) to 0.748 (SE = 0.0497) for subyearling releases. Pooled across all releases, mean survival estimates were 0.754 (SE = 0.1797) for yearling Chinook salmon and 0.653 (SE = 0.2446) for subyearling Chinook salmon.

Median travel time by release from the outfall at river kilometer (rkm) 231.3 to the primary array (rkm 9) was 2.97 d (range 2.9-5.8 d) for yearling Chinook salmon, resulting in a migration rate of approximately 75.0 km/d. From PIT-tag detections using a pair trawl, the migration rate may have been differential for yearling smolts, which tended to slow on approaching the estuary. Subyearling Chinook salmon median travel time was 4.1 d, with a migration rate of about 53 km/d. The majority of detections occurred during daylight and across all tide stages for both species. Avian predation, evidenced by PIT-tag recoveries from estuary bird colonies, accounted for 4.5 and 4.4% of yearling and subyearling Chinook salmon mortality, respectively.

McComas RL, GA McMichael, JA Vucelick, L Gilbreath, JP Everett, SG Smith, T Carlson, G Matthews, and JW Ferguson. 2008. *A Study to Estimate Salmonid Survival through the Columbia River Estuary using Acoustic Tags, 2006*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, and Pacific Northwest National Laboratory, Richland, Washington, for the U.S. Army Corps of Engineers Portland District, Portland, Oregon. Delivery Order E86910060.

In 2006, NOAA Fisheries, the Pacific Northwest National Laboratory (PNNL) and the U.S. Army Corps of Engineers (COE) continued the second phase of a multiyear project to estimate juvenile salmonid survival through the lower Columbia River and estuary. Also, a pilot study was initiated to determine the feasibility of estimating system-wide survival of fish released at Lower Granite Dam.

A total of 972 yearling and 1,957 subyearling Chinook salmon were surgically implanted with acoustic transmitters and passive integrated transponder (PIT) tags. River-run fish were collected from the Bonneville Dam juvenile bypass facility and released back into the Columbia River in groups of

approximately 245. Yearling Chinook salmon were released during 2–27 May (4 releases), while subyearlings were released during 16 June-22 July (8 releases).

Estimates of survival ranged from 0.584 to 0.824 for yearling Chinook and from 0.185 to 1.005 for subyearling Chinook salmon. Pooled across all releases, estimated mean survival was 0.665 (SE = 0.055) and 0.632 (SE = 0.112) for yearling and subyearling fish, respectively. For yearling Chinook salmon, mean travel time from release (rkm 231.2) to the primary detection array (rkm 9) was 4.1 d (range 2.1–17.2 d), resulting in a mean migration rate of approximately 54.1 km d-1. For subyearling Chinook salmon, mean travel time was 4.1 d, resulting in a migration rate of about 54.1 km d-1. For both run types, a majority of first detections on the primary array occurred during daylight hours and during ebb tides. Avian predation, evidenced by PIT-tag recoveries from estuary bird colonies, accounted for at least 2.5 % of mortality for both yearling and subyearling Chinook salmon.

A total of 996 yearling river-run Chinook salmon were surgically implanted with acoustic transmitters and PIT tags and released from the Lower Granite juvenile bypass outfall into the Snake River on 6 and 13 May. Pooled across both releases, mean survival was estimated at 0.787 (SE = 0.0147) to the mouth of the Snake River, and 0.384 (SE = 0.0278) to the lower Columbia River estuary. Mean travel time from release at Lower Granite Dam to the Columbia River estuary was 13.0 d (range 6.6–35.3 d), resulting in a mean migration rate of approximately 52.8 km d-1. For yearling Chinook salmon released at Lower Granite Dam, travel time from the primary array below Bonneville Dam to the primary array in the Columbia River estuary was similar to that of their cohorts released at Bonneville Dam. Yearling Chinook released at Lower Granite dam were detected in the estuary mainly during daylight hours and across all tide stages.

McMichael, GA, RA Harnish, BJ Bellgraph, JA Carter, KD Ham, PS Titzler, and MS Hughes. 2010. *Survival and Migratory Behavior of Juvenile Salmonids in the Lower Columbia River Estuary in 2009*. PNNL-19545, prepared by Battelle–Pacific Northwest Division, Richland, Washington, for the U.S. Army Corps of Engineers, Portland District, Portland, Oregon. Pacific Northwest National Laboratory, Richland, Washington. Report no. Contract no. DE-AC05-76RL01830.

The addition of autonomous receiver arrays to partition the lower Columbia River and estuary into reaches, beginning in 2007, has vastly increased our understanding of the migratory behavior and survival of juvenile salmonids emigrating through the lower 235 km of the Columbia River and estuary.

Estimated survival of acoustic-tagged juvenile Chinook salmon and steelhead through the lower Columbia River and estuary in 2009 was lowest in the final 50 km of the estuary. Probability of survival was relatively high (>0.90) for yearling and subyearling Chinook salmon from the Bonneville Dam forebay (rkm 236) to Three-tree Point (rkm 49.6). Survival of juvenile Chinook salmon declined sharply through the lower 50 km of the estuary. Acoustic-tagged steelhead smolts did not survive as well as juvenile Chinook salmon between Bonneville Dam and the mouth of the Columbia River. Steelhead survival began to decline farther upstream (at Oak Point [rkm 86]) relative to that of the Chinook salmon stocks. Subyearling Chinook salmon survival decreased markedly as the season progressed. It remains to be determined whether later migrating subyearling Chinook salmon are suffering increasing mortality as the season progresses or whether some portion of the apparent loss is due to fish extending their freshwater residence.

This study provided the first glimpse into what promises to be a very informative way to learn more about how juvenile salmonid passage experiences through the FCRPS may influence their subsequent survival after passing Bonneville Dam.

New information regarding the influence of migration pathway through the lower 50 km of the Columbia River estuary on probability of survival of juvenile salmonids, combined with increased understanding regarding the foraging distances and time periods of avian predators should prove useful in developing or assessing management actions to reduce losses of juvenile salmonid smolts that attempt to pass through the estuary on their seaward migration.

McMichael GA, JA Vucelick, B Ryan, L Gilbreath, R L McComas, S Smith, M Carper, D Elliott, T Murray, L Applegate, and C McKibben. 2006. *Alternative Barging Strategies to Improve Survival of Transported Juvenile Salmonids – 2005.* Prepared by Battelle–Pacific Northwest Division, Richland, Washington, the National Oceanic and Atmospheric Administration, Fisheries Service, the U.S. Geological Survey, Western Fisheries Research Center, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Contract no. DACW57-00-D-0009 #11.

In spring and summer 2005, Battelle-Pacific Northwest Division, NOAA Fisheries, and the U.S. Geological Survey Western Fisheries Research Center conducted a study for the U.S. Army Corps of Engineers, Walla Walla District, to determine whether alternative barging strategies might improve the survival of salmon smolts traveling down the Columbia River toward the Pacific Ocean in the northwestern United States. To increase understanding of whether transporting steelhead smolts an additional 204 km downriver would increase their survival to ocean entry, a study was designed and implemented to examine the travel time, distribution, survival, and avian predation rates on Snake River origin steelhead released at the traditional release location (Skamania Landing, rkm 226.9) and an experimental release location closer to the ocean (Astoria Bridge, rkm 22.5). In addition, a new technique to collect pathogen data using non-lethal methodologies was used to determine what pathogen loads were in the hatchery steelhead we tagged and whether there were fish performance differences that could be related to the pathogen loads in individual fish.

Hatchery steelhead of Snake River origin were captured from fish transport barges between John Day and Bonneville dams and then tagged with either a passive integrated transponder (PIT) and an acoustic transmitter (AT) or just a PIT tag. At the time of tagging, non-lethal gill clip samples were collected from all AT-tagged fish for pathogen (*Renibacterium salmoninarum* and *Nucleospora salmonis*) analyses. A total of 1,002 hatchery steelhead, in four AT (and PIT) -tagged groups were released at the Skamania landing and Astoria Bridge sites between May 7 and 23, 2005. In addition, 2,475 hatchery steelhead with PIT tags (no AT) were released at these sites between May 16 and 23, 2005. The PIT-tag-only groups were released to determine whether the AT increased the susceptibility of the steelhead to avian predation.

Detection arrays, consisting of autonomous and cabled receivers were deployed near the mouth of the Columbia River in two arrays. The primary array was located at river kilometer (rkm) 8.4, near the piscivorous bird colonies on East Sand Island. The secondary array was located at rkm 2.6. Data from both arrays were processed and analyzed to determine the travel times, cross-channel distribution, and survival of AT-tagged fish. In addition, to estimate the number of fish in each release group that were eaten by piscivorous birds, the bird colonies were scanned for PIT tags to detect tags from fish released in this study. Gill filament samples were analyzed for pathogen detection by polymerase chain reaction

(PCR) tests. A non-quantitative nested PCR (nPCR) test was used for detection of N. salmonis, and both nPCR and real-time quantitative PCR (qPCR) were used for detection of R. salmoninarum. About 40% of the AT-tagged steelhead were detected near the mouth of the Columbia River.

Transporting steelhead the additional distance from Skamania Landing to the Astoria Bridge resulted in different cross-channel distributions, different time-of-day passage through the area of the mouth of the Columbia River adjacent to the large piscivorous bird colonies on East Sand Island, and different avian predation rates. These changes would be expected to produce a juvenile survival advantage from point of release to ocean entry for fish released at the Astoria Bridge. However, the survival estimates for the Skamania and Astoria release groups in this study did not show a significant survival advantage for fish released at the Astoria Bridge site. The survival estimates in this study were impacted by highly variable detection probability values between and within release groups (dates).

Pathogen analyses by PCR detected *R. salmoninarum* in 41% of the AT-tagged steelhead and N. salmonis in 25% of these fish. Comparisons of proportions of AT-tagged fish that were detected by Alternative Barging Strategies to Improve Survival of Transported Juvenile Salmonids – 2005 the primary or secondary array or both arrays showed no significant differences between fish that were uninfected and those that were infected with one or both pathogens. Similarly, this study showed no detectable influence of the presence or absence of these pathogens on avian predation rates. The *R. salmoninarum* infection levels in all but three fish were very low, however, and only one of the three fish with higher infection levels was detected by the primary receiving array. None of the three fish were detected by the secondary receiving array or on the bird colonies. Because a qPCR test was not available for N. salmonis, the infection levels of this pathogen in the fish were unknown. Although steelhead can be infected by both *R. salmoninarum* and *N. salmonis*, they are less susceptible to clinical disease than certain other species such as Chinook salmon.

Most of the evidence collected in 2005 suggests that a greater proportion of the fish released at the Astoria Bridge would be expected to enter the Pacific Ocean in comparison to those released at the Skamania Landing site 204 km upstream. However, to understand the biologically significant implications of this would require survival studies that estimate smolt-to-adult return (SAR). Use of larger experimental groups of PIT-tagged fish could allow for these types of estimates.

Mesa MG. 1994. "Effects of Multiple Acute Stressors on the Predator Avoidance Ability and Physiology of Juvenile Chinook Salmon." *Transactions of the American Fisheries Society* 123(5):786-793.

Northern squawfish Ptychocheilus oregonensis are the predominant predators of juvenile Pacific salmonids (*Oncorhynchus* spp.) in the Columbia River, and their predation rates are greatest just below dams. Because juvenile salmonids are commonly subjected to multiple stressors at dams in the course of their seaward migration, high predation rates below dams may be due in part to an increase in the vulnerability of stressed fish. I conducted laboratory experiments to examine the predator avoidance ability and physiological stress responses of juvenile Chinook salmon (*O. tshawytscha*) subjected to treatments (stressors) designed to simulate routine hatchery practices (multiple handlings) or dam passage (multiple agitations). Both stressors resulted in lethargic behavior in the fish, and agitation also caused disorientation and occasional injury. When equal numbers of stressed and unstressed fish were exposed to northern squawfish for up to 1 h, significantly more stressed fish were eaten, but this effect was not evident during longer exposures. The lack of differential predation in trials lasting up to 24 h can be explained by the rapid development of schooling behavior in the prey, but other possibilities exist, such as changing ratios of stressed and unstressed prey over time. Concentrations of plasma cortisol, glucose, and lactate in fish subjected to multiple stressors were similar and sometimes cumulative, returned to prestress levels within 6-24 h, and correlated poorly with predator avoidance ability. Mv results suggest that juvenile salmonids are capable of avoiding predators within 1 h after being subjected to multiple acute stressors even though physiological homeostasis may be altered for up to 24 h. Therefore, because juvenile salmonids typically reside in tailrace areas for only a short time after dam passage, measures aimed at reducing physical stress or protecting them as they migrate through dam tailraces may help alleviate the relatively intense predation in these areas.

Mesa MG, MH Averbeck, AG Maule, DG Elliott, amd AL Miracle. 2008. *Mechanisms of Delayed Mortality in Juvenile Salmonids Outmigrating in the Columbia River Basin – Draft Final Report FY 2008*. Prepared by the U.S. Geological Survey, Western Fisheries Research Center, Cook, Washington, the USGS, Seattle, Washington, and the Pacific Northwest National Laboratory, Richland, Washington for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

We investigated possible mechanisms of delayed mortality in Columbia River Basin juvenile spring Chinook salmon (*Oncorhynchus tshawytscha*) that were transported by barge or migrated in-river (run-of–river fish, or ROR). Delayed mortality refers to mortality of fish that occurs in the estuary or ocean that is related to their earlier experiences in the hydrosystem. Possible mechanisms of delayed mortality include physiological dysfunction, poor health, or predation. To investigate these mechanisms, we collected tissue samples from PIT-tagged fish at hatcheries (Dworshak and Rapid River hatcheries, Idaho), from transport barges, and at dams along the Columbia River. We used a suite of methods to document the physiological and health status of barged and ROR fish, including traditional indicators of stress and smoltification, new, cutting-edge cDNA microarrays to develop gene expression profiles, and polymerase chain reaction assays to estimate the prevalence and severity of several fish pathogens. We also evaluated the possible contribution of size-selective predation to delayed mortality by conducting predation tests in the laboratory and examining the diets of predators collected below Bonneville Dam. Plasma cortisol levels were lowest in fish at the hatcheries (< 25 ng/mL), highest in ROR fish (range = 200 – 300 ng/mL), and intermediate in fish that were barged (range = 75 – 175 ng/mL). Thyroxine levels were low in all fish, ranging from about 1 – 3 ng/mL, and the activity of gill Na+, K+-ATPase ranged from 3 – 4 μmol P h-1 mg protein-1 in fish at the hatcheries before increasing significantly in barged and ROR fish (range = 5 – 10 units). There were few significant differences in ATPase activity between barged and ROR fish. The number of genes that were over or under-transcribed increased significantly after fish were released from the hatcheries, and were highest in barged fish and lowest in ROR fish. Overall, transcriptome response was highest in fish from Dworshak Hatchery. For fish sampled at Lower Granite Dam, several genes associated with immune function were over-transcribed, some metabolism-related genes were over and under-transcribed, and stress-responsive genes were mostly down-regulated. Many genes associated with the immune system were up or down-regulated in barged fish, and several stress-responsive genes were also over-transcribed. Very few significant differences in gene expression existed in ROR fish, a notable exception being the down-regulation of a few immune function genes. We tested all fish for the presence of several pathogens, including the bacteria *Renibacterium salmoninarum* (Rs), *Yersinia ruckeri*, *Aeromonas salmonicida* and *Flavobacterium psychrophilum*, infectious hematopoeitic necrosis virus (IHNV), the myxosporean parasite *Ceratomyxa shasta*, and the microsporidian parasite *Nucleospora salmonis* (Ns). The most prevalent pathogens detected were Rs (detected in 85% of fish in 2005 and in 67% of fish in 2006), Ns (detected in 17% of fish in 2005 and in 26% of fish in 2006), and IHNV (detected in <1% of fish in 2005 but in 11% of fish in 2006). Results suggested that year-to-year variation in pathogen profiles occurred, a combination of pathogens were often present in fish, and the increase in IHNV seen in 2006 occurred in barged fish only. Our predation tests in the laboratory indicated that northern pikeminnow Ptychocheilus oregonensis selectively fed on smaller juvenile salmon when the difference in prey size was at least 20, but not 10, mm. Also, we found little evidence of size-selective predation by northern pikeminnow based on a comparison of juvenile salmon consumed versus those available in the environment. Collectively, our results indicated that transport by barge was stressful, activated many stress-responsive and immune function genes, and resulted in some unexplained changes in pathogen profiles of fish (e.g., an increase in IHNV in barged fish). We conclude that the hypothesis of stress-mediated, disease-related delayed mortality, particularly for barged fish, warrants further attention.

Mesa MG and TM Olson. 1993. "Prolonged Swimming Performance of Northern Squawfish." *Transactions of the American Fisheries Society* 122(6):1104-1110.

We determined the prolonged swimming performance of two size-classes of northern squawfish Ptychocheilus oregonensis at 12 and 18-degrees-C. The percentage of fish fatigued was positively related to water velocity and best described by an exponential model. At 12-degrees-C, the velocity at which 50% of the fish fatigued (FVSO) was estimated to be 2.91 fork lengths per second (FL/s; 100 cm/s) for medium-sized fish (30-39 cm) and 2.45 FL/s (104 cm/s) for large fish (40-49 cm). At 18-degrees-C, estimated FV50 was 3.12 FL/s (107 cm/s) for medium fish and 2.65 FL/s (112 cm/s) for large fish. Rate of change in percent fatigue was affected by fish size and water temperature. Large fish fatigued at a higher rate than medium-sized fish; all fish fatigued faster at 12 than at 18-degrees-C. The mean times to fatigue at velocities of 102-115 cm/s ranged from 14 to 28 min and were not affected by fish size or water temperature. Our results indicate that water velocities from 100 to 130 cm/s may exclude or reduce predation by northern squawfish around juvenile salmonid bypass outfalls at Columbia River dams, at least during certain times of the year. We recommend that construction or modification of juvenile salmonid bypass facilities place the outfall in an area of high water velocity and distant from eddies, submerged cover, and littoral areas.

Mesa MG, TP Poe, AG Maule, and CB Schreck. 1998. "Vulnerability to predation and physiological stress responses in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) experimentally infected with Renibacterium salmoninarum." *Canadian Journal of Fisheries and Aquatic Sciences* 55(7):1599-1606.

We experimentally infected juvenile Chinook salmon (*Oncorhynchus* tshawyrscha) with Reinbacterium salmoninarum (Rs), the causative agent of bacterial kidney disease (BKD), to examine the vulnerability to predation of fish with differing levels of Rs infection and assess physiological change during progression of the disease. Immersion challenges conducted during 1992 and 1994 produced fish with either a low to moderate (1992) or high (1994) infection level of Rs during the 14-week postchallenge rearing period. When equal numbers of treatment and unchallenged control fish were subjected to predation by either northern squawfish (Ptychocheilus oregonensis) or smallmouth bass (Micropterus dolomieui), Rs-challenged fish were eaten in significantly greater numbers than controls by nearly two to one. In 1994, we also sampled fish every 2 weeks after the challenge to determine some stressful effects of Rs infection. During disease progression in fish, plasma cortisol and lactate increased significantly whereas glucose decreased significantly. Our results indicate the role that BKD may play in predator-prey interactions, thus ascribing some ecological significance to this disease beyond that of direct pathogen-related mortality. In addition, the physiological changes observed in our fish during the chronic progression of BKD indicate that this disease is stressful, particularly during the later stages.

Mesa MG, LK Weiland LK, and P Wagner. 2002. "Effects of acute thermal stress on the survival, predator avoidance, and physiology of juvenile fall Chinook salmon." *Northwest Science* 76(2):118-128.

We subjected juvenile fall Chinook salmon from the Hanford Reach of the Columbia River to acute thermal stressors in the laboratory that were derided from field data. we assessed the effects of thermal stress on: (1) the extent of direct mortality; (2) the vulnerability of fish to predation by smallmouth bass: and (3) some general physiological stress responses and synthesis of heat shock protein 70 (hsp70). Thermally-stressed fish showed little direct mortality and no increases in vulnerability to predation. However, these fish showed transient increases in plasma concentrations of cortisol, glucose, and lactate, and a dramatic (25-fold higher than controls) and persistent (lasting 2 wk) increase in levels of lifer hsp70. Our results indicate that exposure of Hanford Reach juvenile fall Chinook salmon to such stressors did not lead to significant increases in direct mortality or vulnerability to predation, but did alter physiological homeostasis, which should be of concern to those managing this resource, Because our fish received only a single exposure to one of the stressors we examined, we are also concerned about the consequences of exposing fish to multiple, cumulative stressors-a likely scenario for fish in the wild.

Muir, WD and TC Coley. 1996. "Diet of Yearling Chinook Salmon and Feeding Success During Downstream Migration in the Snake and Columbia Rivers." *Northwest Science* 70(4):298-305.

The objectives of this study were to characterize anti compare the stomach contents and feeding success of yearling Chinook salmon smolts (*Oncorhynchus tshawytscha*), during their downstream migration at three sites in the Snake and Columbia Rivers. From 1987 to 1991, 26 to 38% of the yearling Chinook salmon smolts sampled as they passed Lower Granite Dam, the first dam encountered by migrants in the Snake River, had empty stomachs, in 1991, smolts were sampled further downstream at McNary and Bonneville Dams on the Columbia River on thr same sample dates. Empty stomachs occurred in 3% and 5% of these fish, respectively, and overall stomach fullness values were significantly higher. Smolts ale primarily dipterans (chironomids) al Lower Granite Dam; cladocerans, homopterans, and dipterans at McNary Dam: anti amphipods and dipterans at Bonneville Dam-taxa typical of impounded waters, A series of dams on the Snake and Columbia Rivers has altered the conditions and habitat available for migrating juvenile salmonids and contributed to their decline. Large numbers of hatchery smolts, long residence times, altered food resources, and reservoir morphology may contribute to poor feeding success near Lower Granite Dam and could lead to reduced smolt survival.

Muir WD, DM Marsh, BP Sandford, SG Smith, and JG Williams. 2006. "Post-Hydropower System Delayed Mortality of Transported Snake River Stream-Type Chinook Salmon: Unraveling the Mystery." *Transactions of the American Fisheries Society* 135(6):1523-1534.

Past research indicates that on an annual basis, smolts of stream-type Chinook salmon (*Oncorhynchus tshawytscha*) collected at Snake River dams and transported by barge to below Bonneville Dam have greater post-hydropower system mortality than smolts that migrate in-river. To date, this difference has most commonly been attributed to stress from collection and transportation, leading to decreased disease resistance or predator avoidance ability. Using both hatchery and wild passive integrated transponder (PIT) tagged Chinook salmon, we explored two mechanisms that either separately or jointly contributed to an alternative explanation: altered timing of ocean entry and lost growth opportunity leading to size-selective predation. Based on weekly estimates of in-river survival and adult return rates of smolts that were transported or that migrated in-river between Lower Granite and Bonneville dams, we found greater post-hydropower system mortality for smolts transported early in the season but greater mortality for in-

river migrating smolts later in the season. Migrants took 2-4 weeks to travel between the two dams, while transported fish took less than 2 d. Thus, fish leaving Lower Granite Dam under the two transit modes encountered different conditions downstream from Bonneville Dam. Further, wild and hatchery migrants grew 6-8 and 5-6 mm, respectively, while transported fish had no apparent growth in the less than 2-d barge ride. Using length data and regression equations of size selectivity, we found that transported smolts were more vulnerable to predation by northern pikeminnow Ptychocheilus oregonensis (freshwater) and Pacific hake Merluccius productus (marine) than were migrants; this was particularly true for the smaller wild smolts transported early in the season. We concluded that the most parsimonious explanation for differential post-hydropower system mortality of transported Chinook salmon smolts related not to effects of stress but to differential size and timing of ocean entry.

Naesje TF, EB Thorstad, T Forseth, M Aursand, R Saksgard, and AG Finstad. 2006. "Lipid class content as an indicator of critical periods for survival in juvenile Atlantic salmon (*Salmo salar*)." *Ecology of Freshwater Fish* 15(4):572-577.

The seasonal variation in lipid class composition (triacylglycerols, free fatty acids, cholesterols and polar lipids) was described for juvenile Atlantic salmon sampled at 12 occasions over an 18-month period in the Norwegian River Alta (70 degrees N). Lipid class composition was determined for pooled samples of groups of fish sorted by cohort and condition factor. Mass-specific lipid content ranged from 2.3% and 8.1% of fresh mass, and mass-specific triacylglycerol content between 0.16% and 5.6% of fresh mass. Total lipid content decreased by 34-57% during the winter period, before increasing by 155-176% between May and July. A large proportion of the variation in total lipid content was due to variation in triacylglycerol content (r(2) = 0.95), except for variations at low total lipids levels when triacylglycerols were absent. The temporal variation in polar lipid content was, although to a lesser degree, related to total lipid content (r(2) = 0.62), indicating that the fish also utilised polar lipids as an energy source during periods of starvation. Analyses of 39 individual parr collected in May showed a large individual variation in lipid class composition in the most critical period of the year. It is concluded that information on variation in lipid class composition may give more precise and detailed information of energy status during critical periods, although total lipid content will in most cases give a fair description of the energy status of the fish.

National Oceanic and Atmospheric Administration (NOAA). 2010. "Analyses of juvenile Chinook salmon and steelhead transport from Lower Granite and Little Goose dams, 1998-2008." NOAA Fisheries, Northwest Fisheries Science Center, Fish Ecology Division, Seattle, Washington.

- The report provides analyses of patterns of smolt-to-adult return rates (SARs) relative to in-season migration timing of smolts. SARs of juvenile fish that were transported from either Lower Granite Dam (LGR) or Little Goose Dam (LGS) were compared to SARs of non-transport fish that migrated through the lower Snake and Columbia Rivers in the years 1998 – 2008.
- The measure used to assess the benefit of transport relative to downstream migration was the transport to migrant ratio (T:M), defined as the ratio of SAR for transported fish to that of non-transport migrants for corresponding groups. Statistical models produced estimated values for the SARs of the two groups and the T:M for each day was estimated from those estimates.
- To study seasonal SAR patterns required known dates of juvenile passage. Therefore, migrant groups were formed from PIT-tagged fish that were bypassed (i.e., detected) at the collector dams. The value of information from bypassed migrants has been discounted by some scientists in the region because

bypassed fish generally have lower SARs than fish that pass the collector projects undetected via non-bypass routes (mostly over the spillway, with a small proportion through turbines). During periods of transport, migrants among the non-tagged run-at-large mostly pass via non-bypass routes (bypassed non-tagged fish are mostly transported), so extrapolation of results for bypassed migrants to the run at large could be biased (estimated T:M ratios greater than would have occurred for the run at large). The report addresses this potential bias by carefully considering standards for comparison of SARs and T:M (detailed below).

- Over the years, fish have been PIT tagged both upstream from LGR and at LGR. Tagging location was included as a potential factor in the models of SAR. In some cases where data were available from both tagging locations, SARs were not statistically different between tagging locations. In other cases, SARs differed significantly but relative SARs between transport and migrant fish (i.e., T:M ratio) were the same. In still others, both SARs and T:M differed depending on tagging location.
- The basic unit of data on which the analyses were based was the estimated SAR for a daily group of fish. Each LGR analysis included as many of the following four categories as were available: fish tagged upstream of LGR and transported from LGR; fish tagged upstream of LGR and detected and returned to river at LGR; fish tagged at LGR and transported from LGR; fish tagged at LGR and released in the tailrace of LGR. Each LGS analysis included only two groups, transported and in-river, as all fish were tagged upstream of LGS. Although analyses were based on SARs for daily groups, there was too much sampling variability in the daily points for effective visual display. Instead, our figures included estimated SARs for daily groups pooled into weekly periods. Weekly points, with relatively less "noise," effectively summarized the daily data and provided a clearer picture.
- A statistical regression method (Poisson log-linear regression) was used to fit a curve or a straight line to the daily SAR data points, and to assess the fit statistically. Potential factors to explain SARs were migration group (transported or in-river migrant), tagging location, and date of passage (day of year). Two- and three-way interactions among these factors were also considered. Information-theoretic (AIC-based) methods were used to identify a best-fitting model for each species and rearing-type combination in each year. As from any regression method, the resulting lines and curves represent a "smoothing" of the data points, in this case the estimated daily SARs, and the data points themselves were "scattered" around the smoothed line.
- Details of river environment (e.g., flow, spill, water temperature, number of fish migrating through dams, etc.) were not considered explicitly in this analysis (i.e., measures of these characteristics were not included as factors potentially affecting SAR or T:M).
- Daily T:M ratios estimated from the fitted SAR curves were assessed relative to two different "standards." T:M greater than 1.0 indicated that among fish in the bypass system, those that were transported returned at a higher rate than those that were returned to the river. The second standard, designed for inference to the run at large, was based on a correction factor calculated to compensate for the bypass effect. These correction factors "raised the bar" to a standard higher than a T:M of 1.0. The estimated bypass effect varied by year and species, and the resulting alternative standards ranged from 1.02 – 1.04 for wild Chinook and 1.03 – 1.11 for wild steelhead at LGR and 1.08 – 1.22 for wild Chinook and 1.08 – 1.31 for wild steelhead at LGS. T:M greater than this alternative standard indicated that transported fish in the run at large returned at a higher rate than migrants in the run at large.

- Regression results for each species/rearing-type/year were illustrated with a set of figures: one small figure for each tagging location showing point estimates of SAR for weekly pooled groups, with standard errors, and the best-fit curves or lines from the regression for transport and migrant fish; and one large figure showing the curves for T:M through the season derived from best-fit SAR curves, along with 95% confidence "envelopes" around the curves. Appendix A includes 42 such sets of figures for transport from LGR. Appendix B includes 42 sets for transport from LGS.
- The best-fit curves for T:M ratios were summarized, relative to the 1.0 standard and the alternative standard, in a series of color-coded figures (Figures 2-5 for transport from LGR and Figures 6-9 for transport from LGS). Each horizontal line in the figures represents one migration season for a species/rearing-type/tagging location combination, with a series of color-coded boxes representing days in the migration season. The color coding indicates on which days the estimated T:M was less than the standard, which days the estimated T:M was greater than the standard, and whether the difference between estimated T:M and standard was significant.
- In most cases, estimated T:M remained constant or increased throughout the migration season. For both species and both rearing types in all migration years before 2006, the estimated T:M ratio exceeded the alternative standard (i.e., exceeded the "higher bar" and so therefore also exceeded the 1.0 standard) for fish that arrived at LGR on May 1 or later, and the difference was usually statistically significant.
- In migration years 2006-2008 there have been some exceptions to the post-May 1 pattern: estimated T:M still usually increased through the season, but there were instances when the estimate did not exceed the standards until later in May, and for hatchery Chinook in 2006 the estimated T:M was less than 1.0 throughout the season. It is difficult to determine at this point whether altered spill operations and returning all bypassed smolts to the river during the early part of the migrations in 2006-2008 have resulted in changed T:M ratios compared to earlier years. Estimated T:M ratios for some groups at LGR were apparently lower, at least early in the season (e.g., hatchery steelhead and hatchery Chinook 2006, wild Chinook 2006, and hatchery Chinook in 2008). Adult returns are incomplete for some of these migration years, and final results cannot be evaluated for another year or two.
- The analyses presented in this report are intended to assist managers with the decision of when to transport during the spring migrant period. As noted by the Independent Scientific Advisory Board (ISAB 2008-5), besides T:M ratios for spring-summer Chinook and steelhead, managers should also consider other factors, including maintaining the ability to learn how populations respond to current dam configurations under a range of operations and conditions, the effect of transport on straying rates, and the response to transport of ESUs other than spring/summer Chinook and steelhead. Additional years of adult returns from ongoing and future studies are needed to fully elucidate these issues.

Naughton GP, CC Caudill, ML Keefer, TC Bjornn, CA Peery, and LC Stuehrenberg. 2006. "Fallback by Adult Sockeye Salmon at Columbia River Dams." *North American Journal of Fisheries Management* 26(2):380-390.

We implanted radio transmitters into sockeye salmon (*Oncorhynchus nerka*) in 1997 to determine the (1) fallback percentage and rate at eight Columbia River dams, (2) effect of fallback on adult counts at each dam, (3) relations between spillway discharge and fallback, (4) relations between injuries and fallback, and (5) relations of fallback and survival to spawning tributaries. The rate of fallback, that is, the total Dumber of fallback events at a dam divided by the number of fish known to have passed the dam, ranged from 1.9% to 13.7% at the eight dams. The rate of fallback was highest at Bonneville Dam, the dam with the most complex fishway. Fallback produced overcounts of 2% to 7% at most dams. Fallback was weakly related to spill volume at Bonneville Dam. Significantly more sockeye salmon with head injuries fell back than fish without head injuries. About 40% of the sockeye salmon had injuries from marine mammals, but these injuries were not associated with the rate of fallback. The rate of survival was similar between fish that fell back (68.0%) and fish that did not fall back (67.5%). We suggest that fisheries managers adjust counts for fallback but note that these relationships were obtained under high-discharge conditions. We conclude that fallback biases dam counts and that the relationship between spawning success and fallback should be an area of future research.

Nickelson TE. 1986. "Influences of upwelling, ocean temperature, and smolt abundance on marine survival of Coho salmon (*Oncorhynchus kisutch*) in the Oregon production area." *Canadian Journal of Fisheries and Aquatic Sciences* 43(3):527-535.

The relationships between the marine survival of hatchery and wild coho salmon (*Oncorhynchus kisutch*) in the Oregon Production Area and ocean upwelling, ocean temperature, and smolt abundance were investigated. Hatchery coho appear to be more sensitive than wild coho to changes in upwelling-related factors although this difference may be de~eto errors in the estimates of wild smolts and adults that were used in the analysis. Two levels of upwelling (strong and weak), which are associated with a twofold difference in survival of hatchery coho smolts, were identified. Significant relationships were identified between survival of hatchery smolts and survival of wild smolts that migrated in strong upwelling years and sea-surface temperature during that year. Similar relationships were not as apparent for smolts migrating in weak upwelling years as they were for smolts migrating in strong upwelling years. Each major component of coho production (wild, public hatchery, and private hatchery), when treated separately, as well as public and private hatchery coho combined, exhibited linear smolt-to-adult relationships. Only hatchery plus wild coho that migrated in weak upwelling years and hatchery plus wild coho in all years combined exhibited nonlinear smolt-to-adult relationships. I concluded that these nonlinear relationships were caused by a shift in the stock composition of the Oregon Production Area coho population from predominantly high-survival, wild fish when smolt numbers were Bow to predominantly Bow survival, hatchery fish when molt numbers were high.

Pascho RJ, DG Elliott, and S Achord. 1993. "Monitoring of the in-river migration of smolts from two groups of spring Chinook salmon, Oncorhynchus tshawytscha (Walbaum), with differential profiles of Renibacterium salmoninarum infection." Aquaculture and Fisheries Management 24:163-169.

Broodstock segregation based on the measurement of maternal Renibacterium salmoninarum infection levels by the enzyme-linked immunosorbent assay (ELISA) and the membrane filtration-fluorescent antibody technique (MF-FAT) was previously shown to affect the prevalence and levels of bacterial kidney disease (BKD) in progeny of chinook salmon, Oncorhynchus tshawytscha (Walbaum), during hatchery rearing. Subgroups of fish from that study were marked with passive integrated transponder (PIT) tags, and monitored by PIT-tag detectors during the first 342km of their migration to the Pacific Ocean. Differences in the recovery of tagged fish were significant ($P \leq 0{\cdot}01$) at each detection point and became more pronounced as the fish moved downstream. Cumulative recoveries of fish from the low-BKD group and the high-BKD group, respectively, were 31% and 28% after 116km, 44% and 37% after 176km, and 51% and 42% after 342km. There were no apparent differences in the migration timing of the two groups to the first detection point. The data suggested that in-river survival was higher

in the progeny group from parents that had low R. salmoninarum infection levels or tested negative for R. salmoninarum (low-BKD group) than in the group female parents with high infection levels (high-BKD group).

Parken CK, JR Candy, JR Irvine, and TD Beacham. 2008. "Genetic and Coded Wire Tag Results Combine to Allow More-Precise Management of a Complex Chinook Salmon Aggregate." *North American Journal of Fisheries Management* 28(1):328-340.

Conservation concerns for small, relatively unproductive populations of Chinook salmon (*Oncorhynchus tshawytscha*) limit the utility of fisheries in Canada's Fraser River. To identify population-specific migration time and to index abundance, we analyzed 4,822 fish sampled for genetic variation in 2000 and 2001 and 580 fish with coded wire tags (CWTs) caught from 1987 to 2004 in a test fishery near the river mouth. Population sizes estimated from microsatellite variation were within 3.4% of the known-origin population composition and were unbiased in comparison with known-origin population sizes. All but I of the 30 populations detected by both genetic methods and CWTs had overlapping migration times, but these times differed significantly for only 7 populations. Migration times were identified for another 23 untagged populations identified by using genetics, which resulted in the assignment of migration timing groups (peak passage) for 53 populations as spring (March-May), early summer (June), midsummer (July), late summer (August), and fall (September-October). Population abundance indices at the test fishery were significantly associated with run size at the river mouth. When populations were aggregated by geographic stock structure and migration time, the abundance indices for the test fishery explained 80% of the variation in run size. Incorporating genetic information can substantially improve the utility of test fishery data and thereby allow more-precise management of complex population aggregates such as those in the Fraser River.

Parnel MM, RL Emmett, and RD Brodeur. 2008. "Ichthyoplankton community in the Columbia River plume off Oregon: Effects of fluctuating oceanographic conditions." *Fishery Bulletin* 106(2):161-173.

Ichthyoplankton samples were collected at approximately 2-week intervals, primarily during spring and summer 1999-2004, from two stations located 20 and 30 km from shore near the Columbia River, Oregon. Northern anchovy (Engraulis mordax) was the most abundant species collected, and was the primary species associated with summer upwelling conditions, but it showed significant interannual and seasonal fluctuations in abundance and occurrence. Other abundant taxa included sanddabs (Citharichthys spp.), English sole (Parophrys vetulus), and blaeksmelts (Bathylagidae). Two-way cluster analysis revealed strong species associations based primarily on season (before or after the spring transition date). Ichthyoplankton abundances were compared to biological and environmental data, and egg and larvae abundances were found to be most correlated with sea surface temperature. The Pacific Decadal Oscillation changed sign (from negative to positive) in late 2002 and indicated overall warmer conditions in the North Pacific Ocean. Climate change is expected to alter ocean upwelling, temperatures, and Columbia River flows, and consequently fish eggs and larvae distributions and survival. Long-term research is needed to identify how ichthyoplankton and fish recruitment are affected by regional and large-scale oceanographic processes.

Paulsen CM and TR Fisher. 2001. “Statistical relationship between parr-to-smolt survival of snake river spring-summer Chinook salmon and indices of land use.” *Transactions of the American Fisheries Society* 130(3):347-358.

We used simple regression models to demonstrate an association between land use and parr survival of Chinook salmon (*Oncorhynchus tshawytscha*) from overwintering areas in the Snake River drainage of Idaho and Oregon to the first main-stem dam encountered during emi,oration to the Pacific Ocean. We used data on tagged (passive integrated transponder tags) releases of naturally produced Snake River spring-summer Chinook parr and subsequent tag detections, as well as indices of land use, vegetation, and road density. We spot-checked the land-use and vegetation indices in a field survey of spawning and rearing areas in the summer of 1999, and we believe that they are reliable indicators of land-use patterns. The models also employed month of release, length of parr at release, and a drought index as independent variables. The models were developed and tested using parr tagged from 1992 through 1998. Age-0 parr that reared in wilderness areas (a land-use category; not necessarily federally designated Wilderness Areas) had the highest survival during their last 6-9 months of freshwater residence. In contrast, parr that reared in young, dry forests (typically, intensively managed timber lands) had the lowest survival. Similarly, parr that reared in areas of low road density had substantially higher survival than those in areas of high road density. We concluded that in the area studied there is a close association between land-use indices and survival of Chinook salmon parr during their last 6-9 months of freshwater residence. This analysis suggests that road-building and associated land-use activities in the region may have a detrimental effect on the survival of juvenile Chinook salmon and that mitigative changes in these activities could be warranted because Snake River spring-summer Chinook salmon are listed as threatened under the Endangered Species Act.

Pearcy WG. 1992. *Ocean Ecology of North Pacific Salmonids*. Books in Recruitment Fishery Oceanography,Washington Sea Grant Program, University of Washington, Seattle, Washington.
Abstract

In this book, I address questions concerning the ecology of Pacific salmonids at sea, relevant to all seven anadromous species of Oncorhynchus (five salmon and two trout) found in the northeastern Pacific. My focus will be on processes that affect growth and survival in the ocean as I attempt to establish a connection between salmonid ecology and the physical and biological oceanography of that Pacific region. The first chapter, on phylogeny and anadromy of salmonids, covers freshwater and marine life histories. Then the organization of the book follows the sequence of salmonid migrations into the ocean: the timing of outmigration, the importance of estuaries, and survival in fresh and marine waters. Next, I discuss salmonids in three of the five oceanographic domains delineated for the northeastern Pacific. I devote the longest chapter to coho salmon in the Transitional Domain of the California Current off the coast of California, Oregon, and Washington. Next, I discuss the migration corridor of pink, chum, and sockeye in the Alaska Coastal Current, and then their carrying capacity in the oceanic Central Subarctic Waters of the North Pacific. The final chapter describes salmonid migrations in both coastal and oceanic waters, and possible guidance mechanisms.

Petrosky CE and HA Schaller. 2010. "Influence of river conditions during seaward migration and ocean conditions on survival rates of Snake River Chinook salmon and steelhead." *Ecology of Freshwater Fish* 19(4):520-536.

Improved understanding of the relative influence of ocean and freshwater factors on survival of at-risk anadromous fish populations is critical to success of conservation and recovery efforts. Abundance and smolt to adult survival rates of Snake River Chinook salmon and steelhead decreased dramatically coincident with construction of hydropower dams in the 1970s. However, separating the influence of ocean and freshwater conditions is difficult because of possible confounding factors. We used long time-series of smolt to adult survival rates for Chinook salmon and steelhead to estimate first year ocean survival rates. We constructed multiple regression models that explained the survival rate patterns using environmental indices for ocean conditions and in-river conditions experienced during seaward migration. Survival rates during the smolt to adult and first year ocean life stages for both species were associated with both ocean and river conditions. Best-fit, simplest models indicate that lower survival rates for Chinook salmon are associated with warmer ocean conditions, reduced upwelling in the spring, and with slower river velocity during the smolt migration or multiple passages through powerhouses at dams. Similarly, lower survival rates for steelhead are associated with warmer ocean conditions, reduced upwelling in the spring, and with slower river velocity and warmer river temperatures. Given projections for warming ocean conditions, a precautionary management approach should focus on improving in-river migration conditions by increasing water velocity, relying on increased spill, or other actions that reduce delay of smolts through the river corridor during their seaward migration.

Plumb JM, RW Perry, NS Adams, and DW Rondorf. 2006. “The effects of river impoundment and hatchery rearing on the migration behavior of juvenile steelhead in the lower Snake River, Washington.” *North American Journal of Fisheries Management* 26:438-452.

We used radiotelemetry to monitor the migration behavior of juvenile hatchery and wild steelhead (*Oncorhynchus mykiss*) as they migrated through Lower Granite Reservoir and Dam on the lower Snake River, Washington. From 1996 to 2001, we surgically implanted radio transmitters in 1,540 hatchery steelhead and 1,346 wild steelhead. For analysis, we used the inverse Gaussian distribution to describe travel time distributions for cohorts (> 50 fish) of juvenile steelhead as they migrated downriver. Mean travel rates were significantly related to reach- and discharge-specific water velocities. Also, mean travel rates near the dam were slower for a given range of water velocities than were mean travel rates through the reservoir, indicating that the presence of the dam caused delay to juvenile steelhead over and above the effect of water velocity. Hatchery steelhead took about twice as long as wild steelhead to pass the dam as a result of the higher proportions of hatchery steelhead traveling upriver from the dam. Because upriver travel and the resulting migration delay might decrease survival, it is possible that hatchery steelhead survive at lower rates than wild steelhead. Our analysis identified a discharge threshold (similar to 2,400 m(3)/s) below which travel time and the percentage of fish traveling upriver from the dam increased rapidly, providing support for the use of minimum flow targets to mitigate for fish delay and possibly enhance juvenile steelhead survival.

Porter, R. 2008. *Report on the Predation Index, Predator Control Fisheries, and Program Evaluation for the Columbia River Basin Experimental Northern Pikeminnow Management Program*. 2008 Annual Report. Prepared by Pacific States Marine Fisheries Commission, Bonneville Power Administration, Portland, Oregon. Project Number 199007700 and Contract no. 00026763.

We are reporting on the progress of the Northern Pikeminnow *Ptychocheilus oregonensis* Sport-Reward Fishery (NPSRF) implemented by the Washington Department of Fish and Wildlife (WDFW) on the Columbia and Snake Rivers from May 5 through September 28, 2008. The objectives of this project were to (1) implement a recreational fishery that rewards recreational anglers for harvesting northern pikeminnow > 228mm (9 inches) total length (TL), (2) collect, compile, and report data on angler participation, catch and harvest of northern pikeminnow and other fish species, as well as success rates of participants during the season, (3) examine collected northern pikeminnow for the presence of external tags, fin clips, and signs of tag loss, (4) collect biological data on northern pikeminnow and other fish species returned to registration stations, (5) scan northern pikeminnow for the presence of consumed salmonids containing Passive Integrated Transponder (PIT) tags, and (6) survey non-returning NPSRF participants targeting northern pikeminnow in order to obtain catch and harvest data on fish species caught, and (7) examine and process all northern pikeminnow caught by U.S. Department of Agriculture (USDA) angling crews operating at The Dalles and John Day dams to recover spaghetti and/or PIT tags.

A total of 159,806 northern pikeminnow >228 mm and 3,507 pikeminnow <228 mm were harvested during the 2008 NPSRF season. There were a total of 3,610 different anglers who spent 26,141 angler days participating in the fishery. Catch per unit effort for combined returning and non-returning anglers was 6.11 fish/angler day. The Oregon Department of Fish and Wildlife (ODFW) estimated that the overall exploitation rate for the 2008 NPSRF was 19.5%.

Anglers submitted 167 northern pikeminnow with external spaghetti tags, of which there were 166 with both spaghetti and PIT tags. There were also 123 northern pikeminnow with PIT tags only, along with possible tag wounds and/or fin clips, but without spaghetti tags. A total of 107 PIT tags from consumed juvenile salmonids were detected and interrogated from northern pikeminnow received during the 2008 NPSRF.

Peamouth *Mylocheilus caurinus*, smallmouth bass *Micropterus dolomieue*, walleye *Stizostedion vitreum vitreum,* yellow perch *Perca flavescens*, and channel catfish *Ictalurus punctatus* were the fish species most frequently harvested by NPSRF anglers targeting northern pikeminnow. The incidental catch of salmonids *Oncorhynchus spp*, by participating anglers targeting northern pikeminnow remained below established limits for the Northern Pikeminnow Management Program.

Porter AD, DW Welch, ER Rechisky, MC Jacobs, P Winchell, and Y Muirhead. 2009a. Results from the POST Pilot-Stage Acoustic Telemetry Study on Survival of Columbia River Salmon, 2007. Prepared by Kintama Research Corporation, Nanaimo, British Columbia, for the Bonneville Power Administration, Portland, Oregon. Project No. 2003-114-00, Contract no. 00040974, and BPA Report Document ID: #P114364.

Beginning in 2006, Kintama Research developed a prototype acoustic telemetry array to measure the movements and survival of Snake River spring Chinook smolts in-river and northward through 1,400 km of early-ocean migration. This pilot-scale array is termed the POST (Pacific Ocean Shelf Tracking) array. Using this array we tested the delayed mortality hypothesis by comparing hatchery-origin spring Chinook salmon (*Oncorhynchus tshawytscha*) from the Snake River that migrate through eight dams on their way to the ocean with a mid-Columbia River population (Yakima) that passes through only the four lower Columbia River dams and has approximately five-fold higher smolt to adult return rates. We further compared Snake River spring Chinook that migrated freely in the river (ROR) with smolts from the same population that were transported around the dams. By contrasting the survival of size-matched smolts that are treated equivalently, any tagging effects should be common to both populations and thus allow an assessment of survival beyond the hydrosystem that is relative to cumulative exposure to dams ("delayed" mortality) or due to the effect of transportation on survival ("differential" mortality).

This report focuses on our 2007 results. In 2007, a large number of smolts from both stocks failed to be detected on any part of the array (with only ca. 1/4 of the number detected in 2006 reaching the first detection lines). The decline occurred between release and five-seven days into migration when the tagged smolts reached the first detection lines; survival estimates for subsequent river reaches and out to Willapa Bay, 60 km beyond the river mouth sub-array sited at Astoria Bridge, were generally similar to our estimates for 2006 and 2008. As this report details, the reason for this disappearance in both populations is unclear but appears to be restricted to our study and was not found by independent 2007 PIT tagging efforts. The most likely explanation is that surgical procedures differed in 2007 because we over-handled the smolts in an effort to find sufficient numbers within the targeted size range (140-160 mm; Dworshak Hatchery (Snake River) smolts were unusually small in 2007 while Yakima smolts were unusually large). Unfortunately, the amount of handling was nearly equivalent across all treatment groups in 2007 and we are not able to directly evaluate the effect of different levels of handling. There were also undocumented die-offs of smolts at one of the two holding sites (Yakima) prior to our arrival, which may indicate that the added stress of repeated handling, drugging, and carrying a tag increased the proportion of individuals that died after release to the wild from the hatchery. However, the concurrent tag effects/mortality survival study that we report here does not support this conclusion; all smolts held at the hatchery survived well beyond the date that migrating Chinook failed to appear on the array, suggesting that perhaps the disappearance may be at least partly attributable to a behavioral change that caused smolts to fail to migrate after release (as opposed to a failure to survive). Survivals measured the POST array in both 2006 and 2008 (reported separately) were at levels comparable with those reported from independent tagging studies using the PIT tag system. The initial large disappearance of smolts appears to be a transient phenomenon restricted to 2007 and limited to the early stages of post-release migration.

Using the 2007 data, we found no evidence in support of the delayed mortality theory when survival was measured at the Columbia River mouth (2007 survival (±1SE): Snake, 0.08±0.02; Yakima, 0.10±0.02) or after 60 km of early-marine migration to Willapa Bay (minimum apparent survival: Snake, 0.03; Yakima, 0.05). Snake River smolts had migrated through eight dams and traveled ~850 km from release to the Columbia River mouth, while the Yakima River smolts had migrated through the four mainstem Columbia dams and traveled ~590 km from release to the river mouth. Because sample sizes were small in 2007 due to the large initial disappearance of smolts after release, the 2007 results need to be treated with caution. The limited numbers of smolts reaching the ocean means that we could not also estimate survival to northern Vancouver Island (ca. 600 km beyond the mouth of the Columbia), as intended. In 2006 and 2008 our survival estimates were higher and consistent with PIT tag estimates of survival, but we likewise found no evidence for a difference in survival between the two populations at Willapa Bay or to northern Vancouver Island.

Survival estimates from point of release were six times higher for barged than for freely migrating Snake R smolts (to Willapa Bay; minimum survival (±1SE): barged, 0.17±0.03; ROR, 0.03±0.01). The magnitude of this difference likely reflects the in-river disappearance of the ROR smolts, but survival of barged smolts was also higher in 2006 (survival (±1SE): barged, 0.54±0.12; ROR, 0.28±0.07). When the comparison is restricted to the survival for just the unimpounded river and ocean migration segments traveled in common, the barged smolts fared worse in both years (2007 minimum survival: barged, 0.17; ROR, 0.38; 2006 survivals (±1 SE): barged, 0.54±0.12; ROR, 0.67±0.17).

Both stocks experienced overall ocean mortality in 2006 and 2007 that was approximately equivalent to that incurred in freshwater. The conditions fish encounter in the ocean may thus be an important factor in determining the status of salmonid stocks including Snake River Chinook. If survival in the estuary and ocean is not better than in-river survival, recovery efforts that focuson speeding smolt passage through the hydrosystem may not be successful because they will simply transfer smolts between two environments with similar survival rates. If survival rates are worse in the ocean, then such actions would be counter-productive to conservation goals.

Porter AD, DW Welch, ER Rechisky, MC Jacobs, P Winchell, and Y Muirhead. 2009b. Results from the POST Pilot-Stage Acoustic Telemetry Study on Survival of Columbia River Salmon, 2008. Prepared by Kintama Research Corporation, Nanaimo, British Columbia, for the Bonneville Power Administration, Portland, Oregon. Contract no. 2003-114-00, Grant no. 00021107, and BPA Report Document ID: #P114363.

Beginning in 2006, Kintama Research developed a prototype acoustic telemetry array to measure the movements and apparent survival of Snake River spring Chinook smolts in-river and northward through 1,400 km of early-ocean migration. This pilot-scale array is termed the POST (Pacific Ocean Shelf Tracking) array. Using this array we tested the delayed mortality hypothesis by comparing hatchery-origin spring Chinook salmon (*Oncorhynchus tshawytscha*) from the Snake River that migrate through eight dams on their way to the ocean with a mid-Columbia River population (Yakima) that passes through only the four lower Columbia River dams and has approximately four-fold higher smolt to adult return rates. We further compared Snake River spring Chinook that migrated freely in the river (ROR) with smolts from the same population that were transported around the dams. By contrasting the survival of size-matched smolts that are treated equivalently, any tagging effects should be common to both populations and thus allow an assessment of survival beyond the hydrosystem that is relative to cumulative exposure to dams ("delayed" mortality) or due to the effect of transportation on survival ("differential" mortality).

This report focuses on our 2008 results. We found no evidence in support of the delayed mortality theory over the size range of smolts we studied (>130 mm) as far as 575 km north of the river mouth (NW Vancouver Island). Apparent survival estimates were somewhat higher for the Yakima than for the Snake smolts throughout their migration (e.g., Astoria Bridge survival (±1SE): Yakima 0.46±0.04; Snake 0.30±0.03, Willapa Bay: Yakima 0.17±0.03; Snake 0.12±0.02), but Yakima smolts also traveled a shorter distance to reach the acoustic array (release to Lake Wallula distance: Yakima 115 km; Snake 370 km, median travel time: Yakima 1.4 days; Snake 20.8 days). When survival was adjusted to represent only the section of the migration that both stocks traveled in common, conditional survival estimates were nearly identical out to Lippy Point on northern Vancouver Island (Astoria Bridge: Yakima 0.62±0.04; Snake 0.60±0.04, Willapa Bay: Yakima 0.23±0.03; Snake 0.24±0.02, Lippy Point minimum survival: Yakima 0.05; Snake 0.05).

Apparent survival estimated from release just below Bonneville Dam to the mouth of the Columbia River was 2.5 times higher for barged than for freely migrating Snake River smolts and remained higher as far as Lippy Point on northern Vancouver Island (Willapa Bay: 3.25 times higher; Lippy Point: 3 times higher). However, after an initial decline in survival following release of the Barged smolts (Astoria Bridge: Barged 0.77±0.05; ROR 1.00±0.00), survival estimates for the two groups were very similar when the comparison was restricted to only the unimpounded river and ocean migration segments traveled in common (Willapa Bay survival: Barged 0.39±0.05; ROR 0.40±0.07, Lippy Point minimum survival: Barged 0.07; ROR 0.08).

Our results in 2008 are consistent with previous year's findings. In 2006, apparent survival estimates were similar for the Yakima and Snake stocks (ratio of Yakima to Snake estimates: 0.90-1.1) over the entire migration distance that we monitored. Apparent survival of barged smolts was also greater than it was for ROR smolts to Willapa Bay (2 times higher) with a subsequent reduction in the difference by Lippy Point on Northern Vancouver Island but remained in favor of the barged smolts.

Both stocks experienced overall ocean mortality in 2006 and 2008 that was approximately equivalent to that incurred in freshwater (the initial rapid decline in survival in 2007 obscures any patterns). The conditions fish encounter in the ocean may thus be an important factor in determining the status of salmonid stocks in the Columbia River Basin, including Snake River Chinook. If survival in the estuary and ocean is not better than in-river survival, recovery efforts that focus on speeding smolt passage through the hydrosystem may not be successful because they will simply transfer smolts between two environments with similar survival rates. If survival rates are worse in the ocean, then such actions would be counter-productive to conservation goals.

Porter AD, DW Welch, EL Rechisky, MC Jacobs, H Lydersen, PM Winchell, DW Kroeker, L Neaga, JD Robb, and YK Muirhead. 2010a. Marine and Freshwater Measurement of Delayed and Differential-Delayed Mortality of Snake River Spring Chinook Smolts Using a Continental-Scale Acoustic Telemetry Array, 2009. Prepared by Kintama Research Corporation, Nanaimo, British Columbia, for the Bonneville Power Administration, Portland, Oregon. Project No. 2003-114-00 and Contract no. 46389.

Beginning in 2006, Kintama Research developed a prototype acoustic telemetry array to assess the feasibility of directly measuring movement rates and apparent survival of Snake River spring Chinook smolts in-river and northward through 1,400 km of early ocean migration. Using this array we tested the hydrosystem-induced delayed mortality hypothesis (Budy et al. 2002, Schaller and Petrosky 2007) by comparing survival of hatchery-origin spring Chinook salmon (*Oncorhynchus tshawytscha*) from the Snake River that migrate in-river through eight dams on their downstream migration with a mid Columbia River population (from the Yakima River) that passes through only the four lower Columbia River dams. The Yakima population has approximately four-fold higher smolt to adult return rates and thus serves as a "control" population not exposed to Snake River dam passage.

We also compared the Snake River spring Chinook groups that migrated freely in the river (In-River or IR) with smolts from the same population that were transported around the dams via barge (Transported or T) as a test of the differential-delayed mortality hypothesis. It is argued that transportation of smolts may induce additional stress, which may then reduce survival after they are released from the barge in the lower Columbia River (Williams et al. 2005), or that release timing and size at release of transported fish may make them more vulnerable to predators (Muir et al. 2006). By contrasting the survival of size-matched smolts that are treated equivalently, any tagging effects should be common to both populations and thus allow an assessment of survival beyond the hydrosystem that is relative to cumulative exposure to dams (delayed mortality) or due to the effect of transportation on survival (differential-delayed mortality). This report focuses on our 2009 results.

We found no difference in estimated survival of Snake IR and Yakima IR Chinook smolts supporting the delayed mortality hypothesis. Survival of Snake River smolts was statistically indistinguishable or better than the Yakima River population for all segments of the array between Bonneville Dam and the northern tip of Vancouver Island, approximately one month after ocean entry and 540 km along the continental shelf north of the Columbia River. This result suggests that the disparity in adult returns develops later in the marine life history for other reasons. This conclusion however, applies to larger hatchery smolts (≥13 cm) released during the latter part of the migration period. Applying the same tests to wild smolts, hatchery smolts <13 cm long, or to smolts migrating earlier in the spring will require the use of a smaller acoustic tag than is compatible with the first generation acoustic array.

Similarly, we found no difference in estimated survival of IR and T smolts supporting the differential-delayed mortality hypothesis; survival was higher for the Transported group on the ocean sub-arrays as far as Lippy Point near northern Vancouver Island. These results do not explain the failure of the transportation program to substantially increase adult return rates as a result of avoiding the approximately 50% in-river mortality to Bonneville Dam. As with the delayed mortality hypothesis, the major caveat on this conclusion concerns whether it extends to smolts <13 cm long, to wild smolts as well as hatchery smolts, and to the entire migration period.

Release-timing has been identified as potentially affecting adult return rates (NOAA 2010). However, our analysis found no difference in survival between a group of smolts transported in the early part of the migration and two transported groups held for approximately one month after tagging and released (one week apart) to coordinate their arrival below Bonneville with that of the two IR groups released from the hatchery.

Survival rates (survival per unit distance and per unit time) were approximately equivalent between the freshwater and the early-marine environments for Snake and Yakima In-River migrants. This conclusion holds over a broad range of assumed detection probabilities for the marine sub-array at Lippy Point (N. Vancouver Island), which is statistically the most uncertain aspect of the comparison. Thus, while the goal of the transportation program is initially met by increasing the number of smolts reaching the ocean, if survival rates in the early marine environment are equal to or lower than survival rates in freshwater, no net benefit from transportation can be obtained unless the smolts also subsequently reach a region of high ocean survival sooner. The current array is too coarse to provide clarity on this question. However, this result is consistent with the empirical finding that transported smolts do not return in substantially greater abundance (Buchanan et al. 2007; Muir et al. 2006; Tuomikoski et al. 2009; NOAA 2010) and provides a new perspective on salmon conservation for Columbia River stocks.

Porter AD, DW Welch, EL Rechisky, MC Jacobs, H Lydersen, PM Winchell, DW Kroeker, L Neaga, JD Robb, and YK Muirhead. 2010b. 2006-09 Multiyear Summary & Key Findings from the Pilot-Stage Acoustic Telemetry Study on Hydrosystem and Early Ocean Survival of Columbia River Salmon. Prepared by Kintama Research Corporation, Nanaimo, British Columbia, for the Bonneville Power Administration, Portland, Oregon. Project No. 2003-114-00 and Contract no. 46389.

Key Findings, 2006-2009.

1. No evidence of delayed mortality. The smolt-to-adult return rate of Yakima River Spring Chinook has averaged 3.9 times higher than that of Snake River (Dworshak Hatchery) spring Chinook for the smolt out-migration years 1999-2006. This large difference has been used as evidence supporting the delayed mortality hypothesis, which suggests that Snake River smolts suffer higher mortality after passing Bonneville Dam as a result of the stress of migrating through a total of eight hydrodams rather than just the four mainstem Columbia River dams (Schaller et al. 1999; Budy et al. 2002; Schaller et al. 2007). However, to date our test of this hypothesis has found no difference in estimated early marine survival of these two populations: by the time the smolts reach the northern tip of Vancouver Island, approximately one month after ocean entry and 540 km distant from the Columbia River mouth, apparent survival of Yakima River smolts was not higher than the Snake River population. This result suggests that the survival disparity develops later in the marine phase of the life history. We qualify this conclusion by noting that our test applies to larger hatchery smolts (≥13 cm) released during the latter part of the migration period. Applying the same test to wild smolts, hatchery smolts <13 cm long, or to smolts migrating earlier in the spring will require the use of a smaller acoustic tag and a second generation acoustic array.
2. No evidence of differential-delayed mortality. Although transportation of spring Chinook smolts from the Snake River basin has resulted in minor improvements in adult returns (Buchanan et al. 2007; NOAA 2010), the question remains as to why these improvements are neither consistently nor substantially better than for in-river migrating smolts. This failure has led to the hypothesis that transportation induces additional stress, and consequently a reduction in survival after the transported smolts are released. This reduction in survival is usually termed differential-delayed mortality. We tested the differential-delayed mortality hypothesis by comparing post-Bonneville Dam survival of Snake River (Dworshak Hatchery) smolts that migrated in-river (In-River group; IR) to smolts transported by barge and released below Bonneville Dam (Transport group; T). Post-Bonneville survival to the coastal ocean arrays was either statistically indistinguishable (i.e., “equal” within our statistical capabilities to estimate these values) or better for the T groups in all three study years; therefore, our study does not support the hypothesis that transportation causes significant differential delayed mortality. The major caveat on this conclusion again concerns whether it extends to wild smolts, smolts <13 cm long, and the entire migration period.
3. Freshwater and coastal ocean survival rates equivalent. Several years of largescale telemetry data have now been collected for Columbia River basin spring Chinook migrating within the hydrosystem as well as in the coastal ocean, allowing a unique comparison of survival in these two contrasting environments. Survival rates (survival per unit distance and per unit time) were approximately equivalent between the freshwater and early-marine environments for Snake and Yakima in-river migrants in 2006-2009. This conclusion is dependent upon the detection probability associated with the acoustic sub-array at Lippy Point (N. Vancouver Island). An assessment of how estimated marine survival rate varies with detection probability indicates that the conclusion that the early ocean survival rate is roughly equal to freshwater survival during migration through the hydrodams holds over a wide range of assumed Lippy Point detection probabilities. Thus, while the goal of the transportation program is initially met by increasing the number of smolts reaching the ocean, if survival rates in the early marine environment are equal to or lower than survival rates in freshwater, no net benefit from transportation can be obtained unless the smolts also subsequently reach a region of high ocean survival sooner than would be the case if they migrate in-river. The current first-generation acoustic array is too coarse to provide clarity on this question; however, our general finding is consistent with the empirical observation that transported smolts do not return in

substantially greater abundance than in-river migrants (Buchanan et al. 2007; Muir et al. 2006; NOAA 2010; Tuomikoski et al. 2009).

4. No evidence of an effect of release-timing. Both the timing and speed of migration to the ocean have been implicated as having a role in determining freshwater and marine survival of Snake River Chinook. However, our 2009 analysis found no difference in survival between a group of spring Chinook smolts that were transported shortly after tagging (conventional practice for Transported smolts), and two Transported groups held for approximately one month and released (one week apart) to coordinate their arrival below Bonneville Dam with that of the IR migrants. Some of the smolts that were transported immediately displayed migratory behaviors not seen in the other smolt groups: they travelled more slowly in the lower river/estuary (~1/3 the speed of the later arriving smolts) and were more likely to use the southern side of the river channel at Astoria Bridge rather than northern shore used by the later release groups. These were also the only smolts detected on the Cascade Head sub-array (3 of 200) south of the Columbia River. Because the early-marine survival of these smolts was indistinguishable from that of the later groups, the effect of these migratory behaviors on survival was probably minor, but the data suggests that conventional transport practice may place the smolts in the estuary before they are fully prepared for migration. Caution is needed in generalizing this observation, as it is based upon data for a single release group.

Porter AD, DW Welch, EL Rechisky, WO Challenger, MC Jacobs Scott, H Lydersen, PM Winchell, L Neaga, JD Robb, and YK Muihead. 2011. Marine and Freshwater Measurement of Delayed and Differential-Delayed Mortality of Columbia & Snake River Yearling Chinook Smolts Using a Continental Scale Acoustic-Telemetry Array, 2010. Prepared by Kintama Research Services Ltd., Nanaimo, British Columbia, for the Bonneville Power Administration, Portland, Oregon. Project no. 2003-114-00 and Contract no. 46389.

Since 2006, Kintama Research has used a large-scale acoustic telemetry array to estimate survival of Columbia River Chinook smolts during their seaward and early-ocean migration, and to perform a series of experiments to test hypotheses related to the effects of the Federal Columbia River Power System (FCRPS) on their survival. The acoustic array we designed is the only technology that allows researchers to directly address critical uncertainties and Reasonable Prudent Alternatives (RPA's) listed in the FCRPS Biological Opinion regarding the delayed effects of hydrosystem experience and fish transportation on juvenile survival, as well as the effects of ocean-entry timing and ocean conditions on early-marine survival. The array extended ~1,600 km north of the Columbia River mouth to southeast Alaska and provided early-marine survival estimates, rate of movement and cross-shelf distribution to northern Vancouver Island. The early-ocean period is thought to be critically linked to the abundance of adult returns (Hare and Francis 1995; Beamish et al. 2004; Mueter et al. 2005; Quinn 2005) and is also the time in which delayed effects from hydrosystem passage are most likely to be expressed.

Objectives

The objectives are presented in two distinct groups: i) those that have been long-term elements of the research program since 2006, and ii) those that were specific objectives for 2010.

Long-term objectives 2006-2010

1. Evaluate the evidence of hydrosystem-induced delayed mortality (Budy et al. 2002; Schaller and Petrosky 2007) by comparing survival of yearling Chinook salmon (*Oncorhynchus tshawytscha*) from

the Snake River that migrate in the river through eight dams with survival of Columbia River populations the majority of which pass through only the four lower Columbia River dams.

2. Test the differential-delayed mortality hypothesis that transportation of smolts around the hydrosystem induces additional stress which may then reduce survival after smolts are released from the barge in the lower Columbia River (Williams et al. 2005). We did this by comparing the survival estimates of Snake River yearling Chinook smolts that migrated freely in the river with smolts from the same population(s) that were transported around the dams via barge.
3. Evaluate the relative importance of four habitats (Hydrosystem, Lower river/Estuary, Plume, and Coastal Ocean) on smolt survival by comparing survival rates (per unit distance and per unit time) of yearling Snake River Chinook smolts migrating through these zones. Habitats with significantly enhanced or reduced survivals can be identified as targets for management action.
4. Provide information on the migratory behaviors of yearling Chinook smolts during seaward and early-ocean migration including travel rates and distribution in the coastal ocean along the continental shelf.

Specific objectives 2010

5. Conduct a pilot study to assess the impacts of acoustic-tags on the ability of Chinook smolts to adapt to saltwater. Kintama Research implanted acoustic-tags as per our standard operating procedure. The remainder of this project was subcontracted to Dr. Shannon Balfry from the Faculty of Land and Food Systems at the University of British Columbia (Balfry 2011; Appendix A of this document).
6. Summarize the evidence for possible migration off the continental shelf during the first months of ocean residence by reviewing recent literature and trawl survey data.
7. Assess whether Battelle (Pacific Northwest National Laboratories) and Kintama Research produced comparable survival estimates in the mainstem Columbia River. Kintama was responsible for the field work necessary for our participation in this paired design. Mortality rates and survival profiles for the JSATS- and VEMCO-tagged fish in the lower Columbia River from RKm 390 to RKm 8 were compared by Drs. John Skalski and Rebecca Buchanan from the School of Aquatic and Fishery Sciences at the University of Washington (study presented in Skalski and Buchanan 2010).
8. Using data from 2006-2009, assess the evidence of reduced survival of Snake River yearling Chinook smolts that pass dams using the juvenile bypass facilities at Snake and Columbia River dams compared to the combined survival of smolts that pass through the turbines or spill.

Methods

Acoustic-tagged smolts from the Snake River basin and the mid-Columbia River basin (Snake IR and Columbia IR treatment types respectively) were tracked during their seaward and coastal-ocean migration to evaluate hydrosystem-induced delayed mortality (objective 1). A third group of Snake River smolts was transported to below Bonneville Dam (Snake T) and tracked through the estuary and into the coastal ocean to evaluate differential-delayed mortality (objective 2). The Snake IR smolts were also used to assess the relative importance of the hydrosystem, lower river/estuary, plume, and coastal ocean habitats (objective 3) as well as to assess the effects of the juvenile bypass facilities on survival (objective 8). We described the migratory behaviors (objective 4) including evidence of off-shelf migration (objective 6) for all tagged smolts.

From 2006-2009, the Snake IR and T spring Chinook smolts were obtained from Dworshak National Fish Hatchery (NFH), while the Columbia IR smolts were obtained from the Cle Elum Supplementation and Research Facility (CESRF) on the Yakima River. In 2010, Snake IR and T yearling Chinook smolts of unknown origin were collected from the juvenile fish facility at Lower Granite Dam. In addition, we collected and tagged migrating yearling Chinook smolts, also of unknown origin, at the juvenile fish facility at John Day Dam (Columbia IR) as part of the paired study with JSATS (objective 7) and to compare their survival to the Snake IR group. Smolts were detected on multiple acoustic sub-arrays in the hydrosystem, lower river, and estuary, and at three sites in the coastal ocean between the river mouth and southeast Alaska. Data were uploaded from the array after smolt passage. With these data, we estimated smolt survival using Cormack-Jolly-Seber (CJS) mark-recapture models and then used an information theoretic approach (Akaike's Another Information Criteria, AIC) to compare the performance of additional models parameterized to represent hypotheses about the effects of hydrosystem passage and transportation.

To assess the effects of acoustic-tagging on the ability of smolts to transition to saltwater (objective 5) fall Chinook were tagged with either a V6 acoustic-tag or a PIT-tag, or given a sham surgery. Smolts were held in freshwater for three weeks and then transitioned to seawater where they were held for one month. Samples were collected at representative intervals to assess growth and degree of smoltification.

Key findings

1. **No evidence of delayedmortality.** We have found no reduction in the estimated lower river, estuary, or early-marine survival of Snake River smolts relative to Columbia River smolts (Figure ES.1). This is inconsistent with the delayed-mortality hypothesis, which attributes large reductions in survival of Snake River spring Chinook to the added stress of passage through the Snake River dams relative to their downstream (Columbia River) counterparts. By the time the smolts reach the northern tip of Vancouver Island, approximately 540 km distant from the Columbia River mouth, apparent survival of Yakima River smolts was still not higher than the Snake River population in 2006, 2008 or 2009. The same result held when we moved tagging in 2010 to John Day and Lower Granite dams in order to broaden the range of populations included in the tagging study. Our test applies to larger smolts (≥ 14 cm in 2006; ≥ 13 cm in 2008-2010) released during the latter part of the migration period.
2. **No evidence of differential-delayed mortality.** Although transportation of spring Chinook smolts from the Snake River basin has resulted in minor improvements in adult returns Buchanan et al. 2007; NOAA 2010), the question remains as to why these returns are neither consistently nor substantially better than for in-river migrating smolts. This led to the development of the differential-delayed mortality hypothesis: transportation induces additional stress and consequently a reduction in survival after transported smolts are released. We tested the differential-delayed mortality hypothesis by comparing post-Bonneville Dam survival of Snake River smolts that migrated in-river to smolts transported by barge and released below Bonneville Dam. Survival to the coastal ocean sub-arrays was either on par (i.e., "equal" within our statistical capabilities to estimate these values) or better for the transported groups in all four study years (Figure ES.2). Thus, transportation and release below Bonneville Dam did not reduce survival of smolts compared to in-river migrants to at least as far away as northern Vancouver Island. The major caveat on this conclusion again concerns whether it extends to smolts <13 cm long, and the entire migration period.

3. **Ocean and Hydrosystem survival rates are similar; survivorship is largely a simple function of distance.** We investigated the role habitat plays in the survival of Snake River yearling Chinook smolts during the juvenile migration by fitting a suite of survival models to the telemetry data. We found that the majority of the variability in survivorship can be described as a simple one-parameter exponential rate model with allowances for the survival rate to change for some habitat types and years. In general, distance traveled by the smolts described the level of mortality, with the exception of a higher survival rate by distance in the lower river and estuarine habitats and a lower rate in the plume. The most important finding is that ocean and hydrosystem survival rates were largely indistinguishable (Figure ES.3). This result may explain why barging smolts around the hydrosystem is not more successful in increasing adult Chinook returns (historical returns have been close to 1:1 for transported and in-river migrants). Transportation will not improve survival if it acts to transfer smolts between two habitats with nearly equal survival rates. Our result also has implications for future management strategies, because those actions that accelerate the movement of smolts into the ocean (flow, spill, transport, & reservoir drawdown) will result in greater smolt exposure to ocean conditions. The success of freshwater management actions will thus depend directly on ocean conditions in any given year. For example, altering flow rates to facilitate smolts entering the ocean during periods of good ocean conditions, and retarding their ocean arrival in periods of poor ocean conditions, could be a potentially useful management action.
4. **No evidence that acoustic-tagging affects the ability of Chinook smolts to transition to seawater.** We sub-contracted this study to Dr. Shannon Balfry from the University of British Columbia. Dr. Balfry used a series of smoltification parameters (Na/K-ATPase activity, plasma ions, osmolality) and growth performance characteristics (total feed intake, feed conversion ratio, specific growth rate) to assess the ability of smolts to transition to saltwater. Comparisons were made between 1) a sham group where a surgical incision was made as though a V6 acoustic-tag was going to be implanted, but only a PIT-tag was inserted; 2) a PIT-tagged control group, and 3) an acoustic-tagged group implanted with a V6 dummy acoustic-tag. Average percent tag burden by weight for smolts implanted with the acoustic tag was 5.7% (range=3.3-10.2%). Survival was high for all three groups after seawater transition and no significant differences were found between the experimental groups in either smoltification or growth performance parameters, suggesting that the ability of smolts to transition to saltwater was unimpaired by the V6 acoustic-tags or the tagging process.
5. **Little evidence of emigration from the continental shelf during the early-ocean period.** Systematic detections of smolts on the seaward receivers of the marine sub-array at Willapa Bay in 2006-2009 indicated that smolts were widely distributed across the shelf and may have been migrating off-shelf or around the sub-array. Shelf-oriented migration beyond the current extent of the marine subarrays would result in accurate survival estimates only if the smolts subsequently return to the shelf and are detected at sub-arrays further north (Lippy Point), while permanent emigration off-shelf would result in underestimates of survival. Recent literature and trawl survey data are consistent with the information that was available prior to the original design and deployment of the array: the vast majority of juvenile yearling Chinook smolts remain on the continental shelf during northward migration. The "shelf break" is not sharply defined as an offshore limit to the continental shelf and some individuals may temporarily migrate off-shelf, perhaps in response to local conditions. These few offshore migrants are not expected to be a significant source of error for acoustic telemetry studies of survival along most of the west coast of North America. The acoustic-tagged smolts detected on the outer units of the Willapa Bay sub-array were probably not migrating permanently off-shelf. Instead, it is likely that they were either 1) driven temporarily offshore by the Columbia

River plume, or 2) migrating generally on shelf, but beyond the end of the Willapa Bay sub-array which is deployed at a site where the shelf is narrower than it is along most of the Washington-Oregon coast.

6. **Effect of juvenile bypass facilities on survival.** We examined the effect of passage through the juvenile bypass facilities in the lower Snake and Columbia Rivers relative to smolts that passed through the spill or turbine routes (combined). We found that there was some evidence that bypassed smolts did not survive as well as smolts that took alternative routes within the hydrosystem (all effect terms were negative); however, effects were generally close to zero or had wide confidence intervals. Bypass through multiple facilities did not appear to have a cumulative effect, nor was the probability of bypass related to size (fork length). Although not statistically significant, the negative effects of bypass appeared to be confined to migration within the hydrosystem, and delayed effects of bypass on survival below the hydrosystem were not apparent. These conclusions apply to smolts from the Dworshak hatchery ≥130 mm fork length 2006, 2008-2009.

Railsback SF and KA Rose. 1999. "Bioenergetics Modeling of Stream Trout Growth: Temperature and Food Consumption Effects." *Transactions of the American Fisheries Society* 128(2):241-256.

We investigated bioenergetics modeling of growth as an approach for assessing the effects of temperature changes on stream dwelling rainbow trout (*Oncorhynchus mykiss*). Study objectives were (1) to determine the relative effect of temperature versus food consumption on model-predicted growth and (2) to identify relationships between model-predicted food consumption and commonly measured environmental variables. A bioenergetics model for rainbow trout was calibrated to apparent age-1 growth in summer and fall–spring periods for 10 years at eight Sierra Nevada, California, study sites. Model analyses showed that the observed year-to-year variation in summer growth was related to food consumption but not to temperature and that temperature was more important, but still of secondary importance, to observed variation in fall–spring growth. Growth at all sampling sites appeared lower and more variable in summer than in other seasons, and variation among sites and years in the food consumption parameter P (determined by fitting the model to observed apparent growth) was highly related to environmental variables during fall–spring but not during summer. During fall–spring, 80% of the variation in P was explained by a linear regression model that included temperature, flow, and trout density. Summer P-values were only weakly related to stream gradient. Our data and analysis indicate that (1) when not extreme, temperatures in summer may have less effect on growth than during other seasons and (2) growth is more affected by factors controlling food consumption (including indirect effects of temperature) than by the direct effects of temperature.

Rechisky EL. 2010. "Migration and Survival of Juvenile Spring Chinook and Sockeye Salmon Determined by a Largescale Telemetry Array." Thesis, University of British Columbia, Vancouver, British Columbia.

This thesis documents the use a large ‑ scale acoustic telemetry array to track hatcheryreared salmon smolts during their seaward migration, presents estimates of early marine survival, and describes migration behaviour in the ocean of two species of Pacific salmon from the Columbia and Fraser River basins.

In the Columbia River basin, it is hypothesized that seaward migrating Snake River spring Chinook salmon suffer from "delayed mortality" due to passage through eight hydropower dams or "differential delayed mortality" from transportation via barge around the dams. I tested these hypotheses by comparing survival of in ‑ river migrating smolts from the Snake River basin to 1) a Yakima River population that migrated past only four dams and 2) a Snake River group that was transported around all dams. Early marine survival estimates of nontransported Snake and Yakima smolts from the mouth of the Columbia River to Vancouver Island (a 485 km, one month journey) was equal in both 2006 and 2008 (2007 estimates were not available), which contradicts the delayed mortality theory. Early marine survival for the transported groups was slightly higher than for the in - river migrants, again contradicting the differential delayed mortality theory. These measurements form the first direct experimental test of key theories concerning juvenile fish survival in the coastal ocean.

Cultus Lake sockeye salmon are a genetically unique population from the Fraser River basin and are now endangered due to the very low return of adults in recent years. Mean survivorship of smolts (2004 - 7) from release to the northern Strait of Georgia ranged from 10 - 50%, while survivorship to the final sub - array in Queen Charlotte Strait ranged from 7 - 28%. Cultus Lake smolts displayed four migratory behaviours: northward migration to enter the Pacific Ocean via Queen Charlotte Strait; westward migration through the Strait of Juan de Fuca; migration into Howe Sound before continued the migration north; and migration upstream into Cultus Lake. These are the first direct observations of movement and survival for Fraser River sockeye salmon smolts. The availability of early marine survival data fills key knowledge gaps and as well as permitting direct testing of important salmon conservation hypotheses and rapid scientific advance.

Rechisky EL and DW Welch. 2010. *Surgical implantation of acoustic tags: Influence of tag loss and tag-induced mortality on free-ranging and hatchery-held spring Chinook (O. tschawytscha) smolts*, in Wolf, K.S., and O'Neal, J.S., eds., PNAMP Special Publication: Tagging, Telemetry and Marking Measures for Monitoring Fish Populations—A compendium of new and recent science for use in informing technique and decision modalities: Pacific Northwest Aquatic Monitoring Partnership Special Publication 2010-002, chap. 4, p. 69-94.

Medium to long-term acoustic monitoring (>1 month) of salmon smolts in the ocean requires that telemetry tags have minimal impact on growth and survival. In 2006 and 2008, we implanted acoustic transmitters into the abdominal cavity of spring Chinook salmon smolts (Oncorhynchus tshawytscha) from two populations within the Columbia River basin and tracked them to north of the Alaskan panhandle—a 2,500 km, 3-month long journey. Concurrently, we conducted captive tag effects studies to compare survival, tag retention, and growth of smolts (from the two populations) implanted with dummy acoustic transmitters (DATS) to a control group implanted with passive integrated transponder (PIT) tags, which weigh only 0.1 gram. The acoustic tags used in field studies in2006 weighed 2.6–11.5% of the weight of the fish (in air) and were implanted into smolts ≥140 mm fork length (FL). DATs used in captive studies had identical dimensions as live acoustic tags, weighed 5.2–10.4 % of the weight of the fish, and were implanted into smolts ≥140 mm FL. The acoustic tags and DATs used in 2008 were slightly smaller and were implanted into smolts ≥130 mm FL. Acoustic tags used in field studies weighed 2.9–7.3% of fish weight. DATs used in captive studies were identical to live transmitters and weighed 2.8–7.6% of the weight of the fish.

Overall, short-term (<1 month) tag loss and tag related mortality of captive smolts were negligible for both tag types and both populations. Beyond 1 month, significant acoustic tag loss and tag mortality occurred in one of the two populations (which may be attributed to the sutures). In both years and in both populations, surgery and/or tag implantation caused an initial period of slower growth (compared to PIT tagged fish), followed by growth rates comparable to their PIT tagged counterparts.

We used the captive data to calculate the proportion of migrating fish available for detection (tagged live fish) at two detection sites in the ocean, and then we adjusted survival estimates for migrating smolts to account for tag loss and mortality. The proportion of fish available for detection was >98% at the first ocean detection site 40 km north of the Columbia River mouth, therefore the adjustment to survival was minor (2%). The proportion of fish available for detection at the more distant site (525 km north of the river mouth) was 85% for one population; however, relative to the mortality incurred during migration, the adjustment was relatively minor and the adjusted values fell well within the 95% confidence intervals of the unadjusted survival estimates.

We also compared statistical survival models for migrating smolts to determine if survival was a function of fish fork length at tagging, and we compared our survival estimates to independent PIT tag estimates for the same population in the same year. Survival models indicated that survival was not a function of size at tagging, and independent PIT tag survival estimates were similar to our acoustic tag estimates.

We conclude that short-term acoustic tag loss and tag related mortality were minimal for the size of smolts and transmitters that were used in our studies, and that tag loss that occurred over the longer term was minor when compared to high rates of natural mortality occurring in migrating smolts. Conversely, growth rates of acoustic tagged smolts were affected in the short term but were comparable to PIT tagged fish in the longer term.

Rechisky EL, DW Welch, AD Porter, MC Jacobs, and A Ladouceur. 2009. "Experimental measurement of hydrosystem-induced delayed mortality in juvenile Snake River spring Chinook salmon (*Oncorhynchus tshawytscha*) using a large-scale acoustic array." *Canadian Journal of Fisheries and Aquatic Sciences* 66(7):1019-1024.

Out-migrating Snake River salmon smolts must pass eight major hydro dams before reaching the Pacific Ocean. Direct mortality at the dams is generally low; however, the cumulative stress caused by dam passage is hypothesized to result in delayed mortality, which occurs beyond the impounded section of the river. We tested the delayed mortality hypothesis by comparing in-river and early ocean survival of hatchery-origin spring Chinook salmon (*Oncorhynchus tshawytscha*) from the Snake River to a mid-Columbia River population that passes through only four dams and has higher smolt to adult return rates. Smolts >140 mm fork length were implanted with acoustic transmitters and tracked with the Pacific Ocean Shelf Tracking (POST) array to as far as Alaska. There was no detectable difference in survivorship to the first ocean detection line, 274 km beyond the final dam (SSnake = 29% ± 4%, SYakima = 28% ± 5%), indicating that the survival disparity observed in adult return rates may develop later in the marine life history phase. Our study is the first to estimate survival in the coastal ocean and demonstrates the utility of a large-scale array in testing previously intractable hypotheses.

Roby DD, K Collis, DE Lyons, Y Suzuki, JY Adkins, L Reinalda, N Hostetter, L Adrean, A Evans, M Hawbecker, and S Sebring. 2008. *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River - 2007 Final Season Summary*. Prepared by the U.S.Geological Survey - Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon, Real Time Research, Inc., Bend, Oregon, and the Pacific States Fisheries Commission, Hammond, Oregon, for the Bonneville Power Administration and the U.S. Army Corps of Engineers, Portland, Oregon.

This study investigates predation by piscivorous colonial waterbirds on juvenile salmonids (*Oncorhynchus* spp.) from throughout the Columbia River Basin. The study objectives for the Columbia River estuary in 2007, work funded by the Bonneville Power Administration, were to (1) monitor and evaluate previous management initiatives to reduce Caspian tern (Hydroprogne caspia) predation on juvenile salmonids (smolts); (2) measure the impact of double-crested cormorant (Phalacrocorax auritus) predation on smolt survival; (3) assess potential management options to reduce cormorant predation; and (4) monitor large colonies of other piscivorous waterbirds in the estuary (i.e., glaucous-winged/western gulls [Larus glaucescens/occidentalis]) to determine potential impacts on smolt survival. The study objectives for the middle Columbia River in 2007, work funded by the Walla Walla District of the U.S. Army Corps of Engineers, were to (1) measure the impact of predation by Caspian terns and double-crested cormorants on smolt survival in the mid-Columbia River; and (2) monitor large nesting colonies of other piscivorous waterbirds (i.e., California gulls (L. californicus], ring-billed gulls [L. delawarensis], and American white pelicans [Pelecanus erythrorhynchos]) on the mid- Columbia River to determine the potential for significant impacts on smolt survival.

Our previous studies to evaluate system-wide losses of juvenile salmonids to avian predation indicated that Caspian terns and double-crested cormorants nesting in the Columbia River estuary were responsible for the vast majority of smolt losses to avian predators in the Columbia Basin. Again in 2007, East Sand Island in the Columbia River estuary supported the largest known breeding colonies of Caspian terns and doublecrested cormorants in the world. The Caspian tern colony on East Sand Island consisted of ca. 9,900 breeding pairs in 2007, not significantly different than in 2006 (ca. 9,200 pairs). The size of the Caspian tern colony at East Sand Island has remained nearly stable since 2000. Tern nesting success averaged 0.64 fledglings per breeding pair in 2007, similar to 2006 (0.72 fledglings per breeding pair). Nesting success during 2005-2007 has been lower than during 2001-2004, when nesting success averaged 1.12 fledglings per breeding pair.

The proportion of juvenile salmonids in the diet of East Sand Island Caspian terns during the 2007 nesting season averaged 30% of prey items, similar to 2006 (31% of prey items), but higher than in 2004 (17% of prey items) or 2005 (23% of prey items). Consumption of juvenile salmonids by terns nesting at the East Sand Island colony in 2007 was approximately 5.5 million smolts (95% c.i. = 4.8 – 6.2 million), similar to smolt consumption the previous year (best estimate = 5.4 million smolts; 95% c.i. = 4.6 – 6.1 million). This is less than half the annual consumption of juvenile salmonids by Caspian terns in the estuary prior to 2000, when their breeding colony was located on Rice Island in the upper estuary. Caspian terns nesting on East Sand Island continued to rely primarily on marine forage fishes (i.e., northern anchovy, shiner perch, Pacific herring) as a food supply. Based on smolt PIT tag recoveries on the East Sand Island Caspian tern colony, predation rates on steelhead smolts were particularly high during 2007, at about 14.1% for in-river migrant smolts and 7.7% for transported smolts.

Predation rates on steelhead were 2-12 times higher than those for other salmonid species and run-types. In 2008, the U.S. Army Corps of Engineers will begin implementing the plan "Caspian Tern Management to Reduce Predation of Juvenile Salmonids in the Columbia River Estuary," outlined in the Final Environmental Impact Statement (FEIS) and Records of Decision (RODs) signed in November 2006. This management plan seeks to redistribute a portion of the East Sand Island tern colony to alternative colony sites in Oregon and California by 2015. The plan calls for the creation of up to 7 acres of new or enhanced tern nesting habitat in interior Oregon (i.e., Fern Ridge Lake, Crump Lake, and Summer Lake) and coastal California (i.e., the San Francisco Bay Area) and to actively attract terns to nest there. As alternative tern nesting habitat is created or enhanced, the available tern nesting habitat on

East Sand Island will be reduced from its current size (6 acres) to 1.5 – 2 acres. Habitat enhancement at alternative sites will be accomplished in stages and the reduction of tern nesting habitat at East Sand Island will occur at a ratio of one acre reduced for each 2 acres of habitat created elsewhere. Once fully implemented, the plan would reduce the East Sand Island Caspian tern colony from its current size (approximately 9,500 nesting pairs) to approximately 3,100 – 4,400 nesting pairs. This reduction in the size of the East Sand Island tern colony is intended to reduce tern predation on smolts in the Columbia River estuary by an estimated 2.4 – 3.1 million smolts annually.

The double-crested cormorant colony on East Sand Island consisted of about 13,770 breeding pairs in 2007, similar to the estimate of colony size last year (13,740 pairs). Since our monitoring began in 1997, this cormorant colony has increased by about 275%. Nesting success in 2007 (2.78 fledglings per breeding pair) was the highest ever recorded for this colony, and up considerably from 2006 (1.92 fledglings per breeding pair). As in previous years, salmonids made up a small portion (9%) of the cormorant diet in 2007, while marine forage fish (i.e., northern anchovy) and estuarine resident fish (i.e., sculpin, flounder) made up over 50% of the diet. Despite the lower reliance on salmonids as a food source by cormorants compared to terns, total smolt consumption by cormorants was similar to or greater than that by terns. This is because double-crested cormorants are about four times larger than Caspian terns and the cormorant colony consists of about 40% more nesting pairs than the tern colony. In 2006, cormorants nesting on East Sand Island consumed an estimated 10.3 million juvenile salmonids (95% c.i. = 4.7 – 15.9 million), compared to an estimated 5.4 million juvenile salmonids (95% c.i. = 4.6 – 6.1 million) consumed by terns nesting on East Sand Island (estimates of cormorant consumption of salmonid smolts in 2007 are pending further analyses).

An analysis of salmonid PIT tags detected at the double-crested cormorant colony on East Sand Island indicated that all species of anadromous salmonids (i.e., Chinook salmon, coho salmon, sockeye salmon, steelhead, and sea-run cutthroat trout) from all run-types (fall, winter, summer, and spring), and from all tagged ESUs were susceptible to cormorant predation in 2007. The numbers of PIT tags from the various salmonid species and run-types that were recovered on the cormorant colony were roughly proportional to the relative availability of PIT-tagged salmonids released in the basin, suggesting that cormorant predation on salmonid smolts in the estuary was less selective than tern predation.

In contrast, PIT tag recoveries on the East Sand Island tern colony indicated that steelhead were far more vulnerable to Caspian tern predation as compared to other salmonid species. An analysis of salmonid predation rates, based on the proportion of available PIT-tagged fish subsequently deposited on the cormorant colony, indicated that both hatchery and wild smolts were consumed, with rates averaging between 2 and 5% for most species and run-types of PIT-tagged fish originating upstream of Bonneville Dam. Predation rates in excess of 20% were observed for some groups of hatchery fall Chinook salmon released in or near the estuary.

If the cormorant breeding colony on East Sand Island continues to expand and/or the proportion of salmonids in cormorant diets increases, cormorant predation rates on juvenile salmonids may far exceed those of Caspian terns nesting in the estuary. The discrepancy in predation rates for the two colonies will be even greater if the Caspian tern colony is reduced in size by >50% by 2015, as intended under the management plan now being implemented. Resource management agencies have not decided whether management of the large and expanding colony of double-crested cormorants on East Sand Island is warranted. Elsewhere in North America, management of double-crested cormorants has consisted primarily of lethal control (i.e., shooting of adults, oiling of eggs, and destruction of nests in trees). Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the coast of Oregon and Washington, seem more appropriate in the context of the cormorant colony on East Sand Island, which constitutes nearly 50% of the entire breeding population of the Pacific Coast subspecies P. auritus albociliatus. Studies designed to test the feasibility of employing habitat enhancement and social attraction (i.e., old tires with nest material, decoys, audio playback systems) to relocate nesting cormorants have shown some promise; cormorants were previously attracted to nest and nested successfully (raised young to fledging) on Miller Sands Spit and Rice Island, two islands in the upper estuary where no successful cormorant nesting attempts have been recorded recently. In 2007, habitat enhancement and social attraction were retained at Miller Sands Spit, but removed from Rice Island; the cormorant colony on Miller Sands Spit was again successful in raising young, while there was no cormorant nesting on Rice Island.

In order to reduce cormorant predation on juvenile salmonids from the Columbia Basin, however, it will be necessary to relocate nesting cormorants to suitable habitat outside the Columbia River estuary. In 2007, we conducted a pilot study to test the feasibility of attracting double-crested cormorants to nest at a site remote from the Columbia River estuary and where cormorants had not previously been known to nest. We placed old tires with nest material, cormorant decoys, and audio playbacks of cormorant colony sounds on a floating platform in the Fern Ridge Wildlife Area, adjacent to Fern Ridge Lake near Eugene, Oregon. While double-crested cormorants were repeatedly seen in the area, no cormorants were seen on the platform and no nesting attempts occurred there. This pilot study will be repeated in 2008. While studies of the use of habitat enhancement and social attraction in the Columbia River estuary have been promising, results to date indicate that double-crested cormorants are not as responsive to these techniques as Caspian terns.

As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses will likely require additional research and analysis under NEPA, including assessments of (1) the population status of the Pacific Coast subspecies of double-crested cormorant, (2) the availability of suitable nesting habitat for the subspecies outside the Columbia River estuary, and (3) the potential enhancement of salmonid recovery rates in the Columbia River Basin due to management of cormorants in the estuary. These and other related studies are planned for 2008 and beyond.

The Caspian tern colony on Crescent Island in the mid-Columbia River has received comparatively little attention from salmon management agencies because of its relatively small size (ca. 500 nesting pairs, ca. 1/20th the size of the Caspian tern colony in the estuary) and low annual consumption of juvenile salmonids (ca. 0.5 million smolts, ca. 1/10th the consumption of the tern colony in the estuary). In 2007, there were two breeding colonies of Caspian terns on the mid-Columbia River; about 355 pairs nested on Crescent Island in the McNary Pool and about 40 pairs nested at a relatively new colony site on Rock Island in the John Day Pool. The Crescent Island tern colony declined by 21% from 2006, when 448 breeding pairs nested at the colony; this colony is now smaller than in any year since 1997. It is still the largest Caspian tern colony on the Columbia Plateau, however, and the third largest Caspian tern colony in the Pacific Northwest. The Rock Island Caspian tern colony in 2007 was substantially smaller than in 2006, when 110 breeding pairs attempted to nest there, but was larger than in 2005 (6 breeding pairs), the first year that Caspian terns were known to nest on Rock Island. Nesting success at the Crescent Island tern colony was 0.68 young fledged per breeding pair, up 58% from 2006 (0.43 young fledged per breeding pair). Tern productivity at the Crescent Island colony in 2006 was the lowest recorded at this colony since monitoring began in 2000. In 2007, the Rock Island Caspian tern colony failed to produce any young, apparently due to avian predation on all tern eggs and chicks. In 2006, the Rock Island Caspian tern colony also failed, apparently due to mink predation.

At Crescent Island in 2007, salmonid smolts represented 69% of prey items in tern diets, up slightly from 2006 (63%). We estimated that Caspian terns nesting on Crescent Island in 2007 consumed 360,000 juvenile salmonids (95% c.i. = 250,000 – 460,000), a ca. 10% decline in smolt consumption compared to 2006 (best estimate = 402,000, 95% c.i. = 310,000–500,000). Steelhead comprised an estimated 20.5% of the identifiable salmonid smolts, or roughly 74,000 fish, an increase over the previous year (56,000 fish). Per capita smolt consumption by Crescent Island terns in 2007 (507 smolts per nesting tern across the breeding season) was also greater compared to 2006 (446 smolts per nesting tern). Although no data on diet composition were collected at the Rock Island tern colony, we estimate that 677 smolt PIT tags were deposited on the colony during the 2007 nesting season, indicating that salmonids were a significant part of the diet before the colony failed. A comparison of smolt PIT tags recovered from the Crescent Island and Rock Island tern colonies suggests that Rock Island terns consumed about 1/8th as many PIT-tagged salmonid smolts as did Crescent Island terns, or roughly 45,000 smolts.

Based on smolt PIT tag recoveries on the Caspian tern colony at Crescent Island, the predation rate on in-river migrants from the Snake River (all species and run types) was about 1.1% in 2007, down substantially from 7.5% and 3.8% in 2005 and 2006, respectively. These predation rates have been corrected for both the detection efficiency of PIT tags on-colony and the proportion of PIT tags ingested by terns that were subsequently deposited on-colony. Although predation rates were dramatically down in 2007, the numbers of Snake River smolts available to terns foraging in McNary Pool were substantially up, as fewer fish were collected for transportation at Snake River dams. As in previous years, predation rates on PIT-tagged steelhead smolts were greater than for other salmonid species. In 2007, ca. 4.9% of the hatchery and 4.8% the wild steelhead smolts from the Snake River were consumed by Crescent Island terns (these predation rates are based on the proportion of PIT-tagged fish interrogated passing Lower Monumental Dam between 1 April and 31 July that were subsequently detected on the Crescent Island tern colony). Because fewer Snake River steelhead were transported around McNary Pool in 2007 compared to 2006, a larger proportion of the Snake River steelhead population was susceptible to predation from Crescent Island terns in 2007. Consequently, the total predation rate by Crescent Island terns on the Snake River steelhead ESU in 2007 was the highest observed since 2004. Predation rates on wild steelhead versus hatchery steelhead from the Snake River were similar and not statistically different when pooled over the entire 2007 out-migration; this finding differs from results during 2004 – 2006, when predation rates on hatchery smolts were consistently higher than on wild smolts.

In 2007, the double-crested cormorant colony on Foundation Island in the mid-Columbia River consisted of at least 330 nesting pairs, and was somewhat smaller than in 2006. The largest cormorant colony on the Columbia Plateau in 2007 was again on Potholes Reservoir, where about 1,015 pairs nested in trees at the north end of the reservoir. The size of this colony was also somewhat lower than in 2006. The limited diet data for Foundation Island cormorants suggest that juvenile salmonids represented 16-18% of the diet. For the first time since this research was initiated in 2004, smolt PIT tag recoveries, and in some cases reach and stock-specific salmonid predation rates, were higher for the Foundation Island cormorant colony than for the Crescent Island tern colony. In fact, of all the piscivorous waterbird colonies studied on the Columbia River in 2007, the Foundation Island cormorant colony had the highest per capita consumption rate of PITtagged juvenile salmonids (ca. 11.3 PIT-tagged fish per breeding adult), followed by the Rock Island tern colony (7.87) and the Crescent Island tern colony (7.24). These results suggest that predation rates on salmonid smolts by Foundation Island cormorants are increasing and may now be similar to or greater than that of Caspian terns nesting on nearby Crescent Island. Similar to predation by Crescent Island terns, steelhead were particular vulnerability to predation by Foundation Island cormorants in 2007. Unlike terns, however, Foundation Island cormorants also keyed in on groups of Chinook salmon (both yearlings and sub-yearlings) migrating through McNary Pool. In contrast to the Foundation Island cormorant colony, there is little evidence to suggest that cormorants nesting at the larger colony on Potholes Reservoir are affecting the survival of juvenile salmonids from the Columbia and Snake rivers during the nesting season, based on the paucity of PIT tags from Columbia Basin salmonid smolts recovered at the colony in 2007 (n = 6 smolt PIT tags).

Unlike Caspian terns, which depart the Columbia Basin during the non-breeding season, some double-crested cormorants over-winter on the Columbia and Snake rivers. Overwintering cormorants could potentially affect the survival of hold-over fall Chinook salmon smolts, particularly near Snake River dams. A pilot study to investigate this potential impact suggested that small numbers of cormorants (< 100) over-winter near two lower Snake River dams (Little Goose and Lower Granite) and that salmonids make up a significant, although not predominant, proportion of their diet. Based on identifiable fish tissue in fore-gut samples, juvenile salmonids comprised 11.8% by mass of the diet of double-crested cormorants foraging at Little Goose and Lower Granite dams in 2007 (n = 40 fore-gut samples). Juvenile shad were the most abundant fish found in fore-gut contents, representing 47.7% of prey biomass, followed by centrarchids (22.0%). It should be noted, however, that these diet composition results are based on a small sample size and the counts of cormorants at two dams on the Snake River tell us little about the system-wide abundance and distribution of over-wintering cormorants on the Snake River and their potential impact on survival of juvenile salmonids. In 2008, we plan to conduct more comprehensive surveys of the distribution and abundance of over-wintering cormorants along the Snake River from the confluence with the Columbia River to Lewiston, Idaho. Additionally, we will increase our sampling efforts to measure diet composition in order to better assess the impacts on ESA-listed salmonid stocks, particularly hold-over fall Chinook salmon smolts, of double-crested cormorants overwintering along the lower Snake River.

Compared to Caspian terns and double-crested cormorants, other piscivorous colonial waterbirds that nest along the mid-Columbia River (i.e., California gulls, ring-billed gulls, American white pelicans) are having less impact on the survival of juvenile salmonids from the Columbia and Snake rivers. One gull colony that may be having a significant impact on salmonid smolt survival, however, is the large California gull colony (ca. 3,500 nesting pairs) on Miller Rocks in The Dalles Pool, where 2,653 smolt PIT tags were recovered in 2007. Previous research in 1997 and 1998 indicated that salmonid smolts, and fish in general, constituted a very small proportion of the diet of California and ring-billed gulls nesting at up-river colonies (Collis et al. 2002a). At the American white pelican colony on Badger Island 1,160 smolt PIT tags were recovered in 2007; this represents about 0.64 PIT-tagged smolts consumed per nesting adult at this growing colony. In comparison, double-crested cormorants nesting at Foundation Island and Caspian terns nesting on Crescent Island consumed 11.3 and 7.2 PIT-tagged smolts per nesting adult, respectively. The size of some up-river gull colonies (= 7,000 breeding pairs on several islands) and the Badger Island white pelican colony (> 900 pairs), however, exceeds that of the up-river tern and cormorant colonies and should be taken into account when evaluating overall impacts of avian predation on salmonid smolt survival on the Columbia Plateau. Further research and monitoring is necessary to determine whether particular gull and pelican colonies might be having a significant effect on survival of juvenile salmonids in the lower and mid-Columbia River.

In contrast to the gull and pelican colonies on the Columbia Plateau, previous research on glaucous-winged/western gulls nesting in the Columbia River estuary indicated that these birds consumed significant numbers of juvenile salmonids (Collis et al. 2002a). Gulls nesting on Rice Island (river km 34) ate mostly riverine fishes, including out-migrating salmonids, whereas gulls nesting on East Sand Island (river km 8) ate primarily marine fishes. In 1997 and 1998, juvenile salmonids comprised 10.9% and 4.2% of the diet (by mass) of glaucous-winged/western gulls nesting on Rice Island/Miller Sands Spit and East Sand Island, respectively. PIT tag studies have not been conducted on these colonies, nor have diet data been collected since 1998. As such, the current impact on salmonid smolt survival of predation from gulls nesting at these estuary colonies is unknown.

In 2007 we conducted a pilot study to investigate how smolt morphology, condition, and origin might be related to differences in smolt vulnerability to avian predation. We hypothesized that the probability of smolt mortality due to avian predation increases with the declining physical condition of the fish. We also hypothesized that river conditions and dam operational strategies may be associated with a smolt's vulnerability to avian predators. As part of this pilot study, we scored the condition of 7,088 steelhead smolts that were PIT-tagged and released at Lower Monumental and Ice Harbor dams.

Subsequent recovery of some of these PIT tags on piscivorous waterbird colonies downstream indicated that avian predation is partially condition-dependent, with diseased steelhead or steelhead with severe external damage more likely to be consumed by birds than fish with little or no external damage or disease. For example, steelhead with severe external damage were 1.8 times more likely to be consumed by an avian predator than fish with no signs of external damage. Similarly, there was a positive relationship between the extent of de-scaling of smolts and their vulnerability to avian predation, slight to severely de-scaled fish were 1.2 to 2.4 times more likely to fall prey to birds than smolts with little to no de-scaling. Preliminary results indicate that at least some smolt mortality is compensatory, and that not all mortality due to avian predation is additive.

A system-wide assessment of avian predation on juvenile salmonids based on recent available data indicates that the most significant impacts to smolt survival occur in the estuary, with Caspian terns and double-crested cormorants nesting on East Sand Island combined to consume ca. 7 – 16 million smolts annually during 2003-2006. Although estimates of smolt consumption for East Sand Island cormorants in 2007 are not yet available, combined smolt losses to terns and cormorants nesting on East Sand Island in 2007 are expected to be within this range. Estimated smolt losses to piscivorous birds that nest in the estuary are more than an order of magnitude greater than those observed on the mid-Columbia River. Additionally, when compared to the impact of avian predation on the mid-Columbia River, avian predation in the Columbia estuary affects juvenile salmonids that have survived freshwater migration to the ocean and presumably have a higher probability of survival to return as adults, compared to those fish that have yet to complete out-migration. Finally, juvenile salmonids belonging to every ESA-listed stock from the Columbia River basin are susceptible to predation in the estuary because all surviving fish must migrate in-river through the estuary to reach the ocean. For these reasons, management of Caspian tern and double-crested cormorant colonies on East Sand Island has the greatest potential to benefit ESA-listed salmonid populations from throughout the Columbia River basin, when compared to potential management of other colonies of other piscivorous waterbirds. The Caspian tern colony on Crescent Island and the double-crested cormorant colony on Foundation Island may be exceptions to this rule; management of these small, up-river colonies may benefit certain salmonid stocks, particularly steelhead.

Roby DD, DE Lyons, DPCraig, K Collis, and GH Visser. 2003. "Quantifying the effect of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary." *Canadian Journal of Zoology-Revue Canadienne De Zoologie* 81(2):250-265.

We estimated the consumption of juvenile salmonids (*Oncorhynchus* spp.) and other forage fishes by Caspian terns (Sterna caspia) nesting on Rice Island in the Columbia River estuary in 1997 and 1998 using a bioenergetics modeling approach. The study was prompted by concern that Caspian tern predation might be a substantial source of mortality to out-migrating juvenile salmonids from throughout the Columbia River basin, many populations of which are listed as threatened or endangered under the U.S. Endangered Species Act. The bioenergetics model used estimates of the energy requirements of the tern population and the proportion of tern energy requirements met by various prey types. The resulting estimate of the number of juvenile salmonids consumed by Rice Island Caspian terns was 8.1 million (5.9-10.4 million) in 1997 and 12.4 million (9.1-15.7 million) in 1998. Tern predation rates on juvenile salmonids were substantial, representing up to 15% of the juveniles to reach the estuary from some listed populations. Nevertheless, based on simple age-structured models of salmonid populations, it appears unlikely that management of Caspian tern predation alone would reverse salmonid declines. Management to reduce tern predation could, however, contribute to a comprehensive strategy to recover imperiled salmonid populations in the Columbia River basin.

Roby DD, K Collis, DE Lyons, JY Adkins, P Loschl,Y Suzuki, D Battaglia,T Marcella, T Lawes, A Peck-Richardson, L Bayliss, L Faulquier, D Harvey, E Tompkins, J Tennyson, A Evans, N Hostetter, B Cramer, M Hawbecker, RD Ledgerwood, and S Sebring. 2011a. *Research, Monitoring, and Evaluation of Avian Predation on Salmonid Smolts in the Lower and Mid-Columbia River – Final 2010 Annual Report*. Prepared by the U.S.Geological Survey – Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon, Real Time Research, Inc., Bend, Oregon, and the Pacific States Fisheries Commission, Hammond, Oregon, for the Bonneville Power Administration and the U.S. Army Corps of Engineers, Portland, Oregon.

We conducted field studies in 2010 to assess the impact of predation by Caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus*), and other piscivorous colonial waterbirds on juvenile salmonids (*Oncorhynchus* spp.) in the Columbia River basin. Additionally, we monitored the Caspian tern colonies located outside the Basin that were recently established on alternative nesting habitat for Caspian terns displaced from East Sand Island, as part of the Caspian Tern Management Plan.

The Caspian tern colony on East Sand Island in the Columbia River estuary, the largest of its kind in the world, consisted of about 8,283 breeding pairs in 2010, significantly less than in 2009 and the smallest the colony has been since it became fully established in 2001. Although the recent decline in size of the East Sand Island tern colony was coincident with a reduction in the amount of nesting habitat made available to terns on East Sand Island, nesting habitat did not appear to limit the size of the East Sand Island tern colony in 2010. Based on nesting densities observed at the East Sand Island tern colony over the past several years, plus poor nesting success during the 2010 El Niño, the reduction in available nesting habitat from five acres in previous years to 3.1 acres in 2010 was not the primary cause for the decline in colony size observed in 2010. Further reductions in the amount of Caspian tern nesting habitat provided on East Sand Island in future years will be necessary to realize the goal of relocating a majority of the East Sand Island tern colony to alternative sites, as prescribed in the Caspian Tern Management Plan.

Juvenile salmonids continued to be a large part of the diet of Caspian terns nesting on East Sand Island, comprising 33% of the overall diet in 2010, slightly higher than the 10- year average during 2000-2009 (30%). As in previous years, marine forage fishes dominated the diet of Caspian terns nesting on East Sand Island, comprising 62% of all identified bill loads in 2010. Caspian terns nesting at the East Sand Island colony consumed about 5.3 million juvenile salmonids (95% c.i. = 4.5 – 6.1 million) in 2010, not significantly different than the smolt consumption estimates from the previous two years. Since 2000, the average number of smolts consumed by Caspian terns nesting on East Sand Island was 5.3 million smolts per year, less than half the annual consumption of juvenile salmonids by Caspian terns in the Columbia River estuary prior to 2000, when the breeding colony was located on Rice Island. Further reductions in smolt consumption by terns nesting on East Sand Island will require a significant reduction in the size of the tern colony; future management plans are designed to reduce the size of the East Sand Island tern colony to about one-third its pre-management size.

Implementation of the federal management agencies' Caspian Tern Management Plan for the Columbia River Estuary continued outside the Columbia River basin, with the USACE-Portland District and its state and federal partners building four new Caspian tern nesting islands prior to the 2010 nesting season. Two of the islands are located in Lower Klamath National Wildlife Refuge, California (a 1-acre silt-core island in the Orems Unit and a 0.8-acre floating island on Sheepy Lake); one island is located in Tule Lake National Wildlife Refuge, California (a 2-acre rock-core island in Sump 1B); and one island is located at Summer Lake Wildlife Area, Oregon (a 0.5-acre rock-core island in Gold Dike impoundment). The severe drought in the Upper Klamath Basin and adjacent areas of interior Oregon, however, precluded allocating water to three of the four impoundments where new islands were built. Nevertheless, Caspian terns quickly colonized the new 0.8-acre floating island at Sheepy Lake in Lower Klamath National Wildlife Refuge, where 258 pairs raised 168 young. Nineteen terns that had been banded in the Columbia River estuary were re-sighted at the Sheepy Lake tern island. We continued to monitor four other alternative colony sites constructed by the USACEPortland District in interior Oregon during 2008 and 2009: Fern Ridge Reservoir tern island; Crump Lake tern island; and East Link and Dutchy Lake tern islands in Summer Lake Wildlife Area. No Caspian terns successfully nested at three of these four islands and the fourth experienced very low nesting success, apparently due to adverse weather conditions and low forage fish availability associated with El Niño conditions during the 2010 nesting season.

Diet composition and PIT tag recovery data from Caspian tern colonies in interior Oregon and northeastern California indicated these colonies were primarily consuming cyprinids (i.e., tui chub *Gila bicolor*), centrarchids (i.e., crappie *Pomoxis* spp.), and ictalurids (i.e., brown bullhead *Ameiurus nebulosus*) in 2010. Catostomids (suckers), several species of which are listed under the Endangered Species Act, were not identified in the diet of terns nesting at Crump Lake in 2010. One juvenile sucker (species unknown) was observed at the Summer Lake Caspian tern colony and four juvenile suckers (species unknown) were observed at the Sheepy Lake Caspian tern colony in 2010. Suckers represented a very small percentage (< 0.1%) of identifiable prey items at these two tern colonies. No sucker PIT tags were recovered from Caspian tern colonies in either interior Oregon or northeastern California in 2010.

East Sand Island is also home to the largest double-crested cormorant colony in western North America, consisting of about 13,596 breeding pairs in 2010; 2010 was the second consecutive year where the colony grew by more than 10%. Juvenile salmonids represented about 16.4% of the diet of double-crested cormorants nesting on East Sand Island in 2010, compared with 9.2% in 2009. Double-crested cormorants nesting at this colony consumed approximately 19.2 million juvenile salmonids (95% c.i. = 14.6 – 23.8 million) in 2010, the highest annual smolt consumption ever estimated for the East Sand

Island cormorant colony. In the past two years, smolt consumption by double-crested cormorants nesting on East Sand Island was significantly greater than smolt consumption by Caspian terns nesting on East Sand Island.

Management options to reduce or limit smolt losses to the double-crested cormorant colony on East Sand Island are under consideration by federal, state, and tribal resource management agencies. In order to reduce predation on juvenile salmonids by doublecrested cormorants in the Columbia River estuary, it will be necessary to reduce the size of the cormorant colony on East Sand Island. Non-lethal management approaches, such as relocating a portion of the colony to alternative colony sites along the Pacific coast, seem more appropriate in the context of the cormorant colony on East Sand Island, whose initial growth appears to have occurred largely at the expense of other colonies in the region. As was the case with Caspian tern management in the Columbia River estuary, any management of double-crested cormorants to reduce smolt losses in the estuary will require analysis under the National Environmental Policy Act (NEPA), a process that is currently underway.

Further up-river in the Columbia Plateau region, Caspian terns and double-crested cormorants are also the two bird species responsible for most of the smolt losses to avian predators. Management options to reduce the impacts of these two avian predators on smolt survival along the mid-Columbia and lower Snake rivers are currently being considered by resource managers. In 2010, the largest breeding colonies of Caspian terns in the Columbia Plateau region were on Crescent Island (in McNary Pool) and on Goose Island (Potholes Reservoir, WA), where 375 pairs and 416 pairs nested, respectively. Caspian tern nesting success at the Crescent Island colony averaged 0.52 young raised per nesting pair, higher than in recent years, while the Goose Island tern colony experienced almost complete nesting failure in 2010. Three other smaller Caspian tern colonies in the Columbia Plateau region also failed or nearly failed to produce any young. In 2010, salmonid smolts represented 71% of tern prey items at the Crescent Island colony and 21% of tern prey items at the Goose Island colony; estimated smolt consumption by terns nesting at these two colonies was 420,000 smolts and 122,000 smolts, respectively. The largest colony of double-crested cormorants on the mid-Columbia River was on Foundation Island (in McNary Pool), where 308 pairs nested in 2010. Diet sampling during 2005-2010 indicated that ca. 50% (by mass) of the Foundation Island cormorant diet was juvenile salmonids during May (the peak of smolt out-migration), while less than 10% of the diet was salmonids during early April, June, and July.

A total of 36,764 PIT tags from 2010 migration year smolts were recovered on bird colonies in the Columbia Plateau region. PIT tag recoveries indicated that smolt losses in 2010 were similar for Foundation Island cormorants (8,481 tags) and Crescent Island terns (8,255 tags). Substantial numbers of smolt PIT tags were also detected on the Caspian tern colony on Goose Island in Potholes Reservoir (8,512 tags) and on a mixed California gull (*Larus californicus*) and ring-billed gull (*L. delawarensis*) colony on Miller Rocks in The Dalles Pool (5,045 tags). PIT tags recovered from the Caspian tern colony in Potholes Reservoir were almost exclusively from upper Columbia River salmonid ESUs, while PIT tags recovered on other bird colonies in the Plateau region consisted of smolts from upper Columbia, Snake, and middle Columbia ESUs. Preliminary results indicate that Caspian terns from the Goose Island colony in Potholes Reservoir consumed an estimated 9.6% of the juvenile steelhead (*Oncorhynchus mykiss*) PIT-tagged and released at Rock Island Dam on the upper Columbia River in 2010. Predation rates by Crescent Island terns on Snake River steelhead (ca. 2.8%) and by Foundation Island cormorants on Snake River steelhead (ca. 1.3%) and Snake River sockeye (ca. 1.7%) were also notable in 2010, although lower compared to previous years (2004-2009).

California and ring-billed gulls have nested in large numbers on islands on or near the mid- and upper Columbia River, but these gulls have generally consumed few fish and even fewer juvenile salmonids, with the exception of the gull colony on Miller Rocks in The Dalles Pool (see above). In 2010, the number of gulls counted on the Miller Rocks colony was 5,533, down from 6,016 gulls counted on colony during the 2009 breeding season. Despite this decline in the number of gulls counted on the Miller Rocks gull colony, the number of gulls utilizing Miller Rocks during the breeding season has increased by about 150% since 1998. Similarly, the American white pelican (*Pelecanus erythrorhynchos*) colony on Badger Island in McNary Pool has experienced significant growth since the late 1990's, increasing from 100 adults on colony in 1999 to 1,643 adults in 2010. Unlike the Miller Rocks gull colony, however, pelicans nesting at Badger Island are not consuming large numbers of juvenile salmonids, based on the relatively small numbers of smolt PIT tags detected on the colony. Continued monitoring of these and perhaps other incipient piscivorous waterbirds colonies in the Columbia River basin will be necessary to determine the magnitude and trend for total losses of juvenile salmonids to avian predators in the basin.

Roby DD, K Collis, DE Lyons, JY Adkins, P Loschl, Y Suzuki, T Marcella, L Kerr, A Evans, B Cramer, N Hostetter, BP Sandord, RD Ledgerwood, DR Kuligowski and S Sebring. 2011b. *Impacts of Avian Predation on Salmonid Smolts from the Columbia and Snake Rivers – 2004-2009 Synthesis Report*. Prepared by the U.S. Geological Survey – Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon, Real Time Research, Inc., Bend, Oregon, and the Pacific States Fisheries Commission, Hammond, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Populations of anadromous salmonids (*Oncorhynchus* spp.) in the Columbia River basin are currently the subjects of intense conservation activity following decades of decline. In recent years, avian predation across the basin has been considered a factor limiting recovery of these imperiled fish populations. Caspian terns (*Hydroprogne caspia*), double-crested cormorants (*Phalacrocorax auritus*), American white pelicans (*Pelecanus erythrorhynchos*), California gulls (*Larus californicus*), and ring-billed gulls (*L. delawarensis*) are native piscivorous colonial waterbirds with a history of nesting in the Columbia Plateau region. We investigated the impact on survival of juvenile salmonids from predation by piscivorous colonial waterbirds nesting in the Columbia Plateau region during 2004-2009.

Within the Columbia Plateau region, overall numbers of breeding Caspian terns remained relatively stable during the study period at between 800 and 1,000 breeding pairs at five colonies; the two largest breeding colonies were on Crescent Island in the mid-Columbia River and on Goose Island in Potholes Reservoir. Overall numbers of breeding double-crested cormorants in the Columbia Plateau region decreased during the study period, from about 1,500 breeding pairs to about 1,200 breeding pairs at four separate colonies; the largest breeding colony by far was at the north end of Potholes Reservoir. Numbers of breeding American white pelicans increased at the Badger Island colony on the mid-Columbia River, the sole breeding colony for the species in the State of Washington. Overall numbers of breeding gulls, the most numerous piscivorous colonial waterbirds in the region, declined during the study period. Potential limiting factors for piscivorous colonial waterbirds nesting in the Columbia Plateau region include human disturbance, mammalian predation, availability of suitable nesting habitat, inter-specific competition for limited nesting habitat, and food availability. Overall breeding numbers of Caspian terns and double-crested cormorants in the Columbia Plateau region are an order of magnitude less than the numbers of these two species nesting in the Columbia River estuary, whereas California gulls, ring-billed gulls, and American white pelicans are far more numerous in the Columbia Plateau region than in the estuary.

We used bioenergetics methods to estimate prey consumption by Caspian terns nesting at Crescent Island and double-crested cormorants nesting at Foundation Island, both located in the mid-Columbia River just below the confluence with the Snake River. Taken together, the Crescent Island tern colony and the Foundation Island cormorant colony consumed approximately one million juvenile salmonids annually during 2004 – 2009. Estimated annual consumption of smolts by Foundation Island cormorants ranged from 470,000 to 880,000, while that of Crescent Island terns ranged from 330,000 to 500,000. Consumption of salmon smolts by the Crescent Island tern colony declined during the study period, tracking a decline in colony size. Consumption of steelhead (*O. mykiss*) did not decline, however, perhaps reflecting greater steelhead availability in later years due to reduced transportation rates of Snake River steelhead. There was no apparent trend in smolt consumption by Foundation Island cormorants during the study period. Relative to salmonids, consumption of lamprey was minor, with fewer than 10,000 lamprey macropthalmia consumed per year by both colonies combined.

We recovered passive integrated transponder (PIT) tags from salmonid smolts on nine different piscivorous waterbird colonies in the Columbia River basin to evaluate avian predation on juvenile salmonids during 2004-2009. These nine bird colonies had the highest numbers of smolt PIT tags of any in the Columbia Basin. Predation rates based on PIT tag recoveries were used to determine which salmonid stocks were most affected by avian predation and which bird colonies had the greatest impact on smolt survival. This system-wide evaluation of avian predation indicated that Caspian terns and double-crested cormorants nesting on East Sand Island in the Columbia River estuary were consuming the highest proportions of available PIT-tagged smolts. However, Caspian terns and double-crested cormorants nesting at colonies in the Columbia Plateau region also had significant impacts on survival of specific salmonid stocks. Predation rates by Crescent Island terns on Snake River summer steelhead (7.7%) and by Goose Island terns on upper Columbia summer steelhead (10.0%) were substantial during the study period. Predation rates by Foundation Island cormorants on Snake River summer steelhead (2.0%) and Snake River sockeye (1.7%) were not as high, but notable. Predation rates by gulls and pelicans nesting in the Columbia Plateau region were minor (generally < 0.5% of available smolts) compared to smolt losses from inland tern and cormorant colonies. Hatchery smolts were often more susceptible to avian predation relative to their wild counterparts, although exceptions were numerous. Smolts out-migrating in June and July were often consumed at higher rates by birds than smolts of the same stock that out-migrated earlier (April or May).

Predation rates on PIT-tagged smolts that were adjusted for colony size (i.e., smolt consumption per bird) were substantially higher for terns and cormorants nesting at colonies in the Columbia Plateau region compared to those nesting in the estuary. Thus, while inland colonies of terns and cormorants are much smaller than their counterparts in the estuary, inland colonies can be more reliant on salmonids as a food source. This greater reliance on salmonids, coupled with lower diversity of available salmonid stocks compared to the estuary, is responsible for the unexpectedly high impact of some inland tern and cormorant colonies on specific stocks of salmonids, particularly steelhead. Current management efforts to increase smolt survival through reductions in tern and cormorant predation in the estuary could result in some terns and cormorants from estuary colonies recruiting to inland colonies, potentially resulting in higher predation rates on certain ESA-listed salmonid stocks. Recruitment from estuary colonies may result in small, but significant increases in numbers of these two species nesting in the Columbia Plateau region. Nesting habitat and food supply appear to limit Caspian tern numbers on the Columbia Plateau and the demographic connectivity between the double-crested cormorant colony in the estuary and those on the Columbia Plateau appears limited. Although the number of Caspian terns that could relocate from estuary colonies to colonies on the Columbia Plateau is likely small relative to numbers nesting in the Columbia River estuary (< 1,000 adults), the impact on specific steelhead stocks could be substantial and warrants monitoring.

We investigated factors that influence susceptibility of juvenile salmonids to avian predation using juvenile steelhead from the threatened Snake River stock. Steelhead smolts (n = 25,909) were captured, externally examined, marked with PIT tags, and released to continue outmigration during 2007-2009. Recoveries of steelhead PIT tags on the Crescent Island Caspian tern colony indicated that steelhead susceptibility to tern predation increased significantly with declining steelhead external condition, decreased water discharge, decreased water clarity, and increased steelhead length up to 202 mm (fork length), but decreased for larger steelhead. Recoveries of PIT tags on the Foundation Island double-crested cormorant colony indicated that steelhead susceptibility to cormorant predation increased significantly with declining steelhead external condition, plus steelhead of hatchery origin were more susceptible compared to their wild counterparts. These results indicate that steelhead susceptibility to avian predation is condition- and size-dependent and is influenced by both river conditions and rearing environment (hatchery vs. wild). These findings unequivocally demonstrate that at least a portion of the smolt mortality caused by avian predation in the mid-Columbia River is compensatory.

We also assessed the abundance, distribution, and diet of double-crested cormorants over-wintering on the lower Snake River in eastern Washington to investigate the potential for significant impacts from cormorant predation on survival of ESA-listed fall Chinook salmon that over-winter in the lower Snake River. A monthly average of 256 cormorants was observed on this reach of the lower Snake River. Overall diet composition of cormorants was highly variable and changed as winter progressed. The most prevalent prey types were centrarchids (34.3% by mass), followed by shad (15.0%). Fall Chinook salmon comprised an average of 3.4% by mass of the cormorant diet. Biomass consumption of all salmonids by overwintering cormorants was estimated at 3,100 to 11,000 kg, or about one third of the estimated salmonid biomass consumption by cormorants nesting at Foundation Island. The bulk of the diet of over-wintering cormorants, however, consisted of non-native fishes that compete with or depredate juvenile salmonids.

Based on the results of this study, the greatest potential for increasing survival of smolts from ESA-listed salmonid stocks by managing inland avian predators would be realized by focusing management efforts on Caspian terns nesting at colonies on Crescent Island, Goose Island, and the Blalock Islands. Reductions in the size of these tern colonies would enhance survival of upper Columbia River and Snake River steelhead stocks in particular. More limited enhancement of smolt survival for Snake River steelhead and Snake River sockeye could be achieved by managing the double-crested cormorant colony at Foundation Island. Management of other inland piscivorous waterbird colonies in the Columbia Plateau region would provide relatively small and perhaps undetectable increases in stock-specific smolt survival. Further work is necessary, however, to translate smolt consumption and predation rate estimates into assessments of the potential benefits for threatened and endangered salmonid populations of reducing avian predation in the Columbia Plateau region. The analysis of potential benefits from management of piscivorous waterbirds for restoring ESA-listed stocks of salmonids is key to informed decision-making, as resource managers consider management of specific waterbird colonies on the Columbia Plateau, and identifying management objectives.

Rodgveller C, JH Moss, and AM Feldmann. 2007. *The Influence of Sampling Location, Timing, and Hatching Origin on the Prediction of Energy Density in Juvenile Pink Salmon*. NOAA Technical Memorandum NMFS-AFSC-170, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Alaska Fisheries Science Center, Juneau, Alaska.

Accurate estimation of energy density of fish is important for biogenetic models. Our objectives for this study were to determine which variables could be used to predict energy density instead of estimating energy density directly with bomb calorimetry. Secondly, we examined the variability in energy density relative to the sampling location within the Gulf of Alaska, the stock of origin, and the year the fish was sampled. Juvenile pink salmon *Oncorhynchus* gorbuscha were collected from the Gulf of Alaska during July 2001 and 2002. Energy density (J/g of wet weight) was estimated using bomb calorimetry. Hatchery stocks were identified from otolith thermal marks, and non-thermally marked fish were assumed to be wild. Energy density differed significantly by transect ($P < 0.000$), year ($P < 0.000$) hatchery stock ($P = 0.001$), and the interaction of origin and transect ($P = 0.018$). Body size was not related to energy density. However, % dry weight (dry weight/wet weight) was related to energy density (R2 = 0.93) and thus can be used in regressions to estimate energy density. We used energy densities predicted from a regression with % dry weight in bioenergetic modeling simulations. Error associated with energy density predictions affected bioenergetic models of body growth by up to 7-8% over a 30-day period. This error increased as the water content of fish increased and as the energy density decreased. Biological factors should be considered when predicting energy densities so that errors are minimized.

Roscoe DW and SG Hinch. 2010. "Effectiveness monitoring of fish passage facilities: Historical trends, geographic patterns and future directions." *Fish and Fisheries* 11(1):12-33.

Fishways and other passage facilities frequently prevent or delay the passage of fishes, highlighting the need for effectiveness monitoring. We reviewed the scientific literature from 1960 to 2008 reporting on effectiveness monitoring of fish passage facilities to assess what taxa and life-stages have been studied, the questions that are asked during evaluation, and how these varied over time or by geographic region. We identified 96 peer-reviewed articles of which 68% focused on passage by adult fishes. Salmoniformes was the most studied order (58% of studies). The focus of fishway evaluations did not change over the years, but varied significantly by geographic region. Studies from the tropics had a broader taxonomic scope than studies from temperate locations. Exogenous mechanisms of passage failure, such as environmental, structural and behavioural factors, were studied in 90% of studies from North America but only similar to 50% of studies from Europe, South America and Australia. Endogenous (i.e., physiological) mechanisms affecting passage success were not often assessed anywhere, though they were a powerful means of evaluating mechanisms of failure. Few studies monitored migration after fish had left a facility. To improve effectiveness monitoring of passage facilities, we suggest that both endogenous and exogenous mechanisms need to be studied in an integrated fashion to understand passage failure and to inform design or operational changes that could improve passage efficiency. In addition post-departure monitoring is required to more completely assess the fitness consequences of passage.

Rub AMW, RS Brown, BP Sandford, KA Deters, LG Gilbreath, MS Myers, ME Peterson, RA Harnish, EW Oldenburg, JA Carter, IW Welch, GA McMichael, JW Boyd, EE Hockersmith, and GM Matthews. 2009. *Comparative Performance of Acoustic-Tagged and Passive Integrated Transponder-Tagged Juvenile Salmonids in the Columbia and Snake Rivers, 2007*. Prepared by Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, and the Pacific Northwest National Laboratory, Richland, Washington, for Environmental Resources Branch, Planning and Engineering Division, Portland District, U.S. Army Corps of Engineers, Portland, Oregon. Contract no. W66QKZ60441152.

Evaluation of Acoustic Tags in Migrating Juvenile Salmon

Yearling Chinook Salmon—Migration rates, detection and survival probabilities, and avian predation rates were compared between fish tagged with acoustic versus passive integrated transponder (PIT) tags. During spring 2007, we collected migrating hatchery yearling Chinook salmon at Lower Granite Dam. We tagged 3,818 of these fish with both an acoustic and PIT tag (AT fish) and 46,714 with a PIT tag only (PIT-tagged fish). Samples were designed to be of sufficient size to determine a difference of 5% or more in survival from release to each detection location and to provide statistical power of 80% ($\alpha = 0.10$). Fish were released to the tailrace of Lower Granite Dam on 10 days from 24 April through 14 May.

Two slightly different acoustic tags were utilized: an earlier (2006) model, which weighed 0.64 g in air, and a later (2007) model, which weighed 0.60 g in air. Average tag burden experienced by AT fish was 3.5% of body weight. For both tag treatments, travel times, detection probabilities, and survival were estimated from individual PIT-tag detections at Little Goose, Lower Monumental, Ice Harbor, McNary, John Day, and Bonneville Dams. For AT fish, we also utilized acoustic tag detections from multiple acoustic arrays for these estimates.

Mean detection probabilities were estimated for each detection site. Mean detection probability was higher for AT than PIT-tagged fish at Little Goose Dam, and the difference was significant ($P = 0.004$). However, PIT-tagged fish were significantly more likely to be detected at McNary and Bonneville Dams ($P = 0.018$ and 0.010, respectively). There were no significant differences in detection probabilities between tag groups at Lower Monumental, Ice Harbor, and John Day Dams ($P = 0.59$, 0.134, and 0.721, respectively).

In the Snake River, relative survival (ratio of estimates for AT/PIT-tagged fish) from release to Little Goose and Ice Harbor Dam was not significantly different from one ($P = 0.893$ and 0.285, respectively). However, relative survival to Lower Monumental Dam was 1.05, indicating survival was significantly higher at the 0.080 level for AT fish. In the Columbia River, relative survival was 0.92 ($P = 0.054$) to McNary Dam, 0.82 ($P = 0.010$) to John Day Dam, and 0.79 ($P = 0.001$) to Bonneville Dam. Significant differences in travel times between the two groups were observed only at John Day Dam ($P = 0.041$).

Overall mean PIT-tag recovery from upper river bird colonies was 0.9% for AT fish and 1.0% for PIT-tagged fish. From estuarine colonies, overall mean PIT-tag recovery was 3.3% for AT fish and 2.7% for PIT-tagged fish. Recovery rates were not significantly different between tag treatments at either the upper river ($P = 0.500$) or estuarine bird colonies ($P = 0.243$).

Subyearling Chinook Salmon—In summer 2007, detection and survival probabilities, along with travel time and avian predation rates, were compared between AT and PIT-tagged subyearling Chinook salmon. For these evaluations, we tagged 9,833 river-run subyearling Chinook salmon with both an acoustic and a PIT tag (AT fish) and an additional 26,338 of these fish with a PIT tag only (PIT-tagged fish). Sample sizes were designed to obtain the same statistical accuracy as described above for yearling Chinook salmon.

For AT subyearlings, we separated evaluations for fish 95 mm FL or longer (AT fish) and smaller fish 85-94 mm (AT pilot fish). Mean tag burden was 5.6% (range 1.7-11.3) for AT fish and 9.6% (range 6.8-15.1%) for AT pilot fish. Fish were released to the tailrace of Lower Granite Dam on 27 days from 4 June to 13 July. Late model (2007) acoustic transmitters weighing 0.61 g in air were used exclusively for subyearling evaluations.

Mean probabilities of detection and survival for AT and PIT-tagged fish were estimated from release at Lower Granite to detection at Little Goose and McNary Dam. We were unable to calculate reliable estimates of detection or survival at any other downstream locations due to low detection numbers of both tag treatments. For AT pilot fish, detections were too few for meaningful analyses of detection probability or survival at any downstream location. Mean detection probability was greater for AT than PIT-tagged fish at Little Goose Dam, and the difference was significant ($P = 0.001$). There was no significant difference in mean detection probability between groups at McNary Dam ($P = 0.505$). Mean survival from Lower Granite to Little Goose Dam was significantly higher for PIT than AT fish ($P = 0.003$), as was survival to McNary Dam ($P = 0.001$). Fish belonging to the AT group took significantly more time than PIT-tagged fish to travel from Lower Granite to Little Goose ($P = 0.000$), Lower Monumental ($P = 0.009$), Ice Harbor ($P = 0.036$), and McNary Dams ($P = 0.002$).

Due to a combination of low survival to the estuary and low numbers of PIT-tag recoveries from subyearling Chinook released on or after 30 June, we were unable to make reliable comparisons of avian predation for these fish. For subyearlings released from 4 to 30 June, overall mean PIT-tag recovery from upriver bird colonies was 1.3% for AT fish and 1.7% for PIT-tagged fish. The difference between the two groups was not significant ($P = 0.254$). For fish released before 30 June, PIT-tag recovery from estuarine sites was 2.5% for AT fish and 2.0% for PIT-tagged fish, and the difference was not significant ($P = 0.389$).

GROSS NECROPSY AND HISTOLOGICAL EVALUATIONS OF MIGRATING JUVENILE SALMON

Yearling Chinook Salmon. To provide insight into the mechanism responsible for any tag effects observed, we subsampled study fish at two downstream sites for necropsy and histological evaluation. Up to 10 yearling Chinook salmon from each tag treatment and each temporal group were recaptured during migration using the Separation by Code (SbyC) systems at McNary and Bonneville Dam. A total of 75 AT and 89 PIT-tagged fish were recaptured at McNary Dam, while 64 AT and 79 PIT-tagged fish were recaptured at Bonneville Dam. We did not meet target collection numbers for either group. Recaptured fish were euthanized and examined for tag loss, disease, and histological change due to tag implantation. Kidney tissue samples were also collected and examined for the antigen to *Renibacterium salmoninarum* (Rs), the causative agent of bacterial kidney disease (BKD). A group of 30 non-tagged reference fish was used to provide baseline data for comparisons of gross necropsy, histological evaluation, and assessments of BKD antigen in AT and PIT-tag treatment fish. Reference fish were taken from hatchery yearling Chinook collected at Lower Granite Dam for evaluations of migration behavior and survival.

For both tag treatments, gross necropsy revealed less ceacal fat in fish collected at McNary and Bonneville Dam than in reference fish. Caecal fat was slightly higher in PIT-tagged fish than AT fish collected at McNary and was rated similarly between tag treatments for fish recaptured at Bonneville Dam. Mesenteric fat content was also rated lower in fish from both tag treatments and both dams than in reference fish. Mesenteric fat was higher in PIT than AT fish recaptured at both McNary and Bonneville Dam. Splenic engorgement/enlargement was more prevalent in treatment fish of both tag types than in reference fish. Enlarged spleens were observed in a higher percentage of fish collected at McNary than at Bonnville Dam. Splenic enlargement was observed at a similar rate for both tag treatments in fish from McNary Dam and at a higher rate for AT than PIT-tagged fish in fish from Bonneville Dam.

The percentage of fish observed with food in the stomach increased for both treatment groups from McNary to Bonneville Dam. In subsamples from both dams, PIT-tagged fish had a higher percentage of individuals with food in the stomach than AT fish. Kidney abnormalities were more prevalent in fish recaptured at the downstream dams than in reference fish, but were equally prevalent between the two tag treatments. Liver abnormalities were more prevalent in fish recaptured at both downstream dams than in fish from Lower Granite Dam, and more prevalent in AT than in reference or PIT-tagged fish. Among the gross necropsy comparisons, the only significant difference observed between tag treatments ($\alpha \leq 0.10$) was a greater proportion of liver discoloration in AT than PIT-tagged fish recaptured at Bonneville Dam ($P = 0.095$).

Comparative histopathology metrics varied by recapture site and were mixed with respect to nutritional indicators, with some being higher in AT and others in PIT-tagged fish. Nutritional indicators included liver vacuolation, pancreatic zymogen, pancreatic atrophy, mesenteric adipose, lower intestinal and pyloric caecae mucosal glycogen, and intestinal digesta presence. However, histological indicators of inflammation and healing showed a consistent pattern of higher inflammation and slower healing in AT than PIT-tagged fish. For example, chronic peritonitis was higher in AT than PIT-tagged fish at Bonneville ($P = 0.003$) and McNary Dam ($P = 0.042$). Poor apposition of the incision was also more common in AT than PIT-tagged fish at both dams ($P = 0.000$ for both). Reknitting of the stratum compactum was significantly more prevalent in PIT-tagged fish at McNary Dam ($P = 0.002$), and significantly more prevalent in PIT-tagged fish at Bonneville Dam at the 0.054 level. Incision adhesions were significantly higher in AT than PIT-tagged fish at McNary Dam ($P = 0.008$), as was splenic congestion, an indicator of stress ($P = 0.027$). Incision closure was more prevalent in PIT than AT fish at Bonneville Dam ($P = 0.011$), and incision chronic inflammation severity was rated higher in AT than PIT ($P = 0.001$) at this location.

For yearling Chinook, two significant notable trends were observed in the histology comparisons among size bins composed of both tag treatments combined. At McNary Dam, mesenteric adipose was greater in larger fish (14-16 >13 >11-12 cm; $P < 0.050$); at Bonneville Dam, poor incision apposition was observed more often in smaller fish (11-12 > 13, 14, 15-16 cm; $P = 0.006$).

Rs antigen levels were evaluated using enzyme-linked immunosorbent assay. For hatchery yearling Chinook, Rs antigen levels ranged from 0.070 to 0.131 in reference fish, 0.07 to 0.133 for fish of both tag treatments recaptured at McNary Dam, and 0.068 to 0.298 for fish of both tag treatments recaptured at Bonneville Dam (with two others at 0.463 and 1.613). Since Rs antigen levels were low for all but a few fish, no further analyses were conducted to evaluate differences among collection sites or tag treatments.

Subyearling Chinook Salmon. For subyearling Chinook salmon, up to 10 fish from each release and treatment combination were targeted for recapture using the SbyC system at Bonneville Dam. The SbyC system at McNary Dam was not operating during the study period, so no subyearling study fish could be recaptured. A total of 9 AT, 0 AT pilot, and 71 PIT-tagged fish were collected at Bonneville Dam throughout the summer sampling period. We did not meet our target collection goals for any of the three treatment groups. After recapture, fish were euthanized and examined for tag loss, disease, and histological changes due to tag implantation. A group of 79 non-tagged reference fish were necropsied in the same manner as tagged fish to provide baseline data for comparison. Reference fish were taken from collections of wild and hatchery subyearling Chinook at Lower Granite Dam.

Gross necropsy of reference fish collected at Lower Granite Dam and of treatment fish recaptured at Bonneville Dam revealed some trends among study groups. In general, less caecal fat was observed in fish belonging to both tag treatment groups collected at Bonneville Dam compared to reference fish, and PIT-tagged fish tended to have more caecal fat than AT fish. Similar trends were observed with respect to mesenteric fat content. Liver and kidney discoloration and or abnormalities were more prevalent in fish recaptured at Bonneville Dam than in reference fish, and more prevalent in AT than PIT-tagged fish. However, due to very small sample sizes (N = 9 for the AT group), no definite conclusions could be made based on statistical analysis of the gross necropsy data. None of the gross necropsy comparisons differed significantly.

Results from comparative histopathology analyses between tag treatments showed significant differences in 5 of 43 metrics evaluated in subyearling Chinook recaptured at Bonneville Dam ($\alpha = 0.05$). One additional metric was significant at $\alpha = 0.10$. The majority of the differences occurred in indicators related to inflammation at the site of the incision and healing. Mesenteric chronic inflammation severity was significantly higher in AT fish at the 0.075 level, and chronic inflammation at the incision was significantly more severe in AT fish ($P = 0.011$). For AT subyearling fish, chronic peritonitis and dermal hemorrhage/fibrin were also significantly higher ($P = 0.007$ and $P = 0.009$ respectively). Healing at the incision/injection site was significantly greater in the PIT-tagged fish ($P = 0.001$).

For recaptured fish from both tag treatments, a pattern was found across size bins for the presence/absence of liver lymphocytic infiltrates. These inflammatory cells were observed more often in smaller fish (9-10, 11 cm > 12-13 cm; $P = 0.090$), and mesenteric adipose was higher in larger fish (12-13 cm > 9-11 cm; $P = 0.033$). Myxosporea in the kidney tubules were observed more often in fish belonging to the 9-10 cm than 11, and 12-13 cm bins, and this difference was significant at the 0.092 level. Incision adhesions were observed more often in larger fish (12-13> 9-10, 11 cm; $P = 0.057$).

Rs antigen levels, as measured by ELISA, ranged from 0.070 to 0.213 in reference fish and from 0.078 to 0.442 in fish of both tag types recaptured at Bonneville Dam. Of 70 samples, Rs antigen levels exceeded 0.299 in only 2. Because values for all but a few fish were considered low, no further analyses were conducted.

EXTENDED HOLDING OF ACOUSTIC- AND PIT-TAGGED JUVENILE SALMON

Yearling Chinook Salmon. For extended holding and observation of yearling Chinook salmon, 40 reference fish and 40 fish from each tag treatment (AT and PIT) were subsampled on each of 10 release days during collection and tagging for migration behavior and survival releases (1,200 total). Reference fish were collected, held, and anesthetized as AT fish, but were not tagged. After tagging, reference and treatment fish were transported directly from Lower Granite Dam to the Bonneville Dam Second Powerhouse Juvenile Monitoring Facility. These fish were held in laboratory tanks for a total of 90 d to observe tag loss, tissue response to tagging, and long-term survival. Fish were tested for the antigen to *Renibacterium salmoninarum* (Rs) using an ELISA. We also collected CWTs from hatchery marked fish in each sample group to examine survival trends within individual hatchery release groups.

For fish held for long-term observation, mean survival among the three groups was significantly different after 14 d: survival of AT fish (0.85) was significantly lower than that of PIT-tagged (0.92) and reference fish (0.93; Fisher's LSD; P = 0.027). This difference persisted and continued to be significant (P = 0.012) at 28 d. By 90 d holding, although the trend among treatment groups persisted, differences among group means were no longer significant. Among fish that survived 90 d, mean growth was 3.6 mm greater for PIT-tagged than AT fish (P = 0.068).

No yearling Chinook that survived to the end of the 90-d holding period expelled or dropped an acoustic tag. The AT fish that survived to termination dropped PIT tags at a rate of 2.0% (n = 5 tags, 1 tag lost for releases 1, 3, 4, 6, and 7) while PIT-tagged fish that survived to termination dropped PIT tags at a rate of 0.3% (n = 1, release 1). The difference in PIT-tag loss between treatment groups was significant at the 0.064 level. Both acoustic and PIT-tag losses were determined post-mortem at the time of necropsy. Due to the small number of tags recovered from holding tanks, it was not possible to determine the timing of tag loss.

In fish that died before termination of the study, there were no significant differences in Rs antigen levels among treatment groups (P = 0.774). There were also no significant differences in Rs levels among treatment groups in fish that survived through termination of the study (P = 0.993).

Evidence from CWTs collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to bias the results.

<u>Subyearling Chinook Salmon</u>. For long-term holding evaluations, 40 fish from each of four study groups (reference, AT, AT pilot, and PIT-tag) were subsampled from 9 of the 27 release groups of subyearling Chinook salmon collected at Lower Granite Dam. Reference fish were collected, anesthetized, and held as AT fish, but were not tagged. After tagging, all fish were transported directly to the juvenile monitoring facility at Bonneville Dam. These fish were taken throughout the summer study and held at Bonneville in laboratory tanks for 90 d to observe tag loss, tissue response to tagging, long-term survival, and prevalence of Rs antigen. We also collected CWTs from hatchery fish to evaluate the potential influence of hatchery fish on survival, as described above for yearling Chinook salmon.

In the laboratory, mean survival among treatment groups at 14 d holding was significantly different, with survival significantly lower for AT fish (0.53) than for PIT-tagged (0.94) or reference fish (0.88; Fisher's LSD, P = 0.010). A comparison of mean survival among groups also revealed a significant difference at 14 d (P = 0.000), with the AT pilot group showing considerably lower survival (0.18) than the other three groups. These differences persisted and continued to be significant through the holding period. Among fish that survived to 90 d, mean growth was 4.5 mm higher for PIT-tagged than for AT fish (P = 0.061) and the mean difference in weight gain was 3.4 g (P = 0.246).

For subyearlings that survived to the end of the 90-d holding period, 7.6% of AT fish passively dropped or expelled acoustic tags, while none of the AT pilot fish surviving to termination dropped or expelled tags. Fish losing AT tags were from release groups 11 (4 tags), 12 (1 tag), 16 (1 tag), 17 (1 tag), and 18 (2 tags). The AT fish lost PIT tags at a rate of 3.4% (one tag each for releases 11, 15, 16, and 17), while no PIT tags were lost from the AT pilot or PIT-tagged fish groups. The difference in PIT-tag loss between AT and PIT-tagged fish was significant (P = 0.002). Neither acoustic- nor PIT-tag loss was compared using fish from the AT pilot group due to small numbers of survivors in that group. Similar to the yearling group, tag loss was determined post-mortem at the time of necropsy. Due to the small number of tags recovered from the holding tanks, it was not possible to determine the timing of tag loss.

Rs antigen values as measured by an ELISA for subyearling laboratory fish that died before termination of the study ranged from 0.055 to 2.264. There were no significant differences in Rs antigen levels among study groups (P = 0.584). Rs antigen levels for fish that survived until experiment termination at 90 d ranged from 0.040 to 0.240. Because nearly all fish held to termination had low levels of Rs antigen, significance testing to evaluate differences among groups was not conducted.

Evidence from coded-wire tags collected from laboratory fish indicated that no single hatchery group contributed fish to our study that were obviously compromised in numbers sufficient to cause bias of any study results.

Ruckelshaus MH, P Levin, JB Johnson, and PM Kareiva. 2002. "The Pacific Salmon Wars: What Science Brings to the Challenge of Recovering Species." *Annual Review of Ecology and Systematics* 33:665-706.

Politicians, scientists, government agencies, and the public are all engaged in recovery planning for Pacific salmon. In order for science to fulfill its potential in the arena of salmon recovery planning, several shortcomings of the science and its application to decision-making must be rectified. The definition of conservation units using genetic and phylogenetic inference needs to be sharpened. Ecological analyses must get beyond casting blame for past declines in salmon numbers and examine mixed strategies of management that consider interactions between hatcheries, harvest, hydropower, and habitat factors as well as background natural stresses and invasive species. Glib acceptance of expert opinion and extrapolated or inferred data should be tempered. To deal with uncertainty, recovery teams should engage in scenario analyses in which a wide variety of assumptions are played out. Finally, there is a pressing need for analyses aimed at determining what circumstances and communication strategies give science an effective voice in decision-making.

Ryan BA, M Carper, DM Marsh, D Elliott, T Murray, L Applegate, C McKibben, and S MosterdS. 2007. *Alternative Barging Strategies to Improve Survival of Transported Juvenile Salmonids, 2006*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle Washington, and the U.S. Geological Survey, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla Washington. Contract no. W68SBV60307671 and W68SBV60418618.

During spring 2006, we conducted a study to test the hypothesis that releasing transported juvenile Pacific salmonids *Oncorhynchus*. spp to the lower Columbia River estuary at river kilometer (rkm) 10 would produced higher smolt-to-adult return rates (SARs) than releasing them just below Bonneville Dam at rkm 225. We speculated that releasing transported fish an additional 215 km downstream from the location presently used could decrease smolt mortality due to predation by piscivorous fish and birds. Adults returning over the next several years will provide data to test this hypothesis.

In addition to evaluating a release location for transported fish, we used new, non-lethal techniques to collect fish pathogen data. We determined pathogen loads in study fish to evaluate whether pathogens in individual fish affect vulnerability to avian predators as well as SARs.

On six consecutive Sundays, starting in April 2006 and running through May, run-of-the-river yearling Chinook salmon (*O. tshawytscha*) and steelhead (*O. mykiss*) were collected and tagged with passive integrated transponder (PIT) tags at the Lower Granite Dam juvenile fish facility. Following tagging, fish were transferred to raceways and held until the following day, when they were loaded on barges for transport. A total of 13,729 hatchery and 2,435 wild yearling Chinook salmon were tagged and released downstream from Astoria at rkm 10, while 20,488 hatchery and 3,707 wild yearling Chinook salmon were tagged and released at Skamania Landing (rkm 225). In total, we released 25,726 hatchery and 3,4045 wild steelhead at rkm 10 and 36,210 hatchery and 5,612 wild steelhead at rkm 225.

During each tagging day, 300 non-lethal gill clip samples were collected for pathogen analyses (*Renibacterium salmoninarum* and *Nucleospora salmonis*), for a total of 1,800 samples over the season. All Astoria releases were made after dark on an outgoing tide to reduce avian predation by Caspian terns Hydroprogne caspia and double-crested cormorants Phalacrocorax auritas from the nearby nesting colonies on East Sand Island.

Abandoned bird colonies were scanned to detect PIT tags from fish released from this and other studies, and these data were used to estimate the number of fish from each release group preyed upon by piscivorous birds. These data also allowed us to determine whether infection with R. salmoninarum, N. salmonis, or both pathogens was correlated with predation vulnerability. There was no evidence from the 2006 study that infection of fish with one or both pathogens influenced rates of predation, but *R. salmoninarum* infection levels in the majority of tested fish were low. Current methodologies for assaying *N. salmonis* can only provide numbers of fish infected, not infection levels.

Both of these pathogens are associated with chronic, slowly progressing infections that may not always cause outright mortality, but may make fish vulnerable to secondary infections. Therefore, the pathogens may have more effect on smolt-to-adult returns (SARs) than on short-term mortality, including mortality by avian predation. Overall, *R. salmoninarum* was detected by one or both PCR assays in 77% of wild Chinook salmon, 72% of hatchery Chinook salmon, 73% of wild steelhead, and 70% of hatchery steelhead sampled. N. salmonis was detected by polymerase chain reaction (PCR) in 4% of wild Chinook salmon, 1% of hatchery Chinook salmon, 6% of wild steelhead, and 23% of hatchery steelhead tested.

We will need to wait several years for adult returns to determine the efficacy of releasing transported salmonids at rkm 10 instead of the traditional release site at rkm 225. However, we do know that the new release location affected vulnerability to avian predators; mean avian predation rates were 3.0% for yearling Chinook salmon released from Skamania Landing at rkm 225, but only 0.4% for those released near Astoria at rkm 10. Avian predation rates were 13.8% for steelhead released at Skamania Landing, but only 1.7% for their cohort released at Astoria. These are minimum estimates of the impact of avian predation, as not all tags consumed by birds are deposited or found on colonies. Our results show that releasing fish farther downstream, at night, and on an outgoing tide will reduce avian predation by up to seven-fold on average. This finding is relevant for management actions related to recovery of juvenile salmonids that pass the world's largest Caspian tern and double-crested cormorant colonies during their downstream migration.

Ryan BA, SG Smith, JM Butzerin, and JW Ferguson. 2003. "Relative Vulnerability to Avian Predation of Juvenile Salmonids Tagged with Passive Integrated Transponders in the Columbia River Estuary, 1998-2000." *Transactions of the American Fisheries Society* 132(2):275-288.

Caspian terns Sterna caspia and double-crested cormorants Phalacrocorax auritus that colonize dredge-spoil islands in the Columbia River estuary prey upon millions of juvenile Pacific salmonids annually. We estimated the relative vulnerability of various salmonid stocks to these predators by using data from passive integrated transponder (PIT) tags detected on these colonies; 96,382 tags were detected from the 1998-2000 migration years. On tern colonies, detection rates were highest for tags from steelhead (*Oncorhynchus mykiss*) and lowest for tags from yearling Chinook salmon (*O. tshawytscha*). However, detection rates on cormorant colonies were similar for tags from steelhead and coho salmon (*O. kisutch*) but lower for tags from yearling Chinook salmon. Analyses based on migration history showed tags of transported fish were frequently detected in lower proportions than those of their counterparts that migrated in-river, the pattern being most pronounced in steelhead. Analyses based on origin (hatchery versus wild) showed similar detection proportions for the tags of wild versus hatchery steelhead on both tern and cormorant colonies. In contrast, 3.1% of hatchery versus 1.1% of wild Chinook salmon tags previously detected at Bonneville Dam were detected on a colony, the greater vulnerability of hatchery fish being more pronounced on tern colonies. These tags accounted for 11.5% of steelhead, 4.6% of coho salmon, and 2.6% of yearling Chinook salmon detected at Bonneville Dam, the last downstream impoundment encountered by seaward migrants. These estimates of predation are minimal because detection efficiency was not 100% and tags from many salmonid prey were not deposited on a nesting colony.

Sanderson BL, KA Barnas KA, and AMW Rub. 2009. "Nonindigenous Species of the Pacific Northwest: An Overlooked Risk to Endangered Salmon?" *Bioscience* 59(3): 245-256.

Nonindigenous species, which are associated with the decline of many threatened and endangered species, are a major threat to global diversity. This risk extends to salmonids, the most widespread threatened and endangered species in the Pacific Northwest. Pacific salmonids traverse large geographic areas that include freshwater, estuarine, and ocean habitats in which they encounter numerous nonnative species. For this article, we examined the extent to which introduced species are a risk to threatened and endangered salmon. We identified all documented nonindigenous species in the Pacific Northwest, including fish, invertebrates, birds, plants, and amphibians. Where data exist, we quantified the impact of nonindigenous species on threatened and endangered salmonids. The results indicate that the effect of nonindigenous species on salmon could equal or exceed that of four commonly addressed causes of adverse impacts - habitat alteration, harvest, hatcheries, and the hydrosystem; we suggest that managing nonindigenous species may be imperative for salmon recovery.

Sandford, BP, Zabel, RW, Gilbreath, LG, and Smith, SG. 2012. Exploring Latent Mortality of Juvenile Salmonids Related to Migration through the Columbia River Hydropower System.

The ability to manage anthropogenic actions that affect the dynamics of animal populations requires the identification and understanding of life-stage-specific mortality. This understanding can be confounded when the expression of mortality is removed, in time or space, from its cause. For years, researchers studying endangered Snake River spring–summer Chinook salmon Oncorhynchus tshawytscha have debated the magnitude of mortality that is related to—but expressed after—passage through the Snake and Columbia River hydropower system ("latent" mortality). We conducted

experiments with Chinook salmon to assess the magnitude of latent mortality from two sources: passage through juvenile bypass structures at dams, and transportation with larger juvenile steelhead O. mykiss present in the barge holds. Nearly 129,000 juvenile Chinook salmon (passive integrated transponder tagged) were exposed to different treatment conditions during downstream migration. Study fish were then held in seawater tanks for up to 223 d, and time to mortality was noted for each individual that died. We analyzed survival patterns by using statistical procedures for time-to-event data (i.e., survival analysis). Differential survival between treatment groups was taken to indicate latent mortality caused by the specific treatment. We used a nonparametric Kaplan–Meier analysis to visualize survival patterns and a parametric logistic regression analysis to model the effects of multiple factors. Chinook salmon that were transported with steelhead had significantly lower survival than those that were transported alone. However, there was little evidence for differential latent mortality between Chinook salmon that were not detected at the bypass systems of five dams along the migration route and those that were detected at two to five bypass systems. Our application of survival analyses to individuals subjected to various treatments and held for extended periods produced an effective combination that can be used to test for latent mortality; these results may serve as an initial assessment for further conservation investigations and as a guide to more-targeted research.

Schaller HA and CE Petrosky. 2007. "Assessing Hydrosystem Influence on Delayed Mortality of Snake River Stream-Type Chinook Salmon." *North American Journal of Fisheries Management* 27(3):810-824.

Snake River stream-type Chinook salmon (*Oncorhynchus tshawytscha*) exhibited substantial delayed mortality despite recent improvements in oceanic and climatic conditions. These salmon declined sharply with the completion of the Columbia River hydrosystem in addition to other anthropogenic impacts and changes in oceanic conditions. Previous analytical approaches have compared management options for halting the population decline. The predicted benefits of these options on salmon recovery hinged on whether the source of the mortality that takes place in the estuary and during early ocean residence is related to earlier hydrosystem experience during downstream migration (i.e., delayed hydrosystem mortality). We analyzed the spatial and temporal patterns of mortality for Chinook salmon populations to determine whether delayed mortality for the Snake River populations decreased during the recent period of favorable oceanic and climatic conditions. We found that Snake River stream-type Chinook salmon populations continued to exhibit survival patterns similar to those of their downriver counterparts but survived only one-fourth to one-third as well. The hypothesis that delayed mortality decreased and became negligible with more favorable oceanic conditions appears inconsistent with the patterns we observed for the common year effect and our estimates of delayed mortality of in-river migrants. A plausible explanation for this persistent pattern of delayed mortality for Snake River populations is that it is related to the construction and operation of the hydrosystem.

Schaller H, P Wilson, S Haeseker, C Petrosky, E Tinnus, T Dalton, R Woodin, E Weber, N Bouwes, T Berggren, J McCann, S Fassk, H Franzoni, P McHugh, and M Dehart. 2007a. *Comparative survival study (CSS) of PIT-Tagged Spring/Summer Chinook and Steelhead in the Columbia River Basin – Ten-year Retrospective Analyses Report.* Prepared by the U.S. Fish and Wildlife Service, the Idaho Department of Fish and Game, the Oregon Department of Fish and Wildlife, the Washington Department of Fish and Wildlife, the Columbia River Inter-Tribal Fish Commission, EcoLogic, and the Fish Passage Center, for the Bonneville Power Administration, Portland, Oregon. Project no. 1996-020-00, BPA Contract no. 25634, 25264, 20620; and Project no. 1994-033-00, BPA Contract no. 25247.

The Comparative Survival Study (CSS) Oversight Committee prepared this report to address the recommendation provided by the Independent Scientific Advisory Board (ISAB) to prepare a retrospective synthesis of the methods and results to date on spring/summer Chinook and steelhead in the Columbia Basin. This ten-year summary report describes study methods, results and conclusions based on ten years of monitoring efforts. The Passive Integrated Transponder (PIT) data used in the CSS are analyzed retrospectively, incorporating all juvenile and adult recovery data available for the period 1996 through 2006.

The Ten-Year Retrospective Summary Report analyzes the available PIT-tag data within and across-years, assessing the effects of migration routes, environmental conditions and migration timing on juvenile reach survival rates and Smolt-to-Adult Return rates (SAR). These analyses provide for improved understanding of survival rates and the effects of various environmental conditions and management actions on those rates.

Synopsis of Key Findings:

- Juvenile travel times, instantaneous mortality rates and survival rates through the hydrosystem are strongly influenced by managed river conditions including flow, water travel time and spill levels.
- Statistical relationships were developed that can be used to predict the effects of environmental factors and management strategies on migration and survival rates of juvenile yearling Chinook and steelhead.
- The CSS results indicate that the SAR of transported fish relative to in-river migrants (TIR) varied across species and between wild and hatchery origins. Wild spring/summer Chinook on average showed no benefit from transportation, except in the severe drought year (2001). Hatchery spring/summer Chinook responded to transportation with higher TIR averages across hatcheries than wild Chinook. Wild and hatchery steelhead responded to transportation with the highest TIR. Substantial differential delayed transport mortality ($D < 1.0$) was evident for both species and across wild and hatchery groups for each species.
- Overall SARs for wild spring/summer Chinook and wild steelhead fell short of the Northwest Power and Conservation Council (NPCC) SAR objectives (2% minimum, 4% average for recovery).
- SAR values for these Snake River Basin groups were only one quarter those of similar downriver populations that migrated through a shorter segment of the Federal Columbia River Power System (FCRPS).
- The above lines of evidence for Snake River reach survivals, SARs by passage route, overall SARs, and downriver SARs relative to the NPCC objectives, indicate that collecting and transporting juvenile spring/summer Chinook and steelhead at Snake River Dams did not compensate for the effects of the FCRPS.
- The overall SARs are also insufficient to meet broad sense recovery goals that include providing harvestable surplus for wild Snake River Basin spring/summer Chinook and steelhead.
- Adult upstream migration survival is affected by the juvenile migration experience.Adults that were transported from Lower Granite Dam as smolts exhibited a 10% lower adult upstream survival rate than either in-river migrants or those transported from Little Goose or Lower Monumental Dams.

- Simulations results indicate that Cormack-Jolly-Seber parameter estimates are robust in the presence of temporal changes in survival or detection probabilities.
- Given the different responses of wild Chinook and wild steelhead to transportation, it would seem that maximization of survival of both species cannot be accomplished by transportation as currently implemented.
- Our analyses on in-river survival rates indicate that improvements in in-river survival can be achieved through management actions that reduce the water travel time or increase the average percent spilled for Snake River yearling Chinook and steelhead in the Lower Granite to McNary reach. The effectiveness of these actions varies over the migration season.
- Higher SARs of Snake River wild yearling Chinook were associated with faster water travel times during juvenile migration through the FCRPS, cool broad-scale ocean conditions, and near-shore downwelling during the fall of the first year of ocean residence.

Scheuerell MD and JG Williams. 2005. "Forecasting climate-induced changes in the survival of Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*)." *Fisheries Oceanography* 14(6):448-457.

Effective conservation and management of natural resources requires accurate predictions of ecosystem responses to future climate change, but environmental science has largely failed to produce these reliable forecasts. The future response of Pacific salmon (*Oncorhynchus* spp.) to a changing environment and continued anthropogenic disturbance is of particular interest to the public because of their high economic, social, and cultural value. While numerous retrospective analyses show a strong correlation between past changes in the ocean environment and salmon production within the north Pacific, these correlations rarely make good predictions. Using a Bayesian time-series model to make successive 1-yr-ahead forecasts, we predicted changes in the ocean survival of Snake River spring/summer Chinook salmon (*O. tshawytscha*) from indices of coastal ocean upwelling with a high degree of certainty (R-2 = 0.71). Furthermore, another form of the dynamic times-series model that used all of the available data indicated an even stronger coupling between smolt-to-adult survival and ocean upwelling in the spring and fall (R-2 = 0.96). This suggests that management policies directed at conserving this threatened stock of salmon need to explicitly address the important role of the ocean in driving future salmon survival.

Scheuerell MD, RW Zabel, and BP Sandford. 2009. "Relating juvenile migration timing and survival to adulthood in two species of threatened Pacific salmon (*Oncorhynchus* spp.)." *Journal of Applied Ecology* 46(5):983-990.

1. Migration timing in animals has important effects on life-history transitions. Human activities can alter migration timing of animals, and understanding the effects of such disruptions remains an important goal for applied ecology. Anadromous Pacific salmon (*Oncorhynchus* spp.) inhabit fresh water as juveniles before migrating to the ocean where they gain >90% of their biomass before returning to fresh water as adults to reproduce. Although construction of dams has delayed juvenile migration for many populations, we currently lack a synthesis of patterns in migration timing and how they relate to subsequent survival to adulthood for Pacific salmon, especially for at-risk populations.

2. We studied two groups of Pacific salmon from the Columbia River basin in the northwestern United States currently listed under the U. S. Endangered Species Act. We examined how the proportion of juveniles surviving to return as adults varied with year of migration, date of arrival in the estuary, water temperature and coastal ocean upwelling using data from over 40 000 individually tagged Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*).
3. In general, models with year, day and day(2) had much better support from the data than those with temperature and upwelling. For Chinook salmon, we also found a residual effect of temperature after controlling for day, but the effect was small for steelhead.
4. For both species, juveniles migrating from early to mid-May survived 4-50 times greater than those migrating in mid-June. As expected, however, the estimated peak in survival varied among years, presumably reflecting interannual variation in the nearshore physical environment and trophic dynamics that affect salmon during the critical juvenile life stage.
5. Synthesis and applications. Our results indicate a possible management objective would be to speed arrival to the estuary by increasing springtime river flows. These findings also provide some insight into the mechanisms underlying seasonal differences in survival patterns, but additional studies are needed to better resolve the issue. Future changes to river flow and water temperature associated with climate change and human activities may further alter migration timing, and thus this phenomenon deserves further attention.

Schreck CB, MD Karnowski, BJ Clemens. 2005. *Evaluation of Post Release Losses and Barging Strategies that Minimize Post Release Mortality.* Prepared by Oregon Cooperative Fish and Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Contract no. DACW68-00-C-0028.

Spring/summer Chinook

- Juvenile run-of-river (ROR) spring/summer Chinook migrated to rkm 89 (Stella, WA) more rapidly than their barged (BRG) counterparts from below Bonneville Dam (BON) through the lower Columbia River during 1996-1998. In contrast to BRG fish, most of the variation in migration rate in ROR fish could be explained by flow (KCMS). Differences in migration rates did not translate into differences in estimated survival.
- In 2004, radio-tagged juvenile spring/summer Chinook migrated from the barge release site to the estuary (rkm 46) in 1 – 6 days, compared with 2 – 31 days for acoustic-tagged fish. This variability in migration times could suggest a tagging effect from one of the tags, or it may suggest that one receiver system was more effective at detecting slower fish, or that environmental conditions associated with different release dates randomly affected migration time. Large variations in migration times within a given tag type means that spring/summer Chinook released below Bonneville Dam do not reach the estuary as a distinct group, but rather are distributed over several days.
- CORIE modeling suggests a relationship between water velocity and smolt behavior. The strongest relationship appears to exist during high water velocities (≥ 1 m/s), in which fish and simulated water particle locations correspond, and the fish behavior can be classified as passive. During low water velocities associated with slack tide, the correlation between fish and water were weak and fish behavior was classified as active.

- There were no differences in survival estimates from BON to the upper estuary (rkm 89) between ROR and BRG spring/summer Chinook during 1996-1998. In 2004, there were significant differences in survival estimates between BON and Jim Crow (rkm 46), with radio-tagged fish surviving in greater proportions than acoustic-tagged fish.
- During 1996-1998, 0-40% of all tagged spring/summer Chinook were taken by avian predators compared with 7% in 2004. There were no significant differences in the percentage mortality between BRG and ROR fish for any of these earlier years that were individually examined (1996-1998). There was a significant increase in mortality of BRG spring/summer Chinook during the middle release period in comparison with early and late release periods during 2004.
- Fish condition is a probable variable that affects smolt vulnerability to avian predation. Fish targeted as prey had low Na+/K+ ATPase levels and high incidence of BKD infection. These factors should be examined in more detail to verify their role in susceptibility to predation.

Fall Chinook

- ROR and BRG fall Chinook had similar migration rates from BON to rkm 89 (Stella, WA). Large variability in migration rates indicates that fall Chinook do not reach the estuary as a distinct group. However, migration rates within paired releases had no obvious effect on survival estimates to the upper estuary.
- ROR fish survived in higher proportions than their BRG counterparts during all three releases in 2002 and during four of six releases in 2003.
- Overall percentages of fall Chinook detected on piscivorous bird colonies ranged between 0% and 9%. During the low flow year of 2001, mortality estimates of radiotagged BRG fall Chinook increased steadily throughout the season, whereas ROR fish remained steady at 0%. There were no difference in mortality between BRG or ROR fall Chinook during the higher flow years of 2002 and 2003. It is unknown whether fish condition influenced susceptibility to avian predation.
- Laboratory experiments during 2000-2002 indicated that there were no differences between BRG and ROR fish with respect to numbers infected with BKD, proportion feeding and successfully osmoregulating in saltwater or saltwater preference. In 2001, ROR fish had higher levels of ATPase, suggesting they were more smolted than BRG fish. However, conclusions based on ATPase levels should be considered tenuous. A portion of the BRG fish in one group of the feed intake experiment died, and postmortem examination revealed that these fish were infested with a flavobacteria of marine origin. If other BRG fish had sublethal infection levels, then it is possible that the pathogen could contribute to delayed mortality once the fish entered saltwater. It is not known why BRG fish were more susceptible to this pathogen than ROR fish.
- Fall Chinook migrating to Lower Granite Dam (LGR) in July-August, during which water temperatures can exceed 70o F, are often of poor quality. This poor quality could be reflected in estuary migration success and subsequent marine survival.

Steelhead

- ROR and BRG steelhead had similar migration speeds between BON and rkm 89 (Stella, WA). Large variations in migration times to the estuary suggest that steelhead do not reach the estuary as a distinct group, but rather are distributed over several days. However, migration rates between BRG and ROR fish released on the same day had no obvious effect on survival estimates to the upper estuary.

- There was no difference in survival between radio-tagged hatchery and wild steelhead to Stella, WA (rkm 89) during 2002-2003. ROR steelhead survived in higher proportions than their BRG counterparts from the release site to Stella during all three release periods in 2002. River flow had a significant, positive effect on survival in this particular year. In contrast to 2002, a higher proportion of BRG steelhead survived in four of six releases (middle to late release periods) in the same stretch of river in 2003.
- There was no difference in survival between radio-tagged hatchery and wild steelhead to Jim Crow point (rkm 46). During 2002, survival estimates for radio-tagged BRG and ROR steelhead between the release site and Jim Crow point varied throughout the season, but there were no differences between BRG and ROR fish on any given release. In 2003, although ROR fish appeared to survive in lower proportions than barged fish during the middle and late portions of the run, these trends were not significant. Release day, however, did have a significant effect on survival during 2002 and 2003.
- During 2001, 6% of BRG steelhead and 1% of ROR steelhead were detected on piscivorous bird colonies. Daily river outflows from Bonneville during the study period for this year averaged 4.07 (0.13) KCMS. During 2002, 11% of BRG fish and 17% of ROR fish were detected on piscivorous bird colonies. Daily river outflows from Bonneville during the study period for 2002 averaged 7.05 (0.22) KCMS. During 2003, 30% of BRG fish and 22% of ROR fish were detected on piscivorous bird colonies. Daily river outflows from Bonneville during the study period for 2003 averaged 7.83 (0.20) KCMS.
- There was no difference in the proportions of hatchery or wild steelhead taken by birds during 2001-2003. There were no differences between the proportions of BRG or ROR steelhead taken by avian predators during 2001-2003.
- Acoustic tag data revealed that steelhead using the WA channel rather than other channels had the lowest survival in the area between the Astoria Bridge and the ocean. Low survival of fish using the WA channel may be related to the close proximity of this migration route to the piscivorous bird colonies on East Sand Island.
- During the early outmigration, BRG steelhead have been shown to have low ATPase levels in relation to ROR fish, suggesting BRG fish may not be physiologically ready to move into full-strength saltwater. However, conclusions based on ATPase levels should be considered tenuous. Lab experiments comparing ROR and BRG fish indicated no differences in the proportion of fish infected with BKD, selecting saltwater, actively consuming food, or successfully osmoregulating.

Recommendations

- Data on migration patterns, numbers taken by piscivorous birds, and physiological data suggest that spring/summer Chinook and steelhead may be the best candidates for alternative barge release strategies. These strategies could be the most beneficial during the mid-late portion of the outmigration.
- We recommend testing alternative transportation release strategies consisting of releasing fish lower in the estuary and coupling release location with tidal stage and time of day.

- We recommend evaluation of a strategy consisting of the potential beneficial effects of not transporting early run fish.
- Given that there are differences in fish quality across the runs of spring/summer Chinook, fall Chinook, and steelhead, we recommend development of a monitoring protocol at Snake River Dams that would allow judging of fitness for migration and marine survival under various environmental scenarios (e.g., elevated temperature towards the latter part of the run). This information could be used to make decisions about the proportion of fish that could be transported.

Schreck CB, TP Stahl, LE Davis, DD Roby, and BJ Clemens. 2006. "Mortality Estimates of Juvenile Spring-Summer Chinook Salmon in the Lower Columbia River and Estuary, 1992-1998: Evidence for Delayed Mortality?" *Transactions of the American Fisheries Society* 135(2):457-475.

Recovery of Endangered Species Act-listed salmonids in the Columbia River basin has relied upon the efficacy of the U.S. Army Corps of Engineer's juvenile salmon transportation program to move fish past Snake and Columbia River hydropower dams. The effectiveness of this program has been assessed by the indirect method of comparing smolt-to-adult returns. We present some of the first data and mortality estimates of barged and run-of-river (ROR) radio-tagged juvenile spring-summer Chinook salmon (*Oncorhynchus tshawytscha*) after release in the lower Columbia River, representing years of study. Our data suggest that smolt mortality (1) is very low for ROR and barged fish between Bonneville Dam and the estuary proper, a migratory distance of 180 river kilometers (rkm): (2) Occurs in the lower estuary (rkm 0-46); (3) varies more across dates within a year than between years or between passage types (barged or ROR); (4) increases with time within a season and increasing numbers of avian predators, including Caspian tems Sterna caspia and double-crested cormorants Phalacrocorax auritus; and (5) is estimated to be 11-17% of all smolts annually. Preliminary evidence suggests that at least some smolt mortality is influenced by differential predation by avian predators on Chinook salmon infected with *Renibacterium salmoninarum* and possessing low smoltification levels (relatively low gill Ni+,K+-ATPase activity). Fish type (barged or ROR) did not appear to influence mortality because of avian predation. This project was also the first to identify avian predators as a major source of mortality for out-migrant Columbia River basin salmonids.

Price C and CB Schreck. 2003. "Stress and saltwater-entry behavior of juvenile chinook salmon (*Oncorhynchus tshawytscha*): conflicts in physiological motivation." *Canadian Journal of Fisheries and Aquatic Sciences* 60(8):910-918.

Two experiments were conducted to determine the effects of a mild or severe stressor on the saltwater preference of juvenile spring Chinook salmon (*Oncorhynchus tshawytscha*). To observe the response of fish to an overhead threat, we presented stressed fish with an avian predator model in the second experiment. Experiments were conducted in 757-L tanks containing a stable vertical salinity gradient. Only 69% of fish stressed by being chased for 2 min before saltwater introduction (mild stressor) held in salt water, whereas 95% of unchased control fish preferred the saltwater layer. After the more severe handling and confinement stressor, only 20% of fish entered and remained in salt water compared with 100% of unstressed controls. After the presentation of the avian model, stressed fish holding in fresh water moved into the saltwater layer, but this behavioral response was transient. Fish began returning to fresh water within 10 min, and after 1 h, only 26% of stressed fish remained in the saltwater layer. Stress significantly decreases the saltwater preference of Chinook salmon that would otherwise select full-

strength salt water and may affect behavior in the estuary. Although smoltification primes these fish for seawater residence, stress apparently induced a conflicting physiological motivation.

Smith SG, WD Muir, EE Hockersmith, RW Zabel, RJ Graves, CV Ross, WP Connor, and BD Arnsberg. 2003. "Influence of River Conditions on Survival and Travel Time of Snake River Subyearling Fall Chinook Salmon." *North American Journal of Fisheries Management* 23(3):939-961..

From 1995 to 2000, subyearling fall Chinook salmon (*Oncorhynchus tshawytsch*) reared at Lyons Ferry Hatchery were PIT-tagged at the hatchery, trucked upstream, acclimated, and released into free-flowing sections of the Snake River weekly from early June to mid-July. We estimated survival probabilities and travel time through the lower Snake River and detection probabilities at dams for each weekly release group. The average median time between release and arrival at Lower Granite Dam was 43.5 d. For each group, we split this time into two nearly equal (on average) periods: one when most fish in the group were rearing and one when most fish had apparently begun active seaward migration. The estimated survival for hatchery fish from release to the tailrace of Lower Granite Dam decreased with release date each year. The estimated survival through this reach was significantly correlated with three environmental variables: survival decreased as discharge ("flow") decreased, as water transparency increased, and as water temperature increased. Because the environmental variables were highly correlated among themselves, we were unable to determine whether any factors were more important than the others. All three factors have plausible biological consequences for rearing and actively migrating fish, and survival is probably influenced by all of them and possibly by interactions among them as well. Summer flow augmentation will increase discharge and decrease water temperature (provided the additional water is not too warm) and probably increase the speed of seaward migration of smolts, all of which are beneficial to the recovery of threatened Snake River fall Chinook salmon.

Sogard SM and BL Olla. 2000. "Endurance of simulated winter conditions by age-0 walleye pollock: Effects of body size, water temperature and energy stores." *Journal of Fish Biology* 56(1):1-21.

Survival of age-0 walleye pollock Theragra chalcogramma in the absence of food followed simple bioenergetic models, with large body size, high initial condition, and cold temperatures all increasing survival rates. High survival after >200 days at cold temperatures (<3·0° C) indicated extended tolerance of extreme cold, as long as sufficient body size and condition are attained during the summer growth period. Analysis of body constituents demonstrated a substantial increase in tissue water and depletion of lipid during starvation. Survivors had significantly higher lipid stores than mortalities, and larger fish had higher levels of lipid than smaller fish among experimental survivors, laboratory fish that were never starved, and wild fish. Fish returned to warm temperatures and high rations following 205 days of food deprivation displayed nearly complete recovery, with rapid increases in length, weight, and condition and minimal mortality (6.8%) during the subsequent 3 months. Age-0 walleye pollock collected in September in the Bering Sea were substantially smaller and generally had lower lipid levels than fish used in laboratory starvation experiments, suggesting they are susceptible to size- and condition-dependent mortality during the winter. The results are interpreted with respect to field distributions of age-0 walleye pollock, overwinter survival, and synergistic effects of food and temperature under varying models of climate change.

Suryan RM, DP Craig, DD Roby, ND Chelgren, K Collis, WD Shuford, and DE Lyons. 2004. "Redistribution and growth of the Caspian Tern population in the pacific coast region of North America, 1981-2000." *Condor* 106:777-790.

We examined nesting distribution and demography of the Pacific Coast population of Caspian Terns (Sterna caspia) using breeding records and band recoveries spanning two decades since the first population assessment. Since 1980, population size has more than doubled to about 12 900 pairs, yet the proportion of the population nesting at inland (18%) versus coastal sites (82%) has remained constant. Although the breeding range of the Pacific Coast population has expanded northward into Alaska and farther south in Mexico, there was no net latitudinal shift in the distribution of breeding pairs or new colonies. The distribution of breeding birds among areas changed dramatically, however, with 69% of breeding terns now nesting in Oregon (primarily in the Columbia River estuary) versus 4% during the late 1970s. During the past 20 years, there has continued to be a greater proportion of Caspian Terns breeding at anthropogenic sites compared to natural sites. Estimated annual survival rates for hatch-year and after-third-year birds during 1981 1998 were greater than during 1955-1980, consistent with the higher rate of population increase in recent decades. Fecundity required to maintain a stable population (lambda = 1) was estimated at 0.32-0.74 fledglings pair(-1), depending on band recovery probabilities for sub-adults. Caspian Terns readily moved among breeding sites and rapidly colonized new areas; however, a greater concentration of breeding Caspian Terns among fewer colonies in response to anthropogenic factors is an important conservation concern for this species.

Sykes GE, CJ Johnson, and JM Shrimpton. 2009. "Temperature and Flow Effects on Migration Timing of Chinook Salmon Smolts." *Transactions of the American Fisheries Society* 138(6):1252-1265.

Physiological and behavioral changes occur in the spring when juvenile Pacific salmon (*Oncorhynchus* spp.) undergo smolting. Survival is maximized if the timing of these changes coincides with migration from fresh to marine environments. Therefore, understanding how environmental conditions influence the onset, duration, and termination of smolting can have substantial management implications, particularly for flow-controlled rivers. We used an information-theoretic model comparison analysis to investigate the roles of daily mean temperature, temperature experience (accumulated thermal units [ATU]), photoperiod, and flow on the timing of the downstream migration of Chinook salmon (*O. tshawytscha*) smolts from the Nechako River in central British Columbia. Both binary (migration or not) and count (the total number of migrants) models were developed that predicted the downstream migration of Chinook salmon based on data collected from fish captured at rotary-screw traps from 1992 to 2004. The analyses identified a combination of temperature experience, flow, and the number of spawners as best able to describe the observed migration patterns. In addition, increasing ATU had a positive influence on migration, while increasing flow had a negative influence. Temperature experience was found to have more influence on migration than daily mean temperature. The predictive ability of each model was tested with 2 years of independent data. The count model accurately predicted the general trends in migration and, in particular, the termination of migration, but not the daily fluctuations in movement. By contrast, the binary model predicted whether fish would migrate on a given day with accuracies of 93% and 99%, respectively, for the 2 years tested. Temperature experience was more strongly linked to migration than the daily or threshold temperature; warmer temperatures resulted in earlier migration. Our data suggest that flow plays an important role once migration is under way and may even serve as a termination cue. Furthermore, the number of migrants and the probability of migration was positively related to the number of spawners. Based on the results of this study, flow manipulations that change the timing, duration, or magnitude of temperature and flow in the spring could affect the migration of Chinook salmon. Both temperature and river flow should be considered when one is managing flow-controlled watersheds for salmon productivity.

Tiffan KF, TJ Kock, CA Haskell, WP Connor, and RK Steinhorst. 2009. "Water Velocity, Turbulence, and Migration Rate of Subyearling Fall Chinook Salmon in the Free-Flowing and Impounded Snake River." *Transactions of the American Fisheries Society* 138(2):373-384.

We studied the migratory behavior of subyearling fall Chinook salmon (*Oncorhynchus tshawytscha*) in free-flowing and impounded reaches of the Snake River to evaluate the hypothesis that velocity and turbulence are the primary causal mechanisms of downstream migration. The hypothesis states that impoundment reduces velocity and turbulence and alters the migratory behavior of juvenile Chinook salmon as a result of their reduced perception of these cues. At a constant flow (m(3)/s), both velocity (km/d) and turbulence (the SD of velocity) decreased from riverine to impounded habitat as cross-sectional areas increased. We found evidence for the hypothesis that subyearling Chinook salmon perceive velocity and turbulence cues and respond to these cues by varying their behavior. The percentage of the subyearlings that moved faster than the average current speed decreased as fish made the transition from riverine reaches with high velocities and turbulence to upper reservoir reaches with low velocities and turbulence but increased to riverine levels again as the fish moved further down in the reservoir, where velocity and turbulence remained low. The migration rate (km/d) decreased in accordance with longitudinal reductions in velocity and turbulence, as predicted by the hypothesis. The variation in migration rate was better explained by a repeated-measures regression model containing velocity (Akaike's information criterion = 1,769.0) than a model containing flow (2,232.6). We conclude that subyearling fall Chinook salmon respond to changes in water velocity and turbulence, which work together to affect the migration rate.

Trudel M, S Tucker, JFT Morris, DA Higgs, and DW Welch. 2005. "Indicators of energetic status in juvenile coho salmon and Chinook salmon." *North American Journal of Fisheries Management* 25(1):374-390.

Bioenergetic models frequently rely on published values or models for estimating the energy density of fish, principally because of the cost and effort of obtaining direct measurements. In this study, we developed empirical models of energy density for free-ranging juvenile coho salmon (*Oncorhynchus kisutch*) and Chinook salmon (*O. tshawytscha*) sampled at sea from the west coast of Oregon to Kodiak Island, Alaska, and we evaluated the accuracy of published energy density models commonly used for these species. Our analyses showed that the energy density of juvenile coho and Chinook salmon was strongly correlated to percent dry weight and proximate constituents (especially lipid and, to a lesser extent, protein concentrations) but poorly correlated to body size and condition factor. Percent dry weight of whole fish was the single best predictor of energy density for both species, accounting for more than 90% of the variance in energy density. We also found that percent dry weight in the muscle tissue accounted for 65% of the variance in energy density. Changes in energy density mainly reflected changes in lipid composition. These results indicate that accurate estimates of energy density could be obtained at low effort and cost for juvenile coho and Chinook salmon simply by determining the water contents in whole-fish or muscle samples. Published models overestimate the energy density of juvenile coho and Chinook salmon collected from the Pacific Ocean. This may result from the extrapolation of the models to different size-classes, life stages, or habitats. More caution is needed when models are extrapolated to conditions beyond those that were used for their development.

Tuomikoski J, J McCann, T Berggren, H Schaller, P Wilson, S Haeseker, C Petrosky, E Tinus, T Dalton, and R Ehlke, and M DeHart. 2009. *Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook and Summer Steelhead 2009 Annual Report*. Prepared by the Fish Passage Center, the U.S. Fish and Wildlife Service, the Idaho Department of Fish and Game, the Oregon Department of Fish and Wildlife, and the Washington Department of Fish and Wildlife, for the Bonneville Power Administration, Portland, Oregon. BPA Contract no. 19960200.

This report covers the 10th complete brood year return of adults from PIT-tagged fish. These adult returns are from the 1997-2007 juvenile migrations of hatchery Chinook and the 1994-2007 juvenile migrations of wild Chinook. Also included are adult returns from 1997-2006 steelhead juvenile migrations that originate from wild steelhead on the lower Clearwater River and wild and hatchery steelhead from other tagging operations.

The primary purpose of this report is to update the time series of smolt-to-adult survival rate data and related parameters with additional years of data. This report completes the 3-salt returns from migration year 2005 for wild and hatchery Chinook and steelhead to Lower Granite Dam. For wild and hatchery Chinook, this report also provides 3-salt returns from migration year 2006 and 2-salt returns from migration year 2007 through a cutoff date of August 4, 2009. For wild and hatchery steelhead, it provides completed 2-salt returns for wild and hatchery steelhead that out migrated in 2006.

An additional objective for this year's CSS annual report was to begin to compare PIT tag SARs with SARs estimated from run reconstruction for Snake River spring/summer Chinook as recommended by the ISAB/ISRP (2009). The 2009 activity focused on estimation of Lower Granite Dam wild smolt numbers and their associated variance.

Significant changes in downstream passage conditions for Chinook and steelhead have occurred since the beginning of the CSS study. These changes in passage conditions are reflected in the survival rate and related parameter data and resulting CSS analysis. The 2007 outmigration conditions were characterized by very low flows during the spring migration period in the Snake River, similar to the low-flow conditions in 2001, 2004 and 2005. However, spill for fish passage was provided in 2007 during these low river flows, a notable difference from any year in the historic record. Under the high-spill, low-flow conditions within the Snake River in 2007, juvenile spring/summer Chinook and steelhead exhibited relatively high survival and fast travel times. Spring flows in 2007 were near the Biological Opinion flow targets of 237 kcfs in the lower and middle Columbia River, but unlike previous years, spill was provided 24 hours per day at most projects.

Overall, results presented in the CSS indicate that SARs of transported wild Chinook and steelhead have not met the levels of survival necessary to achieve the Northwest Power and Conservation Council SAR objectives. Similarly, SARs of in-river wild Chinook and steelhead have not met the Council's SAR objectives, but analyses indicate that improvements in survival at the juvenile stage could be achieved through reductions in water transit time and/or increased spill levels. Further, there is evidence that the relative SARs of transported and in-river migrants are a function of in-river survival and that transportation increases steelhead straying rates while reducing adult upstream migration success of both Chinook and steelhead. The effects of transportation and in-river migration conditions on Snake River sockeye are currently unclear, but efforts to PIT-tag sufficient numbers of sockeye began in 2009 and initial adult returns will occur in 2010. Given the complex interactions among management actions and the intended and unintended biological responses within and across ESUs, a comprehensive decision analysis that considers the array of benefits and harms for alternative management options would be informative and valuable for the region, in an effort to consistently achieve regional management objectives.

Synopsis of Key Findings:

- Consistent with findings of the Ten-year Retrospective Summary Report, juvenile travel time, instantaneous mortality rates and survival rates are all strongly influenced by managed river conditions including spill and flow. Notably, juvenile spring/summer Chinook and steelhead exhibited relatively high survival and fast travel times in the Snake River under the low-flow, high-spill conditions of 2007.
- Snake River water transit times and temperatures were nearly identical in 2007 and 2005, but spill was provided in 2007 while it was not provided in 2005. On average, LGR-MCN reach survival rates were 11 percentage points higher for wild Chinook and 12 percentage points higher for wild and hatchery steelhead in 2007 compared to 2005. In addition, LGR-MCN fish travel times averaged 4.4 days faster for Chinook and 1.3 days faster for steelhead in 2007 than in 2005. These results indicate that spill in 2007 increased juvenile survival and decreased fish travel time over what would likely have occurred if a no-spill, maximized transportation strategy had been implemented.
- Overall PIT-tag SARs for wild spring/summer Chinook and wild steelhead fell well short of the Northwest Power and Conservation Council (NPCC) SAR objectives of a 4% average and 2% minimum for recovery. In addition, transportation SARs for wild Chinook and steelhead also fell short of the NPCC objectives.
- Run-reconstruction SARs were also below the 4% average and 2% minimum objectives for recovery. Run-reconstruction SARs showed greater levels of uncertainty when uncertainty in the collection sample was incorporated compared to previous estimates. Even higher uncertainty in run-reconstruction SARs is likely when uncertainty in adult return estimation is included.
- TIRs of both wild Chinook and wild steelhead demonstrated considerable variability across study years and appeared to be associated with in-river survival rates. Expected values of TIRs decreased significantly with increases in reach survival for juvenile Chinook and steelhead. The results from 2007 suggest that the provision of spill may lower TIRs by increasing reach survival, even under low-flow conditions. However, incorporating variation in sample size in analyzing the entire CSS data set (while not incorporating the influence of in-river survival on the estimation of central tendency for TIRs) resulted in the central tendency being greater than one for TIRs of wild steelhead, over the years analyzed. The evidence indicated that the central tendency of TIRs of wild Chinook were not statistically different from one, over the years analyzed.
- Incorporating variation in sample size in analyzing the entire CSS data set demonstrated that average *D* values for wild Chinook were statistically less than one, providing evidence of delayed mortality for transported wild Chinook. The evidence also indicated that wild steelhead *D* values on average were not statistically different from one, a result that is inconclusive as to whether transported wild steelhead express delayed mortality.
- Comparisons of the C0 versus C1 SARs indicate that bypassed fish appear to have a lower SAR than undetected in-river migrants. The magnitude of those differences varied across years.

- Adult upstream migration success from BON to LGR appeared to be negatively affected by transportation during the juvenile outmigration. Overall, the success rate for adults that were transported as juveniles was approximately 9% lower than the success rate for adults that out-migrated in-river.
- Straying rates during the adult migration were higher for individuals that were transported as juveniles versus those that out-migrated in-river. This was statistically significant for Snake River hatchery Chinook and Snake River wild and hatchery steelhead, but not for wild Chinook.

Tuomikoski J, J McCann, T Berggren, H Schaller, P Wilson, S Haeseker, J Fryer, C Petrosky, E Tinus, T Dalton, and R Ehlke, and M DeHart. 2010. *Comparative Survival Study (CSS) of PIT-tagged Spring/Summer Chinook and Summer Steelhead 2010 Annual Report*. Prepared by the Fish Passage Center, the U.S. Fish and Wildlife Service, the Columbia River Intertribal Fish Commission, the Idaho Department of Fish and Game, the Oregon Department of Fish and Wildlife, and the Washington Department of Fish and Wildlife, for the Bonneville Power Administration, Portland, Oregon. BPA Contract no. 19960200.

The 2010 Comparative Survival Study data and analyses report expands on past years' monitoring and analyses and includes new analyses that will continue to be refined in future reports. Smolt-to-adult return (SAR) data for PIT-tagged hatchery and wild spring/summer Chinook and steelhead include adult returns from juvenile outmigrations from 1994 through 2008. Overall SARs are reported for various stocks throughout the Columbia Basin. SARs by juvenile outmigration route are reported for Snake River spring/summer Chinook and steelhead. New analyses of juvenile sockeye passage data have been included and will include adult return analyses in future years.

The addition of 2009 passage data to the historic time series continues to show the importance of spill and flow for in-river juvenile survival and SARs. Higher flows and controlled spill for fish passage increases juvenile survival and smolt-to-adult return rates. Overall, the results of the 2009 monitoring data and analyses indicate that the Northwest Power and Conservation Council SAR objective of 2%-6% SARs for federal ESA-listed Snake River and upper Columbia River salmon and steelhead is not being met for Snake River wild stocks of spring/summer Chinook and steelhead originating above Lower Granite Dam. However, PIT-tag SARs of wild Mid-Columbia River spring Chinook and steelhead generally did fall within the 2-6% SAR range.

The relative benefit of transportation, in terms of "Transport: In-river" ratio (TIR), is directly related to in-river migration conditions and in-river survival. As in-river migration conditions have improved with decreased Water Travel Time (increased flow) and increased spill for fish passage, inriver survival has increased and TIR has decreased. The TIR to reach survival relationship indicates that when in-river steelhead survival is above approximately 55%, transportation will be detrimental to full life-cycle survival. Because the response to juvenile transportation varies widely among species, stocks, and rearing types, and because in-river conditions are dynamic, management of the smolt transportation program presents a mixed-stock fishery challenge. The CSS analyses have begun to reflect the results of recent modifications to hydrosystem operations that affect downstream migrants. The delay of the start of transportation (since 2006) and reduction in the proportion of juveniles transported have resulted in higher transportation SARs. Increased spill for fish passage has contributed to the decrease in proportions of juveniles transported and in turn has resulted in increased in-river survival for all species.

Delayed mortality continues to be documented for spring/summer Chinook transported from the Snake River. New analyses indicate that significant delayed mortality also occurs for steelhead and spring/summer Chinook passing through powerhouse juvenile bypass systems, resulting in reduced smolt-to-adult return rate. Regardless of origin, reducing delayed mortality would correspondingly increase SARs.

In addition to the analyses of the effectiveness of the smolt transportation program to mitigate the impacts of the hydrosystem on Snake River juvenile salmon and steelhead, this CSS Annual Status Report also investigates the impact of juvenile salmon and steelhead transportation on adult migration success. The adult upstream migration success rate is decreased for salmon and steelhead that were transported as juveniles. In addition, steelhead and Chinook that were transported as juveniles exhibit higher straying rates during their upstream migration. Straying of adult steelhead has been identified as one of the greatest limiting factors in the recovery of some middle Columbia ESA-listed populations of steelhead. The benefit of any positive effects for transported juveniles needs to be balanced with any negative effects realized when those transported fish return as adults.

Van Gaest AL, JP Dietrich, DE Thompson, DA Boylen, SA Strickland, TK Collier, FJ Loge, and MR Arkoosh. 2011. Survey of Pathogens in Hatchery Chinook Salmon with Different Out-Migration Histories through the Snake and Columbia Rivers. *Journal of Aquatic Animal Health* 23:62-77.

The operation of the Federal Columbia River Power System (FCRPS) has negatively affected threatened and endangered salmonid populations in the Pacific Northwest. Barging Snake River spring Chinook salmon *Oncorhynchus tshawytscha* through the FCRPS is one effort to mitigate the effect of the hydrosystem on juvenile salmon out-migration. However, little is known about the occurrence and transmission of infectious agents in barged juvenile salmon relative to juvenile salmon that remain in-river to navigate to the ocean. We conducted a survey of hatchery-reared spring Chinook salmon at various points along their out-migration path as they left their natal hatcheries and either migrated in-river or were barged through the FCRPS. Salmon kidneys were screened by polymerase chain reaction for nine pathogens and one family of water molds. Eight pathogens were detected; the most prevalent were *Renibacterium salmoninarum* and infectious hematopoietic necrosis virus. Species in the family Saprolegniaceae were also commonly detected. Pathogen prevalence was significantly greater in fish that were barged through the FCRPS than in fish left to out-migrate in-river. These results suggest that the transmission of infectious agents to susceptible juvenile salmon occurs during the barging process. Therefore, management activities that reduce pathogen exposure during barging may increase the survival of juvenile Chinook salmon after they are released.

Wagner T and JL Congleton. 2004. “Blood chemistry correlates of nutritional condition, tissue damage, and stress in migrating juvenile Chinook salmon (*Oncorhynchus tshawytscha*).” *Canadian Journal of Fisheries and Aquatic Sciences* 61(7):1066-1074.

We used factor analysis to examine the correlation structure of six multivariate blood chemistry data sets for migrating hatchery and wild juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Fish were sampled (1998-2002) from juvenile fish bypass systems at dams or (one data set) from fish transport barges on the Snake and Columbia rivers. Analyses were performed to determine which blood chemistry analytes covaried, to facilitate interpretation of the data sets, and to provide insight into controlling physiological mechanisms. Four underlying factors were derived from the analyses: (i) a nutritional factor composed of total protein, cholesterol, calcium, and alkaline phosphatase, (ii) a tissue damage

factor composed of the enzymes alanine aminotransferase, aspartate aminotransferase, and creatine kinase, (iii) a lipid metabolism factor composed of triacylglycerol lipase and triglycerides, and (iv) a stress factor composed of cortisol, glucose, Na+, and Cl-. Although causal mechanisms cannot be directly inferred from our analyses, findings of published research provide tenable causal mechanisms for the observed structure. The consistency of the correlation structure among data sets suggests that composite (latent) variables may be more reliable indicators of some physiological responses than changes in individual variables.

Wagner T, JL Congleton, and DM Marsh. 2004. "Smolt-to-adult return rates of juvenile Chinook salmon transported through the Snake-Columbia River hydropower system, USA, in relation to densities of co-transported juvenile steelhead." *Fisheries Research* 68(1-3):259-270.

To reduce mortality associated with passage of migrating juvenile salmonids through the Snake-Columbia River Federal power system, a large percentage of smolts migrating from the Snake River basin are currently transported downstream through the hydropower system in fish-transport barges. It has recently been suggested that transportation-associated stressors may reduce the fitness of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and increase mortality after seawater entry. Because the major stressor for transported juvenile Chinook salmon is believed to be co-transportation with larger and more aggressive juvenile steelhead (*O. mykiss*), we tested the hypothesis that smolt-to-adult return rates (SARs) of transported yearling Chinook salmon were negatively correlated with densities of co-transported steelhead. Our analysis, using SARs and barge loading data for groups of Chinook salmon transported on a daily basis in 1995, 1998, and 1999, failed to confirm a relationship between Chinook salmon survival and steelhead density. These results do not preclude the possibility of an undetected inverse relationship between post-release survival of transported Chinook salmon and densities of co-transported steelhead, but do suggest that if such an effect exists it is less important than other factors, such as seasonal changes in estuarine and marine productivity or predator abundance.

Ward DL, RR Boyce, FR Young, and FE Olney. 1997. "A Review and Assessment of Transportation Studies for Juvenile Chinook Salmon in the Snake River." *North American Journal of Fisheries Management* 17(3):652-662.

We reviewed research conducted by the U.S. National Marine Fisheries Service from 1968 through 1989 on the benefits of using trucks and barges to transport migrating juvenile Chinook salmon *Oncorhynchus tsawytscha* from the Snake River around dams and reservoirs in the lower Snake and Columbia rivers. Early results from studies that used trucks indicated that Chinook salmon benefited from transportation: therefore, transportation was adopted as a management strategy by the late 1970s. Our review shows that large-scale transportation by truck was unlikely to benefit survival of juvenile Chinook salmon. Our results from reviewing more recent studies indicate that the use of barges to transport juvenile Chinook salmon may result in improved survival. Benefits may be lower than previously reported because results may have been biased by experimental design: however, even after we adjusted for those potential violations, results from four of six studies on the use of barges indicated that survival of transported fish was higher than survival of fish left to migrate in-river. Because the improved survival from barging may not be enough to ensure recovery of endangered stocks of Chinook salmon, we recommend that management of Snake River Chinook salmon not rely heavily on any one management technique.

Welch DW. 2007. *Pacific Ocean Shelf Tracking (POST) Project; Results from the Acoustic Tracking Study on Survival of Columbia River Salmon*. Prepared by Kintama Research Corporation, Nanaimo, British Columbia, for Bonneville Power Administration, Portland, Oregon. Project No. 00311400. BPA Report DOE/BP-00021107-1.

The degree that hydropower development in the Columbia and Snake Rivers has affected the survival of juvenile salmon is a contentious issue. Snake River and upper Columbia River spring Chinook salmon smolts must migrate through a series of 8 to 11 hydropower dams, respectively, in order to reach the Columbia estuary, and subsequently the Pacific Ocean. Much of the recent research on survival rate trends, differential mortality, and recovery actions for Columbia and Snake River spring Chinook assumes that there is a common ocean effect on juvenile survival (Budy et al. 2002; Deriso et al. 2001) and that the varying conservation status of Columbia River salmon is largely attributed to the development of the hydrosystem (Schaller et al. 1999). Although there has been a growing recognition of the importance of ocean survival to Columbia River salmon stocks (Deriso et al. 2001; Kareiva et al. 2000; Scheuerell and Williams 2005) and therefore the need to incorporate ocean survival rates into survival models (Peters and Marmorek 2001), a technical means of addressing the key questions has been lacking.

In 2006, the POST Columbia River spring Chinook survival study used acoustic telemetry to directly measure early marine survival from two populations of spring Chinook in the Columbia River Basin, and to test two major hypotheses:

1. Is additional “latent” or “delayed” mortality experienced after Snake River smolts pass the eight dams they encounter as in-river migrants? If so, this would be evidence for the PATH hypothesis that cumulative stress from multiple dam passage is reducing the productivity of important Snake River Chinook stocks.
2. Does transporting/barging of Chinook smolts improve early marine survival rates over run of river smolts? If so, then transporting smolts downriver should provide a boost to adult return rates, reducing extinction risk.

To test the first hypothesis we compared survival of Snake River spring Chinook (from Dworshak National Fish Hatchery), which migrate through eight dams, with that of Yakima River Chinook (from the Cle Elum Supplementation and Research Facility). The Yakima population enters the Columbia River just upstream of the confluence of the Columbia and Snake Rivers, and only migrates through the four mainstem Columbia River dams. This stock was chosen for comparison because historically it has had about a 5.2 times greater smolt to adult return rate (SAR) than the Snake River Chinook (Cle Elum SAR's from Bosch and Fast 2006; Dworshak NFH SARs from CSS 2006). Our 2006 study thus allows us to contrast the survival of two stocks whose migration through the mainstem Columbia is similar, and where the major difference between stocks is in the extensive additional in-river migration that Snake River smolts must undertake past the four contentious Snake River dams.

The second hypothesis is confined to the Snake River stock alone, as collection for barging of spring salmon smolts occurs only in the lower Snake River. To test if barging improves the survival rates of these fish, we contrasted the lower river and early marine survival of two groups of transported smolts with the survival of the same two groups of run of river (ROR) Snake R spring Chinook smolts used in the comparison with the Yakima R stock in Hypothesis #1.

Welch DW, MC Melnychuk, ER Rechisky, AD Porter, MC Jacobs, A Ladouceur, RS McKinley, and GD Jackson. 2009. "Freshwater and marine migration and survival of endangered Cultus Lake sockeye salmon (*Oncorhynchus nerka*) smolts using POST, a large-scale acoustic telemetry array." *Canadian Journal of Fisheries and Aquatic Sciences* 66(5):736-750.

Freshwater and early marine migration and survival of endangered Cultus Lake sockeye (*Oncorhynchus nerka*) salmon were studied using the Pacific Ocean Shelf Tracking (POST) array. Smolts were acoustically tagged in 2004-2007, and their migration was recorded within the lower Fraser River and coastal southern British Columbia waters. Most smolts showed rapid directional movement (swimming speeds of similar to 15-30 km.day(-1)). Average exit time from the Fraser River was 4.0-5.6 days after release, and average residence time within the Strait of Georgia was 25.6-34.1 days. Most individuals migrated northward, generally close to the mainland coast. Survival rates, assessed using standard mark-recapture methods, were generally high during the downstream migration (50%-70%), except in 2005 when survival was <20%, possibly because of a late release. Marine survival rates were stable among years, between 10%-30% at a subarray sited 500 km away from the release site. Movement rates were similar to those of previously published work, but the POST array provided direct measurements of movement and estimates of survival and demonstrated the feasibility of establishing continental-scale acoustic arrays for management and conservation of marine species.

Welch DW, EL Rechisky, MC Melnychuk, AD Porter, CJ Walters, S Clements, BJ Clemens, RS McKinley, and C Schreck. 2008. "Survival of Migrating Salmon Smolts in Large Rivers With and Without Dams." *Plos Biology* 6(10):2101-2108.

The mortality of salmon smolts during their migration out of freshwater and into the ocean has been difficult to measure. In the Columbia River, which has an extensive network of hydroelectric dams, the decline in abundance of adult salmon returning from the ocean since the late 1970s has been ascribed in large measure to the presence of the dams, although the completion of the hydropower system occurred at the same time as large-scale shifts in ocean climate, as measured by climate indices such as the Pacific Decadal Oscillation. We measured the survival of salmon smolts during their migration to sea using elements of the large-scale acoustic telemetry system, the Pacific Ocean Shelf Tracking (POST) array. Survival measurements using acoustic tags were comparable to those obtained independently using the Passive Integrated Transponder (PIT) tag system, which is operational at Columbia and Snake River dams. Because the technology underlying the POST array works in both freshwater and the ocean, it is therefore possible to extend the measurement of survival to large rivers lacking dams, such as the Fraser, and to also extend the measurement of survival to the lower Columbia River and estuary, where there are no dams. Of particular note, survival during the downstream migration of at least some endangered Columbia and Snake River Chinook and steelhead stocks appears to be as high or higher than that of the same species migrating out of the Fraser River in Canada, which lacks dams. Equally surprising, smolt survival during migration through the hydrosystem, when scaled by either the time or distance migrated, is higher than in the lower Columbia River and estuary where dams are absent. Our results raise important questions regarding the factors that are preventing the recovery of salmon stocks in the Columbia and the future health of stocks in the Fraser River.

Welker TL and JL Congleton. 2003. "Relationship between dietary lipid source, oxidative stress, and the physiological response to stress in sub-yearling chinook salmon (*Oncorhynchus tshawytscha*)." *Fish Physiology and Biochemistry* 29:225-235.

Relationships between dietary lipid source, stress, and oxidative stress were examined in juvenile Chinook salmon (*Oncorhynchus tshawytscha*). Four different experimental diets were used: menhaden oil (MHO; elevated 20:5n-3 and 22:6n-3), soybean oil (SBO; elevated 18:2n-6), linseed oil (LSO; elevated 18:3n-3), and a mixture of 55% linseed oil and 45% soybean oil (MIX; approximately equal levels of 18:2n-6 and 18:3n-3). Juvenile salmon (initial body weight of 16.0 g) were fed experimental diets for 12 weeks (early March to early June). At the end of feeding, fish subjected to a low-water stressor for 96 h had greater liver and brain lipid peroxidation compared to unstressed controls; peroxidation was not influenced by diet. Diet and stress affected plasma cortisol levels. Stressed fish fed SBO had the greatest cortisol concentrations, followed by MIX, MHO, and LSO (mean concentrations for the SBO and LSO diets differed significantly). The cortisol response to stress may have been influenced by the ratio of prostaglandin 1- and 2- series to prostaglandin 3-series precursor fatty acids provided by the different diets. The results of this study suggest a connection between the physiological response to stress, dietary lipid quality, and oxidative stress. This is the first evidence of such a relationship in fish.

Welker TL and JL Congleton. 2009. "Preliminary examination of oxidative stress in juvenile spring Chinook salmon *Oncorhynchus tshawytscha* of wild origin sampled from transport barges." *Journal of Fish Biology* 75(7):1895-1905.

Migrating juvenile wild Chinook salmon (*Oncorhynchus tshawytscha*), collected and loaded onto transport barges at Lower Granite Dam on the Snake River, were sampled from barges at John Day Dam, 348 km downstream, at 5 day intervals beginning in late April and ending in late May. An increase in lipid peroxidation and decrease in vitamin E in liver were observed from early to late in the barge transportation season. These changes seemed unrelated to changes in plasma cortisol or corresponding glucose levels, which declined from early to late in the season, or the concentration of n-3 highly unsaturated fatty acid (HUFA) concentrations in tissue but may be related to water temperature, which increased during the transport season, or other changes associated with the parr-smolt transformation.

Wertheimer RH and AF Evans. 2005. "Downstream Passage of Steelhead Kelts Through Hydroelectric Dams on the Lower Snake and Columbia Rivers." *Transactions of the American Fisheries Society* 134(4):853-865.

After spawning, iteroparous steelhead (*Oncorhynchus mykiss*) from the Columbia River basin must navigate several hydroelectric dams on their way to the Pacific Ocean. We used radiotelemetry to investigate migration rates, downstream passage routes, and Success of adult steelhead kelts migrating past lower Snake River and Columbia River dams during the springs of 2001 and 2002. Seaward-migrating kelts were collected, radio-tagged, and volitionally released from the juvenile bypass facilities at Lower Granite Dam (LGR) on the Snake River and at McNary Dam (McN) and John Day Dam (JDD) on the Columbia River. Migration success rates from LGR to the study area exit (8 km east of Portland, Oregon) were poorer during the low-flow nonspill conditions of 2001 (4.1%) than in the more typical flow year of 2002 (15.6%). Kelts tagged and released at Columbia River dams had substantially higher migration success than those released on the Snake River; 59.6% and 62.3% of the kelts released at McN and 63.6% and 80.0% of those released at JDD were contacted at the study area exit during 2001 and 2002, respectively. Kelt dam passage was predominately via spillways and surface flow routes, and during periods of spill 90.0% or more kelts typically passed via nonturbine routes. Only 47.2% of kelts were guided out of turbine intakes by screen systems during nonspill periods. Turbine passage, the primary alternative route during nonspill periods, may be a substantial source of kelt mortality. The poor migration success rate of Snake River kelts in both 2001 and 2002 suggests that additional management (i.e., kelt reconditioning, transportation, or both) may be warranted to boost iteroparity rates in this population.

Wiese FK, JK Parrish, CW Thompson, and C Maranto. 2008. "Ecosystem-based management of predator-prey relationships: Piscivorous birds and salmonids." *Ecological Applications* 18:681-700.

Predator-prey relationships are often altered as a result of human activities. Where prey are legally protected, conservation action may include lethal predator control. In the Columbia River basin (Pacific Northwest, USA and Canada), piscivorous predators have been implicated in contributing to a lack of recovery of several endangered anadromous salmonids (*Oncorhynchus* spp.), and lethal and nonlethal control programs have been instituted against both piscine and avian species. To determine the consequences of avian predation, we used a bioenergetics approach to estimate the consumption of salmonid smolts by waterbirds (Common Merganser, California and Ring-billed Gull, Caspian Tern, Double-crested Cormorant) found in the mid-Columbia River from April through August, 2002-2004. We used our model to explore several predator-prey scenarios, including the impact of historical bird abundance, and the effect of preserving versus removing birds, on smolt abundance. Each year, < 1% of the estimated available salmonid smolts (interannual range: 44 830-109 209; 95% CI = 38 000-137 000) were consumed, 85-98% away from dams. Current diet data combined with historical gull abundance at dams suggests that past smolt consumption may have been 1.5-3 times current numbers, depending on the assumed distribution of gulls along the reaches. After the majority (80%) of salmonid smolts have left the study area, birds switch their diet to predominantly juvenile northern pikeminnow (Ptychocheilus oregonensis), which as adults are significant native salmonid predators in the Columbia River. Our models suggest that one consequence of removing birds from the system may be increased pikeminnow abundance, which - even assuming 80% compensatory mortality in juvenile pikeminnow survival - would theoretically result in an annual average savings of just over 180 000 smolts, calculated over a decade. Practically, this suggests that smolt survival could be maximized by deterring birds from the river when smolts are present, allowing bird presence after the diet switch to act as a tool for salmonid-predator control, and conducting adult-pikeminnow control throughout. Our analysis demonstrates that identifying the strength of ecosystem interactions represents a top priority when attempting to manage the abundance of a particular ecosystem constituent, and that the consequences of a single-species view may be counterintuitive, and potentially counterproductive.

Williams JG. 2008. "Mitigating the effects of high-head dams on the Columbia River, USA: Experience from the trenches." *Hydrobiologia* 609(3):241-251.

Worldwide, humans have tremendously altered freshwater ecosystems and arguably, construction of dams has had the greatest effect. Maintaining natural ecological processes and developing mitigation strategies that will maintain species while retaining dam benefits is challenging. In the Columbia River, USA, over the last 30 years more than US$7 billion has been spent on efforts to save historically large runs of salmon. These efforts have included improving passage conditions at dams through construction of efficient fish ladders for adult salmon, effective fish passage facilities for downstream migrating juvenile salmon, voluntarily spilling water to decrease the number of downstream migrants that pass through turbines, modifying dam operations to provide more constant flow and providing additional flow from storage reservoirs to create more natural flow through areas inundated by dams. Construction of hatcheries to offset losses in habitat for wild fish has also occurred. Further, for salmon from the Snake River, the largest tributary to the Columbia River, a large percent of juvenile salmon smolts are collected at upstream dams and transported in barges to the lower river to avoid passage through dams, turbines, and reservoirs. Experiences in the Columbia River suggest that the sum of all of these actions may keep salmon stocks from going extinct, but the technological fixes will not likely provide complete mitigation for altered freshwater ecosystems.

Williams JG, SG Smith, RW Zabel, WD Muir, MD Scheuerell, BP Sandford, DM Marsh, RA McNatt, and S Achord. 2005. *Effects of the Federal Columbia River Power System on Salmonid Populations*. NOAA Technical Memorandum NMFS-NWFSC-63, U.S. Departhment of Commerce, Northwest Fisheries Center, National Oceanic Atmospheric Administration, Seattle, Washington.

This technical memorandum summarizes past efforts to determine direct and indirect effects of the Federal Columbia River Power System (FCRPS) on Columbia River salmon stocks. We based analyses and derived results from juvenile and adult studies through the end of 2003 that address five major areas:

1. adult return rates,
2. transportation evaluations,
3. juvenile migrant survival,
4. links between juvenile survival, travel time, and the river environment, and
5. latent mortality associated with the FCRPS.

(For most past and present methods used to develop linkages between the FCRPS and salmon survival, this report refers readers to references containing the details.)

Our ability to discern FCRPS-related effects relates directly to the quality of available data, which is quite variable. We can precisely estimate survival of downstream migrants from release points to the uppermost dams and through the hydropower system, and we have begun to develop similar capabilities for upstream migrants. For several evolutionarily significant units (ESUs), we have developed a measure of the relative performance of transported fish compared to in-river migrants, but we have limited precision of sample sizes of adult returns. Unfortunately, we have limited ability to quantify the magnitude of hydropower system–related latent mortality. However, we believe a major component of latent mortality is the disruption of timing of transported fish and in-river migrants, and we are beginning to discern some migrational timing effects.

Areas of additional or continued study that would help resolve some uncertainties about effects of the FCRPS include:

- migrational timing and its effect on smolt-to-adult return rate (SAR) for both transported and in-river migrants,
- selectivity of bypass systems, for fish size as well as fish health, and
- mechanisms leading toward latent mortality.

Some of the data limitations noted above arise from the fact that adult return rates provide the best indicator of population performance, but this measure reflects the effects of several confounding factors, of which the FCRPS is but one. Clearly, ocean conditions have the dominant influence on adult return rates, overriding variability associated with the hydropower system. Return rates have increased by an order of magnitude since the upturn in ocean conditions that began in 1999, while survival through the hydropower system has remained relatively constant. Improvements in SAR, however, do not preclude the existence of hydropower system-related latent mortality or an interaction between latent mortality and ocean condition.

Transportation is not a panacea for negative effects of dams on fish stocks. When comparing annual indices of transported, wild, yearling Snake River spring-summer Chinook salmon (*Oncorhynchus tshawytscha*) and hatchery fall Chinook salmon versus in-river fish, in many cases transportation appeared to confer little benefit or harm. However, under certain times of the year and under low-flow conditions (particularly in 2001), transportation appeared to increase return rates of some segments of the yearling migrant populations. Further, the benefits of transportation decreased at transportation sites closer to Bonneville Dam. Thus future operations should focus on optimizing adult return rates, independent of the transportation process currently in operation. Strategies such as "spread the risk" and promotion of diversity suggest we should allow more fish to migrate in the river whenever it appears migration might lead to reasonable return rates compared to the alternatives. At times transportation may provide the best alternative. We note that transportation apparently has not provided any benefit to Snake River sockeye salmon.

Under most conditions, we have estimated relatively high direct (within the hydropower system) survival of yearling juvenile migrants, and substantial improvements in downstream survival appear unlikely, particularly improvements related to passage through dams. Summer subyearling migrants suffer greater mortality in reservoirs than do spring migrants, and improvements in river conditions may confer considerably improved survival. In 2001 the low survival experienced by spring migrants and generally lower survival of summer migrants likely resulted from conditions in the reservoirs, potentially low flow, and possibly a lack of spill. Therefore, we may face diminishing returns in terms of improving survival via technological fixes to dams. Efforts to reduce mortality in the reservoirs, understand how to reduce latent or indirect mortality (mortality expressed downstream of the hydropower system that results from hydropower system passage), and maintain diversity by improving habitat conditions in estuary and freshwater spawning and rearing habitats will likely have the strongest influence on overall stock viability.

For Snake River spring-summer Chinook salmon, we found that increased flow had a benefit to juvenile migrant survival, although the effect was small relative to the detriment that occurs when water temperatures become too high. For steelhead, the benefit of increased flow was apparently greater. However, in our multiple-regression model the benefit is offset somewhat by a countering trend of decreased steelhead survival as the season progresses, possibly related to their increased propensity to residualize as water temperature increased. For yearling Chinook salmon, temperatures above 13°C, typically reached in late May, appeared detrimental to survival.

For both species, we consistently observed a strong relationship between flow and travel time. Thus increased flow may benefit spring migrants by moving them out of the lower Snake River before temperatures become too high.

Flow clearly can affect the timing of smolt migration to the estuary, which appears to greatly influence their SAR. Delayed migration, which reduces available energy reserves in smolts, could affect survival. Low-flow years exacerbate the problem, both within the hydro-power system and in freshwater areas upstream that fish negotiate before arriving at the first dam.

Wilson PH. 2003. "Using Population Projection Matrices to Evaluate Recovery Strategies for Snake River Spring and Summer Chinook Salmon." *Conservation Biology* 17(3):782-794.

I explored the efficacy of alternative actions to recover threatened Snake River Chinook salmon (Onchorhyncus tshawytscha). I compared the potential to increase population growth rates from two different actions: (1) habitat restoration efforts, aimed at increasing egg-to-smolt survival rate, and (2) dam breaching, intended to improve smolt-to-spawner survival. Eight dams obstruct the migration corridor these populations traverse as juveniles (downstream) and as adults (upstream), and a large portion of the juvenile migrants are collected and transported past most of the dams on barges or trucks. I applied sensitivity, elasticity, and direct perturbation analyses to an age-structured projection matrix to predict potential effects from simultaneous, nonproportional changes in multiple survival rates. Throughout the analyses, I explicitly incorporated alternative assumptions about the effectiveness of transportation, which is known to be influential. Results of the numerical experiments suggest that dam breaching has more potential to increase population growth rates than habitat restoration, except for the most optimistic assumption about the efficacy of transportation. I then fit the matrix to historical data to identify life stages in which actual decreases in survival rates have caused the observed declines in abundance. There was no reduction in egg-to-smolt survival, indicating that neither habitat deterioration nor hatchery impacts (in that life stage) caused the stocks to decline. The large decrease in smolt-to-adult survival rate from the historical period, when there were fewer dams, is consistent with the hypothesis that increased stress from transportation and passage through additional dams on the Snake River has elevated delayed mortality levels.

Wilson PH, HA Schaller, CE Petrosky, and J Loomis. 2009. "Judging Cost-Effectiveness of Management of Snake River Salmon: Response to Halsing and Moore." *Conservation Biology* 23(2):475-478.

Halsing and Moore (2008) used Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*) as an example to present a synthesis of biological and economic information to develop a cost-effectiveness tool for assessing management alternatives for threatened or endangered species. Although we believe that elements of their approach could be useful to prioritize management alternatives and illuminate trade-offs between biological benefits and economic costs, we fear that their analysis may be of limited utility for Snake River anadromous salmonid management. Halsing and Moore used outdated, inferior models and parameter estimates to simulate the biological responses they used to rank cost-effectiveness of management alternatives, which depended on small differences between estimated population growth rates. They relied on a precision in estimated population growth rate unwarranted by the data and applied inconsistent economic analysis assumptions across scenarios, casting doubt on their cost-effectiveness findings.

Zabel RW and S Achord. 2004. "Relating size of juveniles to survival within and among populations of chinook salmon." *Ecology* 85(3):795-806.

Understanding relationships between the size of individuals and their subsequent survival can not only provide insights into mechanisms of mortality, but can also identify traits to measure for monitoring at-risk populations. We analyzed a data set of more than 54000 juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from 15 populations over five years. The juveniles were tagged during the summer in their freshwater rearing habitats and then recaptured at downstream sites the following spring after an extended rearing and overwintering period. We measured the length and weight of fish at tagging and computed a "condition index" that determined how fat or thin a fish was relative to others. Among populations, mean

length and mean condition index were poor predictors of survival, but we did detect year and site effects. Within populations, survival was strongly related to the relative length of individuals but not to relative condition index. Our results are consistent with length-related mechanisms of mortality mediated by hierarchical behavior, and thus merely measuring changes in mean values of morphological traits in populations of juveniles may provide little insight into expected changes in population viability. Expanding upon these results, we predicted a nearly 60% increase in selection for juvenile fish length when we extended our observation period through adulthood. Thus, monitoring populations through only a portion of their life history may present an incomplete picture of their survival variability.

Zabel RW, JJ Anderson JJ, and PA Shaw. 1998. “A multiple-reach model describing the migratory behavior of Snake River yearling chinook salmon (*Oncorhynchus tshawytscha*).” *Canadian Journal of Fisheries and Aquatic Sciences* 55(3):658-667.

A multiple-reach model was developed to describe the downstream migration of juvenile salmonids in the Columbia River system. Migration rate for cohorts of fish was allowed to vary by reach and time step. A nested sequence of linear and nonlinear models related the variation in migration rates to river flow, date in season, and experience in the river. By comparing predicted with observed travel times at multiple observation sites along the migration route, the relative performance of the migration rate models was assessed. The analysis was applied to cohorts of yearling Chinook salmon (*Oncorhynchus tshawytscha*) captured at the Snake River Trap near Lewiston, Idaho, and fitted with passive integrated transponder (PIT) tags over the 8-year period 1989-1996. The fish were observed at Lower Granite and Little Goose dams on the Snake River and McNary Dam on the Columbia River covering a migration distance of 277 km. The data supported a model containing two behavioral components: a flow term related to season where fish spend more time in regions of higher river velocity later in the season and a flow-independent experience effect where the fish migrate faster the longer they have been in the river.

Zabel RW, J Faulkner, SG Smith, JJ Anderson, C Van Holmes, N Beer, S Iltis, J Krinke, G Fredricks, B Bellerud, J Sweet, and A Giorgi. 2008a. "Comprehensive passage (COMPASS) model: A model of downstream migration and survival of juvenile salmonids through a hydropower system." *Hydrobiologia* 609:289-300.

Migratory fish populations are impacted worldwide by river impoundments. Efforts to restore populations will benefit from a clear understanding of survival and migration process over a wide-range of river conditions. We developed a model that estimates travel time and survival of migrating juvenile salmonids (*Oncorhynchus* spp.) through the impounded Snake and Columbia rivers in the northwestern United States. The model allows users to examine the effects of river management scenarios, such as manipulations of river flow and spill, on salmonid survival. It has four major components: dam passage and survival, reservoir survival, fish travel time, and hydrological processes. The probability that fish pass through specific routes at a dam and route-specific survival probabilities were based on hydroacoustic, radio telemetry, PIT tag, and acoustic tag data. We related reservoir mortality rate (per day and per km) to river flow, water temperature, and percentage of fish passing through spillways and then fit the relationships to PIT-tag survival data. We related fish migration rate to water velocity, percentage of fish passing through spillways, and date in the season. We applied the model to two threatened "Evolutionarily Significant Units" (as defined under the US Endangered Species Act): Snake River spring/summer Chinook salmon (*O. tshawytscha* Walbaum) and Snake River steelhead (*O. mykiss* Walbaum). A sensitivity analysis demonstrated that for both species survival through the hydropower system was responsive to water temperature, river flow, and spill proportion. The two species, however,

exhibited different patterns in their response. Such information is crucial for managers to effectively restore migratory fish populations in regulated rivers.

Zabel RW, MD Scheuerell, MM McClure, and JG Williams. 2006. "The interplay between climate variability and density dependence in the population viability of Chinook salmon." *Conservation Biology* 20(1):190-200.

The viability of populations is influenced by driving forces such as density dependence and climate variability, but most population viability analyses (PVAs) ignore these factors because of data limitations. Additionally, simplified PVAs produce limited measures of population viability such as annual population growth rate (a) or extinction risk. Here we developed a "mechanistic" PVA of threatened Chinook salmon (*Oncorhynchus tshawytscha*) in which, based on 40 years of detailed data, we related freshwater recruitment of juveniles to density of spawners, and third year survival in the ocean to monthly indices of broad-scale ocean and climate conditions. Including climate variability in the model produced important effects: estimated population viability was very sensitive to assumptions of future climate conditions and the autocorrelation contained in the climate signal increased mean population abundance while increasing probability of quasi extinction. Because of the presence of density dependence in the model, however, we could not distinguish among alternative climate scenarios through mean values, emphasizing the importance of considering multiple measures to elucidate population viability. Our sensitivity analyses demonstrated that the importance of particular parameters varied across models and depended on which viability measure was the response variable. The density-dependent parameter associated with freshwater recruitment was consistently the most important, regardless of viability measure, suggesting that increasing juvenile carrying capacity is important for recovery.

Zabel RW, T Wagner, JL Congleton, SG Smith, and JG Williams. 2005. "Survival and selection of migrating salmon from capture-recapture models with individual traits." *Ecological Applications* 15:1427-1439.

Capture-recapture studies are powerful tools for studying animal population dynamics, providing information on population abundance, survival rates, population growth rates, and selection for phenotypic traits. In these studies, the probability of observing a tagged individual reflects both the probability of the individual surviving to the time of recapture and,the probability of recapturing an animal, given that it is alive. If both of these probabilities are related to the same phenotypic trait, it can be difficult to distinguish effects, on survival probabilities from effects on recapture probabilities. However, when animals are individually tagged and have multiple opportunities for recapture, we can properly partition observed trait-related variability into survival and recapture components. We present an overview of capture-recapture models that incorporate individual variability and develop methods to incorporate results from these models into estimates of population survival and selection for phenotypic traits. We conducted a series of simulations to understand the performance of these estimators and to assess the consequences of ignoring individual variability when it exists. In addition, we analyzed a large data set of >153 000 juvenile Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) of known length that were PIT-tagged during their seaward migration. Both our simulations and the case study indicated that the ability to precisely estimate selection for phenotypic' traits was greatly compromised when differential recapture probabilities were ignored. Estimates of population survival, however, were far more robust. In the Chinook salmon and steelhead study, we consistently found that smaller fish had a greater probability of recapture. We also uncovered length-related survival relationships in over half of the release group/river segment combinations that we observed, but we found both. positive and negative relationships between length and survival probability. These results have important implications for the management of salmonid populations.

Zabel RW and JG Williams. 2002. "Selective mortality in chinook salmon: What is the role of human disturbance?" *Ecological Applications* 12(1):173-183.

While many recovery programs for threatened species focus on acute sources of mortality, understanding some of the evolutionary processes of these species may lead to more effective recovery efforts, especially in cases where human-induced disturbances have resulted in artificial selection pressures. We developed a Monte Carlo test to determine whether Snake River spring/summer Chinook salmon (*Oncorhynchus tshawytscha*) experienced selective mortality as a function of their juvenile length and timing of downstream migration. Actively migrating juvenile fish (smolts) were captured, tagged, and released in 1995 and 1996 approximately 700 km upstream from the Pacific Ocean, and returning adults were detected at the same location. We analyzed data from two groups of fish: those that migrated downstream in-river and those that were barged downstream as part of the juvenile salmon transportation program. These groups were further separated into wild and hatchery Fish. Length at release was significantly greater in returning adults than in the general population for fish that migrated downstream in-river (both wild and hatchery) or were transported (hatchery only). From the 1995 seaward migration, adult returns of both wild and hatchery fish that migrated in-river were composed of fish released significantly earlier than the general population. In contrast, the opposite trend existed for wild and hatchery transported fish. From the 1996 seaward migration, no significant difference in release date was found between returning adults and the original population for any of the groups analyzed. Fish length at migration is a result of factors encountered in early life stages but selectively determines mortality in the smolt-to-adult stage. Thus freshwater habitat improvements, such as salmon carcass supplementation, directed at increasing nutrient levels and thus fish length may result in an increase in overall survival. The development of hydroelectric dams in the migratory corridors of these fish has disrupted their arrival timing to the estuary. Mitigation efforts designed to shift arrival timing toward that experienced prior to impoundment may confer considerable survival benefits.

Appendix B

Synopsis of Select USACE-Funded Research

Appendix B

Synopsis of Select USACE-Funded Research

Several reports and a journal article from research funded by the U.S. Army Corps of Engineers (USACE) on delayed mortality (Arkoosh et al. 2006; Dietrich et al. 2007, 2008; Mesa et al. 2008; Eder et al. 2009a, b; Dietrich et al. 2010) are summarized in Appendix D. Here, we review the research by first highlighting valuable findings, evaluating the associated methodologies, and then discussing the findings in the context of mechanistic hypotheses for differential delayed mortality (*D*).

B.1 Valuable Findings

The most notable findings were the travel rates of barged and run-of-river (ROR) migrants in the lower river and estuary (LRE) (Eder et al. 2009a), the lack of evidence for size-selective predation by Northern pikeminnow below Bonneville Dam (BON) in a field survey (Mesa et al. 2008), and the barge conditions conducive to minimizing pathogen transmission between fish (Dietrich et al. 2010).

Barged fish travelled through the LRE slower than ROR migrants (Table B.1**.**; Eder et al. 2009a). They also travelled at a slower rate in the estuary (27.8 km/d; rkm 35.6 to 8.5) than in the lower river (49.3 km/d; rkm 202 to 35.6). The data show that longer travel times were associated with lower survival rates. The longer travel times and associated lower survival rates of barged fish would decrease *D*.

Table B.1. Travel Times and Survival Rates of Juvenile Spring/Summer Chinook Salmon in the Lower River and Estuary (summarized from Eder et al. 2009a). The data font is altered to highlight the matching patterns between travel times and survival rates.

Effect	Location	Barged Fish	> or <	Run-of-River Fish
Travel Time	Lower river	**3.4 d**	>	*1.7 d*
	Seasonal pattern	Decrease (5.3-2.2 d)		None (1.8-1.6 d)
	Estuary	**1.0 d**	>	*0.5 d*
	Seasonal pattern	Decrease (1.5-0.6 d)		None (0.55-0.51 d)
Survival	Lower river	*0.92*	<	**0.97**
	Seasonal pattern	Increase (0.89-0.98)		Increase (0.90-0.98)
	Estuary	*0.78*	<	**0.89**
	Seasonal pattern	Increase (0.72-0.89)		None (0.92-0.90)

There was little support for size-selective predation in a field survey, which consisted of approximately 2500 juvenile Chinook salmon and 65 N. pikeminnow over four sampling periods (Mesa et al. 2008). Juvenile salmonids consumed were statistically the same size as barged migrants in May 2004, the same size as ROR migrants in May 2005, and significantly larger than barged and ROR migrants in late June 2004 and 2005. The data collection related to the lengths of juvenile salmon available in the environment was an important feature of the survey that allowed rigorous testing of size-selective predation as a mechanistic factor of *D*.

Increased pathogen prevalence among barged fish is hypothesized to decrease their survival and consequently decrease *D*. Evidence that disease transmission occurs at water-exchange rates, fish densities, and pathogen prevalence commensurate with actual levels in the field is an important finding (Dietrich et al. 2010). Furthermore, the authors determined that the barge conditions favorable for minimizing pathogen transmission among fish during transportation were low fish densities (< 0.3 lb/gal) and high water-exchange rates (three operating engines; 16,500 gpm).

Other noteworthy findings that are consistent with other published research include the following:

- Na^+/K^+-ATPase activity levels were lowest at the hatchery, followed by barged fish and then ROR migrants. These results support the hypothesis that the ROR survival is greater than barged fish because of increased osmoregulatory ability, which would translate to decreased *D*.
- Blood protein levels were higher among barged fish than among ROR migrants after hydrosystem passage. This may involve higher nutritional status among barged fish, and higher stress and relatively poor feeding among ROR migrants. Both cases suggest effects that would increase *D*. Furthermore, at the conclusion of the net pen holding experiment in the LRE, blood protein levels of barged fish were nearly twice those of ROR migrants.
- The percent of lipids by wet weight was highest at the hatchery (4.7%–7.0%), decreased at LGR (1.6%–2.6%), and was lowest among barged fish (1.2%–1.6%) and ROR migrants (0.4%–0.5%) after hydrosystem passage. These rates are comparable to findings from other studies (Congleton et al. 2005). The low energetic reserves among ROR migrants relative to barged fish suggest effects that would increase *D*.
- Lysozyme activity, an immune function known to increase during infections, was higher among barged fish than ROR migrants after hydrosystem passage. This may indicate that higher pathogen prevalence occurs among barged fish than ROR migrants, or that barged fish are now better prepared to reduce and resist pathogens.
- Among the chemical contaminants tested, Dworshak Hatchery ROR migrants had levels of lipid-adjusted total polychlorinated biphenyl greater than 2400 ng/g lipid, which is the National Oceanic and Atmospheric Administration (NOAA) Fisheries' estimated threshold of adverse effects upon which enzyme induction and mortality can occur. The lower volumes of lipids available to sequester contaminants in ROR migrants relative to barged fish may cause increased toxicological effects, which would consequently increase *D*. However, the effects of single contaminants and synergistic effects of contaminants on immune function are unknown.
- Gene expression work in its exploratory phase helped to identify several genes associated with stress, immune function, metabolism, and osmoregulation. How these changes in genetic expression affect *D* is unknown, but interestingly, up- and down-regulation of genes was more prevalent in barged fish.

B.2 Evaluation of Experimental Design and Analysis

Care in the design of experiments and the interpretation of results about the value of *D*, as a ratio of survivals, is especially important. This section evaluates the strengths and weakness of the selected studies in providing support for the various hypotheses about *D*.

B.2.1 Net Pen Holding Experiments (Dietrich et al. 2008; Eder et al. 2009a, b)

In determining relative mortality rates of barged fish and ROR migrants post-BON, the net pen holding experiments in the LRE are a more realistic set of experiments than laboratory experiments. However, a few features of the methodology or challenges in the implementation limit the interpretations of the results. These features include

- the possibility that location and duration of the experiments were not representative of the migration environment for either barged or ROR fish
- the possibility that disease transmission within net pens was not representative of the migration environment for either barged or ROR fish
- the lack of tagging in Reference fish.

The assignment of test animals to exclusively freshwater or estuarine sites is an aspect of the experimental design that is unlikely to represent the conditions experienced by migrating juvenile salmonids. Fish undergoing smoltification likely select sites that match their current capacity for osmoregulation (Sigholt et al. 1995). Prolonged exposure of smolts to freshwater may cause a reduction in gill Na^+/K^+-ATPase activity (Stefanson et al. 1998), while an abrupt introduction to seawater may cause an initial adaptation (crisis) period lasting about 4 days followed by a stabilization period of about 8 to 10 days (Bath and Eddy 1979; Handeland et al. 1998). Measurements of the gill Na^+/K^+-ATPase activity of fish during the net pen holding experiments would be informative. We could determine how well the fish were maintaining homeostasis at the osmoregulatory level in fresh and in estuarine waters, whether there are differences between barged fish and ROR migrants, and whether the data would support the hypothesis that differential osmoregulation among fish could result in differential predation risk (Schreck et al. 2006). Furthermore, some fish diseases such as mycotic infections (Saprolegnia) may diminish dramatically in seawater and cause lower mortality rates than in freshwater. Fish in net pens at the estuarine site had lower pathogen prevalence than those at the freshwater site, and overall had very low mortality rates (Eder et al. 2009b). Thus, it is important to acknowledge and discuss the results in the context of an environment where fish encounter drastically different conditions (freshwater versus estuarine conditions) over time.

Deciding on appropriate time scales of experiments to yield meaningful results can be difficult. The net pen holding experiments were 28 days in duration, while the travel time from rkm 202 to rkm 8.3 was as long as 9 days and as short as 2 days. Interpretation of the relative net pen mortality rates in freshwater 19 to 27 days beyond the LRE travel time may not accurately reflect relative mortality rates because these fish would have migrated beyond the estuary in that time frame. In addition, mortality rates over long periods of time can be affected by the introduction of new stressors and changes in fish condition not caused by the original stressors that were the intended focus of testing.

The density of fish in the net pens may be artificially high and cause higher disease transmission rates among the test animals than under natural conditions. The rate of 85% of morbid fish with diseases may be unnaturally high. It is unclear what the fish density in the net pens was. The number of fish tested in net pens was sometimes reported, but the number of net pens, their dimensions, and their proximity to each other were not described. Dietrich et al. (2010) showed that the lowest level of disease prevalence tested (7%) caused disease transmission to other fish at densities of 0.3 lb/gal. Artificially high pathogen prevalence may lead to overestimating the importance of disease as a factor of *D*.

Tagging can affect the performance and survival of fish (Brown et al. 2006, 2010; Rub et al. 2009). In addition to being from a different source, Reference fish were not tagged and showed very low rates of mortality in the net pen holding experiments. The lack of tagging in Reference fish makes it difficult to accurately compare this group to barged and in-river migrating treatment fish. Eder et al. (2009a) interpreted the low mortality rates of this group as an indication of a minimal negative influence of net pen duration and location. They also interpreted the low rates of mortality among Reference fish at the Sand Island test site and the lack of statistically significant differences among barged, ROR, and Reference groups (unlike the Tongue Point location) as an indication that this site did not provide "in situ challenge stressors." Although cumulative mortality rates of barged fish and ROR migrants were higher at Tongue Point than at Sand Island, the mortality rates of Reference fish were also low. Given that Reference fish mortalities were low, the authors could have claimed Tongue Point also did not provide "in situ challenge stressors." The untagged Reference fish were informative in showing that mortality rates can be low in the LRE, but it is difficult to assume that they were representative of groups entering the hydrosystem, and especially of the tagged fish in other groups. In addition to these untagged fish, another group of Reference fish should be tagged and tested in the same manner as the barged fish and ROR migrants for more appropriate comparisons of mortality rates. Barged fish and ROR migrants were tagged at LGR, and were placed in net pens approximately 2 to 19 days after tagging and release from LGR. Reference fish should thus be tested 2 and 19 days after tagging also.

B.2.2 Pathogen Transmission Experiments (Dietrich et al. 2010)

To evaluate pathogen transmission from "Donor" fish to "Susceptible" fish, pathogen prevalence was evaluated up to 100 days after cohabitation. From the results collected on Day 0, pathogen transmission was minimized by keeping fish densities low and water-exchange rates high. This linear relationship between fish densities and pathogen prevalence rates also occurred on Day 35. However, on Day 100, a significant interaction factor was observed between fish densities and water-exchange rates. The authors thus recommended that if fish densities were high (> 0.3 lb/gal) in the barges, decreasing water flows would help to minimize pathogen transmission. The results from Day 0 and Day 35 are informative and useful for management decisions. However, we believe the results from Day 100 should be interpreted with caution. Data collection should be made on a time scale of days or a few weeks for meaningful interpretation of results. Other factors and environmental conditions would likely affect fish 100 days after the implementation of tested factors. Also, lowering water-exchange rates may decrease dissolved oxygen available to fish at high water temperatures.

B.2.3 Laboratory Experiment and Field Survey to Determine Size-Selective Predation (Mesa et al. 2008)

The authors examined the hypothesis of size-selective predation as a mechanism of *D* in two complementary types of studies. The controlled experiment provided a clear assessment of the behavior, and the field survey with relatively large sample sizes provided an investigation of natural occurrences. Overall, the authors showed that size-selective predation can occur under controlled conditions, but that it likely does not occur below BON with N. pikeminnow.

B.2.4 Microarrays and Hybridization (Dietrich et al. 2007; Mesa et al. 2008)

Microarrays are a great platform for exploratory work to determine changes at the level of transcription that suggest changes in gene expression. Differences in gene expression between barged and ROR migrants can indicate areas for further exploration. However, as Mesa et al. (2008) note, interpretation of results is challenging and the immediate usefulness of the data is limited because of the low sample sizes, the overwhelming amounts of genetic data, and the high rate of unannotated expressed sequence tags. Furthermore, complex interactions occur between the environment, physiology, and genetics. For example, changes in gene expression can signify a distressed organism responding to a stressor or an organism effectively acclimatized to changing conditions. Microarrays and hybridization are useful for exploratory work, but much more research is needed to link those results to patterns in *D*.

B.3 Evaluation of Conclusions from Reports and Alternative Interpretations of Results

We have re-examined the results of the selected studies relative to the conclusions drawn. In the next section, we consider whether those results are consistent with alternative interpretations.

B.3.1 Disease as a Factor in Differential Delayed Mortality

The patterns of pathogen prevalence and mortality in holding and challenge experiments show mixed patterns. If disease were the primary mechanistic factor hypothesized to affect *D* or to represent the overall health of fish (Arkoosh et al. 2006; Dietrich et al. 2007, 2008; Eder et al. 2009b), pathogen prevalence patterns are expected to correlate with the mortality rates.

Barged fish generally had higher rates of pathogen prevalence than ROR migrants immediately post-BON (Van Gaest et al. 2011; Table B.2). This is consistent with patterns of $D < 1$. However, ROR migrants had higher mortality rates than barged fish at the conclusion of the disease challenges and net pen holding experiments (Table B.3). This is consistent with patterns of $D > 1$. It is important to note that Dietrich et al. (2007, 2011) observed higher mortality rates in barged fish than ROR migrants over a few weeks after collecting their samples and prior to their disease challenge experiments. Thus, effects of culling in barged fish after hydrosystem passage, as well as culling of ROR migrants during hydrosystem passage, are important to consider. ROR migrants experience mortality during hydrosystem transit and previous studies have indicated a role for pathogens in this mortality (Pascho et al. 1993).

Table B.2. Rates of Most Prevalent Pathogens Were Generally Greater in Barged Fish Than in ROR Migrants Immediately Post-Hydrosystem

Pathogen	Prevalence in Barged Fish	> ≈ or <	Prevalence in ROR Fish	Study
R. salmoninarum	60.6%	>	44.4%	Dietrich et al. (2008)
Saprolegniaceae	13.2%	>	7.7%	Dietrich et al. (2008)
IHNV	25%	>	5%	Mesa et al. (2008)
Metabolic lesions	44%	≈	43%	Eder et al. (2009a)

IHNV = infectious hematopoietic necrosis virus.

Table B.3. Mortality Rates Were Lower in Barged Fish Than in ROR Fish at the Conclusion of the Disease Challenges or Net Pen Holding Experiments. FW represents freshwater and SW represents seawater.

Study	FW/SW	Barged Fish Experimental Mortality Rate		ROR Migrant Experimental Mortality Rate
Arkoosh et al. (2006)	SW	28%	<	65%
Dietrich et al. (2007)	SW	67%	<	83%
Dietrich et al. (2008)	FW	21.7%	<	48.8%
Eder et al. (2009a)	FW	18%	<	44%
Eder et al. (2009b)	FW	35%	<	39%

The net pen holding experiments sometimes showed barged migrants exhibiting higher rates of mortality in approximately the first 10 days. The greatest difference between barged fish and ROR migrants was only 3.4% on Day 6 (Dietrich et al. 2008) and 5.3% on Day 10 (Eder et al. 2009a). These patterns are consistent with those of $D < 1$, even if the difference in these net pen mortality rates were small, statistically significant, and possibly biologically significant. Also, the patterns of initially higher mortality in barged fish than ROR migrants only occurred in some occasions: in barged and ROR Dworshak Hatchery fish (Dietrich et al. 2008), in barged hatchery fish, and in “Bonneville” hatchery fish (Eder et al. 2009a). “Bonneville” fish were run-at-large and thus patterns could be explained by the origin of the fish. Furthermore, the ROR migrants showed considerably higher net pen mortality rates than barged fish at the conclusion of the net pen holding experiment.

Table B.4 illustrates that low mortality rates were observed at the estuarine site (Eder et al. 2009a, b). This may be due to the reduction of pathogens that deteriorate in seawater, such as *Saprolegniaceae*. Another possibility is that pathogens, such as *R. salmoninarum* and *Listonella anguillarum*, which can thrive in seawater (Banner et al. 1986; Sanders et al. 1992; Elliott et al. 1995), occurred at low rates (0% to 5%) in the year of the Eder et al. (2009a, b) studies. Higher prevalence of these pathogens may cause higher rates of mortality at the estuarine site, and may facilitate discernable differences between barged and ROR migrants. Replication of this study in years of high pathogen prevalence of *R. salmoninarum* and *L. anguillarum* would be needed to confirm this.

Table B.4. Qualitative Results of Pathogen Prevalence and Net Pen Mortality Rates in Freshwater and Estuarine Sites. Short term is approximately 10 days, and long term is 28 days. The text font is highlighted to emphasize the contradictory patterns of pathogen prevalence and mortality rates in the lower river.

Location	Effect		Barged Fish	ROR Migrants
Lower river (freshwater)	Pathogen prevalence		**High**	***Low***
	Net pen mortality rate	Short term	Moderate	Moderate
		Long term	***Moderate***	**High**
Estuary (brackish)	Pathogen prevalence		Low	Low
	Net pen mortality rate	Short term	Low	Low
		Long term	Low	Low

The seasonal net pen mortality rates in freshwater do not show consistent patterns. Barged fish showed a seasonal increase in mortality rates in the studies by Dietrich et al. (2008) and Eder et al. (2009b), and a decrease in the Eder et al. (2009a) studies. ROR migrants were limited in their sample sizes, thus seasonal trends for their mortality rates were only determined by Dietrich et al. (2008) and indicated that net pen mortality rates of ROR migrants increased across the season. The seasonal and spatial patterns of disease prevalence were also variable. The couple of trends that did appear were the lower prevalence of *R. salmoninarum* in the late group of ROR migrants relative to barged fish and earlier ROR migrants (Dietrich et al. 2008), and the prevalence of *Saprolegniaceae* increasing with migration distance. The importance of these findings to *D* is unclear.

Overall, disease may be responsible for a portion of post-hydrosystem mortalities of fish; however, the patterns are complex and sometimes may be overwhelmed by other factors. Infectious disease dynamics are complex processes that are influenced by a myriad of intrinsic and extrinsic factors. Health and disease exist upon a continuum with both disease progression and remission occurring during the infection cycle. Single snapshots of pathogen prevalence may not reveal where the animals are in the infection cycle. In addition, a variety of biases can affect the ability of pathogen prevalence estimates (apparent prevalence) to reflect true prevalence. For instance, a major bias is pathogen-associated mortality whereby infected fish are removed from the population before sampling, resulting in a lower estimate of prevalence. Pathogen-associated mortality may be occurring in ROR migrants during hydrosystem passage (Pascho et al. 1993). Thus, estimates of pathogen prevalence at BON may be higher in barged fish because they have not been subjected to pathogen-associated mortality. Treating the barged and ROR as parallel but independent groups and investigating how pathogens influence each population may be more informative.

Density and confinement can have major impacts on pathogen dynamics because they alter the relationship between host and pathogen and can influence opportunities for pathogen exposure. Extrapolation of results from net pen holding experiments to fish in the river and estuary may not be valid because of the radically altered host-pathogen relationship.

B.3.2 Travel Time as a Factor of *D*

The travel times of fish in the LRE may better explain patterns of *D* than disease alone. Relatively slow travel rates may be caused by incomplete smoltification. Schreck et al. (2006) hypothesized that fish that were not fully smolted stayed in the freshwater lens closer to the water surface than in seawater, and consequently had increased susceptibility to avian predation. Barged migrants, especially those early in the season, may be more susceptible to avian predation than ROR migrants. Predation, which is likely an important factor in *D*, is eliminated when experiments are conducted in net pens. Disease could also stress fish and reduce predator avoidance capability through a couple of mechanisms: 1) by producing slower response time to attacks by piscivorous birds and fish, and 2) by altering the fish's ability to enter seawater, thereby increasing its susceptibility to avian predation.

B.3.3 Size-Selective Predation as a Factor of *D*

Muir et al. (2006) hypothesized that differential growth opportunity between barged and ROR migrants caused differential predation risk in the freshwater and marine environments. Furthermore, smaller sized hatchery Chinook salmon are more likely to enter the bypass route and be transported on a barge (Congleton et al. 2005; Zabel et al. 2005). Muir et al. (2006) demonstrated size-selective predation among barged and ROR migrants by N. pikeminnow (freshwater) and Pacific hake (*Merluccius productus*, marine) with regression equations of selectivity. Controlled laboratory experiments also showed support for size-selective predation when prey had a difference of at least 20 mm in length (Mesa et al. 2008). However, as Mesa et al. (2008) note, barged and ROR migrants only differed in size by 5 to 8 mm at BON (Muir et al. 2006). Furthermore, the field survey overall failed to find supporting evidence for size-selective predation among N. pikeminnow below BON (Mesa et al. 2008). Schreck et al. (2006) also determined with radio-tagged barged and ROR spring/summer Chinook salmon that predation was minimal in the lower river. Thus in the lower river, differential predation risk and predation in general are not important factors of *D*. However, size-selective predation in the estuarine and marine environments is still possible. Field surveys in addition to the regression model of selectivity would be needed to determine if size-selective predation truly occurred in the estuarine and marine environments.

B.4 Report Highlights

The highlights of seven publications documenting research funded by the USACE that are referenced in Section 3.0 of this report are summarized in this appendix. For each publication, the full reference is provided and the main research goal(s) is defined, followed by sections that describe the study methods, results, and conclusions. The methods vary across studies, but may include descriptions of fish-sampling practices, laboratory and field experimentation (including the collection of physical and biological data), fish physiological and health status, and/or fish predation, as appropriate.

B.4.1 Arkoosh et al. 2006

Arkoosh MR, AN Kagley, BF Anulacion, DA Boylen, BP Sandford, FJ Loge, LL Johnson, and TK Collier. 2006. "Disease susceptibility of hatchery Snake River spring-summer Chinook salmon with different juvenile migration histories in the Columbia River." *Journal of Aquatic Animal Health* 18:223-231.

Main research goal: Assess the health of spring-summer Chinook salmon with three different migration life histories (no bypass, bypass, and barge transportation) by disease (*Listonella anguillarum*) challenge experiments in seawater that yielded cumulative incidences of mortality (2002 outmigration).

B.4.1.1 Methods

Samples

In 2002, 129,000 yearling spring-summer Chinook salmon were tagged with passive integrated transponder (PIT) tags at the Rapid River Hatchery (RR); 3200 of the tagged salmon were recaptured at Lower Granite Dam (LGR) and transported to BON as the barged treatment group, and the rest were separated and queried by Separation by Code (SbyC) and PIT Tag Information System (PTAGIS) to determine occurrences of bypass at LGR, Little Goose Dam (LGS), Lower Monumental Dam (LMN), McNary Dam (MCN), and John Day Dam (JDA). In-river fish collected at BON from May 11 to 18 and May 26 to June 3 were categorized into treatment groups of no bypass life history or bypass life history (at least one dam bypass).

Experimentation

All fish samples collected at BON were transported to the Fish Disease Laboratory (FDL) at the Hatfield Marine Science Center (HMSC) in Newport, Oregon, for experimentation. In the first disease challenge, the lethal concentration of *L. anguillarum,* which yielded 50% incidence of mortality (LC50) on day 10, was determined by testing six different concentrations (range: 2.5×10^6 to 1.6×10^8 colony-forming units [cfu]/mL) with a 1-h exposure. Sample sizes were 6 replicates of 40 fish (20 barged, 10 with ≥ 1 bypass, 5 with ≥ 2 bypass, and 5 with no bypass). After the disease treatment, fish were transferred to seawater tanks and mortalities were observed for 10 days. A subsample of morbid fish was tested to confirm the presence of *L. anguillarum* in the kidneys. In the second disease challenge, fish were tested with the LC50 determined in the first disease challenge. Sample sizes were 14 replicates of 39 fish (16 barged, 11 with ≥ 2 bypass, 12 with no bypass). Control fish (14 replicates of 39 fish with the same proportions of treatment groups) not exposed to *L. anguillarum* were also tested and observed for mortality.

Analysis

A nonparametric approach (Marubini and Valsecchi 1995) was used to analyze the cumulative incidence of mortality and standard error. Background mortality rates from the control fish were subtracted from treatment fish before analysis.

B.4.1.2 Results

In the first disease challenge, with replicates of concentrations 2.8×10^6 and 1.4×10^7 cfu/mL pooled, the percentage of cumulative mortality over the 10-day observational period for barged fish was significantly less than that of no-bypass fish ($p=0.005$), but not significantly less than that of bypass fish. In the second disease challenge, with the predetermined LC50 concentration of 6×10^6 cfu/mL and larger sample sizes, barged fish had a significantly lower percent cumulative mortality than no-bypass fish ($p < 0.001$) and bypass fish ($p < 0.001$).

B.4.1.3 Conclusions

Based on an assessment of health via cumulative percent mortality of spring-summer yearling Chinook salmon acutely exposed to *L. anguillarum*, barging is more successful than bypass as a migration strategy.

B.4.2 Dietrich et al. 2007

Dietrich J, D Boylen, D Spangenberg, C Bravo, D Thompson, E Loboschefsky, M Arkoosh, T Collier, and F Loge. 2007. *Disease Susceptibility of Hatchery-Reared Yearling Snake River Spring/Summer Chinook Salmon with Different Migration Histories in the Columbia River*. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Code BPS-00-10.

Main research goals: Replicate the Arkoosh et al. 2006 study, by determining the relative health and cumulative incidences of mortality of barged, in-river no bypassed, and in-river bypassed yearling spring-summer Chinook salmon in disease challenges with *L. anguillarum* in seawater at HMSC-Fish Disease Laboratory (FDL). In addition, record the environmental and physiological characteristics to compare them with the performance of the fish in the disease challenges.

B.4.2.1 Methods

Samples

In 2006, 45,000 yearling spring-summer Chinook salmon were PIT-tagged at each of two hatcheries (Dworshak Hatchery [DWK] and Rapid River Hatchery [RR]) and pooled with an additional 17,000 individuals at each hatchery PIT-tagged for the Comparative Survival Study. All collected fish were detected by SbyC. The barged treatment group of fish were collected at LGR, placed in net pens in the barge holds, barged to BON, and then trucked to HMSC-FDL. The ROR migrants were collected at the BON Juvenile Fish Monitoring Facility and trucked to HMSC-FDL. Two types of control fish were collected—one that was collected at LGR and trucked to HMSC-FDL (which the authors label as an experimental group) and another that originated directly from the Leaburg Hatchery (Leaburg, Oregon). Laboratory Experimentation

Similar to Arkoosh et al. 2006, two disease challenges were conducted: one to determine the LC50 (bacterial concentration required for 50% mortality on the ninth day of the challenge) among seven different concentrations tested, and the second to test at the LC50. Test subjects were exposed to *L. anguillarum* for 1 hour and subsequently observed for mortality over a 9-day period. Sample sizes consisted of 20 LGR controls, 20 transported, 20 in-river, and 7 Leaburg controls. The second disease challenge was replicated three times. Table B.5 lists the physical and biological data that were collected during laboratory experimentation.

Table B.5. Physical and Biological Data Collected by Dietrich et al. (2007)

Characteristic	Units of Data	Sample Size	Method/Comments
1. Water temperature	°C	Daily measurements	From USACE hydrometeorological database
2a. Influent discharge	kcfs	Daily measurements	From USACE hydrometeorological database
2b. Spill rates	kcfs	Daily measurements	From USACE hydrometeorological database
3. Migration rate	River miles/d		
4. Total and fork lengths	cm	All fish when tagged at hatcheries, when collected at LGR and BON, and at the end of the disease challenge	
5. Mass	g	All fish collected at LGR and BON and at the end of the disease challenge	
6. Condition factor	g/cm^3 x 100	All fish collected at LGR and BON and at the end of the disease challenge	
7. Chemical contaminants in stomach contents, bile and gutted whole body	ng contaminant/g wet mass or lipid or bile	90 total (5 individuals x 3 sites x 3 time periods x 2 hatchery origins)	PAHs, PCBs, DDTs, PBDEs, and organochlorine pesticides

Table B.5. (contd)

Characteristic	Units of Data	Sample Size	Method/Comments
8. Osmoregulation status, Na^+/K^+ ATPase activity	µmoles ADP/mg protein/hour	216 total (18 individuals x 6 treatment or control groups x 2 time periods)	Tissue preservation (Zaugg 1982; McCormick and Bern 1989). ATPase activity processing (McCormick and Bern 1989)
9. Incidence of infectious diseases	Presence/absence	36 from LGR, 31 barged, 111 ROR, and x from Leaburg Hatchery collected throughout migration period	Visual inspection of fish, microscopic examination of gill tissue and skin scrapes, pathogen analysis of kidney tissue samples, ELISA for *R. salmoninarum*
10. Immunologic gene expression	Fold change (reference is fish from all treatment groups, unitless); expression ratio (Barge to In-river, unitless)	4 fish from each replicate treatment and control tank prior to challenge, and 2 and 7 days after challenge	Microarrays; liver tissue samples

ADP = adenosine diphosphate; BON = Bonneville Dam; d = day(s); DDTs = dichlorodiphenyltrichloroethanes; ELISA = enzyme-linked immunosorbent assay; I/B = in-river-to-barge; kcfs = kilo cubic feet per second;LGR = Lower Granite Dam; ng = nanogram(s); PAHs = polycyclic aromatic hydrocarbons; PBDEs = polybrominated diphenyl ethers;PCBs = polychlorinated biphenyls; ROR = run-of-river; USACE = U.S. Army Corps of Engineers

B.4.2.2 Results

Laboratory Experimentation

In the first disease challenge, the LC50 was determined to be $8.0 \cdot 10^4$ cfu/mL. From this challenge at LC50, several patterns in cumulative percent mortality were observed: 1) ROR migrants had greater mortality than barged fish; 2) ROR migrants had greater mortality than fish collected at LGR; and 3) no significant difference in mortality existed between barged fish and fish collected at LGR. In the second disease challenge, the same patterns among groups in the first disease challenge were observed. Mortality rates of Leaburg Hatchery fish were used to confirm that the fish from the three treatment groups did not die from husbandry practices.

Physical and biological data related to the following parameters were collected:

- **Water temperature**. The river temperature increased from 8°C in mid-April to 13°C in late May. The authors concluded that water temperature had no influence on the juvenile Chinook salmon because the temperatures were generally within the optimal range of 10°C to 15.6°C and less than the maximum of 18°C (State of Oregon).
- **Influent discharge and spill rates**. At the time of the study, the average rate of spill from Snake River dams was 134.4 kcfs, and from Columbia River dams it was 322.9 kcfs. The average percent spill of influent discharge was 36.3% (48.8 kcfs) at LGR and 33.5% (108.2 kcfs) at BON. The authors speculated that migration rates were higher during this study than during the one conducted in 2002 because of the increased volume of water spilled.
- **Migration rates**. Migration rate linearly increased as the juvenile Chinook salmon swam further down the hydrosystem (i.e., with increasing distance from release point): 3.58 river miles [RM]/d

(RR) and 2.26 RM/d (DWK) at LGR, and 7.64 RM/d (RR) and 7.65 RM/d (DWK) at BON. Sampled fish tended to have a slower migration rate than all PIT-tagged fish.

- **Total lengths**. RR juvenile Chinook salmon were 15.0 cm long at LGR and 15.4 cm long at BON, and DWK juvenile Chinook salmon were about 14.3 cm long at LGR and 14.8 cm long at BON. The authors noted that the increase in length may be due to growth or culling of smaller sized fish. At the time of tagging, the fish were considerably smaller (< 10 cm) than when they were migrating out of the hydropower system, and by the end of the challenge study the RR fish had grown 0.6 cm and the DWK fish had grown 2.5 cm from the time they were collected at BON.
- **Mass**. RR juvenile Chinook salmon weighed 29.2 g at LGR and 29.9 g at BON, and DWK fish weighed 24.3 g at LGR and 26.4 g at BON. When comparing across the outmigration period, RR early cohorts were heavier than late cohorts while their lengths were the same, and DWK fish had the same mass while their lengths increased over the season.
- **Condition factor (CF)**. The CF was generally above 1.0 and tended to decrease throughout the outmigration season for both RR and DWK.
- **Chemical contaminants in stomach contents, bile, and gutted whole body**. Too few stomach contents were available for analysis. In bile, polycyclic aromatic hydrocarbon (PAH) levels were similar to levels determined for fall Chinook salmon, but could not be compared to studies that found adverse health and suppressed immunological effects because levels were measured by wet weight and not bile. In gutted whole bodies, lipid-adjusted Σ dichlorodiphenyltrichloroethanes (ΣDDTs) were greater than the 500 ng/g lipid threshold for adverse health effects in the laboratory and at about the lower range of 30 ng/g wet weight in the field, but considerably lower than the U.S. Environmental Protection Agency threshold of 150 ng/g wet weight beyond which toxic accumulation occurs in fish-eating predators. For lipid-adjusted ΣPCBs, only DWK ROR migrants had level greater than 2400 ng/g lipid, which is the NOAA Fisheries' estimated threshold of adverse effects upon which enzyme induction and mortality can occur. The organochlorine pesticides detected were low in concentration relative to levels observed for DDTs and polychlorinated biphenyls (PCBs).
  - There was no detectable accumulation of contaminants by wet weight for barged or ROR migrants. However, lipid-adjusted concentrations of contaminants increased in ROR migrants because of the decrease of lipid reserves as they pass through the hydrosystem. The lower volume of lipids available to sequester contaminants may cause increased toxicological effects. The authors hypothesized that increased levels of contaminants would alter immune function, increase disease susceptibility, and increase mortality in their disease challenges. Contaminant levels and incidences of mortalities were generally higher in fish from BON relative to fish from LGR, and higher in fish from DWK relative to fish from RR. It is important to note that the effects of single contaminants and synergistic effects of contaminants on immune function are unknown.
- **Osmoregulation status, Na+/K+- adenosine triphosphatase (ATPase) activity**. After 2 days of holding in freshwater at the laboratory, ROR migrants (12.18 μmol ADP/mg protein/h) had higher levels than barged fish (7.53 μmol ADP/mg protein/h). By the ninth day of holding, all four treatment and control groups had the same levels of Na+/K+ ATPase activity. The authors note that these samples were collected from May 13 to 15 at LGR and BON, and that different patterns may have been occurred for earlier migrating fish.

- **Incidence of infectious diseases (bacterial, viral, parasitic)**. Among the fish mortalities that occurred in the laboratory tanks throughout the season, most of the fish were infected with Saprolegnia spp. ("fuzzy tail" disease; range 7% to 44%) and infectious hematopoietic necrosis virus (IHNV; range: 14% to 100%), and to a lesser extent with bacterial infections of Flavobacterium sp. and pseudomonas spp. and the parasite Ceratomyxa shasta. The authors observed no difference in incidences of infection between barged fish and fish collected at LGR. However, these rates were higher than those for ROR migrants.
  - Among the 111 ROR migrants collected at BON from May 16 to 17, none was infected with *R. salmoninarum* (bacterial kidney disease [BKD]), while 1.6% of RR migrants and 5.7% DWK migrants were infected with IHNV.
  - In the samples of fish held in laboratory tanks and unchallenged, delayed disease-induced mortality observed in barged fish and fish collected at LGR was greater than that for ROR migrants. During the initial 3 weeks of holding, a period comparable to the travel time for hydrosystem passage of ROR migrants, mortality rates associated with infectious diseases for groups of barged fish and fish collected at LGR were upwards of 20% relative to ROR migrants. The authors remark that the sources of natural infections and the influence of barge and bypass activities on disease transmission remain unknown.
- **Immunologic gene expression**. After the disease challenge, barged fish had greater expression intensities than ROR migrants for three genes: 1) lipocalin, associated with the acute immune response; 2) serum albumin 1 precursor, associated with osmotic blood pressure regulation; and 3) cathespin K precursor, associated with cellular degradation of proteins. Conversely, ROR migrants had greater expression intensities than barged fish for seven genes, the top three of which were 1) C1q-like adipose specific protein, associated with carbohydrate metabolism and possibly the stress response[1]; and 2&3) differentially regulated trout proteins 1 and 2, which have unknown functions. A couple of the other interesting genes were precerebellin-like protein, associated with the acute immune system, and biotinidase precursor, associated with processing of fats, carbohydrates, and proteins.

B.4.2.3 Conclusions

In the disease challenge, barged fish survived better than ROR migrants. This supports the hypothesis that passage through hydropower system is stressful and barging alleviates the stress associated with passage through the hydrosystem and improves post-hydrosystem survival.

Biological characteristics that match the results in the disease challenge (i.e., barged fish performed better than ROR migrants) include the following:

- shorter travel times from LGR to BON
- higher CF
- lower lipid-adjusted contaminant concentrations.

[1] C1qASP was not found in the National Center for Biotechnology Information database, the accession number given is a typo (accession number of a differentially regulated trout protein related to immune function was typed).

Characteristics that did not match patterns in the disease challenge (barged fish relative to ROR migrants) include the following:

- greater length and mass in ROR migrants than barged fish
- lower Na^+/K^+-ATPase activity at time of collection and no difference in Na^+/K^+-ATPase activity by end of disease of challenge
- higher incidences of infectious diseases.

Furthermore, differences in the biological characteristics of fish from the two hatcheries also reflected their survival patterns in the disease challenge where RR fish performed better than DWK fish. These differences include shorter travel times, greater total length and mass, lower levels of toxins, and lower incidences of disease infections.

The authors conclude that the most interesting gene overexpressed in barged fish was related to the acute immune system, while that of ROR migrants was associated with the stress response. However, with further research, we could not find information on the C1qASP gene and its association with the stress response. Also, the two genes remarkably overexpressed (expression intensities of 110,000 and 1.5 million) have unknown functions, and thus further research is needed for this information to be useful. Finally, interpretation of gene expression must be done with caution because upregulation of gene expression could be in response to a negative condition (i.e., stress) or could have already resulted in the alleviation of a negative condition (i.e., adaptation to the stress).

B.4.3 Dietrich et al. 2008

Dietrich J, D Boylen, B Fleenor, J Groff, G Hutchinson, J Osborn, S Strickland, D Thompson, A Van Gaest, T Collier, M Arkoosh, and F Loge. 2008. *Estimate of Hydrosystem Delayed Mortality Associated with Barged and In-River Outmigration Life-History Strategies of Snake River Spring/Summer Chinook Salmon*. Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Code BPS-00-10.

Main research goals: Expand on the Arkoosh et al. 2006 (2002 outmigration) and Dietrich et al. 2007 (2006 outmigration) studies related to disease susceptibility and post-hydrosystem survival of barged and in-river migrating yearling spring/summer Chinook salmon. More specifically the research related to the 2007 outmigration was intended to accomplish the following:

- Estimate delayed mortality of the fish in net pens placed at freshwater sites in the lower Columbia River and estuary.
- Determine water quality (water temperature, dissolved oxygen, pH, conductivity, pathogens in water) and biological characteristics of the fish (size, mass, energetic reserves, immune function, chemical contaminants, and disease prevalence) that influence post-hydrosystem survival across the outmigration season.

B.4.3.1 Methods

Samples

Nearly 140,000 yearling spring-summer Chinook salmon from RR and DWK hatcheries were PIT-tagged and released in 2007. The ROR treatment group of fish was detected by SbyC at the BON Juvenile Fish Monitoring Facility, collected, and transported by truck to the net pen sites (Blind Slough and Tongue Point). The barged treatment group of fish was detected by SbyC at LGR, collected, placed in net pens in barge holds, and transported to BON, where the fish were transferred to trucks and transported to the net pen sites.

Field Manipulative Experimentation

The samples of barged and ROR fish in net pens at Blind Slough and Tongue Point were fed and observed for mortalities over 28 days. Table B.6 lists the physical and biological data that were collected during the Dietrich et al. (2008) study.

Table B.6. Physical and Biological Data Collected During the Dietrich et al (2008) Study

Characteristic	Units of Data	Sample Size	Method/Comments
1. River conditions			
a. Temperature	°C		
b. Flow	(data not reported)		
2. Barge water conditions			
a. Temperature	°C		
b. Dissolved oxygen	mg/L		
3. Net pen conditions			
a. Temperature	°C		
b. Dissolved oxygen	mg/L		
c. pH	unitless		
d. Specific conductivity	mS/cm		
4. Histopathology of morbid fish from net pens: disease prevalence	% of individuals infected among mortalities	1187 fish (64% of all mortalities)	Gills and internal viscera collected for various histological processing and microscopic examination.
5. Pathogen prevalence (11 species) a. Fish samples b. Water samples	a. % of individuals infected among all fish examined b. Presence/ absence	1200 fish (10 fish pre- and 10 fish post- net pen holding experiment × 12 net pens); various water samples at hatcheries, LGR, MCN, BON, challenge net pens	Anterior head kidney tissue collected Water samples (Rajal VB et al. 2007a, b methods) DNA and RNA extraction, cDNA conversion, PCR assay, gel electrophoresis (water), capillary electrophoresis (fish)
6. Migration rate	(data not reported)		
7. Fork length	cm		
Mass	g		
Condition factor	CF= g/cm^3 x 100		

Table B.6. (contd)

Characteristic	Units of Data	Sample Size	Method/Comments
8. Lipids a. Whole lipids b. Lipid classes	% wet weight % total lipids		a. Sum of composite samples determined in b. b. Thin layer chromatography with flame ionization detection (Ylitalo et al. 2005)
9. Immune Function a. Hematocrit b. Lysozome	a. % PCV b. µg/ml HEWL equivalents		a. Microhematocrit centrifuge, Total blood volume and PCV measured b. Microplate turbidimetric method
10. Chemical contaminants	ng/g wet weight ng/g lipid		gas chromatography/mass spectrometry

BON = Bonneville Dam; cDNA = complementary deoxyribonucleic acid; CF = condition factor; cm = centimeter(s); DNA = deoxyribonucleic acid; g = gram(s); HEWL = hen egg-white lysozyme; LGR = Lower Granite Dam; MCN = McNary Dam; mg = milligram(s); ng = nanogram(s); mS = millisiemen(s); PCR = polymerase chain reaction; PCV = packed cell volumes; RNA = ribonucleic acid

B.4.3.2 Results

Field Manipulative Experimentation

When comparing all barged versus ROR migrants (across both net pen sites, both hatcheries, and three outmigration periods), mortality was greater (3.4%) in barged fish than ROR migrants during the first 10 days of the net pen holding experiment. Thereafter, this pattern reversed with ROR migrants having greater mortality (27.1%) than barged fish. The Blind Slough site generally showed greater mortality than the Tongue Point site, and it also exhibited patterns of a second increase in mortality towards the end of the 28-day challenge period. DWK fish had greater mortality for barged groups than RR fish, while the opposite pattern occurred for ROR migrants. The net pen mortality of ROR migrants increased across outmigration season among the early, middle, and late cohorts. Among barged fish, the middle cohort had the lowest net pen mortality, followed by the early and late cohorts.

Physical and biological data related to the following parameters were collected:

- **River conditions.** Water temperatures increased from 9°C in mid-April to 15°C in late May at BON. These temperatures were within the optimal range of 10°C to 15.6°C, and below the maximum of 18°C for migrating salmon (Oregon Department of Environmental Quality). River flows were not reported in the results section.
- **Barge water conditions.** Water temperatures ranged between 9°C and 14°C, and dissolved oxygen was within acceptable ranges of 8.2-12.6 mg/L.
- **Net pen conditions.** Water temperatures increased from approximately 11.5°C to 18.3°C across the season, and Blind Slough generally had temperatures from 0.5°C to 2°C greater than Tongue Point. Dissolved oxygen was greater than 8.8 mg/L, and it was generally 2 mg/L lower at Blind Slough than at Tongue Point. pH ranged between 7.05 and 7.5 at Blind Slough, and between 8.05 and 8.85 at Tongue Point. Specific conductivity ranged between 0.06 mS/cm and 0.1 mS/cm at Blind Slough, and varied between 0.13 mS/cm and 0.29 mS/cm at Tongue Point. Water was constantly flowing through Tongue Point, while less than 40% of the water at Blind Slough was replaced at each tidal cycle.

- **Histopathology of morbid fish from net pens.** The four most common infectious diseases, starting with the highest, were mycosis, enteric ceratomyxosis, membranous glomerulopathy, and BKD. Rates of mycotic infections most closely followed the patterns of cumulative mortality in net pens. Rates of enteric ceratomyxosis and membranous glomerulopathy were low during the challenge initially, but then increased at greater rates in ROR migrants than in barged fish. BKD had a low persistence in both treatment groups. The prevalence of all diseases, except for mycosis in the in-river group, was greater at Blind Slough than at Tongue Point. Disease prevalence was also greater in late cohorts than early and middle cohorts.
- **Pathogen prevalence survey.** Among the water samples collected, BKD was detected in barge holds once in late April when fish were unloaded, and a couple of times at Blind Slough in mid-May and early June. *Saprolegniaceae* was detected a total of seven times at the MCN tailrace, BON bypass and tailrace, barge holds upon loading and unloading, and Blind Slough. In fish samples, BKD or *Saprolegniaceae* were detected in at least one individual from each sample. Across all sampling sites, 60.6% of barged fish and 44.4% of ROR migrants were positive for BKD. The prevalence of BKD among fish increased by 5% from LGR (~25%) to MCN (~30%) and 21% from LGR to BON (~45%) among ROR migrants, and by 37% from LGR (20.6%) to BON (57.4%) among barged fish. Transmission of *R. salmoninarum* likely occurred during barging via shedding from diseased individuals originally infected at hatcheries. Transmission of *Saprolegniaceae* was also likely during barging via shedding from diseased ROR migrants.
- **Migration rate**. Not reported.
- **Fish length, mass, and CF.** ROR migrants, as they migrated through the hydrosystem, gained as much as 1 cm in length and 3 g in mass. There was only a decrease in mass between the hatcheries and LGR. CFs at the hatcheries were about 1.5 and decreased to 0.95 at LGR and 0.88 at BON. CFs remained below 1 throughout the net pen holding. Also, fish CFs at Blind Slough were lower than those at Tongue Point.
- **Lipids.** For DWK fish, percent lipid by wet weight was 7.0% at the hatchery, and decreased to 2.6% at LGR. Post-hydrosystem, lipids were 0.5% in ROR migrants and 1.5% in barged fish. Lipid levels of RR fish followed the same pattern as DWK fish. Lipid levels were 4.7% at the hatchery, and decreased to 1.6% at LGR. At BON, lipid levels were 0.4% in ROR migrants and 1.2% in barged fish. Triglycerides, the predominant energy store in fish, were over 90% of lipids at the hatchery. The levels decreased to less than 25% once fish reached BON. Interestingly, at the conclusion of the 28-day net pen holding experiment, the triglyceride levels were very low (3%) for ROR migrants at Blind Slough relative to all other treatment groups and locations, which regained higher levels of triglycerides over the 28-day net pen holding experiment.
- **Immune function.** Hematocrit, the proportion of blood volume that is occupied by red blood cells and serves as a measure of fish health, was on average 48% for fish at the hatcheries, and significantly increased after hydrosystem passage to 58.7% in barged fish and to 54.0% in ROR migrants ($P < 0.0001$). During net pen holding, both treatment groups significantly decreased in hematocrit levels. Also, hematocrit levels decreased throughout the season among the early, middle, and late cohorts. For lysozyme activity, high levels (relative to reference levels of fish at DWK and RR prior to release) occurred significantly more often in barged fish than ROR migrants at the start of net pen holding ($p < 0.0005$). After 14 days of the net pen holding experiment, barged fish had lower lysozyme activity than ROR migrants ($p=0.0001$); and by the end of the challenge both groups were not statistically different ($p = 0.2223$).

- **Chemical contaminants.** The chemical contaminant with the highest levels that would affect fish health was PAH at levels between 2.3 and 7 μg PAH/g fish per day across all treatment groups and locations. Threshold levels as low as 2.3 μg PAH/g fish per day can cause negative physiological effects, and levels as low as 0.7 μg PAH/g fish per day can adversely affect growth. For DDT, the fish analyzed generally did not exceed adverse health threshold levels determined in the laboratory (5000 ng DDT/g lipid). Only RR ROR migrants at BON had levels of 5400 ng DDT/g lipid, which is comparable to this threshold. The highest levels of ΣPCBs, which were 1400 ng/g lipid in ROR migrants, did not surpass adverse threshold levels (2400 ng ΣPCBs/g lipid). Polybrominated diphenyl ether (PBDE) levels were less than 500 ng PDBE/g lipid, and were also less than levels that can enhance disease susceptibility (1600 ng PBDE/g lipid). The determination of any apparent patterns in accumulation of contaminants was limited by small sample sizes. By and large, levels of DDT, ΣPCBs, and PBDEs by lipid mass increased in ROR migrants from DWK and RR to BON, and ROR migrants generally had higher levels of these contaminants than barged fish. Levels of PAHs in the bile remained low across this distance, then increased during the net pen holding experiment.

B.4.3.3 Conclusions

Overall, ROR migrants had higher disease susceptibility and cumulative mortality rates than barged fish during the 28-day net pen holding experiment. Biological characteristics that supported this mortality pattern in ROR migrants relative to barged fish were lower CF, lower lipid levels post-hydrosystem and a likely greater mobilization of contaminants, and concentrations of DDT and PAH above threshold levels. Conversely, characteristics that did not support this pattern (ROR relative to barged fish immediately after hydrosystem passage) were greater length and mass, same levels of hematocrit, lower levels of lysozyme, and lower prevalence of diseases.

The initial and relatively small amount of mortality in barged fish could be due to weak and diseased individuals. Once they were culled, barged fish survived better than ROR migrants throughout the rest of the net pen holding experiment. This initial higher rate of mortality among barged fish is a pattern consistent with the mortality of barged fish in holding tanks during the initial 3 weeks of the Dietrich et al. (2007) study.

Environmental characteristics that may have increased mortality rates were higher water temperature, lower dissolved oxygen, and lower water flow/exchange at Blind Slough relative to Tongue Point.

The authors concluded that in-river migration history, barging, and environmental conditions each exacerbated infectious diseases among migrants, and that the majority of mortalities during the net pen holding experiment were due to diseases.

B.4.4 Mesa et al. 2008

Mesa MG, MH Averbeck, AG Maule, DG Elliott, amd AL Miracle. 2008. *Mechanisms of Delayed Mortality in Juvenile Salmonids Outmigrating in the Columbia River Basin – Draft Final Report FY 2008*. Prepared by the U.S. Geological Survey, Western Fisheries Research Center, Cook, Washington, the USGS, Seattle, Washington, and Pacific Northwest National Laboratory, Richland, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Main research goal: Determine mechanisms of delayed mortality of yearling Chinook salmon related to physiological condition, disease, and size-selective predation.

B.4.4.1 Methods

Samples

The control and treatment groups were PIT-tagged spring Chinook salmon collected at DWK and RR ("control group"), LGR ("control group"), transport barges (transport group), and JDA and BON (ROR group).

Physiological and Health Status

Samples were collected to estimate plasma cortisol levels, thyroxine levels, Na+/K+-ATPase activity, number of genes over- and under-expressed. Complementary DNA (cDNA) microarrays were used to develop gene expression profiles. Pathogen prevalence was quantified by real-time quantitative PCR for *R. salmoninarum*, *Yersinia ruckeri, Aeromonas salmonicida, Flavobacterium psychrophilum* IHNV, myxosporean parasite *Ceratomyxa shasta,* and microsporidian parasite *Nucleospora salmonis*.

Size-Selective Predation

Manipulative predation experiments were conducted in a laboratory setting with N. pikeminnow and spring Chinook salmon with a 10-mm difference in length for test 1, and a 20-mm difference in length for test 2. In a field survey, length frequency distributions were determined for transported yearling Chinook salmon at BON, ROR yearlings at the BON Juvenile Fish Monitoring Facility, and yearling Chinook in N. pikeminnow diet below BON. Samples were collected from May 9 to 24, 2004, June 27 to 30, 2004, May 11 to 20, 2005, and June 26 to 30, 2005.

B.4.4.2 Results

Physiological and Health Status

Plasma cortisol concentrations were lowest in fish at the hatcheries (< 25 ng/mL), intermediate in fish that were barged (range = 75–175 ng/mL), and highest in ROR fish (range = 200–300 ng/mL). Thyroxine concentrations were low in all fish (1–3 ng/mL). Gill Na^+/ K^+-ATPase activity were low (3–4 µmol P h^{-1} mg $protein^{-1}$) at the hatcheries early in the season, and high (5–10 µmol P h^{-1} mg $protein^{-1}$) in barged and ROR fish during outmigration. The most notable changes in gene expression were up- and down-regulation of immune system-associated genes in barged fish and over-transcription of stress-responsive genes in barged fish. Very few significant differences in gene expression existed in ROR fish, with the exception of down-regulation of a few immune function genes. Other genes differentially expressed included metabolism, protein biosynthesis, electron transport, development, apoptosis, nucleosome assembly, and protein polymerization. The most prevalent pathogens detected were *R. salmoninarum* (detected in 85% of fish in 2005 and in 67% of fish in 2006), *N. salmonis* (detected in 17% of fish in 2005 and in 26% of fish in 2006), and IHNV (detected in < 1% of fish in 2005 but in 11% of fish in 2006). An increase in IHNV was observed in 2006 and occurred in barged fish only. Year-to-year variation in pathogen profiles occurred. A combination of pathogens was often present in fish.

Size-Selective Predation

In the laboratory experiment, N. pikeminnow selectively fed on smaller juvenile salmon when the difference in prey size was at least 20 mm, but not 10 mm. The diet analysis showed little evidence of size-selective predation by N. pikeminnow based on a comparison of juvenile salmon consumed versus those available in the environment.

B.4.4.3 Conclusions

The authors concluded that, overall, barged fish were more affected than ROR migrants based on their results for pathogen prevalence and gene expression. Although the authors determined that size-selective predation by N. pikeminnow occurred among prey with at least a 20-mm difference in length in manipulative experiments, they concluded that size-selective predation did not occur below BON. The authors recommend continued research on disease-related delayed mortality and refinement of gene expression research from cDNA microarrays to a relatively small number of target genes with known functions. This would help generate more information about the patterns of fish health for both modes of transport and migrants experience with chronic or acute stress.

B.4.5 Eder et al. 2009a

Eder K, D Thompson, R Buchanan, J Heublein, J Groff, J Dietrich, J Skalski, C Peery, M Arkoosh, T Collier, and F Loge. 2009a. *Survival and Travel Times of In-River and Transported Yearling Chinook Salmon in the Lower Columbia River and Estuary with Investigation into Causes of Differential Mortality*. Prepared by the University of California, Davis, California, the University of Washington, Seattle Washington, the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, the University of Idaho, Moscow, Idaho, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Codes BPS-00-10 and SPE-06-2.

Main research goals: As an annual replicate study and extension of the Dietrich et al. (2007) study, the goals of this study were to do the following:

- Estimate survival and travel time through three reaches from LGR to rkm 8.3 for barged and in-river migrating yearling Chinook salmon.
- Determine survival in a 28-day net pen holding experiment at Tongue Point (freshwater site) and Sand Island (saline site).
- Associate covariates (release date/migration timing, collection source, LGR and BON discharge, length, weight, CF, histopathology, pathogen prevalence, blood protein levels) with patterns of survival and travel times.

B.4.5.1 Methods

Samples

From mid-April to late May 2008, yearling Chinook salmon were collected and acoustic tagged (using the Juvenile Salmon Acoustic Telemetry System [JSATS]) and PIT-tagged at LGR, and either released for in-river migration through the hydropower system or barged to BON and subsequently released. Additional run-at-large yearling Chinook salmon were collected at BON or JDA and acoustic and PIT tagged. Reference fish from the RR stock were raised at the Newport Research Station FDL, but not tagged. A subsample of barged fish, a subsample of ROR migrants, the run-at-large fish tagged at BON, and the Reference fish were collected at BON and trucked to net pens at Tongue Point and Sand Island. Toward the end of the season, ROR migrants were collected at JDA rather than at BON because of high flow conditions that resulted in operational changes and low collection efficiency.

Experimentation and Analysis

Experimentation and analysis considered travel time and survival and involved a net pen holding experiment.

Travel Time and Survival

Estimates of travel times and survival were determined through the Federal Columbia River Power System (FCRPS) and in the LRE for three different reaches: Reach 1, LGR to rkm 202; Reach 2, rkm 202 to rkm 35.6; Reach 3, rkm 35.6 to rkm 8.3. Fish were tagged with JSATS acoustic tags and detected by concomitant detection arrays deployed as part of other ongoing studies. Covariates measured and tested for travel time and survival were 1) collection source and holding duration; 2) length and weight at time of tagging; 3) collection, tagging, and release dates; and 4) average daily discharge at both LGR and BON. The relative survival ratio between barged and ROR migrants (B:I ratio) was determined for the three reaches separately and combined. Furthermore, bird predation was estimated from PIT tags recovered on East Sand Island.

Net Pen Holding Experiment

A 28-day challenge experiment in net pens was executed at Sand Island (saline site, rkm 7) and Tongue Point (freshwater site, rkm 29) for barged fish, ROR migrants, BON fish, and Reference fish from early, middle, and late season passage cohorts. Covariates measured and tested for net pen mortality were 1) migration timing, 2) fish condition at tagging, 3) handling at LGR, 4) environmental conditions, 5) barged or in-river migration, and 6) fish health pathogen.

B.4.5.2 Results

Travel Times and Survival

As shown in Figure B.1, in Reach 1 (LGR to below BON, rkm 202), barge transportation (36 hours) was much quicker than in-river migration (10 to 19 days). Survival of barged fish was approximately twice as high as that of ROR migrants. The B:I ratio was highest in this reach among the three tested, and ranged from 1.56 (middle cohort) to 1.97 (early cohort).

In Reach 2 (rkm 202 to 35.6), travel time was longer for barged fish (2 to 5 days) than for ROR migrants (approximately 1.7 days), and decreased from 3 times longer in duration early in the season to 1.3 times longer in duration late in the season. Survival was slightly higher for ROR migrants than for barged fish. The B:I ratio ranged between 0.86 (middle cohort) to 0.98 (early cohort). Survival was generally highest in this reach for ROR migrants, even though their travel speed was slowest in this reach. For barged fish, survival was second highest in this reach.

In Reach 3 (rkm 35.6 to 8.3), the travel time was again longer for barged fish (0.6 to 1.5 days) than for ROR migrants (approximately 0.5 days), and decreased from 2.7 times longer in duration early in the season to 1.3 times longer in duration late in the season. Mirroring this pattern of travel time was the B:I ratio, which increased from 0.77 to 0.98 across the season.

Despite the poorer survival of barged fish in Reaches 2 and 3 relative to ROR migrants, overall survival across all three reaches was greater for barged fish than for ROR migrants.

Bird predation was greatest for barged fish in the early and middle season (7%) and lowest for ROR migrants across the season and for barged fish in the late season (2% to 3%).

Covariates of Survival

Collection, tagging, and release dates were highly correlated. Fish weight and length were also correlated. The correlation between single variables and survival in Reach 1 or 2 and 3 were determined. In Reach 1, survival of ROR migrants was significantly ($\alpha = 0.05$) correlated with fish length at tagging, weight at tagging, and holding duration. The collection date was only significant at the level of $\alpha = 0.1$. In Reaches 2 and 3, none of the covariates was significantly correlated with survival of ROR migrants. For barged fish in Reach 1, collection, tagging, and release dates, and the collection source were significantly correlated with survival; and in Reaches 2 and 3, collection, tagging, and release dates, length and weight at tagging, holding duration, and BON discharge were significantly correlated with survival. No multivariate analyses were performed with the survival data.

Covariates of Travel Time

All of the single variables tested against travel time of barged and ROR migrants in each of the reaches were highly significant, except for holding duration of ROR migrants and travel time in Reach 2. Multivariate regression analyses were performed.

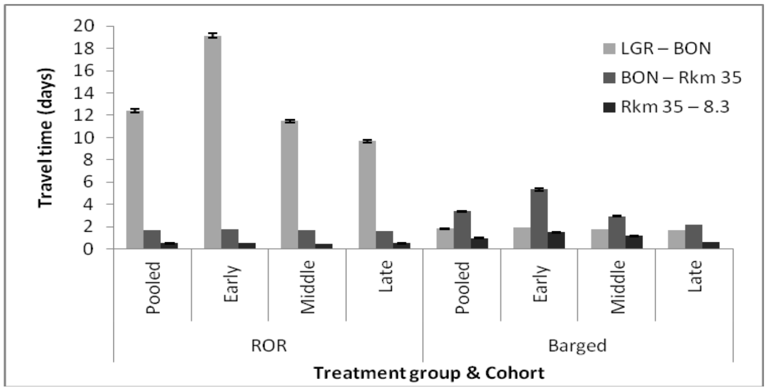
Net Pen Holding Experiment

The most striking pattern was that mortality rates were greater at the freshwater site (Tongue Point) than at the saline site (Sand Island). Unfortunately, there were no ROR migrants challenged at Tongue Point because of limited sample sizes, and thus direct comparisons to barged fish were not possible. The closest surrogate for ROR migrants were run-at-large fish collected at BON, which had a very similar mortality pattern to that of barged fish.

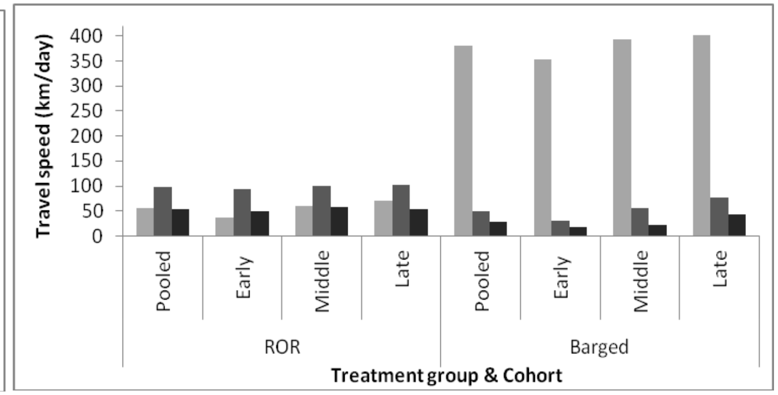
Among barged fish, mortality rates decreased across the season. Furthermore, ROR migrants collected at JDA in the latter part of the season had lower net pen mortality rates than those collected at BON earlier in the season. However, whether this was due to reduced in-river migration or a seasonal effect cannot be deciphered.

Reference fish, which were neither tagged nor passed through the FCRPS, had low mortality rates. The low mortality rates could be associated with the lack of tagging, hydrosystem passage, or both.

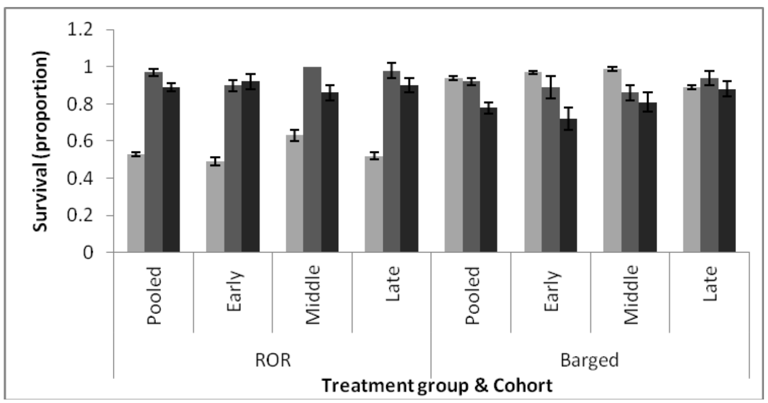
I. Travel Time



II. Travel Speed



III. Survival



IV. B:I Ratio

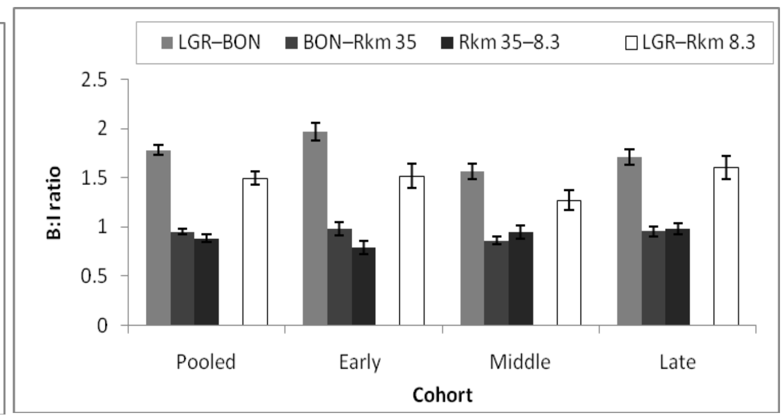


Figure B.1. Travel Time, Travel Speed, Survival and B:I Ratio of Yearling Chinook Salmon Outmigrating the FCRPS in 2008. Error bars represent standard error. (Summarized from Eder et al. 2009a)

Pathogen Prevalence Determined by Histopathological Examination (Microscopic Examination of Tissue)

Live fish were sampled at various times during and locations in the hydrosystem passage and at the end of the net pen holding experiment to determine baseline of health and infectious stressors. Low levels of BKD and mycotic infections were observed at LGR, JDA, and after the net pen holding experiment. Ceratomyxosis showed the highest pathogen prevalence among ROR migrants (94%) and BON fish (92%), followed by barged fish (34%) and Reference fish (17%). Metabolic lesions appeared to increase throughout the hydrosystem and post-net pen holding experiment, but remained low in the Reference fish. Also, higher pathogen prevalence was generally observed at Tongue Point than at Sand Island.

Histopathological analysis was also performed on fish that died in the net pen holding experiment to determine probable causes of mortality. The main diseases associated with mortality among barged fish were metabolic lesions and mycotic infections, and among BON fish were mycotic infections. The absence of ceratomyxosis among barged fish may be due to the minimal amount of time exposed to habitat where the disease is transmitted by an intermediate host, a freshwater worm (*M. specisoa*).

Pathogen Prevalence Determined by Polymerase Chain Reaction (Genetic Analysis)

Among the water samples, only *Saprolegniaceae* was detected. From the fish tissue samples collected in the hydropower system and net pens, the most prevalent pathogens detected were *R. salmoninarum* (≤ 22% prevalence) and *Saprolegniaceae* (≤ 7% prevalence). The percent prevalence observed for *R. salmoninarum* was considerably lower than that observed by other studies (Elliott et al. 1997; Arkoosh et al. 2006 Dietrich et al. 2008), and that for *Saprolegniaceae* was consistent with the usual chronic rates of infection responsible for low and steady rates of mortality (Mueller 1994; Roberts 2001). Limited sample sizes restricted any conclusive patterns that could be determined for barged and ROR migrants.

Covariates of Net Pen Fish, Alive After 28 Days

At the level of net pens, statistically significant relationships were determined between the prevalence of mycotic infections at Tongue Point and the single factors of collection date at LGR, collection source, or discharge at BON. No significant relationships were determined with pathogen prevalence of *R. salmoninarum* and ceratomyxosis. At the level of fish, only holding duration was significantly related to pathogen prevalence at Tongue Point.

Blood protein levels, an indicator of nutritional status and body condition, were significatly related to barging, collection date, and discharge at BON as single factors for fish at Sand Island. However, the slope parameters were not reported, and correlation among factors also occurred. The authors note that barged fish had higher blood protein levels than ROR migrants, which may indicate higher nutritional status among barged fish, and higher stress and consequent poor feeding among ROR migrants.

B.4.5.3 Conclusions

Based on the B:I ratio between LGR and rkm 8.3, barging is beneficial. The survival of acoustic-tagged (JSATS) spring-summer Chinook salmon was overall greater among barged fish than ROR migrants from LGR to rkm 8.3, despite the 19% decreased survival of barged fish below BON to rkm 8.3.

The lower survival rates in the LRE among barged fish may be due to their relatively slow travel times and thus increased exposure to predation. The B:I ratio mirrored the decreasing pattern of travel time across the season.

In the regression analysis for travel times, nearly all of the covariates measured and tested—1) collection source and holding duration, 2) length and weight at time of tagging, 3) collection, tagging, and release dates, and 4) average daily discharge at both LGR and BON)—were individually statistically significant. Correlations among factors make it difficult to objectively determine which mechanisms were biologically significant. Similarly, in the regression analysis for survival, the majority of the single covariates tested were significant, except for in-river migrant survival in Reaches 2 and 3, where none was significant.

In the net pen holding experiment, higher mortality was observed at the freshwater site (Tongue Point) than at the saline site (Sand Island). At Tongue Point, mortality rates were similar among the barged fish and the run-at-large ROR migrants. The three most prevalent pathogens among fish that died were *Saprolegniaceae*, *R. salmoninarum*, and ceratomyxosis. Among the fish that survived, ROR migrants showed higher proportions of pathogens than barged fish. However, low sample sizes and consequently lack of treatment groups, as well as low detectable levels of pathogens, prevented robust implementation of statistical analyses and conclusive interpretations. Also, some inconsistent patterns in pathogen prevalence were observed between the histopathological analysis and the genetic analysis (polymerase chain reaction), between the live fish sampled in the hydropower system and in net pens, and between live and dead fish in net pens. Among live fish in the hydropower system and in net pens tested by histopathological analysis, ceratomyxosis was most prevalent, while these fish tested by genetic analysis showed BKD to be most prevalent. Furthermore, in the net pens, dead fish had the highest prevalence of metabolic lesions and mycotic infections even though ceratomyxosis was most prevalent among live fish.

B.4.6 Eder et al. 2009b

Eder K, D Thompson, J Dietrich, D Boylen, A Van Gaest, S Strickland, J Groff, M Arkoosh, and F Loge. 2009b. *Hydrosystem Delayed Mortality Associated with Barge and In-River Outmigration Histories of Snake River Spring/Summer Chinook Salmon with Investigation into Possible Causes of Differential Mortality – DRAFT*. Prepared by the University of California, Davis, California, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington. Study Code BPS-W-00-10.

Main research goals: As a second year (2008 outmigration) replicate of the Dietrich et al. (2008; 2007 outmigration) study, the main goals were as follows:

- Determine the extent of cumulative mortality among barged and in-river spring-summer yearling Chinook salmon after hydrosystem passage in a net pen holding experiment in the LRE.
- Relate environmental and biological characteristics of the outmigrants to their survival rates in the net pen holding experiment and during migration through the LRE. This included the spatial and temporal patterns of pathogens and disease of outmigrating spring-summer Chinook salmon.

B.4.6.1 Methods

Samples

The following fish were sampled:

- Barged fish: PIT-tagged at Clearwater Hatchery and RR, collected at LGR, barged to BON, trucked to net pens in the LRE.
- ROR migrants: PIT-tagged at Clearwater Hatchery and RR, collected by SbyC at BON, trucked to net pens in the LRE.
- Reference fish: RR eggs raised at the Newport Research Station's FLD, trucked to net pens in the LRE.

Field Manipulative Experimentation

The samples of barged and ROR fish in net pens at Tongue Point (freshwater site) and Sand Island (estuarine site) were fed and observed for mortalities over 28 days.

Physical and biological data were collected related to the following: pathogen prevalence by histopathological analysis (live and morbid fish) and by genetic analysis (live fish), smoltification status, fork length, weight, CF.

B.4.6.2 Results

Field Manipulative Experimentation

The cumulative mortality rates of spring-summer yearling Chinook salmon in the net pen holding experiments were greater at Tongue Point (freshwater site) than at Sand Island (saline site). At Tongue Point, ROR migrants exhibited greater mortality rates than barged fish. Mortality rates of Reference fish remained low. Fish from the two hatcheries had similar patterns in their mortality rates. For barged fish at Tongue Point, the early and middle cohorts had relatively low mortality rates compared to the late cohort.

- Physical and biological data collected related to pathogen prevalence and ATPase activity levels. Overall, barged and ROR migrants showed similar pathogen prevalence immediately after hydrosystem passage, but ROR migrants showed greater pathogen prevalence than barged fish in the net pen holding experiments. From the pathological analysis of live fish, the prevalence of metabolic lesions increased from Clearwater Hatchery and RR to BON in both in-river and barged fish. In the net pens, prevalence of ceratomyxosis markedly increased among fish, and predominantly in ROR migrants. Pathogen prevalence of live fish determined by genetic analysis was low, generally less than 5%, and mostly absent in the net pens.
- ATPase activity levels were lowest at the hatchery, followed by barged fish and then ROR migrants. In mid-to-late May, ATPase activity markedly increased and peaked. Overall, the CF decreased throughout the season. The CF was generally greater among barged fish than ROR migrants, but body mass was greater among ROR migrants than barged fish. Early cohorts had a greater CF, mass, and length than middle and late cohorts. Throughout the duration of net pen holding, the CF of barged fish increased, but that of ROR migrants decreased. Reference fish increased in CF mass and length throughout the net pen holding.

B.4.6.3 Conclusions

The cumulative mortality rates of spring-summer yearling Chinook salmon in the net pen holding experiments were greater at Tongue Point (freshwater site) than at Sand Island (saline site), possibly due to the total pathogen prevalence, which increased at Tongue Point but decreased at Sand Island. The results at the freshwater site are consistent with what was observed in the first year (Dietrich et al. 2008) of this study.

A few of the physiological and morphometric measures of fish did not support the results for cumulative mortality in net pens. ROR migrants had higher mortality rates in net pens, but had higher smoltification levels, mass, and length than barged fish. The two characteristics that were consistent with relative mortality rates were CF and growth in the net pens.

B.4.7 Dietrich et al. 2010

Dietrich J, J Osborn, D Boylen, G Hutchinson, S Strickland, A Van Gaest, T Collier, and M Arkoosh. 2010. *Disease Transmission among Snake River Spring/Summer Chinook Salmon under Laboratory Controlled Transportation Conditions.* Prepared by the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Newport, Oregon, the University of California, Davis, and the Northwest Fisheries Science Center, National Oceanic and Atmospheric Administration, Seattle, Washington, for the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla,Washington. Study Codes BPS-W-00-10 and TPE-W-04-1.

Main research goal: Estimate pathogen prevalence after transmission of *R. salmoninarum* between juvenile Chinook salmon under two water-exchange rates and three fish densities similar to conditions in fish transport barges.

B.4.7.1 Methods

Pathogen Shedding Experiment

The authors determined the most appropriate time scale for testing *R. salmoninarum* shedding and disease transmission. Juvenile Chinook salmon were injected with *R. salmoninarum* and shedding of *R. salmoninarum* was measured (by the membrane filtration-fluorescent antibody test) every 48 hours over a 36-day period. The time with the highest rate of shedding after injection was used for testing in the horizontal transmission experiment.

Horizontal Transmission Experiment

The horizontal transmission experiment addressed the impacts of infection prevalence, water-exchange rate, and fish density.

Impact of Infection Prevalence

Four treatments of *R. salmoninarum* prevalence in Donor Fish were tested: 7%, 17%, 26%, and 40%. Donor Fish were injected 22 days prior to the cohabitation period. The cohabitation period of Donor and Susceptible Fish was 60 hours to simulate the 24-hour holding period in raceways and 36-hour duration of barge transportation. Fish were maintained at 0.3 lb/gal water. After the cohabitation period, pathogen prevalence and quantity (number of *R. salmoninarum* copies/reaction) among Susceptible Fish were measured in gills and kidneys.

Impact of Water-Exchange Rate and Fish Density

Two water-exchange rates (X1: 2.0 exchanges/h and X2: 5.7 exchanges/h) and three fish densities (D1: 6 g/L, D2: 21 g/L, and D3: 60 g/L) were tested in a full factorial design. Kidneys and gill tissue samples from necropsied fish were quantified for *R. salmoninarum* prevalence and number of *R. salmoninarum* copies at 0, 35, and 100 days after the cohabitation period.

B.4.7.2 Results

Results derived from the pathogen shedding experiment were as follows:

- Mean time to death was 31 days.
- Shedding from control fish was 0.1 cells/field.
- Minimum rates of shedding of treatment fish was detected 10 to 16 days after injection.
- Maximum rates of shedding were 321 million cells/L and occurred 28 days after injection.

Results from the horizontal transmission experiment included the impacts of infection prevalence, water-exchange rate, and fish density.

Impact of Infection Prevalence

Prevalence from gill tissue samples showed very high rates of *R. salmoninarum* among Susceptible Fish (91 to 99%). Based on the kidney tissue samples, there was a positive relationship between prevalence among Susceptible Fish and *R. salmoninaurm* prevalence from Donor Fish.

Impact of Water-Exchange Rate and Fish Density

At Day 0, there was no significant difference in *R. salmoninarum* prevalence between the two exchange rates. Across the three fish densities, there were high rates of infection among the gill tissue samples but still no significant difference among treatment groups. In the kidney tissue samples, there was a positive relationship between *R. salmoninarum* prevalence and fish density.

At Day 35, *R. salmoninarum* prevalence increased with fish density independent of the water-exchange rate. More specifically, at the low exchange rate, disease prevalence increased with density, but was not statistically significant. At the high exchange rate, disease prevalence at high fish density was significantly higher than that at the two lower fish densities. There were no significant differences in number of *R. salmoninarum* copies per reaction among treatment groups.

At Day 100, *R. salmoninarum* prevalence was overall greater than at days 0 and 35. At the low exchange rate, *R. salmoninarum* prevalence was greater at D1 (60%) than at D2 and D3 (10% and 26%, respectively). At the high exchange rate, *R. salmoninarum* prevalence was greater at D3 (70%) than at D1 and D2 (both 0%). At Day 100, the quantity of *R. salmoninarum* of X2D3 was greater than that from the X2D3 groups at Days 0 and 35. The quantity of *R. salmoninarum* of X1D3 was greater than that from the X1D3 group at Day 0.

Contour plots of *R. salmoninarum* prevalence across water-exchange rates and fish densities showed the following: at Day 0, a linear relationship with only fish density, and at Day 100, a relationship with water-exchange rate, fish density, and an interaction between the two factors. The lowest disease prevalence occurred at high exchange rates and low fish densities. The highest disease prevalence occurred at low exchange rates and low fish densities, and at high exchange rates and high fish densities.

B.4.7.3 Conclusions

Horizontal transmission of *R. salmoninarum* can occur from Donor Fish occuring at prevalences as low as 7%, and possibly lower. This is comparable to rates of *R. salmoninarum* prevalence observed on barges in 2007 (9% to 70%) and 2008 (0% to 5%). At a short time scale (Day 0 and Day 35 post-cohabitation), disease prevalence increased linearly with fish density. At a long time scale (Day 100 post-cohabitation), disease prevalences were highest at low water-exchange rates and low fish densities, and also at high water-exchange rates and high fish densities. Thus, the authors recommend that at fish-loading densities less than 0.3 lb/gal, water-exchange rates should be 5.5 exchanges per hour (i.e., three pumps in operation). At fish densities greater than 0.3 lb/gal, exchange rates should be 1.8 exchanges per hour (i.e., one pump in operation).

Appendix C

Effects of Tagging on the Behavior and Survival of Salmonids

Appendix C

Effects of Tagging on the Behavior and Survival of Salmonids

Table C.1. Effects of Tagging on the Behavior and Survival of Salmonids

Species	Fish Size	Tag Type	Tag Burden	Effects	Likely effects on *D*	Study
Fall Chinook salmon	122-198 mm FL; 22.2-99.0 g	AT tag	6.7% of fish's body mass in air	• No difference in swimming performance in respirometer 1-d versus 21-d post-surgery between AT-tagged, sham tagged, and control fish • No difference in predation with active versus inactive AT tags	No No	Anglea et al. 2004
Sockeye salmon	102-133 mm FL; 7.6-14.6 g	AT tag	4.5-10.3% of fish's body mass in air	• Tagged fish had **lower** critical swimming velocity (U_{crit}) than control or sham fish 48 hours after tag implantation • No effect on growth over 21 days • No mortalities	Maybe No No	Brown et al. 2006
Fall Chinook salmon	94- to 125-mm FL; 7.2 to 23.1 g	AT tag	3.1-10.7% of fish's body mass in air	• No difference among tagged, untagged, and sham-tagged groups 48 hours after tag implantation • No effect on growth over 21 days • Tagged group had **higher** mortality after 21 days but could be confounded by poor health	No No No	Brown et al. 2006
Spring/summer Chinook salmon		JSATS and PIT tags	2.7% of fish's body mass in air	• Travel times, detection probabilities, survival rates, and avian predation rates were similar between JSATS-tagged and PIT-tagged spring/summer Chinook	No	Hockersmith et al. 2008

Table C.1. (contd)

Species	Fish Size	Tag Type	Tag Burden	Effects	Likely effects on *D*	Study
Spring/ summer and Fall Chinook salmon		JSATS, PIT tags, and integrated transmitters		• No significant differences in mortality or growth between non-tagged, PIT-tagged, integrated JSATS and PIT-tagged, and non-integrated JSATS and PIT-tagged over a 90-d period • No yearlings expelled acoustic tags • Up to 7.8% subyearlings expelled acoustic tags 5 to 63 days post-surgery • Inflammation from implantation, which can lead to infiltration of fibrous tissue into internal organs, occurred in ~20% of subyearlings (< 101 mm and < 12 g) • Non-integrated tagging recommended over integrated tagging because of higher loss of acoustic tags than PIT tags	No No Maybe	
Spring/ summer and Fall Chinook salmon		JSATS and PIT tags		• Minimal FL without adverse effects on growth was 88 mm • Minimal FL without negative influence on survival was 95 mm (7.6% tag burden by mass of a 9.2-g fish) • JSATS tag expelled only in subyearlings < 108 mm (4.8% tag burden)	Maybe Maybe Maybe	
Spring/ summer and Fall Chinook salmon		JSATS and PIT tags		• Little evidence that acoustic-tagged fish had reduced performance relative to PIT-tagged fish in either predator avoidance ability, tag loss, or tissue response tests		
Coho salmon	9.5 to 16 cm	AT tags	15-17% tag size to body size; 7-8% by mass	• No effect on growth, survival, tag retention, swimming performance and physical condition for 300 days post-surgery	No	Chittenden et al. 2009

Table C.1. (contd)

Species	Fish Size	Tag Type	Tag Burden	Effects	Likely effects on *D*	Study
Chinook salmon		Dummy ultrasonic transmitters	2.6- 8.8% of body mass	• Survival over 42 days was significantly lower in fish receiving gastrically implanted transmitters (21%) than for the gastric-sham (66%), surgery (61%), surgery-sham (58%), and control treatments (90%).	Maybe	Hall et al. 2009
				• Control fish had higher survival than all other groups over 42 days	Maybe	
				• Surgical insertion into the peritoneal cavity is the preferred method of transmitter implantation		
				• Transmitters should be less than 5.8% of the fish's body mass to reduce transmitter-related mortality	Maybe	
Spring Chinook salmon		PIT and CWT tags		• 2.0% loss of PIT tags before release	No	Knudsen et al. 2009
				• 18.4% loss of PIT tags 6 months to 4 years after release	Maybe	
				• Tag loss rate not correlated with age of return, therefore most tag loss occurred within 6 months	No	
				• SAR of PIT-tagged fish **underestimated** by 25% because of tag loss and reduced survival	Maybe	
				• PIT-tagged induced mortality up to 33.3%; mean 10.3% across all years	Maybe	
				• PIT-tagged adults were **smaller** than non-PIT-tagged adults	Maybe	
				• No difference in migration timing of PIT-tagged and non-PIT-tagged adults in upper Yakima River	No	

Table C.1. (contd)

Species	Fish Size	Tag Type	Tag Burden	Effects	Likely effects on D	Study
Spring/ Summer Chinook salmon		AT and PIT tags; PIT tag		FCRPS migration:		Rub et al. 2009
				• Detection probabilities **higher** for AT than for PIT at LGS	Maybe	
				• Detection probabilities **higher** for PIT than for AT at MCN and BON	Maybe	
				• No differences at other dams		
				• Relative AT/PIT survival = 1 at LGS and ICH		
				• Relative AT/PIT survival **greater than** 1 at LMN		
				• Relative AT/PIT survival **less than** 1 at MCN, JDA, and BON		
				• No difference in AT- and PIT-tag recovery rates at bird colonies	No	
		AT and PIT tags		Necropsy and histology:		
				• **Less** caecal and mesenteric fat in tagged fish compared to Reference fish at MCN and BON	Maybe	
				• Splenic engorgement/enlargement and kidney abnormalities greater in tagged fish than Reference fish	Maybe	
				• Liver abnormalities **greater** in AT- than in PIT-tagged fish	Maybe	
				• Higher inflammation and **slower** healing in AT- than in PIT-tagged fish	Maybe	
				• Low *R. salmoninarum* antigen levels observed	No	
		AT and PIT tags; PIT tag	3.5%	Holding experiment:		
				• Survival of AT-tagged fish **lower** than PIT-tagged and Reference fish significantly after 14 days, but n.s. trend by 90 days	Maybe	
				• Growth 3.6 mm **greater** in PIT- than in AT-tagged fish by 90 days	Maybe	
				• After 90 days, no AT-tag expulsions occurred, 2% of AT fish had PIT-tag expulsions, and 0.3% of exclusively PIT-tagged fish dropped tags	No	
				• No difference in *R. salmoninarum* antigen levels among groups	No	

Table C.1. (contd)

Species	Fish Size	Tag Type	Tag Burden	Effects	Likely effects on *D*	Study
Fall Chinook salmon		AT and PIT tags; PIT tag		FCRPS migration:		
				• Detection probability **greater** for AT- than PIT-tagged fish at LGS	Maybe	
				• Survival **greater** for PIT- than AT-tagged fish from LGR to LGS and to MCN	Maybe	
				• Travel time **greater** for AT- than PIT-tagged fish from LGR to LGS, LMN, ICH, and MCN	Maybe	
				• No difference in recovery rates at bird colonies	No	
		AT and PIT tags		Necropsy and histology:		
				• **Less** caecal and mesenteric fat in tagged fish compared to Reference fish at BON	Maybe	
				• **Greater** liver and kidney discoloration and abnormalities in tagged fish than Reference fish at BON	Maybe	
				• **Greater** inflammation, chronic peritonitis, dermal hemorrhage/fibrin in AT- than in PIT-tagged fish	Maybe	
				• Low *R. salmoninarum* antigen levels observed	No	
	> 95-mm FL for subyearlings; 85- to 94-mm FL for pilot subyearlings	AT and PIT tags; pilot AT and PIT tags; PIT tag	5.6% for subyearlings; 9.6% for pilot subyearlings	Holding experiment:		
				• Survival of AT-tagged fish (0.53) significantly **lower** than PIT fish (0.94) and Reference fish (0.88) after 14 days, and through to 90 days	Yes	
				• Survival of small sized AT-tagged fish (pilot AT fish) considerably **lower** at 0.18 after 14 days	Yes	
				• After 90 days, PIT-tagged fish 4.5 mm **longer** and 3.4 g **heavier** than AT-tagged fish	Yes	
				• 7.6% of AT-tagged fish and none of the AT pilot fish lost AT tags	Maybe	
				• 3.4% of AT-tagged fish and none of the AT pilot fish lost PIT tags	Maybe	
				• No difference in *R. salmoninarum* antigen levels among groups	No	

Table C.1. (contd)

Species	Fish Size	Tag Type	Tag Burden	Effects	Likely effects on *D*	Study
Chinook salmon	80- to 89-mm FL	AT and PIT tags	4.5-15.7%	• **Significant differences** in growth and survival rates between tagged and control fish over 30 days	Maybe	Brown et al. 2010
				• Survival impaired in fish less than 11.1 g (> 6.7% tag burden)	Maybe	
				• Growth affected in fish less than 9.0 g (> 8.2% tag burden)	Maybe	

AT = acoustic transmitter; BON = Bonneville Dam; FCRPS = Federal Columbia River Power System; FL= fork length; ICH = Ice Harbor Dam; JDA = John Day Dam; JSATS = Juvenile Salmon Acoustic Telemetry System; LGR = Lower Granite Dam; LGS = Little Goose Dam; LMN = Lower Monumental Dam; MCN = McNary Dam; PIT = passive integrated transponder

Appendix D

Workshop Agenda

Original photo credit: Scott Butner

Workshop Agenda

Snake River Basin Differential Delayed Mortality Workshop

10-11 May 2011
Portland, Oregon

Snake River Basin Differential Delayed Mortality Workshop

Sponsors

U.S. Army Corps of Engineers
Walla Walla District
201 N 3rd Avenue
Walla Walla, WA 99362

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Location

Marriott Courtyard Portland Center
550 SW Oak Street
Portland, OR 97204
503-505-5000
1-800-606-3717

2011 Differential Delayed Mortality Workshop Agenda

10 May 2011, 13:00–17:30

Session 1: Introduction		
Time	*Title*	*Presenter / Facilitator*
13:00	Welcome address	Derek Fryer & David Trachtenbarg
13:10	Snake River Differential Delayed Mortality Synthesis Report - *With Interactive Discussion*	Jim Anderson, Jennifer Gosselin & Kenneth Ham
14:30	Open Discussion (30 min)	Kenneth Ham
15:00	***Break***	
Session 2: Fish Pathogens and Physiology		
15:10	Impact of Pathogens on Differential Delayed Mortality Among Salmonids in the Columbia River Basin: Review and Synthesis	Maureen Purcell
15:30	Hydrosystem Delayed Mortality Associated With Barge and In-River Outmigration Histories of Snake River Spring/Summer Chinook Salmon With Investigation Into Possible Causes of Differential Mortality	Frank Loge
15:50	Physiological, Transcriptional, and Behavioral Responses of Transported and In-River Migrating Juvenile Salmonids in the Columbia River: Insights Into Mechanisms of Delayed Mortality?	Matt Mesa
16:10	Open Discussion (40 min)	Kenneth Ham
Session 3: Bypass Influences on Survival Estimates		
16:50	Within-Season Patterns of Smolt-to-Adult Return Rates of Transported and In-River Migrant Yearling Chinook Salmon and Steelhead	Steven Smith
17:10	Open Discussion (15 min)	Kenneth Ham
17:25	End of day remarks	Derek Fryer

11 May 2011, 08:55–17:00

Time	*Title*	*Presenter/Facilitator*
8:55	Morning remarks	Kenneth Ham
Opening Presentation to Sessions 4 & 5		
9:00	A Model to Identify Significant Factors in the Seasonal Pattern of Delayed Mortality	Jim Anderson
Session 4: Arrival Time and Travel Time in the FCRPS, Lower Columbia River & Estuary		
9:20	Survival of Juvenile Chinook Salmon During and After Barge Transport in 2010 With a Comparison of Barged to In-River Survival Through the Lower 150 km of the Columbia River and Estuary	Geoff McMichael
9:40	Survival and Travel Times of In-River and Transported Yearling Chinook salmon in the Lower Columbia River and Estuary with Investigation Into Causes of Differential Mortality	Frank Loge
10:00	Migration Pathways, Travel Time, and Survival of Acoustic-Tagged River-Run and Barged Yearling Chinook Salmon in the Columbia River Estuary	Ryan Harnish
10:20	Evaluation of Hydrosystem Delayed Mortality Among Juvenile Salmonids In the Columbia River Estuary	Dick Ledgerwood
10:40	***Break***	
10:55	Discussion (1 h 05 min)	Kenneth Ham
12:00	***Lunch***	
Session 5: Ocean Conditions		
13:00	Keep on Truck'n? Interactions Between Conservation Measures and the Environment Lead to Unintended Consequences For an Endangered Species of Pacific Salmon in the Columbia River Basin	Kirstin Holsman
13:20	Understanding Seasonal and Within Seasonal Marine Mortality of Columbia River Juvenile Salmon Marine Survival	Bob Emmett
13:40	A Simple Cause for *D*: Equivalent Hydrosystem & Coastal Ocean Survival Rates	David Welch
14:00	Discussion (1 h)	Kenneth Ham
15:00	***Break***	
Session 6: Synthesis & Open Discussion		
15:15	Discussion (1 h 35 min)	Kenneth Ham
16:50	Concluding remarks	Derek Fryer

Workshop Abstracts

Snake River Basin Differential Delayed Mortality Synthesis

James J. Anderson[1*], Jennifer L. Gosselin[1], and Kenneth D. Ham[2]

Extended Abstract

In response to a request from regional fish managers**, a synthesis report was drafted to compile a summary of all pertinent information relevant to differential delayed mortality (*D*). After this present *D* workshop, the final report will also include key uncertainties and data gaps, areas of future research, and specific actions that may affect *D*.

In this interactive presentation, we present 12 potential factors of *D* and their related hypotheses (Fig. 1). For each one of the factors, we (1) summarize relevant research (Table 1), (2) rank the factor by degree of importance to *D* patterns and level of uncertainty in the data and conclusions (Table 2), (3) suggest possible areas of future research, (4) consider what actions may affect *D* in context of BiOp RPAs and RM&Es, and (5) briefly solicit feedback and discussion from workshop participants.

Overall, we found that *D* generally exhibits variation with arrival timing to and travel time through the hydrosystem. The strong effect of passage timing on *D* most likely involves corresponding temporal changes in fish length, estuary and ocean predation, and upwelling. The correspondence of passage timing with fish physiology and disease appears to have secondary effects on *D*. Time-independent factors include dam operations (spill versus transport), barging conditions (e.g., alternative barging strategy), and adult straying during upriver migration. Factors that likely have little influence on *D* include pre-hydrosystem conditions, lower river conditions and predation, and certain barging conditions (e.g., co-transportation with steelhead, dissolved metals, and noise).

We hypothesize that when *D* is < 1 in the early season, barged spring/summer Chinook salmon and steelhead relative to their ROR counterparts are smaller in length, exhibit lower levels of osmoregulation, and have slower travel rates and greater susceptibility to predation in the estuary (Fig. 2). In mid-season, generally *D* is > 1; barged fish increase their osmoregulatory ability and length, and decrease their travel time in the lower river and estuary, while the energetic reserves of ROR migrants decrease. All of these factors are hypothesized to result in higher survival rates in barged fish than in ROR migrants during the middle of the migration season. When *D* is sometimes < 1 again at the end of the season, we hypothesize that the increased surface-water temperatures result in higher rates of disease and energy loss among barged fish. Thus, barged fish have lower survival rates than ROR migrants at the end of the run. For fall Chinook salmon, we hypothesize that the low survival rates of barged fish relative to ROR migrants throughout the season are also caused by high surface-water temperatures, which decrease the condition and energetic reserves of barged fall Chinook salmon and increase disease prevalence. An extended open discussion will follow the presentation.

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**As part of the regional process of the Studies Review Workgroup of the U.S. Army Corps of Engineers' (USACE's) Anadromous Fish Evaluation Program.

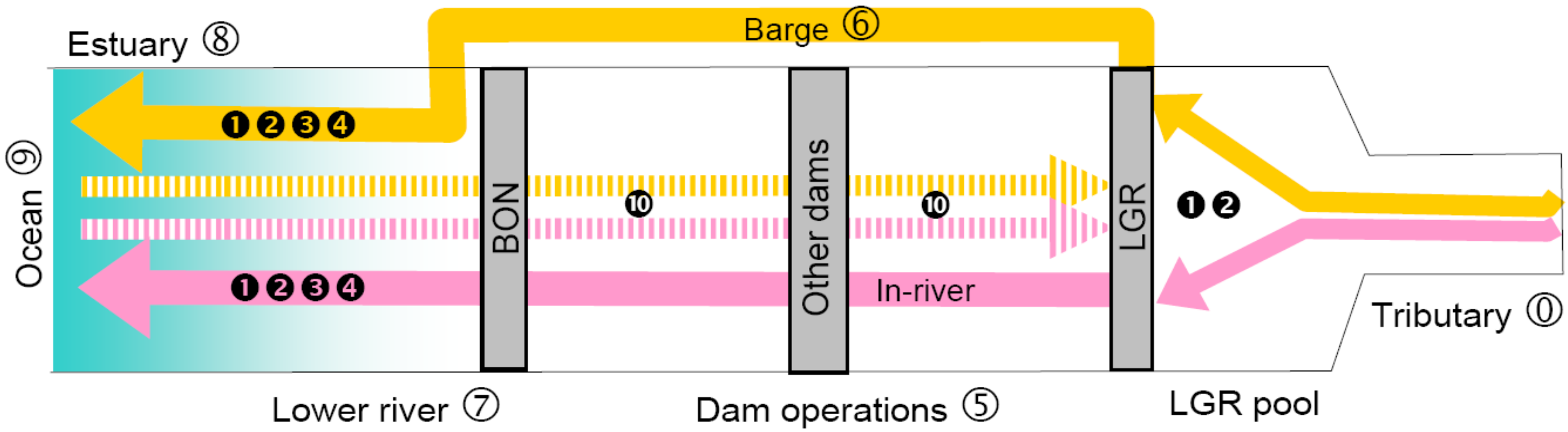

Figure 1. Conceptual Model of Locations of the Principal Factors Affecting the Differential Delayed Mortality Between Barged and ROR Migration Smolts. Open circled numbers designate factors have an environmental source and closed circles designate factors related to the state of the fish. Numbers represent factors as follows: ⓪ Prehydrosystem conditions, ❶ arrival time and travel time, ❷ fish length, ❸ fish physiology, ❹ fish disease, ⑤ dam operations, ⑥ barging conditions, ⑦ Lower Columbia River conditions and predators, ⑧ estuarine conditions and predators, ⑨ oceanic conditions, ❿ straying, and ⓫ tagging. LGR represents Lower Granite Dam and BON represents Bonneville Dam. The other dams are Little Goose Dam, Lower Monumental Dam, Ice Harbor Dam, McNary Dam, John Day Dam, and The Dalles Dam.

Table 1. Interactions Between Fish Condition/Behavior and Environment. Dots qualitatively represent potential magnitude of effect on *D*.

	Environment					
Fish Condition/ Behavior	⓪ Prehydrosystem Conditions	⑤ Dam Operations	⑥ Barging Conditions	⑦ Lower River Conditions & Predation	⑧ Estuarine Conditions & Predation	⑨ Oceanic Conditions
❶ Arrival Time & Travel Time	●● Achord et al. 2003	●● Schaller et al. 2007a			●● Scheuerell et al. 2009; Eder et al. 2009a	●● Scheuerell et al. 2009
❷ Length	●● Crozier et al. 2010	●● Zabel et al. 2005			● Muir et al. 2006	● Muir et al. 2006
❸ Physiology		● Budy et al. 2002	●● Budy et al. 2002; Clemens et al. 2009		●● Schreck et al. 2006	● De Robertis et al. 2005
❹ Disease	● Dietrich et al. 2008		● Dietrich et al. 2010		● Arkoosh et al. 2006; Dietrich et al. 2007, 2008; Eder et al. 2009a, b	
❿ Straying & Fallback		● Keefer et al. 2008a; Ruzycki and Carmichael 2010				
⓫ Tagging		● NOAA 2010			● Rub et al. 2009; Brown et al. 2010	●

Table 2. Factors of *D* Categorized by Degree of Importance to *D* and Level of Uncertainty in the Data and Conclusions

	Low Uncertainty in the data and conclusions	High Uncertainty in the data and conclusions
High Importance to *D*	❶ **Hydrosystem arrival time & travel time** (Connor et al. 2004; Anderson et al. 2005; Connor et al. 2005; Clemens et al. 2009; Scheuerell et al. 2009, NOAA 2010) ❿ **Adult straying** (Keefer et al. 2008a; Ruzycki and Carmichael 2010)	❷ **Fish length** (Zabel and Williams 2002; Congleton et al. 2003; Connor et al. 2004; Zabel and Achord 2004; Williams et al. 2005; Zabel et al. 2005; Marsh et al. 2006; Eder et al. 2009b) ⑤ **Dam operations** (ISAB 2008a, 2010; NOAA 2010) ⑧ **Estuarine conditions & predators** (Schreck et al. 2005; Schreck et al. 2006; Roby et al. 2008; Eder et al. 2009a) ⑨ **Ocean conditions & upwelling** (Scheuerell and Williams 2005; Zabel et al. 2006; Keefer et al. 2008b; Scheuerell et al. 2009)
Moderate Importance to *D*		❸ **Fish physiology** (Budy et al. 1998; Congleton et al. 2001, 2003, 2005; Schreck et al. 2006; Dietrich et al. 2007, 2008; Eder et al. 2009b) ❹ **Disease** (Arkoosh et al. 2006, Dietrich et al. 2007, Dietrich et al. 2008, Mesa et al. 2008, Eder et al. 2009a, Eder et al. 2009b, Marsh et al. 2010c, Dietrich et al. 2010, Dietrich et al. 2011) ⑥ **Barging conditions** (McMichael et al. 2007; Ryan et al. 2007; Marsh et al. 2008b; Marsh et al. 2010c) ⓫ **Tagging effects** (Anglea et al. 2004; Brown et al. 2006; Hockersmith et al. 2008; Chittenden et al. 2009; Knudsen et al. 2009; Rub et al. 2009; Brown et al. 2010; NOAA 2010)
Low Importance to *D*	⑦ **Lower river conditions and predators** (Schreck et al. 2006, Mesa et al. 2008) ⑥ **Barging conditions** (Congleton et al. 2000; Wagner et al. 2004; Congleton et al. 2005; Clemens et al. 2009; Halvorsen et al. 2009)	⓪ **Pre-hydrosystem conditions** (Zabel and Williams 2002; Achord et al. 2003; Connor et al. 2003; Smith et al. 2003; Achord et al. 2007; Sykes et al. 2009; Tiffan et al. 2009; Crozier et al. 2010)

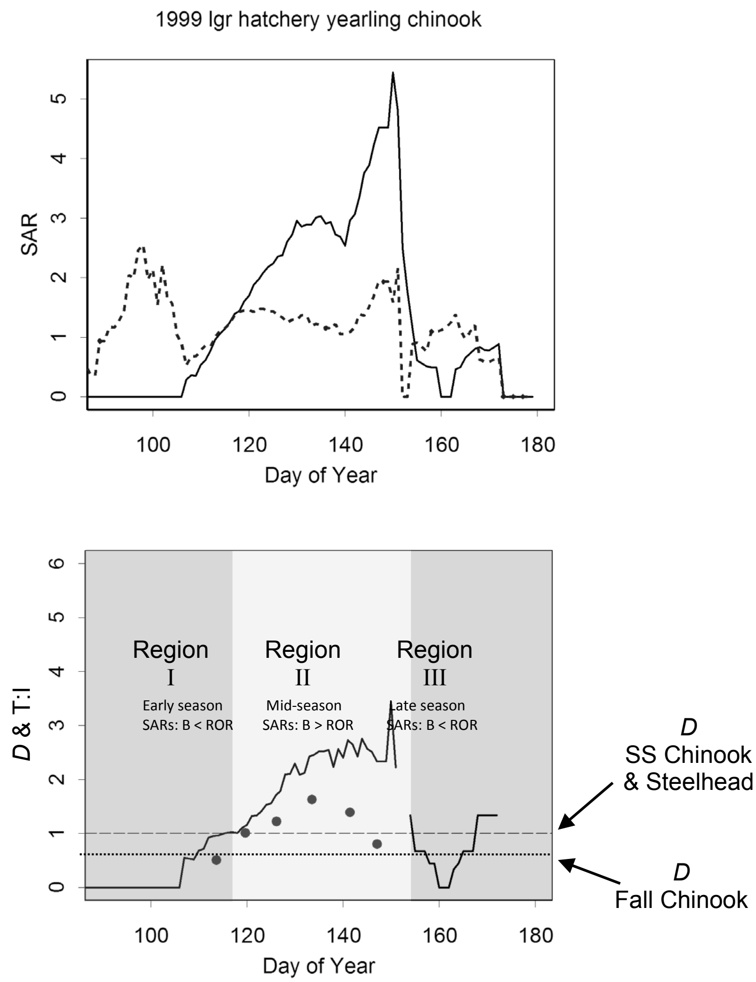

Figure 2. Upper Frame: Representative Example of the Temporal Variations in SAR Rate for Hatchery Spring Chinook in 1999 for Barged Fish (—) and ROR Migrants (- - -) (Anderson et al. 2005). Similar patterns are evident for wild spring Chinook and wild and hatchery steelhead. Lower frame: Ratio of transport to in-river SAR rate (T:I) for spring Chinook (—) (Anderson et al. 2005) and weekly *D* (•) for spring Chinook in 1999 (Muir et al. 2006). Arrows indicate across-year average estimates of *D*. Regions indicate early season (Region I), where *D* < 1, middle season (Region II) where *D* ≥ 1, and late season (Region III), where *D* < 1. Region patterns I, II, III are representative of spring/summer (SS) Chinook and steelhead; Region III is representative of fall Chinook.

Impact of Pathogens on Differential Delayed Mortality Among Salmonids in the Columbia River Basin: Review and Synthesis

Maureen Purcell[1*], Diane Elliott[1], and Jim Winton[1]

Abstract

Infectious disease patterns in natural populations are highly dynamic and a multitude of extrinsic and intrinsic factors influence both host and pathogen. These complexities create difficulties in defining the role of pathogens in differential delayed mortality (*D*). Studies to monitor fish health have been conducted in the Columbia River Basin over a number of years and both the prevalence and severity of several important salmonid pathogens are known to vary among species, locations, seasons and years. In general, a trend towards higher pathogen prevalence in barged fish relative to run of river (ROR) fish at Bonneville Dam has been observed. However, direct comparison of the health of barged and ROR fish is confounded by the differential mortality experienced by the ROR fish in the hydropower system, as well as the different time frames required to enter and exit the hydropower system. Our presentation will focus on the question of whether pathogens are a major driver or a predictor of smolt to adult return rate (SAR). We will review and synthesize existing pathogen prevalence datasets in the context of that question. Finally, we will discuss advances in non-lethal detection of fish pathogens and health biomarkers, which may facilitate future experimental studies.

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Hydrosystem Delayed Mortality Associated With Barge and In-River Outmigration Histories of Snake River Spring/Summer Chinook Salmon With Investigation Into Possible Causes of Differential Mortality

Kai Eder[1], Donald Thompson[1], Erik Loboschefsky[1], Joseph Groff[1], Derek Fryer[2], and Frank Loge[1*]

Abstract

Replicate studies in 2002 and 2006 have shown that juvenile salmon with in-river life-histories are more susceptible to disease during planned laboratory challenge with an infectious agent (e.g., *Listonella anguillarum*) than barged fish, implying that transport may help mitigate adverse health effects of the FCRPS. However, barged fish were observed to have high incidences of natural infections resulting in mortality within the first few weeks of laboratory holding. A subsequent survey found significantly greater pathogen prevalence in barged fish than fish left to outmigrate in-river, suggesting that transmission of infectious agents may occur during transport. Studies conducted in 2007 and 2008 held barged and in-river fish in net pens at two locations within the lower Columbia River estuary (LRE). Various pathology, pathogen prevalence, smoltification, and condition factor metrics analyzed in these studies suggested that the health of barged and in-river outmigrants may be playing a contributing role in differential mortality in the LRE.

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Physiological, Transcriptional, and Behavioral Responses of Transported and In-River Migrating Juvenile Salmonids in the Columbia River: Insights Into Mechanisms of Delayed Mortality?

Matthew G. Mesa[1*]

Abstract

We investigated possible mechanisms of delayed mortality in Columbia River Basin juvenile spring Chinook salmon *Oncorhynchus tshawytscha* that were transported by barge or migrated in-river (run-of–river fish, or ROR). Delayed mortality refers to mortality of fish that occurs in the estuary or ocean that is related to their earlier experiences in the hydrosystem. Possible mechanisms of delayed mortality include physiological dysfunction, poor health, or predation. To investigate some of these mechanisms, we collected tissue samples from PIT-tagged fish at hatcheries (Dworshak and Rapid River hatcheries, Idaho), from transport barges, and at dams along the Columbia River. We documented the physiological status of barged and ROR fish by measuring traditional indicators of stress and smoltification and using cDNA microarrays to develop gene expression profiles. We also evaluated the possible contribution of size-selective predation to delayed mortality by conducting predation tests in the laboratory and examining the diets of predators collected below Bonneville Dam. Plasma cortisol levels were lowest in fish at the hatcheries (< 25 ng/mL), highest in ROR fish (range = 200 – 300 ng/mL), and intermediate in fish that were barged (range = 75 – 175 ng/mL). Thyroxine levels were low in all fish, ranging from about 1 – 3 ng/mL, and the activity of gill Na^+, K^+-ATPase ranged from 3 – 4 µmol P hr^{-1} mg $protein^{-1}$ in fish at the hatcheries before increasing significantly in barged and ROR fish (range = 5 – 10 units). There were few significant differences in ATPase activity between barged and ROR fish. The number of genes that were over or under-transcribed increased significantly after fish were released from the hatcheries, and were highest in barged fish and lowest in ROR fish. Overall, transcriptome response was highest in fish from Dworshak Hatchery. For fish sampled at Lower Granite Dam, several genes associated with immune function were over-transcribed, some metabolism-related genes were over and under-transcribed, and stress-responsive genes were mostly down-regulated. Many genes associated with the immune system were up or down-regulated in barged fish, and several stress-responsive genes were also over-transcribed. Very few significant differences in gene expression existed in ROR fish, a notable exception being the down-regulation of a few immune function genes. Our predation tests indicated that northern pikeminnow *Ptychocheilus oregonensis* selectively fed on smaller juvenile salmon when the difference in prey size was at least 20, but not 10, mm. Also, we found little evidence of size-selective predation by northern pikeminnow based on a comparison of juvenile salmon consumed versus those available in the environment. Collectively, our results indicated that transport by barge was stressful and activated many stress-responsive and immune function genes, and that size-selective predation by fish may not play a significant role in delayed mortality. Future work should include sampling of PIT tagged fish in the estuary to document any changes in their physiology or health.

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Within-Season Patterns of Smolt-to-Adult Return Rates of Transported and In-River Migrant Yearling Chinook Salmon and Steelhead

Steven G. Smith[1], John G. Williams[2], Douglas M. Marsh[1], William D. Muir[3], and Richard W. Zabel[1]

Abstract

Analyses of patterns of smolt-to-adult returns (SARs) related to juvenile migration timing were based on hatchery or wild smolts entering the bypass systems at Lower Granite and Little Goose Dams, 1998-2008. Models of return rates were estimated for transported (T) and in-river migrants (M), and resulting estimated T:M ratios analyzed. Poisson log-linear regression and AIC methods were used to investigate a family of models where SARs were potentially functions of migration group (T or M), tagging location (upstream from or at Lower Granite Dam), and date of passage. Bypassed fish were used so that each fish had a known date of passage. Never-detected fish could not be used for these analyses because their passage dates are unknown. However, available data indicating that never-detected fish typically return at higher rates than bypassed fish were incorporated by adjusting the standard to which T:M ratios were compared to assess efficacy of transportation for the run at large. Model results varied in detail across years and species, but general results were (1) T:M ratios remained constant or increased throughout the season; (2) for both species and both rearing types in migration year 2005 and earlier, T:M ratio exceeded standards for fish that arrived on May 1 or later; (3) T:M ratios were lower in more recent migration years than in earlier years; they still increased throughout the season but did not exceed standards until later in the season. In one case (hatchery Chinook in 2006) the ratio was less than 1.0 throughout the season. Reasons for the decrease in T:M ratio are uncertain, but may be related to changes in management: altered spill operations and returning all bypassed smolts to the river during the early parts of the migrations in 2006-2008.

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Opening presentation to Sessions 4 and 5

Identifying Significant Factors in the Seasonal Pattern of Delayed Mortality

J.J. Anderson[1*], J.L. Gosselin[2], W.D. Muir[3] and R.A. Hinrichsen[3]

Abstract

Studies indicate the ratio (*D*) of the survival of transport to ROR hatchery spring Chinook increases from less than one early in the season to greater than one near the end of the season. Hypotheses explaining this pattern have focused on the effects of transport stress, selective collection of smaller fish, lost growth opportunity, incomplete smoltification and ocean entrance timing. However, none of the studies considered the factors together and therefore the relative significance of factors is unknown. To identify factors we cast the proposed hypotheses in a comprehensive multi-linear model and fit the model to weekly values of *D* between 1997 and 2008. Using AIC selection criteria, we found hydrosystem arrival date (x), x^3, differential cumulative heat exposure between transport and ROR migrants and flows at Lower Granite and Bonneville dams were significant. While several mechanisms contribute to these covariates, seasonal changes in behavior of transported in the estuary and heat stress in ROR fish are potentially most important.

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Survival of Juvenile Chinook Salmon During and After Barge Transport in 2010 With a Comparison of Barged to In-River Survival Through the Lower 150 km of the Columbia River and Estuary

G.A. McMichael[1*], J.R. Skalski[2], K.A. Deters[1], M. S. Hughes[1], K.D. Ham[1], J. Kim[1], R.A. Harnish[1], and D.M. Trott[1]

Abstract

To estimate survival during barge transport from Lower Granite Dam on the Snake River to a release area downstream of Bonneville Dam (lowermost dam on the Columbia River), a distance of 470 km, we used a novel adaptation of a release-recapture model with 1,494 acoustic-tagged yearling Chinook salmon (*Oncorhynchus tshawytscha*) smolts. Smolts were collected at Lower Granite Dam and surgically implanted with acoustic transmitters and passive integrated transponders and divided into three groups: 1) a group released into the raceway with the population of fish that were later loaded into transportation barges (RB; barged); 2) a group held in a net-pen suspended within the general barge population until 5–6 h prior to barge evacuation, at which time they were confirmed to be alive and then released into the general barge population (RA; control); and 3) to validate a model assumption, a group euthanized and released into the barge population 5–6 h prior to barge evacuation (RD; dead). Six replicates of these groups were loaded onto fish transport barges that departed from Lower Granite Dam between 29 April and 13 May, 2010. Detections on acoustic receiver arrays between 70 and 220 km downstream of the barge evacuation site served as the basis for estimation of survival within the barge. Tag-life corrected estimates of reach survival were calculated for barged and control fish in each of the six replicate trials. The ratio of survival from release to rkm 153 for barged fish relative to control fish provided the estimate of within-barge survival. The replicate survival estimates ranged from 0.9503 (SE = 0.0253) to 1.0003 (SE = 0.0155). The weighted average of the replicate estimates of within-barge survival was computed to be S= 0.9833 (SE = 0.0062). This study provides the first active telemetry documentation that the assumed survival of 98% inside barges during yearling Chinook salmon smolt transport appears to be justified. Survival of other species or stocks by barge or for any species/stock by truck remains unknown. Comparisons of survival of barged versus in-river migrating yearling Chinook salmon smolts between rkm 153 and rkm 8 showed that in-river fish survived at a significantly higher rate (0.8439, SE = 0.0094) than the transported fish (0.7922, SE = 0.0205).

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Survival and Travel Times of In-River and Transported Yearling Chinook Salmon in the Lower Columbia River and Estuary With Investigation Into Causes of Differential Mortality

Kai Eder[1], Donald Thompson[1], Rebecca Buchanan[2], Joseph Heublein[1], Joseph Groff[1], John Skalski[2], Chris Peery[3], and Frank Loge[1*]

Abstract

Differential mortality of transported and in-river yearling Chinook salmon in the lower Columbia River and estuary (LRE) was assessed using Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic tags and concomitant detection arrays. Estimates of the Barge to In-River Survival Ratio for the entire study area between Lower Granite Dam and RKM 8.3 indicate that barging of yearling spring Chinook salmon enhances survival through the FCRPS. However, survival ratios for the LRE suggest a higher incidence of mortality in barged fish than in in-river fish, and lowest survival for fish transported early during the outmigration season. The lowest survival for both barged and in-river fish in the LRE occurred between RKM 35.6 and 8.3, a location representing both the furthest point of saltwater intrusion into the estuary and the nesting location of avian predators. Mean travel times of in-river fish between RKM 202 and 8.3 were consistently around 2.3 days for the entire outmigration season, whereas for barged fish the values decreased from 7.9 to 3.1 days over the course of the outmigration season. Slowest travel times coincide with the zone of salt water incursion into the estuary, suggesting that barged fish may be physiologically or behaviorally less prepared to enter the ocean than in-river fish. The longer transit times of barged fish may increase the risk of predation: for example, bird predation estimates derived from PIT tags recovered at East Sand Island were considerably higher in barged study fish (7%) than in-river study fish (4%). Other measured variables correlated with a higher survival probability included (a) large fish size, (b) short estuary residency, (c) high discharge at Bonneville Dam, and (d) late season migration.

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Migration Pathways, Travel Time, and Survival of Acoustic-Tagged River-Run and Barged Yearling Chinook Salmon in the Columbia River Estuary

Ryan Harnish[1*] and Geoffrey A. McMichael[1]

Abstract

We compared migration characteristics of acoustic-tagged river-run and barged yearling Chinook salmon passing through the lower 50 river kilometers (rkm) of the Columbia River estuary during the spring of 2010. Using data collected from over 70 acoustic telemetry receivers deployed between rkms 50 and 3, we determined the joint probability of migration and detection (λ), travel times, and survival probabilities (S) in multiple pathways of three separate reaches. From rkm 50, barged fish were more likely to remain in the navigation channel (λ = 0.70) to rkm 37 than river-run fish (λ = 0.64; P = 0.03). Barged fish that migrated in the navigation channel took more time to travel to rkm 37 (median = 6.8 h) than river-run fish (median = 4.5 h). Survival from rkm 50 to rkm 37 was similar for barged (S = 0.97-0.99) and river-run (S = 0.98-1.01) fish regardless of pathway (P > 0.66). Between rkms 37 and 22, most river-run and barged fish left the navigation channel as evidenced from the higher λ values in the Washington shoreline channel (λ = 0.41-0.62) than in the navigation channel (λ = 0.11-0.28) at rkm 22. Differences in travel times were variable between barged and river-run from rkm 37 to 22, depending on migration pathway. Survival between rkms 37 and 22 was relatively high and similar (P > 0.25) for barged (S = 0.95-1.02) and river-run (S = 0.97) fish, regardless of pathway. From rkm 22, most barged and river-run fish migrated to rkm 8 in the Washington channel. However, barged fish were more likely to cross-over from the Washington channel to the navigation channel (λ = 0.35) than river-run fish (λ = 0.21; P < 0.01), which were more likely to remain in the Washington channel (λ = 0.65) than barged fish (λ = 0.53; P < 0.01). Barged fish took more time to migrate through this reach (medians = 2.4-4.5 h) than river-run fish (medians = 2.2-2.8) in both channels. Of all the reaches we examined, survival probabilities were lowest between rkms 22 and 8, with survival being lowest in the navigation channel for river-run (S = 0.92) and barged (S = 0.89) fish. The probability of survival from the Washington channel at rkm 22 to rkm 8 was 0.95 for barged and river-run fish. No significant differences in survival were observed in either pathway between barged and river-run fish (P > 0.62).

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Evaluation of Hydrosystem Delayed Mortality Among Juvenile Salmonids In the Columbia River Estuary

Richard D. Ledgerwood[1*], Robert J. Magie[2], Matthew S. Morris[2], Amy L. Cook[2], and Benjamin P. Sandford[1]

Abstract

Mortality of juvenile salmonids in the estuary or ocean related to their passage through the hydropower system is potentially evidenced by changes in migration timing, physiology, or abundance. Rates of delayed mortality may change through the migration season, and delayed mortality may be expressed prior to ocean entry or after. We have observed temporal differences in estuarine abundance of juvenile salmonids with known migration histories from detections of PIT-tagged individuals in the estuary using a surface pair trawl. These differences in estuarine abundance relate to differences in smolt to adult return ratios (SARs) and can provide insight into the mechanisms of delayed hydrosystem mortality in relation to migration histories and timing. Isolation of mortality that occurs during the freshwater migration from mortality that occurs in the ocean is key to discerning whether SARs differ for fish entering the ocean at different times. Barged fish (BR) arrive in the estuary about 17 days earlier than their inriver migrant cohorts. We compared pair-trawl detections of river-run (RR) fish previously detected at Bonneville Dam with those of fish released just below the dam on the same date. Both groups of PIT-tagged fish have been sampled annually with the trawl since 1998 at a location approximately 160 km below Bonneville Dam. At this location, BR groups were comingled with RR groups, and daily sampling documented temporal trends in relative abundance (detection %) and travel speed for the two respective groups. Travel speed to the estuary has generally been slower for transported than for river-run fish traveling under the same flow volumes, while differences in the ratios of BR to RR detection rates have varied through the migration period in some years but not in other years. Changes in detection rates and travel speed associated with migration history might be symptomatic of other biological or physiological factors related to survival. Recent development of a mobile separation by code system for sampling fish routed through the pair trawl provides an additional opportunity to resample BR/RR fish in the estuary. The system can be used to evaluate fish performance metrics such as disease or gene expression related to survival or temporal differences in SARs. Understanding the mechanisms and specific timing of delayed mortality would enable evaluation of SARs based on time of ocean entry independent from freshwater impacts.

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Keep on Truck'n? Interactions Between Conservation Measures and the Environment Lead to Unintended Consequences for an Endangered Species of Pacific Salmon in the Columbia River Basin

Kirstin Holsman[1*], Mark D. Scheuerell[2], Eric Buhle[2], and Robert Emmett[3]

Abstract

Conservation management of depleted species requires understanding of dynamic processes influencing individual survival; failure to account for the interaction of selection processes and management interventions can result in unintended outcomes that undermine recovery efforts. In the Columbia River basin, various conservation and restoration efforts have largely failed to increase the production of threatened Pacific salmon (*Oncorhynchus* spp.) populations. Here we considered (1) how inter-and intra-annual variability in marine environmental conditions affect survival of Chinook salmon (*O. tshawytscha*) during their time in the ocean; and (2) how those effects depend on whether the salmon are of hatchery or wild origin, and whether they migrated to sea naturally or were transported downstream around various hydroelectric dams. We used data from more than one million fish individually-tagged from 1998-2006 to evaluate the probability of an individual fish returning as an adult in relation to its life-history, migration route, and a suite of environmental factors including river flow, water temperature, coastal upwelling, and the abundance of predator, forage fish, and prey. We found that current efforts to transport salmon downstream strongly favor hatchery fish, and may hinder the survival of wild Chinook salmon. We further found that, except for select periods when river flow is particularly low, wild fish that traveled downriver through the hydropower system had higher subsequent survival to adulthood than their transported counterparts. We also found evidence that competition and predator aggregation negatively affects ocean survival, and that the effects vary with fish density and a variety of climatic conditions. Our results have broad implications for conservation of salmon as well as other species in other systems, and they highlight the importance of considering the interacting effects of both anthropogenic and natural factors on the long-term viability of at-risk species.

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Understanding Seasonal and Within Seasonal Marine Mortality of Columbia River Juvenile Salmon Marine Survival

Robert Emmett[1*] and Doug Marsh[2]

Abstract

Identifying the environmental factors that influence seasonal and within season (i.e., weekly) mortalities of juvenile salmon is a complex task. This is because causes of mortality are poorly understood and sources of mortality change both annually and weekly. While we have begun to understand the large scale oceanographic forces that influence annual marine survival (e.g., PDO, El Nino, etc.), we have made little progress in identifying the physical and biological forces in the estuary and nearshore ocean that influence within season or weekly marine survival. Since 1998, groups of Snake River PIT tagged juvenile salmon have been monitored to identify their weekly smolt to adult returns (SAR's). In this presentation I attempt to relate a suite of estuary/ocean factors during the smolt migration period with weekly estimates of SAR.

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A Simple Cause for *D*: Equivalent Hydrosystem & Coastal Ocean Survival Rates

David W. Welch[1*] and Erin L. Rechisky[1]

Abstract

Transport of Snake River Spring Chinook smolts around the 8-dam hydrosystem (which is typically achieved in ca. 2 days and with negligible direct mortality during transport) was expected to double adult returns because mortality in the hydrosystem is approximately 50%. However, several studies conclude that the average T:IR ratio of spring Chinook is only around 1.1:1. Most theories revolve around the possibility that transported smolts are weakened by transportation, and that their subsequent survival is reduced as a result.

Since 2006 we have used the prototype acoustic array POST to test the theory that the relative survival below Bonneville of transported Snake R hatchery reared spring Chinook smolts is reduced relative to groups of In-River migrants. The Dworshak stock (released at Kooskia NFH) was used as the source stock for Snake River Chinook in 2006-09, but in 2010 tagging moved to Lower Granite Dam to allow tagging the entire cross-section of stocks that were of an acceptable size for the acoustic tags used (>140 mm in 2006 and >130 mm FL in 2008-2010).

In each year where we conducted a comparison of Barged and In-River migrant Snake River Chinook, survival below Bonneville was either statistically indistinguishable in each of the migration segments monitored or (in one single case) favored Transported smolts: the unimpounded lower river & upper estuary (to Astoria), the “Plume” (Astoria to Willapa Bay), and the coastal ocean (Willapa Bay to NW Vancouver Island), located one month of travel time and ca. 600 km north of the river mouth.

If below Bonneville survival of Transported & In-River migrant smolts is equal, why does transport not produce the expected doubling of adult returns since hydrosystem mortality is eliminated? One possible hypothesis emerges from considering the estimated survival rates (per day) in the hydrosystem and in the coastal migration corridor: these rates are similar. It seems possible, therefore, that transportation does not decrease post-Bonneville survival of barged smolts, and is therefore successful; however, transport also reduces the time smolts spend migrating in-river while increasing their exposure time to the coastal ocean. The degree of benefit from transportation may thus depend upon the relative balance of survival rates between the ocean and hydrosystem, which T:IR ratios may be tracking. Further testing of this hypothesis seems warranted, as well as developing a “reality check” on the acoustic tag data by comparing the results from the array with those generated by the PIT tag system when the adults eventually return home.

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Session 6: Synthesis & Open Discussion

Appendix E

Differential Delayed Mortality Workshop

Appendix E

Differential Delayed Mortality Workshop

The Differential Delayed Mortality Workshop occurred over a day and half on 10–11 May at the Marriott Courtyard in Portland, Oregon. A synopsis of this report including potential factors of *D* (Section 4), the heterogeneity and culling model (Section 3.2), and a comprehensive model (Section 3.1) were presented at the workshop. General investigative strategies and their recent studies were presented by researchers specializing in the fields of physiology, disease, travel timing and behavior, and ocean conditions in relation to *D*. Feedback on this report was solicited prior to, during, and after the workshop via an online survey and handouts. Below is a synopsis of the presentations, discussions, and feedback received.

E.1 Presentations and Related Discussions at the Workshop

Please see Appendix E for the workshop agenda, which includes the presentation authors, titles, and abstracts. Please see Appendix F for a list of participants and transcriptions of select presentations and discussions at the workshop. Below is a synthesis of select presentations and discussions to complement the abstracts provided in the agenda.

E.1.1 Welcome Address

Derek Fryer (USACE) welcomed all participants to the workshop and introduced the reasons for being at the workshop. The first four-part reason was derived from the NOAA Fisheries FCRPS Biological Opinion Research, Monitoring, and Evaluation (RM&E) Strategy 2; i.e., to investigate and quantify *D* associated with transportation, to investigate post-BON mortality related to arrival timing and transportation, to monitor and evaluate the effectiveness of the transportation program and operations, and to conduct a workshop every other year. The second reason was that fishery managers requested a synthesis and review of current research related to *D* through the Anadromous Fish Evaluation Program (AFEP) Studies Review Work Group. The final and overall reason was to identify main factors, hypotheses, and critical uncertainties of *D*. Derek then described the history and early efforts of fish transportation, which included planes, trucks, and barges. Annual estimates from 1978 to 2009 of barged and trucked fish were shown. Derek next took participants on a pictorial "barge ride" through the FCRPS. He showed photos of each dam and estimates of percent fish passing through each route and their respective survival rates. Derek finished his presentation by commenting that barging is only one of many factors that contribute to patterns of *D*. He listed the 12 factors considered in the current working draft of the synthesis report. He reminded participants that the goals of the workshop and synthesis report were to identify potential factors not yet considered and to identify which factors were believed to be most influential to *D*. Doing so would help develop future research goals and analytical approaches to address critical uncertainties of *D*. In a broader context, the ultimate goal is to maximize SAR rates by improving hydrosystem management with flexibility in fish operations.

E.1.2 Synopsis of Synthesis Report

Jim Anderson and Jennifer Gosselin (Anderson Consultant) presented parts of the synthesis report and Kenneth Ham (PNWD) facilitated the question-and-answer and discussion periods. Jennifer began the presentation by describing and outlining similarities and differences between the terms *D*, T:I, and latent mortality. General annual and seasonal patterns of *D* were shown. She then described the approach the authors of the report took with regard to identifying factors that may be of interest to managers and areas for future research. The approach was to categorize the factors identified from Task 2 (Synthesis & Review of Literatures Related to *D*) into a matrix of "Degree of Importance to *D*" versus "Level of Uncertainty" (see Section 6.1). The categories that may provide the greatest insight to managers would be factors falling into the category of "High Importance to *D*" and "Low Uncertainty." Similarly, factors falling into the category of "High Importance to *D*" and "High Uncertainty" may be areas where future research could be concentrated. Jennifer then synthesized hypotheses and research findings related to 7 of the 12 factors identified in the report. These were arrival timing and travel time, fish physiology, fish disease, dam operations, estuarine conditions and predators, ocean conditions, and tagging effects. RM&E specifically related to each factor were listed and some ideas of future research were suggested to help workshop participants start brainstorming.

Jim described the comprehensive hypothesis for *D*. He then introduced a new way to model culling (a concept that originated from the CSS Delayed Mortality Workshop in 2004). His model differed from the original concept (in which mortality of barged fish that would have occurred within the FCRPS had they migrated in-river now occurs post-BON), because it includes heterogeneity among individuals and the strength of selection against fish. See Section 3.5 for more information about the model and results.

Jennifer ended the presentation with a thought experiment, which showed that only small differences in the ratio of barged to ROR survival in different environments (lower river, estuary, early ocean, ocean, upstream migration) and over the life span of salmonids were required to obtain observed estimates of T:I. Another possibility is that the largest difference occurs in the early ocean phase.

E.1.3 Methods for Investigating Pathogens

Maureen Purcell (U.S. Geological Survey) presented the "Role of pathogens in differential delayed mortality among salmonids in the Columbia River Basin" (co-authored by Diane Elliott and Jim Winton, Western Fisheries Science Center, Seattle, Washington). The presentation provided background for understanding investigative research approaches to pathogens, and showed that there are tools available to help make inferences about infection dynamics in barged and ROR fish.

Fish occur and continually move along a continuum of "Susceptible"-"Exposed"-"Infected"-"Recovered/Exposed." The processes of transmission, progression, and remission cause fish to move back and forth along this continuum. At each of these stages, non-pathogen-associated mortality can occur, while pathogen-associated mortality only occurs in the "infection" stage. It is difficult to discriminate between the two types of mortality and to directly estimate pathogen-associated mortality. The challenge of assessing disease in natural populations is that the processes of transmission, progression, and remission are highly dynamic, and they are influenced by a range of intrinsic and extrinsic factors. Thus, longitudinal studies are necessary to determine where fish are in this dynamic cycle and ultimately determine whether pathogens are a major driver of differential survival. These longitudinal studies would include examining "apparent prevalence" (i.e., number of cases in a population at a given time) and "pathogen intensity" (i.e., mean pathogen level of infected animals) and linking these metrics to survival. To determine whether pathogens influence differential recruitment of barged and ROR fish, one would need to conduct pathogen surveys of tagged fish above or at LGR and at an endpoint (a common point of detection) such as BON or the LRE. Accuracy of apparent prevalence can be affected by sample size, substructure within the sample, the true prevalence (i.e., when true prevalence is very high or very low), fish collection/sampling biases, and pathogen-associated mortality (animals that have died from the pathogen). Because barged fish have a very short transit time through the hydropower system, we generally expect low direct and indirect pathogen-associated mortality. Detectable changes may be possible for acute pathogens or by using proxies such as shedding. In ROR migrants, their longer travel times through the hydropower system allow a progression of pathogens to occur, which in turn can lead to pathogen-associated mortality and lower estimates of apparent prevalence. Furthermore, as ROR migrants migrate to the LRE and ocean, progression and remission may be occurring. Thus, the endpoint that would lead to the greatest power for determining whether pathogens influence *D* should be measured in the LRE.

Validated, quantitative, and non-lethal techniques are available to detect key salmon pathogens. Non-lethal detection that provides a good proxy for true infection is possible with quantitative polymerase chain reaction of samples collected from the gill. Biomarkers can help measure responses at the molecular, cellular, or tissue level and estimate the effects of pathogens at the organism and population levels. Designing a biomarker involves three phases: 1) discovery, 2) validation in controlled studies, and 3) validation in longitudinal field studies. In the discovery phase, global gene expression profiling has been accomplished for *R. salmoninarum* (Metzger et al. 2010) and for infectious hematopoietic necrosis virus (IHNV) (Purcell et al. 2004, 2006). In the validation phase, changes in biomarkers have been linked to disease outcomes for *R. salmoninarum* (Purcell et al. in preparation) and IHNV (Purcell et al. 2010). This sets up the possibility of validation in longitudinal field studies, and it should be possible to determine whether pathogens influence *D* and to what degree.

E.1.4 *D*: A Glass Theory

Frank Loge (UC Davis) presented different ways of perceiving *D* at a comprehensive level, rather than summarizing five studies in which he and his colleagues have worked on over the past several years. These studies have been presented at other regional meetings and have been published in peer-reviewed papers and annual reports (Arkoosh et al. 2006; Dietrich et al. 2007, 2008; Eder et al. 2009a, b). Frank first described *D* with words, equations, and a diagram. He then conceptually compared the amount of post-BON mortality to the amount of liquid in a glass. One glass would be for the transport group, and another glass for the ROR group. Conceptually, he stated that we would like to fill up each glass with the different amounts of mortality that occurred due to different factors such as disease, predation, and straying. He then used this concept to highlight two problems. In the first case, when $D = 1$, the glasses are the same size no matter how differently one would fill them up with the various "amounts of mortality" caused by different factors. However, what actually is of interest is the difference in the volumes of the glasses. Thus, what may be more appropriate is to fill the glass with the "amounts of differential mortality." That way, one could determine the relative significance of each factor-related mortality to the total amount of mortality. The second problem is that the glass of differential mortality is tiny compared to the total extra mortality. Frank showed that with $SAR_{Transport} = 1.39\%$, $SAR_{ROR} = 0.90\%$, $V_{Transport} = 0.98$, $V_{ROR} = 0.56$, $D = 0.88$, extra mortality = 98.4%, and differential extra mortality = 0.19%. Some challenges were listed: 1) Is the volume of the tiny glass a management concern? 2) How big is the tiny glass? 3) What fills the tiny glass? 4) What are the differential characteristics that influence survival of returning adults? 5) The issue of correlation versus causation. 6) Can empirical data be collected accurately on a reasonable time scale for adaptive management? 7) Should the focus be on extra mortality rather than differential extra mortality? To end the presentation, preliminary data on the returns of 2008 outmigrating spring Chinook salmon related to the Eder et al. (2009a) study were shown. Estimates of *D* were 0.98 for in-river and transported fish that were not "reconditioned" (i.e., placed in net pens and fed for 28 days in the LRE), 1.51 for fish "reconditioned" and released at the mouth of the LRE, and 1.3 for fish "reconditioned" and released below BON.

E.1.5 Physiological, Transcriptional, and Behavioral Responses

Matt Mesa (USGS) presented "Physiological, transcriptional, and behavioral responses of transported and in-river migrating juvenile salmonids in the Columbia River: insights into mechanisms of delayed mortality?" which is a summary of the Mesa et al. (2008) report. Please see abstract in Appendix E for key results from this study.

E.1.6 Estimates of T:I Including Non-Tagged Fish

Steve Smith (NOAA National Marine Fisheries Service [NMFS]) presented "Within-Season Patterns of Smolt-to-Adult Return Rates of Transported and In-River Migrant Yearling Chinook Salmon and Steelhead" which is a summary of the NOAA (2010) report. Please see abstract in Appendix E for some key results from this report.

E.1.7 A Model to Identify Significant Factors of *D*

Jim Anderson (Anderson Consultant) presented "Modeling factors generating seasonal pattern of differential delayed mortality" (please see abstract in Appendix E). The approach to identifying factors of *D* was to develop sub-models for each factor tested, combine all the sub-models into one grand multi-linear model, define weightings of the factors, and run Akaike information criterion model selection. The sub-models developed were 1) dam passage experience related to spill, 2) hydropower system passage experience related to flow, 3) energy density related to heat, 4) predator exposure in the estuary related to fish length and travel time, and 5) ocean conditions related to upwelling. With data on spring/summer Chinook salmon SAR rates, the factors determined significant were heat, arrival day at LGR, arrival day at LGR cubed, flow at LGR, and flow at BON. Yearly and seasonal predicted estimates of *D* corresponded with observed estimates. Mechanisms involved with the parameters were hypothesized. The heat exposure represented energy loss experienced by ROR fish during in-river passage compared to barged fish that experienced a negligible loss. The arrival date at LGR captures the seasonal pattern of fish size at LGR, the decrease in travel time in the LRE over the season, and the changing conditions in the estuary and ocean. The arrival date at LGR cubed captures the decline of avian predation on smolts later in the season, and the decline in the rate of barged fish travel time in the LRE. Flow at LGR captures fish condition and flow at BON captures the effect on travel time of barged fish in the LRE.

E.1.8 Survival Rates in Barges and in the CRE

Geoffrey McMichael (PNWD) presented "Survival of Juvenile Chinook Salmon During and After Barge Transport in 2010 With a Comparison of Barged to In-River Survival Through the Lower 150 km of the Columbia River and Estuary." Please see Appendix E for key results from these studies.

E.1.9 Survival and Travel Times in the CRE

Kai Eder (UC Davis) presented "Survival and Travel Times of In-River and Transported Yearling Chinook Salmon in the Lower Columbia River and Estuary with Investigation into Causes of Differential Mortality," which is a summary of the Eder et al. (2009a) report. Please see Appendix E for key results from this study. At the end of the presentation, Kai showed some additional results. The distribution of travel times of the early cohort group (i.e., released or barged from LGR April 24–May 2) spanned between 4 days and 28 days, and peaked at 6 days. This right-skewed distribution provides a better understanding of the possible dynamics between travel time and predation risk. Preliminary estimates of SAR rates were 0.59% for in-river migrants, 1.01% for barged fish, and 1.65% for fish that were barged then placed in net pens in the LRE and fed for 28 days. SAR rates of barged fish were 0.84% for the early cohort and 1.05% for the late cohort (i.e., barged from LGR May19–21). SAR rates of barged fish held in net pens were 1.96% for the early cohort and 3.48% for the late cohort. Thus, it appears that late-migrating barged fish held in net pens have the highest SAR rates among the three different treatments and three different seasonal cohorts tested.

E.1.10 Migration Pathways in the Estuary

Ryan Harnish (PNWD) presented "Migration Pathways, Travel Time, and Survival of Acoustic – Tagged River – Run and Barged Yearling Chinook Salmon in the Columbia River Estuary." The results presented were an adventitious analysis of data from of a study in the McMichael et al. (2010) report to compare travel times and survival rates of yearling Chinook by specific pathways within reaches between rkm 50 and rkm 8. Please see the abstract in Appendix E for the results.

E.1.11 Evaluation of Delayed Mortality in the Estuary

Richard Ledgerwood (NOAA NMFS) presented "Evaluation of Hydrosystem Delayed Mortality Among Juvenile Salmonids In the Columbia River Estuary." Please see abstract in Appendix E. Since 1998, trawls have detected 1.8% of barged fish and ROR counterparts detected at BON. The distribution for travel time of ROR yearling Chinook and ROR and barged steelhead from BON to Jones Beach peaked at approximately 2 days, while that of barged yearling Chinook salmon peaked at 2.6 days. The distributions of travel times between BON and the estuary were right-skewed with relatively very few ROR fish and many barged fish in right tails. Travel speeds observed in 2010 were generally greater for ROR yearling Chinook salmon and steelhead than for their barged counterparts throughout the season. Travel speeds generally increased throughout the season, and appeared to positively relate to flow rates at BON. Similar patterns were observed in 2009. For subyearling fall Chinook salmon, travel speeds decreased throughout the season. Early in the subyearling outmigration season, ROR migrants were faster than barged fish, while at the end of the season, ROR migrants and barged fish had approximately the same travel speeds. Investigations of the diel passage from 2007–2010 showed that ROR Chinook salmon migrated at all times of the day and night with little change in their travel times. The barged counterparts were released during the day and night in 2007, but only at night in 2008 and onwards. Travel times of barged fish were greater than those of ROR migrants. An analysis of data collected from 2000 to 2010 showed that the differential travel times were approximately 0.4 days for Chinook salmon 0.1 days for steelhead. In 2010, detection rates of yearling Chinook salmon were greater for ROR migrants than for barged fish early and late in the season, but the same in the middle of the season. For steelhead, detection rates were always greater for ROR migrants than for barged fish. These patterns may be indicative of *D* patterns. In 2009, detection rates were greater for ROR than for barged Chinook salmon, but were same among ROR and barged steelhead throughout the season. In 2010, avian predation rates of ROR and barged Chinook salmon were approximately the same (from S. Sebring AFEP Review), while avian predation rates of ROR steelhead were about 3.5 times and barged steelhead 4.5 times greater than those of Chinook salmon. Also, in 2010, detection rates of fish transported from LGR or from LGS and LMN were the same in Chinook salmon, but were lower for LGR-barged steelhead LGS–LMN barged steelhead. The Mobile Separation by Code could be used to target ROR migrants and barged fish in the estuary. Travel time and growth could be determined in those samplings.

E.1.12 Factors from the Freshwater and Ocean Environments Related to *D*

Kirstin Holsman (NOAA NMFS) presented "Keep on Truck'n? Interactions Between Conservation Measures and the Environment Lead to Unintended Consequences for an Endangered Species of Pacific Salmon in the Columbia River Basin." Please see abstract in Appendix E for key results and interpretations.

E.1.13 Annual and Seasonal Survival in the Marine Environment

Robert Emmett (NOAA NMFS) presented "Understanding Seasonal and Within Seasonal Marine Mortality of Columbia River Juvenile Salmon Marine Survival." Please see abstract in Appendix E for an overview of the presentation. Robert began the presentation by listing two overarching goals: to identify potential physical and biological indicators of high marine survival throughout the season, and to selectively use transportation and time hatchery releases to optimize SAR rates. Two general hypotheses are that annual and weekly SAR rates are influenced by environmental conditions in the estuary and first few days or weeks of at sea, and that marine survival is affected by forage fishes that are alternative prey and zooplankton that are food for growth. Variables that are recorded on a daily basis include zooplankton abundance from acoustic data, forage fish abundance also from acoustic data, satellite chlorophyll or irradiance, direction of nearshore currents, direction and size of the plume, river flows, river temperatures, river turbidity, sea surface temperature, sea level pressure, tidal stage, and upwelling. Daily information that would be valuable include abundances of predator fish, marine mammals, and birds, estuarine forage fish and zooplankton, and salmon prey. Robert ended his presentation by quoting Keith Devlin, a math professor at Stanford University, who said "complex systems are inherently non-unravenable. The best you can do is gain a holistic understanding."

E.1.14 Equivalent Hydrosystem and Coastal Ocean Survival Rates

David Welch (Kintama Research Services) presented "A Simple Cause for *D*: Equivalent Hydrosystem & Coastal Ocean Survival Rates." Please see abstract in Appendix E.

E.2 Open Discussion at the End of the Workshop

We began with a discussion of the species and rearing types with which management and research are dealing. Modifications to the working framework of the "importance versus uncertainty" matrix of *D* factors were suggested. We determined some key uncertainties, data gaps, and areas for future research and monitoring related to *D*. The discussion ended with a general discussion of information needed to help with decisions of actions. Please see Appendix F for a transcription of this open discussion.

E.2.1 Species and Rearing Types

Some participants thought that we are dealing with a mixed population and thus we can only manage in a way that would be suitable to most of the four groups (i.e., hatchery and wild Chinook and steelhead). Others thought that the mixed population could be separated by species because it is already separatedto some degree. Also, the transportation program appears to be working for steelhead, but a better response from Chinook salmon could be sought; the difference was greater than that between hatchery and wild fish. Concerns were raised about a program that would separate steelhead for transportation and bypass Chinook salmon because it appeared that preliminary research on transporting Chinook separately from steelhead showed that transporting did not improve their adult return rates. Also, diminished swamping effects could reduce the benefits of in-river migration for Chinook salmon. It was brought up that we used to essentially transport some parts of the year. But more recently, there was a regional consensus to increase spill during years of low flow and we will have to wait to see the results from the application of this new strategy. This part of the discussion ended with a plug for understanding the underlying mechanisms involved in transportation. Current strategies appear to be based on a probabilistic model where we adopt a strategy that generally works best under existing conditions. An understanding of the mechanisms would, in the long-term, help in making decisions with the operational tools at hand. Research on specific mechanisms has been focused on in Chinook salmon, but more research on steelhead could help determine why transportation benefits these fish. This knowledge could then be used for Chinook salmon.

E.2.2 Modifications to the "Importance Versus Uncertainty" Matrix

A draft version of the "Factors by Degree of Importance in Relation to *D* versus Level of Data Gaps and Uncertainty" (also termed "Importance versus Uncertainty" matrix; Table 4.3) was presented at the workshop. Below are suggestions for how to improve the "Importance versus Uncertainty" matrix.

E.2.3 Straying

There were some difference of opinions with regard to whether straying (❿) should be categorized by high, moderate, or low level of importance. Some thought that because straying affects adults, its relative effect on *D* is large; protecting the adult population is of low uncertainty; and we can get good estimates of conversion rates. Others thought the impact of straying on conversion rates was minimal and hence of little effect on *D*, and straying would only be an issue if other strays were coming into the population (i.e., Snake River Basin), rather than those leaving the population (i.e., to stray to John Day and Deschutes rivers). In general, there are also differences in stray rates by species and rearing types: higher in steelhead than Chinook, and higher in hatchery than in wild. But it appeared that better organization of information and rationales would be needed before deciding the final categorization of straying.

E.2.3.1 Fish Health/Performance Metrics

It was suggested that fish length (❷), fish physiology (❸), and fish disease (❹) be lumped into one category of health or fish performance. These three factors are closely related and have been categorized as being of relatively high importance. The factors were not lumped together because there was already a categorization of factors that are fish-centric and factors related to the environment. Also, there tends to be a loss of information when there is too much generalization. It was also suggested that fish length be moved down in importance, while fish physiology and fish disease be moved up in importance.

E.2.3.2 Genetics

Genetics plays a role in many factors such as physiology, disease resistance, adult straying, and growth rate. However, genetics does not appear in the "Importance versus Uncertainty" matrix. It appears that we do not know much about the genetic impacts of transportation on these populations. Fish performance indices, such as genetics, likely have different metrics of good performance for hatchery versus wild fish. Thus, we need to consider whether genetics is an area where research could help support a management action to improve adult returns.

E.2.3.3 Lower River and Estuary

It was suggested that the factor of the lower river (⑦) be categorized with greater importance in the matrix. However, the distinction was made between the lower river where survival was relatively high and the estuary (⑧) where survival is lower, especially in the lower 50 km.

E.2.3.4 Arrival Timing

It was suggested that factors related to arrival timing, such as hydrosystem arrival timing (❶), estuary conditions (⑧), and ocean conditions (⑨), be lumped together.

E.3 Key Uncertainties

A key uncertainty is a state in which we have limited knowledge and in which it is difficult or impossible to describe existing and future states. If additional research could reduce those uncertainties, it could improve the ability to take actions that achieve the desired outcomes for fish.

E.3.1 Estuary and Ocean Conditions and Timing of Barging

Overall, relating seasonal patterns of estuary and ocean conditions to *D* would be useful. It was suggested that indices of turbidity, perhaps measured by chlorophyll, could be used to determine appropriate times of barging. For example, in 2005, most of the fish were transported, however ocean productivity was low and the fish may have survived better if transportation had been delayed. In 2010, it may have been a similar situation of low ocean productivity, but the delayed transport may have been appropriately timed.

E.3.2 Proportion Transported Versus Proportion In-River and Dam Operations

Because *D* is a ratio, it is difficult to determine exactly how it is affected by improvements in transportation (which generally increase *D*) and by improvements in in-river conditions (which generally decrease *D*). Furthermore, SAR rates can be low even if *D* is high (e.g., 2001), and SAR rates can be high even if *D* is low. Relationships between *D* and SAR rates could be further investigated. Effects of passage routes (turbine, bypass, or spill) on *D* are also not well known. One last suggestion related to this discussion was to determine how hatchery releases below Ice Harbor Dam (ICH) affect ROR migrant survival, as well as how hatchery releases below BON affect both ROR and barged fish survival.

E.3.3 Culling

Workshop participants appeared to have different definitions and interpretations of culling. Culling was perceived to mean the "weaker" fish that die whether we transported them or not. It was also perceived to mean natural selection experienced by fish migrating from the hatcheries to below BON. Culling was considered and discussed at the CSS Delayed Mortality Workshop in 2004, and it has been revisited again in this current report (Section 3.5).

E.3.4 Differences Between Species and Between Rearing Types

Determining which characteristics and behaviors explain why steelhead benefit from transportation more than spring/summer Chinook salmon can be insightful. Likewise, determining why hatchery Chinook fare better in the transportation program than their wild counterparts can also be informative. This information could be used to improve the transportation program. For further discussion see Section 6.3.

E.4 Data Gaps and Areas of Future Research/Monitoring

A data gap is an area where we can collect specific data to increase our understanding of mechanisms involved with *D* patterns. Data gaps and future research/monitoring areas are presented here.

E.4.1 Fish Monitoring Program

It was suggested that PIT-tagged fish could be collected at dams and monitored for fish length, disease, and physiological condition. A long-term concerted monitoring effort could provide a lot of information for this general gap in data about fish condition. This would help address many questions related to *D* as well as other management questions. Fish could also be collected in the lower river and monitored for length and indices of health.

E.4.2 Collection Bias

Whether there is a collection bias for "weaker" fish in the juvenile bypass system was a recurring question. Additional data would be required to determine whether collection bias exists, and whether it is biased towards fish with smaller sizes, disease, low lipid content, etc. Additional data and analyses could address whether the collection bias is related to *D*. Some studies mentioned that have investigated areas related to collection biases include a study by Maule et al. in the 1980s looking at cumulative stress at MCN, Elliott et al. (1997) looking at bacterial kidney disease, and Buchanan et al. (2011) looking at bypass effects.

E.4.3 Disease

Since the mid- to late 1990s, Idaho Fish and Game has instituted a fish health program that may have a lot of disease profile information for hatchery fish. It may be worthwhile to explore this data set in relation to *D*.

E.4.4 Fish Length

Fish length was mentioned as a data gap. Video monitoring of fish as they pass the dams was suggested as a method for measuring fish length. However, the issue of precision in data collection was brought up. It will likely be difficult to detect a signal with small differences between bypassed versus transported fish (i.e., 2, 3, or 4 mm). The fish that survive to East Sand Island are on average 3–4 mm longer than the size of fish tagged for JSATS.

E.4.5 Research/Monitoring Useful For Specific Actions

Before the conclusion of the workshop, there was a brief discussion of what sort of information would be useful to help determine whether to barge, when to barge, where to barge, who to barge, and how to barge. There was first some discussion on which metric (i.e., T:I, *D*, and SAR rates) would be the most useful criterion. In general, optimizing SAR rates is the goal, but *D* and T:I are used to determine how we can improve the transportation program. A few of the suggestions for research/monitoring were as follows. Monitoring the ocean and the estuary was mentioned as a way to help determine when and where it is most appropriate to barge. It was also suggested that it should be determined how increased flow early in the season would affect the survival of early barged fish. Determining when to release barged fish to minimize predation risk in the estuary was proposed. And finally, there was some discussion about how artificially altering the migration timing of fish by barging may be beneficial in maintaining the diversity of late migrating fish that otherwise would experience low in-river survival.

E.5 Feedback Received

Below is a summary of the feedback received before, during, and after the workshop. We have organized the feedback into categories of general comments, other *D* factors to be considered, and areas of future research. A Differential Delayed Mortality Survey was distributed electronically and in hard copy form before and during the workshop; the survey and results are in Appendix G. We have incorporated the research ideas and suggestions for improvement in the report. Where appropriate, we have included responses to the comments.

E.5.1 General Comments

General comments included the following:

- A description of how to interpret *D* in relation to T:I and in-river survival rates through the FCRPS is needed. This would help folks understand what absolute values of *D* really mean and the usefulness of *D*.
  - We have added this information to the report.
- A prioritization and ranking of RM&Es would be useful, and the factor matrix (i.e., “Importance versus Uncertainty” matrix) can help with this. Another criterion could be whether or not transport operations could be practically managed in relation to a specific factor.
  - We considered this in the roadmap of future research.
- The focus on *D* is misplaced. *D* is not informative to estimates of SAR rates. SAR rates of ROR and barged fish should be measured and examined separately.

– SAR rates are ultimately the metric we aim to increase. However, because estimating survival in the ocean for barged fish and ROR migrants separately is impossible, consideration of *D* is useful because it eliminates the immeasurable effects in the ocean. We cannot isolate FCRPS effects across years unless we investigate the ratio of SAR rates.

E.5.2 Other Factors That Could Be Considered

Additional factors to be considered included the following:

- arrival time and travel time in the lower part of the estuary
- size, disease, and physiological condition of fish at ocean arrival
- explicit consideration of interactions between factors
- the probability of passage through different dam passage routes in relation to dam operations.

E.5.3 Areas of Future Research

Future areas of research were identified, as follows:

- Several participants suggested collecting fish in the lower river, estuary, and early ocean for measurements of length, disease, and physiological condition. This would allow comparisons with fish at LGR and BON. Fish could be collected in a towed array if the mobile Separation by Code system is operated.
- Specific topics of research in the estuary include 1) the effect of barge release timing on avian predation risk in the estuary; 2) identification of areas of high mortality in the estuary, their potential causes, and possible solutions; and 3) within-season nearshore survival of ROR and barged fish. The behavior and survival of fish related to these three research topics could be examined by taking advantage of studies that use large number of JSATS-tagged fish released in the Snake River for dam survival. It would only require implanting paired groups of barged fish with JSATS tags and deploying JSATS receivers at strategic locations in the estuary and nearshore ocean. By taking advantage of the ROR fish already tagged for dam survival studies, the cost would be considerably reduced.
- Disentangling the effects of size/condition from those of arrival timing to LGR and ocean.
- Indicators of ocean conditions and mechanisms that affect survival throughout the season.
- Whether low *D* occurs only in small sized fish.

Appendix F

Transcript of Workshop Meeting

Appendix F

Transcription of Meeting Discussions

Snake River Basin
Differential Delayed Mortality
Workshop

May 10-11, 2011
Marriott Courtyard Portland Center
Portland, Oregon

Sponsored by: U.S. Army Corps of Engineers (USACE), Walla Walla District

Facilitated by: Kenneth D. Ham, Pacific Northwest National Laboratory (PNNL)

Coordinated by:
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David A. Trachtenbarg, USACE, Walla Walla District
Jennifer L. Gosselin, Anderson Consultant
James J. Anderson, Anderson Consultant
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Transcribed by: Kathleen McCaw, USACE

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(a) Workshop presenter

NOTE: The sound system in the meeting room was out of adjustment on the day of the meeting, and the sound engineer was not available to make an adjustment. As a result, recordings were of reduced quality and made creating this transcript difficult. Special thanks are due to Kathleen McCaw, USACE, for making the extra effort and delivering the best possible transcript under the circumstances.

F.1 Welcome

Derek – welcome to 2011 delayed mortality workshop. It's been a few years since a workshop has been held, last one in 2004. Couple of housekeeping items – we have some handouts for the presentations today, and we have a 60 percent draft copy of the differential delayed mortality synthesis report. We're currently still accepting comments on the 60 percent draft, and will continue to do so for about another week. At that time, we'll take those comments and combining it with everything we talk about here today into a draft final report. That draft final report will likely be coming out around early June. Then there will be a short window of about a month for comments, three weeks to a month to comment on that 90 percent draft. Then we'll shoot for our final report in early to mid-July, I think that's the way the contract has been written.

I pulled this information out of the 2010 BiOp, with supplemental … In that BiOp RM&E strategy 2 … the first one here under critical uncertainties is investigate and quantify delayed differential effects associated with the transport … in the FCRPS … The other ones on there were all relative to transportation that in some way played into delayed mortality. … Investigate post-Bonneville mortality effect of changes in fish arrival timing and transport to below Bonneville; monitor and evaluate the effectiveness of the juvenile fish transportation program and modifications to operations. It also says in the BiOp that we will conduct a workshop every other year.

This synthesis report we've been working on came out of our AFEP SRWG group. It was a request from fishery managers to summarize the information we have to date and present that information to them so that people can start getting their heads around what I consider a very complex issue. That's what we're here to do, is to try and summarize, also to identify the main hypothesis and importance of these factors, which ones are the heavy players contributing to differential delayed mortality, and also to potentially develop a road map document so that this can guide where future research might go, developing research objectives and/or new analytical techniques for … differential delayed mortality.

For barge survival over the years, it's been assumed and calculated to be 98 percent, but we haven't … What was the highest system survival rate for last year for spring Chinook? Bill, do you know that number off the top of your head? Bill – No, maybe 51 percent. Derek – If we assume 98 percent survival rate, and we had a 51 percent in-river survival rate, we're getting into the crux of what delayed mortality is, you'd assume that bypassing those fish all around the hydrosystem that we'd increase the survival. In fact, in a lot of cases we don't see that. We see *D* value of around 1, it means a wash. The question would be, why are those fish that were barged all the way around the hydrosystem dying at a potentially higher rate than run of the river fish? That's really what we're going to be diving into here today.

But barging is only one part of the equation. When you start reviewing data and looking at different hypotheses that are being tested or looked at or discussed in the literature, you come up with a whole list of other items where barging is actually just one small part. We're going to be talking about several of these today, so I'm not going to go into them in detail, other than to point out actual barging process … The goals of the workshop and synthesis report were to identify potential factors not yet considered; to identify which factors are believed to be the most influential to *D*; identify and develop research and potentially new analytical approaches aimed at addressing the critical uncertainties of *D*; with the overall ultimate goal of increasing life cycle adult returns. The secondary goal is improving hydrosystem management and flexibility of fish operations to try and maximize those SARs.

F.2 Session 1

Snake River Differential Delayed Mortality Synthesis Report – presented by Jennifer Gosselin

ARRIVAL TIME AND TRAVEL TIME.

FISH PHYSIOLOGY. Al G – I have a general question. You already made some determinations and conclusions … but we haven't had a chance to read the report. Jennifer – We tried to review all of the literature and named some certain ideas and hypotheses (to begin a) road map of where we want to focus future research, and which actions might be important that could affect *D*. What we'd like to get from the group is feedback on some of these ideas. I suggest these just to get everybody thinking. Or you could say, you know what, that's garbage, and suggest something else. These are ideas to get the group thinking and get some feedback. Al G – Are we going to look at the scoring table that you have at this point? Jennifer – Yes … another factor you have in your handout, the full version of this, and we can discuss that right now, whether we think fish physiology should be categorized here, or maybe somewhere else. Kenneth – That's one of the ways we can play that out … other people with similar thoughts that indicate how important it is. All these are going to be part of the discussion at the end.

Paul W - … the feeding activity, or the growth of fish that are barged … fish did not grow through the hydrosystem, the fish that went in-river, but they were … fish … found that they do grow, the wild fish. Is that a fact that can be stated that way? Hatchery fish do not grow on their journey through the hydrosystem, but wild fish do feed actively, they actually gain weight. Are we that definitive, or is that a big unknown? Jennifer – What graph are you looking at? Paul – Energetic reserves in ROR depleted. It seems as though … hatchery fish are going to die because … can't hear … Jennifer – This hypothesis came up … looking at the lipids, the proteins, we looked at … and we saw that there were pretty low ROR migrants, especially when they reach Bonneville dam, even though this is looking at … season, whereas barged fish they were pretty high. For example, when we were looking at the fish at Lower Granite, you compare hatchery fish to the wild fish, they seem to have double the amount. So we were thinking that perhaps it's because the fish coming out of hatcheries, it's like they came from an all-exclusive resort … whereas the wild fish have been living in the real world for a while, and they're getting to a point where it's a more realistic level of lipids that fish just have when they're living out in the wild. It's interesting that that level is the same … can't hear … so the high levels of lipids in hatchery fish at Lower Granite just might be because they've recently left the hatchery.

?? – can't hear … wild more growth … Jennifer - … growth and length are different than looking at energy density or lipid content also. And here we're not looking at length, that was another factor that we skipped. Matt – Is there any context with, this is a little bit hard to do, because there's not many salmonid populations that don't deal with dams. How much energy loss do fish in undammed rivers show? For example, do you have any information from juvenile salmon in Alaska? … energy of these fish growing or changing conditions is actually a part of smoltification, that's what they do. It would be helpful in the hatchery/wild question, it's really important, but it would be helpful to try to gain some context in the future by seeing if you can get some information on the proverbial wild undammed fish – how much do they lose on average? How far out of the ballgame are we here with fish in the Columbia? Jennifer – Yes, it would be interesting to compare, to see what is the baseline … Frank – Physiology is a huge deal. I'd caution you in using the term physiology when … physiology can mean a lot more things. … in the final report, change the wording of that to reflect what you're actually talking about. Jennifer – Yes, we can talk about any one of these factors for a whole day, and yes, physiology does cover a lot of different things. We try to comment on that by emphasizing that physiological patterns are complex, we are only exploring two out of hundreds of indicators that are out there.

FISH DISEASE. ?? – One concept, I'm trying to get my head wrapped around this, I'm thinking in terms of sampling bias, in terms of comparing populations. We don't really know the characteristics of those populations. There's some uncertainty in that framework. The idea that we have target populations of interest, barged and not barged, but we also have the sample populations, which … can't hear … I think for me, if we can put this in the context of what are those characteristics of population that we're actually sampling, and distinguish from the population that is our target population … from my own perspective, that's what I'm trying to do … To put all this in a framework like this, and address those questions – this reminds me of some concerns that Jim Congleton raised, … culling effect … Jennifer – It's important that we consider which stocks we're looking at, and also within each stock population; we have the sampling group, and whether the sample is representative of the population.

Russ? – I have a question and a comment. What was the pre-challenge that you did? Jennifer - … paper is in press right now … What they found is, they collected the fish … and then ran challenges to these … fish. I'm trying to remember off the top of my head, the pre-challenge meaning that there was a bunch of fish that died right after they collected, before they ran the challenge. If you look at just the challenge ... the ROR fish didn't do as well as barged fish. But that may be because the barged fish were culled, those fish that died in the pre-challenge phase. You can think of them in terms that they were already culled. If you look at the total line of mortality from the time they were collected, barged fish did worse.

Russ – My comment is on the disease aspect. I understood, and probably some of the folks in this room came up with the hypothesis that is very logical to me, if they have interaction between migration timing and disease, that the early transport of fish, because the collection transportation system exposes fish to pathogens, cause a lot of lateral transmission, that the early transported fish were not ready to enter saltwater, and you had worse disease outbreaks, is my hypothesis. Whereas the later transported fish are ready to enter saltwater, which helps mitigate the disease that they allegedly caught in the collection barging process. So 1) I think disease is important, and 2) it's highly linked to the timing issue, it seemed logical to me when I heard the hypothesis. Jennifer – can't hear … Frank – I just wanted to make one quick comment … at least … can't hear … specific hatcheries, so we're not dealing with ROR fish, and the number of fish that are sampled are designed to be … 5 percent difference in prevalence at 95 percent confidence interval. It still allows you, in terms of diversity of … I think we designed the sampling regime to deal with that … One thing I cannot comment on is whether or not there's preference in selection group diseased fish in the bypass … in that sense, we might be sampling a subgroup of out-migrants who are not exposed … that's the hypothesis … otherwise it should be a representative sample. Jennifer – I think there's a paper by Diane Elliot looking at BKD, and they found that fish that had higher BKD levels were entrained in the bypass system …

Matt – One point to keep in mind, because the next day and a half we'll be talking about disease – Frank mentioned the word prevalence, and I want to make sure everyone understands the difference between pathogen prevalence and clinical disease – it's really important, because with the molecular tools being developed today, literally able to detect a single pathogen in fish, he's going to attribute to a prevalence test. BKD is a good example, or at least it used to be a good example, now you don't see it as much as you did 10 or 15 years ago. But you can test a lot of fish with BKD and find one cell, and if you tested 100 fish, you might find 90 of them with one cell, and that would be a 90 percent prevalence … going from that to clinical disease is quite a different ballgame. Pathologists understand that stuff, I'm not really sure that the other folks do, so keep that in mind when you talk. I think it's an important concept to keep in mind as you go through creating the tables and thinking about what contributes to *D*. Jennifer - … I guess it's clinical signs of disease rather than pathogen prevalence? Matt – I think we do, we don't just look at … cells, we'll determine both. Pathologists know clinical signs just like a doctor would for humans, but we just have to keep in mind that when you see some of the data later on today, some of that might be reflective of prevalence, and it's very easy to confuse that with clinical disease and thinking to the future that this might be a pathogen that gets hold of them and causes mortality in fish. It's very likely that fish could deal with the pathogen and never be affected by it at all. You have to be careful when you talk about that.

Maureen – I agree with Matt. The current problem … can't hear … accuracy is highly dependent on diagnostic … can't hear … Matt's absolutely right, the presence of pathogen doesn't mean disease. We know that fish can be … this is not a measure of … Derek – I have a follow-up comment on the disease challenge study that we were just talking about. I felt that this was a pretty key finding, that we should keep under consideration … I'm going to read right from the abstract of the Dietrich et al. paper (An Evaluation of the Influence of Stock Origin and Outmigration History on the Disease Susceptibility and Survival of Juvenile Chinook Salmon. “"The results suggest that the health status of fish and their history prior to entering the hydropower system (hatchery of origin and outmigration path) are critical variables affecting conclusions drawn from studies that evaluate mitigation strategies." By understanding the heath and condition of fish as they arrive at LGR we can do a better job at evaluating the benefits of one mitigation strategy over another … status of that population is so you have a better understanding of what that survival number actually means.

DAM OPERATION EFFECTS. Kenneth – We're going to hold questions until the end.

ESTUARINE CONDITIONS AND PREDATORS.

OCEAN CONDITIONS.

TAGGING EFFECTS.

Jennifer – Before we go to Jim, we can take comments on these factors. We have covered dam operations, estuary conditions, ocean conditions, and tagging. ?? – I think maybe you have oversimplified the relationship between spill and transportation rates … in case of low flow conditions we actually have a higher proportion of spill … We need to go back and rework that a little bit. The other thing I noticed was the temperature hypothesis; in the lower river everything I've ever seen shows that the river is pretty excellent, and I'm not sure there's much in the way of selectivity, if fish would be able to choose the temperature … can't hear … Jennifer – That was from the Clemens and colleagues paper. They thought … ?? – So arrival time and travel time … is one of the factors, and say, for example, estuarine conditions and predation, or ocean conditions are also, as we just saw, really … when those fish were … and arrived at the ocean – just arrival time, or depends on the travel time? Jennifer - … the factors are all interrelated, but we tried to tease it apart to talk about it. ?? – … a lot of times it seems like one of the big factors is arrival time and travel time, and maybe we can tease out the factors that they are also responsible for – longer travel times, or different arrival times, but it seems like those are … Jennifer - … can't hear … when they arrive at Lower Granite? Or also the travel time within the hydrosystem? ?? – I don't know how to do it. Jennifer – We looked at pre-hydrosystem conditions a little bit, and it's hard to determine how it affects barged and ROR migrants. … How do you test that? I think oftentimes research is looking at just improving survival by improving conditions. It could be varied to increase survival, but then how do you determine whether it has an effect on barged fish versus ROR migrants?

Al Giorgi – What's the thinking on the tag effects? Why were these studied? … Jennifer - … treatments barge versus ROR, or was the sample representative of the population? Al – … with respect to *D*, so barge versus ROR. Jennifer – I don't know. … We could look at that further to see if there is a bias between barged and ROR fish. Al – It's given a pretty high rating … Jennifer - … estimates of T (*D*?) are affected because the bypassed fish experience lower survival relative to the population, so our estimates of *D* are affected. That's why, it's not necessarily that *D* would get affected because of the tagging …

Jennifer – You should have this table in your handout also. This relates to fish condition and factors that exist in the environment. The studies that we thought had high importance to *D* were the ones with one dot, (two dots?) moderate importance, and the ones that are blank either have no information or we didn't think were important to *D*. If you think of any other key papers that should be included in here, or combinations of factors that you think are important, circle them or comment and let us know.

Jennifer – Now Jim will present the comprehensive hypothesis. Jim – This is going to be rather short. As we looked at all this data, the main thing we realized is that there are definitely … or intervals where a certain set of processes seem to be dominating … *D*. I just want to point this out. Here we have three areas (comprehensive hypothesis graph) that we need to be thinking of. The early region is where ROR fish do better than the barged fish. The middle region is where the barged fish do better, and in the later region (ROR do better) … we also have larger fish, they have a higher *D* than the subyearlings. These values here are … can't hear … As we go forward and try to understand the hypothesis, what we think might be useful is to … can't hear … to look not so much at species level, but to look at this in terms of fish, they're all fish, but they have different … One of the more interesting hypotheses was first encountered by Schreck, who presented the idea that in the estuary there's a change in the behavior of the fish. Early in the season, the barged fish are smaller, they like to stay in freshwater for whatever reasons. Maybe they're not smolted, maybe they have a higher disease prevalence … Smolted fish are ROR fish, so these fish, early in the season, are more susceptible … Later on in the season, the barged fish are more like the ROR fish, and the difference in *D* declines because it's more similar. This would suggest that travel time on the barged fish through the estuary was pretty … over the year. The ROR fish apparently have approximately the same travel time through the estuary. So barged fish are more susceptible, they're higher in the water column early in the season. Later in the season they're more similar to river fish. I call this the Schreck hypothesis. It makes sense, although the details that cause a fish that's different here, similar here, are not fully understood. We just have a few minutes left. We can discuss this hypothesis or go over it later.

Matt Mesa – Has it been substantiated with field data? There should be enough PIT-tag return data from bird colonies to either look at barge versus ROR fish that were PIT-tagged, or just do an analysis by condition … I assume there's data up here to refute or substantiate this hypothesis. Jim – I'm not aware of anybody that has done that to date, but I am aware of somebody who is in this room who is pursuing getting his Ph.D. and wants to look at that data, and that's Jeff Rutter who is right there. I think it's a great idea. Frank – There is a paper related to this, Nathan Alstetter, who is at … OSU working with … He recently put out a paper, and I don't know if he concluded it with a summary or not, but they found a direct correlation to external fish conditions and avian predation rates in the Columbia River, it wasn't down at the estuary. But it supports the idea that the health status isn't what it seems in rates of predation. I see it in lipid I can't remember all that they found … Jim – This particular hypothesis seems to be percolating. You shake things up, and this one always comes out.

Dick Ledgerwood – We've been analyzing PIT-tag data from East Sand Island tern and … cormorant colonies, looking specifically at large in-river fish. We'll talk a little bit about that tomorrow. Generally the conclusion has been that there has not been significant differences in predation rates of … migrations. I think there might be reason to stack that data … Matt? – Would that be by time also, Dick? Early versus middle? Dick – Yes, we group them by week, passage or released from barge, so that's the way it's been analyzed. Jim – I think we'll probably discuss this further. This is kind of a central topic to the workshop.

Al – Your trajectories in those plots you showed, individuals (which slide?). In that complex right there, which set of those would you expect is represented by your barged fish? Jim – This group here would be, let's say, all barged fish. So the vitality of the change in the condition of the fish is going to be different for barged fish compared to ROR fish. If we look at this in terms of smoltification, we would have these going up, and for barged fish they would be rather low throughout that period, and for ROR fish, if we were looking at vitality after they exit the hydrosystem, they would be higher. Al – I'm just trying to put those two groups in this context … Jim – This is a different way of looking at things. I'm not sure we can actually estimate the numbers within this, or the parameters, but I think it's a more realistic way of looking at the problem of delayed mortality. And it points out that it's a difficult problem.

Ken – Jim, can I clarify that it isn't as if we were trying to suggest that they all start out with those … trajectories and then they're changed by their experience … can't hear … Jennifer – Jim developed this model ... first considering a hypothesis in 2004 … 2004 workshop … mortality that barged fish wouldn't experience had they been migrating in-river just as late to post-Bonneville dam. I think Jim felt this showed that it's not just a simple displacement for mortality, but rather it is affected by the condition of the fish vitality, and put it in context of the condition that they experience also, which is the red line that would show which fish were culled. It was not just a simple displacement of fish mortality rate in the hydropower system to post-Bonneville dam, but it depends on other things – the heterogeneity, the condition of the fish, and the environment that they experience. This is a way of measuring that. Jim – So there's a disconnect in how we're thinking of the problem … everybody understands that their experiences going through the hydrosystem affect fish below the hydrosystem. The theories that we've been using to describe mortality are not really designed to look at that, so what we're trying to do is build a more tractable, quantitative way to …

Jennifer – Taking all the factors that we looked at and put it in a more linear order of downstream, lower river, estuary, early ocean, later ocean, and upstream environments. Looking at the T:I ratio as we covered already, we expect it to equal 2. We know that survival in barges is pretty high, and survival in ROR is (half?). If survival of these two groups were identical … then we expect T:I to equal 2. But we don't. We see something that's closer to 1. So let's say that the survival of the barged fish is just a little bit lower than survival of ROR fish – these little differences accumulate and then we can see that T:I is equal to 1. We can argue about the … This is just another way of seeing the ratio for each of these factors. … We don't cover the estimates of survival in the early ocean and later ocean, so let's say … most of what happened occurred in the early ocean, and we can still get a low T:I ratio. I think our message here is that with multiple factors, small differences add up across environment and across years. Or perhaps that … early ocean, or is it perhaps something else? If you want to play around with the numbers, I have it in an Excel spreadsheet. … we see that many factors have potential to affect *D* itself, or our ability to estimate *D*, and environments where we have measurements of survival don't explain patterns of *D*. We attempted to ... these factors, and that would be the start of one of the discussions, and also another … can't hear … only get actions that may affect *D*, and don't we all wish we could just press the easy button and figure this out.

F.3 Session 2

Impact of Pathogens on Differential Delayed Mortality Among Salmonids in the Columbia River Basin:

Review and Synthesis – presented by Maureen Purcell

Maureen – What I'm going to focus on is this question – whether or not pathogens really are a major driver in this system or not. In Jim's … report, he (says) 'Disease is of moderate importance with high data uncertainty.' The issue here is, I don't really think this high data uncertainty is a reflection of the quality work that's been done. … pathogens are a very complicated system. We tend to think about infectious diseases in terms of this model here, which is called FIRR, derivations of the Aspire model.

?? – When you're talking about the power of S and how many animals you might need … 1,000, 10,000, 100,000? Maureen - … like I said, the (tool? pool? A name?) makes her higher career out of figuring out sample sizes for these groups of studies, but there are some good online tools. Accutools is one of them. Really what you want to know is, you want to detect the pathogen with 95 percent confidence, plus or minus 10 percent accuracies. In the end you have to assume, usually, a prevalence. Let's say you assume 50 percent prevalence in population – I'm thinking of one study I looked at; some of the predictions were like 700 animals. It can be really high, and that number changes depending on the actual prevalence you assume you have. The reality is … the higher the number, the better.

?? – … progression of disease … how many days are we talking about? Maureen – I think it depends on the pathogen. Basically, in a couple of days, we know from studies that Paul Merica, Paul Richriver do out of their baroscope lab, if you're talking a radiovirus, … natural populations that are apparently healthy, were in limited captivity, and in 4 days 8200 fish are dead. So if you're talking radical virus, it's difficult to say, because it's a very fast process. If you're talking about something like …bacterium, I think what you wouldn't want to do is pull them out for at least a couple of weeks post-Bonneville to see if those early changes manifest. I think you can't really make sweeping conclusions. For instance, some of this saltwater versus freshwater progression – it depends on the pathogen. If you're talking about surface fungal pathogen versus IHN, you're going to get, whether or not it's going to be improved or exacerbated by staying in freshwater.

?? – I'm curious to know whether … (study author names?) can't hear … I heard that that's also seen in Chinook … can't hear … Maureen – We certainly haven't done anything like Christy has done. That was a massive, massive amount of money and research effort to do that. But I really think that both … essentially have done those studies in the lab, and I think what we could do is get more power by targeting in on those particular genes. What Christy Miller saw was some signatures of viral infection. She saw poorer survival in fish that had certain interferon type patterns, so she made a prediction that that might be barge associated. But certainly we know that those genes get turned on in presence of a virus.

We may not be able to actually detect the virus, but we may be able to get some power by looking at those gene networks. I think you have to be very careful, because those genes change really rapidly. We've never actually used those markers in PIT-tagging wild populations, so it's difficult to know how well they would perform.

Derek – I have a couple of quick comments. RSW fish, when they go over the MPS it's really important, several delayed mortality studies have … in the past … can't hear … separation by code, or migration, … another sampling … LoMo … can't hear … you attempt to do that, it's very difficult to do that in time to get your animal in the fish … Then the last thing is, we did make an attempt … hands on the fish below Bonneville to see whether or not their health status changes over time … did a lot of … on in-river migration condition, they're holding fish that want to swim out to the ocean. Sampling fish … post-Bonneville is very challenging. Maureen – Like I said, I'm a microbiologist, I'm not a fisheries biologist, so I can't tell you how to actually do this and get those animals. But I do think that to really be able to focus those questions, you need that defined cohort. But I also think that you have that problem, as soon as you can find an animal, you change that transmission, that progression, and that remission so dramatically and so fast it is difficult, like you said, to be able to make important conclusions … Matt – I would say that it used to be a difficult challenge, but it's not anymore. …Kenneth – Maureen set up a pretty challenging structure for answering these things in fish below Bonneville, and there are some other things that Frank is going to talk about … these are the things that we do instead of recovering the fish …

Hydrosystem Delayed Mortality Associated with Barge and In-River Outmigration Histories of Snake River Spring/Summer Chinook Salmon with Investigation into Possible Cases of Differential Mortality – presented by Frank Loge

Matt – What was the rationale behind the reconditioning of fish, and what entailed reconditioning, what did you do? Frank – The design of this study was not a reconditioning study. The design was to look at disease processes in the estuary. But I'm trying to represent this to you conceptually – this is the most concrete evidence I could possibly put forth on this idea that *D* is being penalized by unhealthy fish getting on the barges. That's the primary purpose. Reconditioning in the net pens, unhealthy fish die, so your mortality can be seen. The idea is that the ones that didn't die, we fed them, we nurtured them, they officially looked healthier. We have measures of improvements in their lipids and all that other stuff. There's evidence to suggest that they were reconditioned in the sense that their health status improved … Al – How long did you hold them in the net pens, and where did you release them? Frank – We held them in the net pens for 28 days. I can't remember the dates. We basically barged fish about every week, and we partitioned them weekly into the two net pen locations. Then we released them 28 days later. Then we look all those barges and then we grouped them somewhat, not artificially, but we grouped them into early, middle, and late periods, and that was based on the distribution of barged fish. So we'd say, here's the distribution of how fish are actually barged, so you know that the first third of that distribution is going to be … Al - … with your … information, if the confidence limits around those estimates …? Frank – I haven't estimated confidence levels, I didn't have time beforehand. My guess is it's (not?) going to be very large, because the study was not designed for this purpose … we're estimating SARs … can't hear … We do have enough to estimate numbers, but it's not … that a lot of people would like to see …

Derek – Those fish that are held in those net pens weren't purposely reconditioned, they were being held to monitor delayed mortality and look at disease. They were fed a small ration of food during the time that they were held. Over time the weak ones died, the strong ones survived and actually started looking healthier and more vigorous more active … It made me wonder what happens if you're really throwing a heavy ration of food at them. They were just basically trying to keep them alive, feeding them minimum rations. As Frank said, this was not designed as a … experiment, we looked at it as, I wonder what it did to the SARs of those fish that we held and fed … we released them …

?? – I have questions about the specific numbers … back to slide … When I'm looking at it, just … can't hear … I'm trying to compare where those measures, so for example we have 1.64 … is that a percentage of the fish that survived from the net pen, or released from it? … 1.65 versus 1.01 … Frank - The denominator is the fish we release in front of the dam, and the numerator is adult fish that are returned … ?? – So if half of your fish died, the percentage of the ones that … is actually lower …? Frank – Yes. It's that idea that *D* might be being unfairly penalized by this group of fish that are going to die once you release them below the estuary. They're going to die no matter what, so you're not seeing benefit … because you deal with … fish that are going to die no matter what, and those fish would probably die … in-river survival estimates. This is a theory, and I can't say for certain, but I can say for certain that *D* did go up, and in the barge, was because … ?? - … mortality …

Frank – Right. Another idea here is if you go and look at the (end actions?), one action would be to take your barged fish, or take … late in the season, when barging is shown to be a benefit to the fish, and hold them in net pens for 28 days, recondition them, and weed out the ones that are unhealthy, and then base your SAR estimate on the fish that are … net pens. An alternative way to say this is, make the fish get on the barge – Russ, you don't like this … ?? – I'm just wondering how much penalizing of *D* is due to … can't hear … in the case of the river fish that are in the river for a longer period than barged fish, the SAR has been calculated with the same length of time … is constant over time … Frank – What I can say is if you look at the survival estimates of 28 days, they generally flatten out. You see this culling effect over 14-20 days …it's not like if we held the fish longer we would have gotten more mortality. Certainly if we held the fish for a shorter time we'd have less mortality. We did see it flatten out. This idea that we did … We do have data to support that.

Derek – My comment is more on thinking about the relative importance of energy reserve on survival. It may indicate potentially that if you fed them a little bit for several weeks, I'm … Frank – It's a great point. We had hoped as part of the study to have an in-river group that were going to be held in net pens that we could actually get assessed SAR rates to see if reconditioning would have had an impact. This study here, 2008, to pull the trash racks on the high flows, … We did get a few in-river fish, but it was just a bad year. But in concept, a good one in the sense that in theory these fish, we're taking in-river fish … And we do have data from 2007 to support that idea. We just don't have JSATS data, but in 2007 we did … and we do show the lipid concentrations …

?? – Did any fish that returned as adults come from Tongue Point, or are they all from East Sand Island? Frank – It was a mix between the two. Certainly holding fish in saltwater, all indications are that's what you … If you actually implement this … the saltwater holding the animals … freshwater … Matt – I agree with your health concept. The one issue, though, going back to your statement at the end, the point you're trying to across is putting all these unhealthy fish into barges, and … Have you thought of what is an unhealthy fish? … Frank - … the vitality … Matt – Vitality is an abstract concept. … We could go back and forth, but I'm wondering if you could characterize or profile what is an unhealthy fish? What would cause fish to be put in a barge and then 14 days after they're released below Bonneville they're going to die? If you could characterize that, would you care to speculate on whether or not you could see that? Could you discern these? Frank – Yes and yes. I don't know what measure of health would be, I don't know what a measure of vitality necessarily would be, but I do believe that's an important question that should be prioritized as a high risk or high uncertainty outcome in this matrix. I think once that's defined and demonstrated that it's true, you could probably develop techniques … Now that we know we can handle the management implications, that you can factor those fish out in the calculation of the …

Jim – I too like the idea of health, and I like to call it vitality. Because it's an abstract issue, it doesn't mean that it's not a good concept. It is a good concept. … What you're saying is that fish are being culled because of transporting diseased fish. Jennifer did an interesting study for … where she took fish from Bonneville run-of-river … barges and subjected them to a temperature challenge. She found that the barged fish survived longer than the in-river fish throughout the season. That goes against the idea that the barged fish are weaker. It appeared in that case that the barged fish were actually stronger. So we have basically two counter ideas on whether to barge, two alternative hypotheses … how we can pull those apart. My final point is that your sample, by looking, by adding, extra mortalities is not mathematically correct, because what we need to do is multiply survivals. I don't think you intended to … the mathematical rigors, but it certainly threw me off. Your small glass, I don't think it's a relevant measure because we're multiplying things together too. I think there's a problem where people shouldn't look at these things in terms of added … instead of … This adds some confusion. Frank – You're right. I agree with you in the sense that it should be multiplied together and not added. I'm trying to make the point through that. But if nothing else, you can just look at the extra mortalities … of barged fish and transported fish … that would result in the *D* … Jim – And that was the point to our thought experiment. Frank – Exactly. I'm saying there's some continuity in terms of what you're saying and what we're saying here, is that the mortality ... difference between barged and in-river fish is very small. My experiment is to try to hack at what's causing those differences, that was the point I was trying to make … It could be a challenge in how you actually design an experiment to capture that. I'm not saying it can't be done, but it's just a challenge.

Physiological, Transcriptional, and Behavioral Responses of Transported and In-River Migrating Juvenile Salmonids in the Columbia River: Insights Into Mechanisms of Delayed Mortality? – Matt Mesa, presenter

Matt – (end) The one thing that we're missing, in my opinion, we've talked about this before, our data is missing it, I think the work from Frank and his colleagues is missing it, because there are those of us who just don't believe that a net-penned fish is representative of a fish in the estuary. So sampling animals, sampling the same known cohort of fish in the estuary to try and get a handle on how much things are changing after they leave Bonneville dam would be a good direction to go in the future. I think the technology exists now where you can do that.

Jim – I notice in your differential predation, in the function of length, that the difference was 10 millimeters. There seemed to be about 90 percent … survival was decreased by 10 percent. … In our topics we looked at the factors, and you could attribute .9 percent difference in survival … I would take this data right here and suggest that this shows significant contribution to *D* … due to size and predation. I want to emphasize that there are multiple factors altering *D*, and you don't get much of an impact, you can't say that it's not significant. All these things can have … I would view this as evidence that there is a selective issue … Matt – I probably should have been clearer. I understand what you're saying. I should have said in these tests there is no statistical difference. You're right in saying that there is (?). Jim – … You can go through every one of these and say the same thing. … Derek – It may not be statistically significant … Matt – Right, and it could be contributory. Your points are well taken. … Remember the thing about Bill Muir's paper, they just told you what the predators were capable of doing. It didn't tell you what they did. …

?? - … a lot of difference in the gene expression in barged fish versus ROR fish, that can be explained by the culling effect in the river? … use the survival rates of … can't hear … culling hypothesis we have the same kind of transcription rates. … could it explain …? Matt – I suppose it could, but it's looking at it from a different way, because the barged groups and the ROR groups, the differences that you see in those graphs, both groups aren't (are?) compared to fish at Lower Granite. They're not compared to themselves. We don't compare ROR fish to barged fish, but you could do what you're saying by artificially reducing the size of the barged population. I see what you're saying. And yes, I think the data would lend itself to that.

?? – I noticed that you had some contradictory indicators of stress … Matt – No, it's a good insight on your part. We noticed the same thing. We see these high cortisol levels in these ROR fish, but the gene expression is not substantiating it. It could be culling. It's more likely a sample size and individual variation problem. If you notice on those graphs, when Maureen was talking about sample sizes, these were small sample sizes of fish. Large from a gene expression profile viewpoint, but still pretty small. I really don't have any explanation for that, why cortisol levels were so high. I think what you're saying is we should have seen something in the gene expression profile that substantiated that, and we did not.

F.4 Session 3

Within-Season Patterns of Smolt-to-Adult Return Rates of Transported and In-River Migrant Yearling Chinook Salmon and Steelhead – presented by Steve Smith

Jim - … If you did not have the spill program the last few years, how many more fish would you have returned? Steve – … we made a prediction for steelhead in 2010. We don't know how that's going to turn out. Bill, do you know? It was in the 10s of 1000s. Bill M – 30,000. Steve – This a good point … some of the things that I talked about here today is that there's a temptation to make statements that are kind of umbrella, overall, for the species and the stocks that we're talking about. … we were looking specifically at steelhead. There may have been less effect, even a benefit, to Chinook, of delaying transport … Jim – The spill itself is putting fish back in the river, but you can't really look at that within this analysis. Steve – You can make some assumptions about it … additional fish that are in the river.

Russ – One thing that you said a couple of times is since we have been delaying the start of transportation for the … population, that we don't have any data. But I do know that … and his crew have been collecting, tagging, bypassing, and transporting fish since mid-April. It needs to be here. So we do have that outside early season transport. Steve – I know there have been some experimental barges. That's true. Bill? - … data is in those figures. 2007. Steve – 2007 was the last year for some of these. Where it's available, we'll use it. But I guess my point was we don't have the continuous data throughout the whole month of April, or starting April 10.

Russ – Another point is that we have seen, and I wonder what some of the thoughts are, in the past couple of years, especially for steelhead, we've seen a dramatic improved direct survival and migration rates, which should improve the relative adult return rates of the in-river fish. It's one of things that I want to bring up, is that a lot of folks, including Frank … The role of a manager is not to improve *D* values to make transportation look better. The goal is to figure out how we can improve adult return rates. Ignoring transported fish that die downriver makes *D* look better, but does that improve adult return rates? That's one of the things I'm looking at, and it's what can we do, looking at *D*, is try to figure out, are things we're finding out going to help us to improve transportation programs. That's what we're looking for here. The other thing that's one of my concerns is for a lot of this analysis we have a lot of years in there where we did not have a real effective spill program. It appears the last couple of years that we may have found a new reality. … how we've done it in past years … how we're going to do it in the new reality. It may not be the best approach. Steve – I deal with the data that we have.

Kenneth – Are there any general comments about anything you've seen today? Bill? I'd like to talk a little bit about the vitality idea based on some of my earliest years as a biologist … one year when all the screens got plugged in the collection raceways and … in the bypass system, the fish were just too weak to swim against the current … that first wave of fish that came out of hatcheries were sort of dead on arrival even though they were still alive. … talked to … at Bonneville this last week, he said that they still see that to some degree with the hatchery releases close to Bonneville. That doesn't explain most of the delayed mortality season wild fish … they would have been culled (pulled?) out of the population long before they had … Granite. …

Dave Marvin? – I'd like to talk about the duh factor, and that is my delayed response to challenge presented by Jennifer before the last break. With all of the various parameters that we have for these different components … For example, a 98 percent survival for barged fish. That's something that seems to be a constant … you had some studies that had shown, but it's rather sparse data, a somewhat different survival rate … 95 or 96 percent barge survival rate for the system up to 98 percent. … being able to validate. We have a lot of values … that we've used over the years and have not necessarily been validated, and we may be using a constant out of context of 98 percent for spring Chinook and then we want to shift the discussion to steelhead, and how is that going to impact … I'm just kind of curious, since I don't have any information directly to be able to independently validate any of the values that are put down there. How confident are you (group) in the different survival components … Kenneth – Pretty confident. Russ – As a manager, I don't care if barged survival is 94 or 98 percent. … It doesn't really matter … return rates … change your … *D* slightly. If barged survival was only 94 percent, do you change … The real thing is what brings them back as adults.

Kenneth – Tomorrow we're going to get a chance to put some of these ideas into action. … what we should be doing, and how that's going to help … Derek – Thanks to the presenters for participating and to the folks for being here; … discussion is the whole point of the workshop, to try and iron out some of these issues that some people may call good data sets, somebody else might not. Good discussions today.

F.5 Session 4

Identifying Significant Factors in the Seasonal Pattern of Delayed Mortality – presented by Jim Anderson

Al – Is this Chinook data? Yes. Did you run steelhead through the same process? Jim – No, because we don't have a lot of data. We should probably do that. … Bill has provided us with data up to 2008 now, so we have a better data set for steelhead. Al - … just terns, or terns and cormorants? Jim – What we do is just say birds are following a parabolic … so they're low in the beginning … can go high and go low. We don't have bird density in it, what we do is we have x and x squared, where x is the arrival time at Lower Granite dam. We don't bird densities over a period of time …

Derek – Do you have some examples in mind of what kinds of studies you've thought about that could contribute to a better understanding of …? Jim – I hope we get into that this afternoon. Since we're under contract to come up with something, if we don't get help, we're going to do it ourselves, so you'd better help us. It would be really worthwhile to have better information on the fish that are entering the hydrosystem, and better information on the fish when they exit the hydrosystem. Derek – You mean overall condition? Jim – Overall condition and size. Dick had some comments on that. Dick – I want to ask about avian predation decline in-season. I couldn't read the scale. I think you showed a peak in May. I think avian predation from a colony, what peaks in the middle of May is that the chicks hatch and it continues well into July. Even at that point, the birds that disperse from the colony don't leave the river. I don't think that's correct.

Jim – I misspoke, because this peak is going through August. … What … is doing is looking at the rates of change of the bird predation, and the rate of change of the velocity of the fish. This … that comes up has to do with the fact that the rate change of the birds is slowing down. That's the best explanation I can give for that. It's a multiple linear model. … how quickly the predation or migration time is changing over the season. … I'm surprised that they ended up being significant in the model.

Barbara Shields - …can't hear … birds in the equation? Jim – There's no birds, there's just a term that y squared, which is the arrival time … captures the nonlinearities that you expect to see in bird densities. I don't have … much real data in this thing. I have when the fish arrive, and if you look at this here, this is what's driving … Each of the terms is … We know differential can be exposure, because we know the temperature and the travel time. We know they're not spilled, we know the difference in travel times of the fish, we know when they arrive at Lower Granite dam, we know the upwelling, and we know the flow. We express birds in terms of the … and this is capturing the fact that the greater the bird densities are increasing and slowing them down. This also captures the fact that the rate at which the travel time is speeding up. I apologize that this is a rate term, these are not evident – you build a model, you put it together, and that term pops out. It tells me this is more complicated than we could possibly imagine. Barbara – I understand your graph. The bird density increases as chicks hatch, and drops … My question is about bird density. Where did you get that? Jim – We don't have any bird density, all we have is a time component, and what I believe that time function is saying is the fact that the bird density is leveling off is interacting with the fact that the *D* is decreasing at the end of the season. I struggled with this for a long time. *D* goes up up up most the year, here it drops off at the end of the season. … because everything is stabilizing.

Steve Smith – Most of the results you've shown here were your … model, but you're going to have … model the uncertainties … did you look at any model averaging, or percentage of results in terms of variable weights or anything like that? Jim – This is weighted according to the number of returns in these fish. It strongly concludes the impacts of weighting. Steve – I think that's weighting your data within the model … your AIC results, using that … a number of different models? Jim – Yes. Steve – And then you've shown us the results of the model as AIC … Jim – Oh, OK, sure. Which terms are actually the most stable across the AIC block dimension. Steve – Were there other models that had nearly the same … Jim – Arrival date and heat are two important … this term here, if you use a slightly different weight, use a different weighting scheme this time … these two always … This makes sense. This is what your T:I ratio is showing. Later in the season T:I is higher, and it's a linear effect. What we're finding here is … multiple factors are affecting *D*, and they are changing the function of condition or day that the fish went through the hydrosystem. It can be size, it can be changes in the behavior of the fish in the estuary. It can be … differences in collection efficiency, which is a function of size, which is a function of arrival date. This basic result is pretty solid. …

Steve - … can't hear … you don't choose a single best model. … consider the effects of the other models that the data also support. Jim – OK. ?? – You pointed out … have you checked out the sensitivity of the model to … weirs …2001 and 1997 to see if you had anything left when you take those out? Jim – Yes. You take out 2001 and you get the same result. Looking at this statement so many different ways … we have a couple more years we can add to it, it will probably all fall apart, and what I would do is extend this model … We have a cubic term in here. I challenge Steve to put a cubic term into your model and then stand up here and try to justify it. When we do it this way, it's there and you can't throw it out. It ends up saying, I'm here, and you can't throw me out. … I think this points to the need, irrespective of whether or not this is correct, arrival time at Lower Granite dam is important to the pattern of T:I and to *D*, and it has multiple factors. Each one has a small component. If we want to understand how to improve T:I and how we could understand the whole dynamic, we should be measuring condition of fish at the top of the system and at the bottom of the system, in ways that we can then text particular hypotheses on arrival time and impacts …

?? – Jim, good job of defining the complexity of the issue. … My first question is why … can't hear … Question two has to do with what the different stocks, maybe that could explain some of the relationship between the length and the in-river transport, getting closer … My third comment is based on something Jim Conklin asked me, and that is … need to know the condition of the fish when he enters the system … Jim – To your question number 1, there's two reasons we didn't use a nonlinear model. One is, I didn't know how to put plating into that in a way that you can in a linear model. … The second reason is that when we start using these nonlinear models, we exceed my capacity to do this. I didn't have time to learn, I would probably have to go back to school in order to be able to do that. I was hoping to get a quick and dirty result from this back when I started in 2007. As far as the stocks being different, I think … seasonal factor evidence was really reflecting that. Stocks are changing as we go through the system, and their response to … The fish are bigger, and whether or not they're different because they're maturing or because they're really from different rivers of origin, I think that's a good question to ask.

Matt – I wanted to ask about your heat component, and if you could describe that in more detail. I'm assuming that some of your information came from Jim Conklin's work. You have 10 years of data you were working with, and your energy density component, or the loss of energy in ROR fish, where did that come from, from Jim's work? And how did you expand that out? Jim – It's inspired by Jim's work. It's just the average temperature they experience and the time it takes them to go through the system. There's no real data defining that. This differential between in-river and transported fish, this is what it looks like over the season. I spent a lot of time using more complicated heat equations, and you can get different results. It begins to not make a lot of sense. I was hoping to be able to bring everything together in the model and then … You think that's of course crazy, but my first set of data went through 2004, and I was getting an R squared of .9 on this model. Then Bill gave me some more data, and it just fell apart. I was hoping that we could find the proper relationship between heat experience and energy density … That's pretty simple, it's just travel and the average temperature. To … heat exposure early in the year, because they're moving slower, but we know that temperature is much lower early in the year and it gets higher later in the year. But adding that complexity, it made things worse. I tried many things like that. It would be great to have real information on what are the lipid contents of these fish over season at the top and the bottom of the system. This whole model is just a step along the way to understand what we might want to look at.

Matt – I think not only that, but almost a biogenic (?) approach would be helpful here, also, not only knowing your lipid content as well as look at how temperature influences the … Temperatures will change from your ... for fish, temperature is everything. Temperature is the factor. Jim – Right, and I tried to put in biogenic components to this, and it just turned it into nonsense.

?? – … can't hear … simple sensitivity … if some of these parameters, like time of arrival in the estuary … it's a very complex model. My real question is how much those terms actually have contributed to the change in survival we see … how sensitive the results are to that. … parabolic relationship … Jim – Yes, I can show you. ?? – So obviously it's a long way into the season, so time of entry in that model might not be that sensitive … Jim – I've looked at some of that in preparation to try and publish this, and you can see it right here. Remember this … has differential heat and arrival time, arrival time in …, and flows, and that's it. What we find is that this pattern right here is due to … then for each year, it's shifting up or down because of the flow component. These are popped up here because of the heat component. If you look at this spread right here, the model is trying to capture that in terms of the differentials of flow, which I would like to interpret in terms of the changes of condition for fish from year to year and … All we're saying here is there are a lot of factors that can … relationship. Kenneth - … pointed out the importance of having a data set. Once you start working with anything in a 10-year data set in this realm, you find out there's all these … factors available as data … It's certainly a challenge.

Survival of Juvenile Chinook Salmon During and After Barge Transport in 2010 with a Comparison of Barged to In-River Survival Through the Lower 150 km of the Columbia River and Estuary – presented by Geoff McMichael

Matt – You're at river kilometer 37 where you saw that decrease in survival? Can you say anything about what the estuary conditions were at the point and out? Is it full salinity water, or do you know? Geoff – That's about where salt ledge intrudes. Ryan Harnish will talk a little bit more later this morning about the … that's the location where it gets real wide, upstream from Astoria, Taylor Sands is there. A lot of fish, ROR and barged, are crossing over Taylor Sands in that area, so they're maybe coming down the navigation channel and then moving over towards the Washington channel. Some of the reading I've done recently, it looks like the Washington channel is more ocean dominated and the Oregon channel is more river dominated. Maybe in response to that mixing of saltwater closer to the surface in the Oregon channel. … Birds are the primary driver … Matt - … does JSATS have the capability to … Geoff – No. … pressure sensors … low on the list of priorities. I would sure like to know. Derek - … as part of the downsizing of JSATS … new injectable JSATS tag …

Barbara - … what year are the results you have up here? Geoff – 2010. Dave Marvin – How comparable are those in-river fish to the John Day release to your population … given that you most likely have the Umatilla contribution, the Yakama contribution, upper … contribution. They're not only larger fish, but that population most likely included different population profiles. Geoff – Yes, they are very different. It's an opportunistic analysis. There's some Snake River fish in that group, tagged at John Day, but how many I don't know. I know the fish that were tagged at John Day, the mean size was quite a bit larger than that 133 or 135 that we tagged at Lower Granite. Barbara – Did you take … samples from those fish to answer that question? Geoff – No, that's a great idea though.

?? – I assume you were able to … fish from either the control group, the John Day group, and … groups. …can't hear … Geoff – I have, looking at the other groups, it's still the majority that were detected on the terminal array going straight out. The proportions that … were a little larger on the ROR fish … What we saw was before about mid-May when ocean current directions change, more of the fish went out of the south, and after mid-May when surface currents were more northerly directed, more went north. These fish … Derek – I'm going to put you on the spot for a second. What is the management application for this lower 18 kilometers … the survival … can't hear … What do you think can be done, what needs to be studied? Geoff – I think we've learned a lot in the last few years in particular, so it was about 2008 when we started putting receivers in … indicated that the bulk of the fish went down the navigation channel. … they couldn't follow them this far down, so they stopped fishing … navigation channel in front of Astoria and leading over to that Washington channel. It helps us understand a lot more of where the birds are getting fish, and obviously the relocation from … Island to East Sand was a good thing … The flexibility to deploy your arrays where you want and estimate survival with those different locations gives you the precision with which we're able to estimate survival. It gives you the opportunity to evaluate the avian predation … with the better level precision …

Matt – What are the management actions at the bird colonies right now? Is there a bird person here? Chris Pinney – There is a plan for terns. They're moving the breeding pairs to other states. The EIS says … birds at East End Island … must provide habitat … can't hear … There is an experiment going on at East End Island now, they're chasing 50 (15?) percent of breeding cormorants off, we'll see if that hazing works. … Right now it's replacement of habitat … cormorants, try to get them out to the ocean. They'll stay on the west side … There is an active plan trying to get rid of the birds. But really nobody wants them, the states don't want them. There's a lot of organization with the states …

Al – Do you have a corresponding chart for the in-river migrants? Are they showing the same pattern? Geoff – Where they died off, you mean, or where the mortality spikes? Al – No, in your ocean slides. Geoff – I might have one, I'll get it at the break. For ROR fish, they exit … Al – The implication being … river pattern, so when you barge fish you're not going someplace they wouldn't normally … Geoff – This is one year … ocean current fishes. Al – It's typical salmon, though, right? Geoff – No, they're not receivers or … can't hear …

Survival and Travel Times of In-River and Transported Yearling Chinook Salmon in the Lower Columbia River and Estuary With Investigation Into Causes of Differential Mortality – presented by Kai Eder

Derek – Can you go back to your slide that shows the distribution of infection over time in the net-penned fish? I'm going to throw a question out to the group to try and stimulate some conversation here. In those graphs, would you say you just described differential delayed mortality with those graphs? Is that differential delayed mortality? Kai – Not just one factor is differential delayed mortality, as we've learned today. The components that we looked at are pretty important, and they're a lot more complex than what I've shown you today, we have that in the report. For example, there's obviously pathogens that we see in in-river fish that are not affecting the barged fish. … because they've picked them up along the way. It was interesting to see that certain diseases were very prevalent in causing a lot of mortality in freshwater areas where they didn't affect fish mortality in the net pen site, which had a higher salinity. We did only see, barged fish, with these fish we worked with – we had another big net pen study going on too – for this acoustic-tagged fish, we only saw 20 percent of mortality, of all the mortality we saw in net pens, 20 percent happened at Sand Island, and 80 percent at Tongue Point. Also, of that 80 percent, more than half died of mycotic infections. I know that didn't answer your question.

Frank – I have a comment to what I talked about yesterday a little bit. Just to give you an idea again of the fraction, of what you need to actually increase your … to have an impact on SARs. The hydrosystem …

study of survival of 45 percent. If you wanted to double the SAR rate, say from 1 to 2, you have to increase the survival by up to about 60 percent in the hydrosystem to see any impact on the SARs. Whereas if you want to have a staying impact outside of the hydrosystem, you have to increase the survival rate by about 1 percent. … prioritize in the river … and also ideas of what percentages are needed where … Kai – Did you just calculate those numbers now? Frank – Yes.

Barbara – When you calculate that higher SAR for the … that's the net pen fish barged versus the regular barged fish. Yes. Was the SAR calculated on all the fish that were put into the net pen, or just the survivors? Kai – Those are just the survivors. We talked a little about that yesterday. I subtracted those to look at what are the SAR rates of the survivors, but we also did include them, I don't have the number, and I said earlier that SAR rate is about 1.2 to 1.3, so … obviously lowers it. It shows that you do have mortality in the net pens, especially for the … the overall goal to increase survival of returners … Barbara – I had another comment … this is a quantitative … let's think of the long term consequences of the population's … genetic basis … the barged fish aren't exposed during that critical window. You're not getting … mortality if you keep those populations strong, you're looking at selective pressure. Those survivors who … higher SARs cannot get winnowed out, so we can actually damage … natural genetic … Your data is really powerful … Derek – Are you suggesting we need to expose our fish to more disease to make them stronger? Barbara – It makes the population stronger. It's selective pressure maintaining the alleles for resistance at multiple … in the … population. The window of infection is as smolts. The returning adults, it's not going to do its job of winnowing out the genetically susceptible members of the population. That stage is being artificially bypassed. According to the results, that's the strongest evidence I've seen of, oh my god, that's what's happening. That graph is very powerful, it jumped out at me.

Matt – Can you go back to your net pen graph? Have you ever received any criticism of that data? Can you describe any criticism you've received from this information? Kai – What I know, this section is a huge part of the report, and there's many, many different ways we analyze. We took samples all the way from Lower Granite, and we looked at prevalence. I know that goes back to the discussion … the pathogen is there, but it does not automatically mean anything in terms of, is there going to be a disease outbreak, are they going to recover, are they going to die. This data was just to show you that when you actually look at causes of mortalities in the net pens, we can identify what these fish died from. Matt – Let me reframe the question. Do you think this occurs in fish that aren't in net pens? Kai – We did see mycotic infections quite a bit in the barges. Why we're putting up this data is to figure out if travel times, the main point was travel times increased, so we have a longer freshwater exposure, what could that do? Obviously holding them for 28 days you can see that mycotic infections increase, but there is substantial mortality coming from mycotic infections, even in the first 7-9 days, … early barged fish that traveled up to 36 days through the lower estuary. So if they spent most or quite a bit of their time in the freshwater, I do think mycotic infections could pose a substantial problem.

Frank – I'm going to answer this question a little bit more closely. We have no basis to believe otherwise. Unless you can provide evidence that this is not happening, we can claim that it is. … All I'm saying is until someone provides evidence that this is not happening, we are working on the basis that this is happening. Dick - … temperature differences between holding at East Sand Island and Tongue Point through the season. Do you have that? Kai – We do in our report. All I can tell you is that East Sand Island temperatures were lower, but Tongue Point temperatures never reached … we didn't have that problem in … critical temperatures that you think would affect mortality. In the report there is daily data listed for the whole net pen study period. Jim – You should put up your travel times slide. I hadn't noticed this, was this in the report? Kai – No. Jim – This really brings out something that seems important to me, is that we're trying to characterize these fish in terms of their averages, and if culling (?) is important … it's going to be affecting the weaker fish. This gives me real evidence that there's, particularly in the early group, there's a huge distribution asymmetry in the health and vitality of these fish that shows up in the travel time. We might need to move away from presenting just the mean values, and really giving the data – I think we don't really have the right tools yet. … Then maybe what Frank is saying is really impacting fish that are taking 26 days to move out, but the survivors are taking 6 days. These are entirely different populations … We need to include this type of data … in our analysis.

?? – What percentage of the fish in the net pen were morbid? If you multiply the disease rates by that, what would they be? Is it a significant number of fish, or … Kai – As far as I know, there were about 180 mortalities, about 140 at Tongue Point, and 40 at Sand Island, out of a total of 888 fish loaded into the net pens. Frank – Show the slide on the mortalities (Estimates for Barged Cohorts …). We integrated the travel time into the … ?? – It's a very small proportion of the overall … Frank – That's been captured in the net pens, figuratively speaking, say there's 20 percent mortality in the JSATS early in the season, 5 percent of that would be captured by using the net pen. … ?? – … for most years we were tagging …

Maureen – I have to say something about … mycotic infections of course are very … if you don't literally interpret … We don't think that mycotic infections are major killers of fish in the river. It could be a marker that these animals are stressed … Now that question becomes, is that stress coming from the barging? … can't hear … But I think the more interesting point … is this idea of, are we increasing genetic susceptibility to pathogens by bypassing the exposure to pathogens. That's a hard question to answer, because conceptually, from evolutionary theory, that makes some sense, but how do we really see evidence of that occurring? For instance, there was a lot of concern with … that we're going to increase genetic susceptibility in the population by culling out … That has never really come to fruition. … see in genetic resistance to a pathogen, we want … exposure … To my knowledge, we've always seen improvements in smolt-to-adult returns in survival when … pathogens. … there is an advantage to including all fish. Frank – … these mycotic infections were systemic infections …Maureen – What was the pathogen? Frank - … Maureen - … is still a very opportunistic … Frank – I agree with you, I'm saying it wasn't just a fungus growing on the outside of the animal, these were actually in the organs and tissues of the animals …Maureen – I think … the question is, what's driving the susceptibility in those animals. I think it's probably a combination, I don't think we can really say. Are fish holding in the net pen …

Migration Pathways, Travel Time, and Survival of Acoustic-Tagged River-Run and Barged Yearling Chinook Salmon in the Columbia River Estuary – presented by Ryan Harnish

Al – I have a question on your detection efficiencies for different locations. You showed some information where … can't hear … you demonstrated the detection efficiencies of those grids was the same or you had independent estimates … Ryan – A fish that isn't detected by the aligned receiver in either of those channels, but is detected downstream, so you know that they've passed by …

Dave Marvin – In the study did you have an opportunity to look at diedal and tidal influences on detections at various … Ryan – I have not, but I'm hoping to possibly look into that in a variate (ovariate?) analysis … such as tide, fish length, time of year, and … to see what variables … can't hear … Dave Marvin? - that would be very useful information in looking at susceptibility to avian predation … Ryan – Yes, and I think tide probably a big one. Fish get to … particularly susceptible to avian predators, and they get there on a … tide … fairly quickly have a lower susceptibility to avian predators … Dave Marvin – If they get there at 3 in the morning they probably have a lot lower probability.

Derek – I want to comment on some of your comparisons between … caveats … probability of migration path … significant for different stocks of fish … I just wanted to caution … I found the migration pathway information very interesting. Ryan – Yes, these are two very different groups of fish. They're the same fish that Geoff was comparing, so the fish collected at John Day are 150 millimeters on average, and these barged fish are 130 millimeters, obviously from rather different stocks.

Jim – I thank you for giving us some valuable data. There's also computational … dynamic models that if you used to compare fish movement to a barged … because you know … the fish location and you know where it ends up. … you could then (put a partner in?) at that point, see where that partner goes, see if these fish are approximately … or whether or not there's some behavioral problem. I would encourage you to go beyond … variate analysis, and really dig into time of day, time of tide, and extract more out of … I would also encourage you to compare your movement data of your ROR fish with barged fish. And also gather information that there's real significant difference in early migrants … if your data shows something about that component … relates to … estuary, that's valuable. You have to take that data further to answer those questions, but it's great data.

Geoff – I'll respond a little bit to that. … travel time … The second part, digging into it deeper, this analysis was unfunded, and it's certain to continue that way. Unless one of the … sponsors it, it won't get done. ?? – I would just suggest, I know your sample sizes are dropping down and you start slicing this up more and more, but … can't hear … transporting your barged group … completely overlap with your in-river migrants … focus on just a direct comparison between those groups within that time frame … It might give you a clearer distinction between those … Ryan – Yes, as Geoff pointed out, it wasn't funded, so it just kind of, the in-river analysis was already done for separate studies, and we just tacked on … I'll try to make the time. ?? – … looking at survival probability per hour … Ryan – I have not looked at that, but that's probably a good idea. … survival was lower for fish that took longer, so it's worth looking into.

Evaluation of Hydrosystem Delayed Mortality Among Juvenile Salmonids in the Columbia River Estuary –

presented by Dick Ledgerwood

Geoff – The … data … what's your confidence in the quality of that data? Dick – I think anytime you're PIT-tagging … measurement at time of tagging and … no better than the quality of the person pushing that pen. I think with a large enough and systematic sample that's it as good as … They don't tag these fish for me, so we're hoping that whoever is doing that tagging does a good job. … I think it's pretty valid.

David Welch – What was your (growth?) increments in the first stage? It looked like it was about half a millimeter. Dick – I think it was .6 when we … but I want to emphasize that this was a snapshot of fish collected in one day. We would like, and we have proposed to do this two or three times a week throughout the season, and at least get that target group of barged versus in-river. I think there's a very good chance that at certain times we could target very specific release groups down to a hatchery source, or fish with previous history.

?? - … I think you said that barged fish have a tendency to stay together as a group on release, you say 80 percent of them. Dick – That would be my conclusion. Early season, I think there's more variability and more sign of delay in meandering (?). But what's amazing, especially if you run through multiple years, is that we never see a fish, particularly in-river fish, that came through 12 days later, or 30 days later, they were pulling in the side channels upstream on us, then coming back later we would see that. That's just virtually demographics. Barged fish are more likely, and you saw that one little … about ten days later – that might be real, it could be a (missed-barge?) assignment. It's pretty unusual down to the head of the estuary. We don't really have a lot of full reversal in May … But as you get into the lower estuary, oftentimes you're going to get extreme … so they're going to slow down. But do they slow down equally, I think is an important question.

?? – It appears that right now we release the fish below Bonneville within a several hour period, and then their arrival to the bird island is sort of driven by that timeframe. If you change the release time of the fish from the barge so they would arrive at bird island … instead of having them arrive as randomly, which sometimes would be first thing in the morning, and the group just gets hammered by the birds. We could consider changing the release timing to take advantage of their travel time and predict … Dick – We're 100 miles downstream from that release point. We see any given day's release over a 3-day period. So trying to time the second day of availability … from downstream into the estuary would be very difficult. Alternating barges (?) … it seems like a good plan, I think it did lower the predation rate significantly, but there may have been other factors.

?? – I'm interested in your sort by code system. Can you describe that, and how accurate it is at just swiping one individual PIT-tagged fish … Dick – First of all, let me say this – until M4 comes out, we don't have sort by code per se, unless we want to go back and get a … with those 2,000 tower … We're waiting on M4. What we're doing right now is we're diverting PIT-tagged fish. In the peak day that we've ever had … PIT-tagged fish, we had 1200 detections in a 24-hour period. Realistically, we're … separation by code for one shift, 8 hours, we might, if we diverted every PIT-tagged fish in that time period, we're at 300 fish. I don't think it's a real key factor, because secondary processing … again sort fish. I would have set the diversion gates to be very liberal at diverting fish-tagged fish, and by that get another 10 fish to look at the species composition associated with it. It's not really a problem unless there's … injury … We're still working on those fine details, but I think we have a good chance of solving those problems … We do have a flow measurement to … that velocity about 10 fps, and with … that's a critical factor in this. But I think it's going to take some patience and time to get it … the way we would like to see it work. I think we've made really good progress, I'm amazing at how well it worked last year.

?? – I was also curious … if you had the technology and everything set up, how soon could you start using this? Dick – If we're going to put it in the water tomorrow … and we put in a bigger pump. Our biggest problem last year is we didn't have enough … watering capacity, and we didn't have enough flow volume coming up into the system to attract fish efficiently. So if put on a different pump, and we've added dewatering across the front and on the … and now we can theoretically go all along … so we'll be able to fine-tune, and that was really the critical factor when we diverted into that, put a smaller tank on we have a surface capability … So we had to modify it after we had it down there last year, and that's what we're taking it from. I think we've addressed all those, and hopefully we'll see it improve, lower the impact on fish …

?? – When we were working on the design for the system, we definitely didn't want to reinvent the wheel. We … the systems that are already there. The fish facilities at the dams were … 8 to 10 fps of water running through the flumes is pretty standard. That's exactly what we tune the system to have on the NSIC system. With that, you have very accurate timing in the … I would say more often than not when you're diverting PIT-tagged fish, if you only diverted one fish, bypass minimum, unless you wanted a live fish. Periodically we take 5-minute samples, 15-minute samples. We had one evening when we took just under a 1-minute sample and picked up 250 sockeye. … designed so we could just … Dick – We also diverted 47 chum in the middle of the river, where they shouldn't have been. … That was very unexpected to me …

F.6 Session 5

Keep on Truck'n? Interactions Between Conservation Measures and the Environment Lead to Unintended Consequences for an Endangered Species of Pacific Salmon in the Columbia River Basin –

presented by Kirstin Holsman

Jim – Between high forage fish and low forage fish environments, … north and south predominance of currents (?) … Have you thought about possible impacts of the fish going where they go when feeding in the estuary, so they're not getting lost … can't hear … You kind of attribute this all to some forage fish … wondering about other alternatives. Kirstin – Absolutely … possibly their own mechanism but also maybe capturing … other processes that are going on. Things like upwelling … this sort of analysis is really good for coarse-cut exploration, then it needs more actual salmon … Jim – Two more questions. Have you looked at the salt density from hatcheries below Bonneville dam? Kirstin – No, we have not looked at that. Jim – That's something I was wondering about, because there are a lot of fish that come in from below the dam which are going to be interacting with fish in the estuary. Kirstin – That's interesting, I hadn't thought of putting that in there … Jim – One other thing, then. What do you think is the mechanism behind the impacts of … ? Kirstin – I think probably flow is the proxy for turbidity. There may be two things. … movement through the system … can't hear … so the flow … would be affecting the fish … just in terms of getting them through the system, but it's also … a proxy for turbidity, and once they get into the ocean environment … the turbidity in that environment affects … predators. I think it's probably a turbidity issue. I think Bob is going to talk a little about …

Understanding Seasonal and Within Season Marine Mortality of Columbia River Juvenile Salmon Marine Survival – presented by Bob Emmett

Jim – I'm confused. If you have lower density for forage fish, you have higher … You were saying that early in the year there were no forage fish … it seems to me … these are contradictory hypotheses. We don't have a temporal variation between early, late, and middle in the broader scale analysis. … you guys just told us two different things basically using the same data. … fundamentally unraveling … Why do we care about this? Why don't we just transport the fish … T:I ratio is going to be greater than 1 …

Bob – The first question, which was … the temporal issue, if you look at the data that Kirstin provided, she didn't really provide any April … We didn't talk about species of forage fish. I think that's a big part of why we differ to some degree. Kirstin – Also … yours is hatchery fish. Bob – Yes, I'm looking at hatchery fish. Kirstin – Mine also includes wild fish … can't hear … Bob – Your second question, why do we care? That's really a philosophical question, not a science question. Jim – I disagree with you, I think that is a good science question. Bob – You think that's a good science question? The first question, to me, is what are we managing for? Are we managing the hatchery or the wild fish? Jim and others – Both, and they're all mixed up. Jim – If we can make a model that we can determine, given the variability of T:I ratio, if we had the absolutely best information when we transport a fish, we can … then we can take, since we know … the optimum way to run stuff in the model, and then transport at that point, then compare the differences in productivity versus adult returns. How much have we lost? And then a comparison of whether or not that's significant. We can then ask the question, how much have we lost with the … program compared to not transporting anything. With our current spill program, it looks like we're losing a lot of steelhead. That would be an interesting and pretty simple model …

Bob – I thought about that too. You could just figure out overall what is the best kind that you see? Some years you'd be wrong. Jim – We're doing that right now with delayed transportation because of the study that Kenneth and I did in 2005. I forgot about that, so I'll remind you. We're compromising right now without actually seeing how much … better we can do. Bob – For me personally, scientifically, I would really like to have a handle on some of the mechanisms involved. Then, kind of like the weather service, have an index or something that I feel a little better about, an indicator of the best time to do some of this, instead of just hanging your hat on T:I index. Jim - … If your forage fish measures and your acoustic arrays gave us some information that would give us a better estimate of adult returns one or two years later, that would help in the management of the species …

David Welch – The big picture, big question here, is that this is not a steady state system. … what's happening now … policy makers and decision makers, they need to understand where the problems are … say this is likely the reason for this thing to happen … can't hear … bigger issues down the road … climate change … how to base decisions on that …

A Simple Cause for *D*: Equivalent Hydrosystem & Coastal Ocean Survival Rates – presented by David Welch

Discussion while waiting for presentation to load

Kenneth – Do you have further comments so far? Al - … different classes of studies … understand what processes might be explaining delayed mortality. Then we have another class of studies that is trying to resolve what we really do about it – the controls, and where do we go from here? Somehow I think we have to disentangle that and figure out what the managers want to hear, because it seems to me that from the Corps standpoint and fisheries resource managers are more concerned about what we can really control, and what we would do differently than we're doing today, based on this collective information we're seeing so far. Right now I don't see anything obvious. We'll get into that conversation at some point, it seems like that's where we're going … The other issue that I think is still looming is that most of our SAR information ends at the period when we really just started … spill (?) … so we have a whole new dynamic out there for in-river fish that aren't collected … we're not going to get that picture for another 4 or 5 years. … Those are the kinds of things that I'm mulling.

Kenneth - … focus on what we think is promising and what is important to *D* … Russ - … I'll second Al. I'm pretty confident that the relative … for steelhead, when we were transporting (89 percent?) of them, and in-river survival averaged 38 percent - … different than the past couple of years, when we transported only 35 or 45 percent … number of survivals were 62 to 69 (?) percent … The other thing is that … from I've seen over the long term … I don't think what we were doing in the past was that good … so we need to do something better. These … are helping us learn as we try to figure out what we can modify … so we can get better adult returns … can't hear … stay within that range and make a plan based on that while we figure out what we can do better, is cost-effective … that's why I don't want to just pick a date and stick with it …

Jim – I'm all for doing more research. It's a question worth asking, what more can we actually do … ? I think maybe a little bit in the early season you can do something. I think the real value … if we have a way to predict … can't hear … Russ - … I was one of those advocating for this workshop. As a manager … can't hear … What do we already know, and where do we need to focus on the next round of research. …

Back to David Welch's presentation

Kirstin - … studying these in hatchery fish? David – Probably some model fish from the LGR tagging in 2010 … Kirstin - … opposite effects of transport on hatchery versus wild fish … David - … can't hear … Al – David, you said that ... about 400 fish that were tagged at Granite in the barge, and about 380 that were in-river? … How many of those fish survived to be detected between Willapa Bay and Lippy Point? David – Survival rate to Lippy Point is about 10 percent of what's released … one common comment is that our sample sizes are small, the survival rate … percent, standard error … can't hear … really large samples, so long as you're not … Al – I see where … some of the years you did your study, you have an array to the south. How many years did you do that? David – In 2006 we had … did not put that in until October. … In 2009 … Al – So for one year it was a functional array to the south, where you documented … David – That's going on this year as well, of course we don't know the results … Al – So the survival estimates they reported for many years, it seems like it's been conditional for the fish. David – It's conditional on a couple of things. One is the transported fish don't do something different from the in-river migrant fish, and also that they don't go off the shelf. Depending on these samples, … behaving in the same way. For example, … what we call survival also includes immigration … it's still fair to make comparisons as long as we're comfortable with the assumption that transported barged fish … can't hear … So there are those types of questions that need to be resolved. The reason I ran the animation again … The 2009 fish, there were certain behavioral differences. We only picked those up in the early … You can see some of these orange balls when the migration …

Al – I guess the point being … when those treatment control groups hit the plume of the ocean, they take the same course, and in the same proportions. If their timing is a little different, the currents are going north or south … David – That's why we held the fish back, because we wanted those fish to hit the ocean, or hit Bonneville, at the same time … The bottom line of course is we cannot say what happens in areas that don't have instrumentation. Where we do have instrumentation, the animals seem to move, we have pretty good mixing of the animals between the two release groups. They actually do spread out quite a bit, but by the time in-river fish get down to Bonneville dam, the fastest fish from the second group have almost caught up with the fastest fish from the first release group, as they spread out over a 7 to 10 day period …

Derek - … length distribution of the fish tagged. I'm just guessing because I didn't see the full size distributions of the fish from the smolt monitoring program … it looked to me like a lot of those fish were up to average size or larger. We've been talking the last day and a half quite a bit about the importance of size, especially in marine survival, and also in freshwater survival. I'm wondering if you could comment on that, and how that might be influencing some … David – … the overall distribution we tried hard …

The folks that were doing the tagging have to work out things between six different groups, so … at the same time select so that they get comparable sizes. … This is a fairly complicated graph. We just published this this week for the British Columbia (?), where 2,500 smolts … five days, four species … can't hear … It's possible that there's growth … size-specific mortality, because some fish grow better than others … we're not seeing anything that's related to the size … Chinook, coho, sockeye, and steelhead … probably the most important take-home message is this: (I can't hear the important message!!) …

Frank – Did you see any difference in the survival of barged and in-river fish … ? David – The answer is no, so there is not a consistent difference, particularly one where survival of barged fish is lower than the in-river migrants. The only case that we have is some 2010 … plume area … where they transport a group for this area only. I have statistically lower survival in in-river migrants. Other years … no different or slightly higher … So we see it in one year, but we also … Frank – … from that, have you concluded that there really is no difference in *D*, or *D* in one? … I can give you numbers that vary from hatchery to hatchery, but the survival from Bonneville back to Lower Granite is generally around 1 percent, or … mortality 99 percent … barged and in-river fish. If you have a *D* of 2, you're looking at about a 1 percent difference in survival. David – If it persisted over the whole life history. Frank – Correct. Then the second time would have to be such that you … to say definitively that *D* is … David – Sure, but I'm also giving you what I think is a plausible alternative. Mortality rates in the ocean … so what's happening is the focus is being on … why is there a heterogenic (?) influence from barging and the recent survival. In fact, barging in my view has not changed the survival. It's removing these fish from one spot to another, and mortality rate is the same. You're not going to get a benefit from barging unless you release to a place where survival is better …

Geoff - … I think my real question has to do with representativeness. If you're only tagging (longer) fish, that's probably about half of the population available to be barged that isn't being … see a significant relationship … it may be that there's … I caution everyone to … those results to the barged population at large. David – I think Bob Emmett showed a slide … of the smallest PIT-tagged fish to come. … I agree with you, Geoff. I've heard it several times, and … that says small fish survive more poorly than big fish … The issue is not that smaller fish don't survive as well, the issue is if there is more of an effect from barging on the smaller fish that we didn't tag …

Jim – I have a student … on the influence of size on SARs, a theory-based model, and we'll look at the size distribution of … what comes out of this is that you have to have a step function in very low survival in very small fish, and then as there's an increase in survivals, fish get bigger, and then the fish get big enough so they avoid predators … I think you're showing this … it's the fish at the upper end of that step, and I agree with all your results, but the delayed mortality that we're talking about that's going on … they're smaller and so you're not telling the whole story. What you need is to tag those smaller fish to get the whole story. You can't say that there's no influence of size, I'll give you a big solid piece of work based on … that shows there's a step function in predation … susceptibility and size. …

Jim – I have two other things. One is … the other is that by holding your fish back, you are perturbing their development, so you're not really comparing fish the way that others are, which is the date they leave Lower Granite dam. They arrive in the ocean at different times. So you're delaying the movement of barged fish, so there comes a significant change that the fish were trying … David – I agree with your statement, but there's a fundamental philosophical difference in how we approach the problem. Since we have limited funds we have to decide how … I would dearly love to have … two early release groups, but we just didn't have as an option … two choices … pattern of barged fish. I chose choice B, because I didn't want to confound two things, which are time of arrival and treatment, because then … in 2009 we did have that early release group. … suggested that some of those smolts come back into the river … it's sort of a cascade effect. The majority went north … can't hear …

Jim - … So what we're really talking about is that there's two effects. One is condition of fish coming into the system, and how they're different when they come out of the system below Bonneville dam. … We can't disentangle those things … The other point, and I think might have looked at this, if you look at your dots floating downstream, a lot of that's coming up to your first detection point, then they all sit there. Then about halfway through all the dots arrive, and one of them pops out and goes to the next detection point. That seems to be an indication that there's a probability of going from one detection point to the other … when they arrive at that point. So you do an analysis to see whether or not there is a time dependency of movement to the next point. …David – Did you see that in the ocean or are you looking at that in freshwater? Jim – I saw that basically in the lower river, and it looked like all the way up the system there was … The first fish that arrived at the detection point didn't go on … it was the ones that arrived later to that point. That seems to indicate some kind of temporal ocean effect that's changing the mortality, and you should be able to build a model to determine whether or not that delay is … David – I'll have a look at it … In the annual reports to EPA we certainly comment that in-river smolts are not just … the first release group doesn't get to the ocean much earlier than the second group … There's barely a delay. They're choosing not to go … Jim – But I'm not talking about this delay, just the probability of making it to the next segment. It depends on when they arrive, it depends on timing. I think you have the data to be able to show that.

David – Good point. … I should say there's one thing … because … step function below that I didn't look at. We see in this data, this is the 2010 tagging for John Day dam. You see all these groups are above the … line, so smolts from John Day dam … on to the ocean actually had a better survival than bigger fish. … can't hear … Jim – I could show that it can't be continuous. David – I tend to agree with you, but you have the size wrong (?).

Kirsten - … back to the interaction between … wild and hatchery … Do they expect higher mortality if they transport wild fish than they would … Then to confound it even more there is … can't hear … David – I'll have to think through what you're saying, but there's a big philosophical difference … have complicated systems … we have to be really simple, very focused to get at transport versus in-river fish – they have to make the ocean at the same time … Kirstin - … 2010 data … you might be able to clarify … David – The only way … to clarify this would be to have … every day release 100 fish, … can't hear … then barge down so they arrive at Bonneville at the time the in-river migrant come down. At that point … then say, well, we're not going to sample, we tag them Tuesdays and Thursdays … you may come back where we are right now, which is that you have two release groups. … Kirsten - … if the goal is to increase wild salmon in the system … hatchery fish … just keeping in mind that there is … can't hear … David - … I wouldn't model, I'd say let's test it, and put the wild fish into the barge with tags … disease because of close proximity to the hatchery fish, which are more likely to have a disease … that's how you test …

Russ – I agree with Jim … I think that you can't separate out the management decision of transport or in-river and different arrival timing in the ocean. That's one of the concerns I've had with your previous research, is that we try to get the fish down to the ocean at the same time, yet in our management decision we are choosing maybe incorrectly, but to get the fish down there at a different time, we choose to either transport, pull out a fish migrating in-river. So you have a different transport … than in-river fish, it's nothing we can do in management. We can't say, all right, all these fish that passed through Lower Granite dam through spill, you guys go earlier, … fish … in transport … go later so we get them to the ocean at the same time – that's not what happens. What happens is the fish that we collect at Lower Granite dam, we have to make a decision of whether we want to transport and get them down the river faster, or do we want to bypass … and they get there later. That's our management decision. So your 2010 design, I would encourage you to continue that, because I think that's going to provide us more useful information as far as our management decisions, and likely, as we all agree, that part of the *D* that we observe is not hypothesized … we've observed that PIT-tagged fish … it is real, and part of that, we all agree, is likely due to transported fish … early, and maybe too soon. So I encourage you to continue the 2010 design, collecting fish at Lower Granite dam, or you could release them at the hatchery at the same time. Don't try to … get them to the ocean at the same time, try to get them at Granite at the same time, because that's …

David - … we were willing to have three … groups … that would disentangle your question, plus the scientific question … handling effects from barging reduce the survival, which is a science question. The other side of this is, I don't disagree with you that *D* … What I'm suggesting to you is that it's not important because of barge … it's because the animals get to the ocean at different times. Survival in the ocean for … is lower than in the hydropower system … not because of the effects of the barge … I think barging is being unfairly (blamed) when in fact it's ocean conditions that cause those problems. … ocean conditions significantly … you may want to have them take longer to get out of the river … spending more of your life in a less hostile environment. Those are the sorts of questions …

Dick – I would be remiss not to suggest another alternative. There are some major groups that are PIT-tagged, Kooskia comes to mind, that are based on one or two days early in the season to migrate through the estuary almost the entire time. You could target specific groups and group by code, and tag at the head of the estuary, and use those fish …

F.7 Session 6

Synthesis and Open Discussion

Kenneth – We do know that from today's and yesterday's talks that we have a lot of complexity here. I'm hoping we might be able to cut through a little bit of that. One thing that we should probably throw out there to start the fireworks is, are we talking about wild or hatchery or both? Any thoughts on that? Al – I think you're talking about mixed population, you don't have any way around it. That's what you have to deal with. Russ – I would say it a little bit different – they're mixed, and so in our management we're not going to be able to … unless someone wants to … so we have to manage as a group wild and hatchery Chinook, steelhead, sockeye, lamprey, coho, whatever's coming down. But I think as far as evaluated delayed mortality … I think we want to focus on wild fish because ESA (focuses) on them. Jim – I think you have to look at all fish coming down to try … we can't just understand wild fish … Geoff – It's one size fits most. If you have a fish in your hand, then you're not going to separate them in your hands, make different decisions for different for different fish … Al – It seems like the wild steelhead and hatchery steelhead, people are pretty happy with their performance … the transportation programs, and would like to see a little better response out of Chinook, but you have a mixed population. So would you shift over away from what you know works with steelhead towards some other alternative that favors Chinook? I don't know what that would be, frankly. I think you're trading off species, you're not trading off wild and hatchery.

Kenneth – That's really the next question. If we decide … and we argue about whether we're going to favor the performance of the wild … I think the question is, is it going to work for steelhead no matter what we do for Chinook, and therefore we should argue about Chinook? What approach do we take here? David – I think you have to take each separately. You try to hold all of this in your head, and you're just not going to … What you have to do is do wild and hatchery, Chinook and steelhead, separately, and then at the end the managers are going to have to say, well, within all four of those, how do we make a hybrid (?) decision because it's sub-optimum for something. Even with what I've heard today, I'm not completely convinced that I believe hatchery and wild fish necessarily do differently. Just because of where I come from … that's the correct interpretation. We need to figure out what the … issue is for hatchery fish, and figure it for wild fish. Then we put that in front of the managers, because they have more choices … barging and not barging. … can't separate fish … there's a different answer for different groups, that needs to be laid out … decision as to whether you barge or not barge.

Kenneth – I don't totally disagree, but I guess I think we're not starting from zero, and we do have some of the managers here. The question is, from where we're starting, where do we need to move? What do we need to do next to improve our ability to manage … David – Let me be clear – I'm not suggesting … no study. What I'm suggesting is saying, does barging help or hurt for those four groups. Then it's a subjective decision as to whether or not, how do you apply that? … develop a research agenda for …

Derek – I'm just going to comment that I think we can do a little bit of separation, and I know Russ and I will probably butt head on this. But as far as separating steelhead and Chinook, I think at least for portions of those populations, we're already doing that … So there's a major benefit, more so for steelhead, in transport, it might … that direction. Al – I thought the literature was telling us, the recent stuff, that we're not getting that much of a benefit out of the separation … I'm really concerned about it. We should have hit Granite hard a long time ago, because that's where we're collecting all the fish.

Russ – I think part of that was that the initial idea, from my understanding … on separation is that the hypothesis on why transportation didn't work as well for Chinook is that stress from transporting them with steelhead. So the idea there separation so that we could transport Chinook separate from steelhead. But when we did the research where we transported them separately, it didn't seem to improve their adult return rates, so we moved away from it. Now you have folks like Derek who are proposing that since the data we have on hand on adult returns – and I caution everyone that we may be in a new reality on the benefits of transportation for steelhead – but in the past years, their thinking is that there may be a period there when we leave all fish in-river, and then maybe switch to a period where we sort out and transport primarily the steelhead, and still bypass the collected Chinook as an interim strategy, is what Derek proposed, there's some regional thought to that. It's one that as a manager I'm concerned about, because I'm one of those who believes that the whole is greater than the sum of its parts. I think leaving all the fish migrating together has a lot of benefit as far as, these are schooling fish for a reason. They migrate more efficiently together. There's a lot of research that individuals don't do as well … as a group does. Also, we swamp the predators, which allows the predators to feed more selectively, and just pick off injured or sick fish that likely have a lower probability of adult return, which I think is a good thing. It's part of the reason why I've been in support of this management decision to start transportation at a later date, and leaving that early migration cohort in-river together.

Kenneth – I'm trying to capture all of this good discussion, because I feel we need to set some framework first, in terms of are we going to talk about steelhead and Chinook today … ?? – I'll take a shot at this. I think the 2008 Biological Opinion was one of the major cruxes. Within that document was this … between what we thought we knew about wild Chinook and what we thought we knew about wild steelhead. How do you balance that operation to try and do what's best for both, to the extent possible? … along the lines of what Russ said yesterday … maximize adult returns for both groups. If you can do that through transport some times of the year, that makes sense to do that. If not, it makes sense to pull back from transport. We saw how popular that was. There's been a lot of discussion in the region with ISAB; we had discussions about low flow operations, and basically the regional consensus to go forward was, we're doing something new right now, we don't know exactly what the results are going to be, we have some issues with straying (?) rates for those species … that we want to keep doing this for a while to see what those sensitivities are. We're kind of in a holding pattern right now, from my perspective, on continuing to do some of these things that we know are good for one species or the other. We're doing it on the basis, I think somebody said earlier, a probabilistic model. We've done this … 5, 6, 8, 10 years, and on average it's best for these fish at this time. What I think we're lacking as managers is without having some sort of a mechanism that's understood, we're just kind of doing this … if something changes in the future, how are you supposed to intelligently react with the operational tools that you have in order to continue to get those benefits and try to maximize the SARs under high flow years, low flow years, … If we had some mechanistic understanding of what are the forces that are driving these general patterns, I think in 5, 10, or 15 years that we'd be in a much better place. That's what I'm interested in, is trying to figure out what are some of those mechanisms, the little tiny things, …

Kenneth – So you're making a case to continue with this line of basic research … ?? – We learned a lot about Chinook, and that's good, but we still don't know why transport seems to be working so well for steelhead. Russ is absolutely right, we have higher survival rates in-river than we've seen for awhile, but the jury's still out until we get results back on what that really means. If it drops you from a … that's information … Kenneth - … as one of the key uncertainties, a mechanistic understanding of … I have these categories of key uncertainties, data gaps, areas of future research, and specific actions. Those are really driven by our contract, our directive, to come up with a report at the end of this, that's why I have those categories. But you can work around those however you want. I think maybe right now it would be good to take this framework that we put forth and see if people want to shoot holes in that and move things around, and then get back to what it is that's important, then go from there to how those key uncertainties ...

Frank – Before we move over, I think we should probably … I personally, as a researcher, not as a manager, of this system, feel like there's been an awful lot of times when we've come together and shared research, and I feel like the management implications aren't as clear as people would like. I'm not saying anyone is at fault here. But would anyone else like to share some of the things they'd like to see from a management perspective before we get into where we're at and where we're going to go? More of a mechanistic understanding is one, but are there a few other things the managers would like to see happen with *D* research?

Kenneth – I think that's where we're going to get to by doing this. We have to somehow get this complexity under control. We've already heard how complex it is. If you wouldn't mind, Frank, can we go to this framework and start to debate about what's important, and then say what is it about those important things … I'm trying to impose some structure here. …

Russ – You have the key uncertainties, and one of those that I would like for the researchers to reduce the uncertainty debate about, is are we collecting weaker fish in our collection bypass systems, whether they're smaller, diseased, lower lipid content, or whatever. It's one of those, and I know a lot of the researchers in here, thinking about tagging, clipping fish to answer these, but I would like to encourage researchers to go back – I know Rebecca and Skalski did that big bypass effects – and look at that data. There's a couple of things, as someone who looks at it as a whole, is that in the years when we didn't spill much, and so the bypasses were collecting a bigger portion of fish, do we still see this? Or when we spill a whole bunch, and bypass systems, we're collecting very few of the fish. Do we see a change in that relationship if there is one there? That's one of the things I'd like to look at, because that's been a concern to me. There have been years when we have collected 80 percent of the Chinook. If they're collecting weaker fish, then 80 percent of the fish are weaker? No, I think that there's … The other thing that concerns me is that a lot of these folks have seen a bigger relationship in size for steelhead and hatchery Chinook, but our bypass effect in *D* value, effects that we see, are greater for wild Chinook. Tie what you see as far as potential collection bias, does that match up what we see as far as differential adult return rate?

David – We just started tagging at the dams last year, and it was a bit of an eye-opener. I have some concerns that the bypass systems are not collecting weaker fish, but maybe harming the fish, simply because you're basically have to build a … sorting machine and take smolts … this stream of water through it. We saw a fair amount of mechanical scaling in fish that was happening just because you have a lot of rushing water and hard parts there. Then we're also dosing these fish with MS-222 a couple of times because the people who are tagging don't actually dose the fish, the fish are dosed first, and then they get re-dosed or re-anesthetized, and none of us know what MS-222 does to these fish. I do have some concerns … maybe what's happening in the bypass system is not so much that they're selecting weaker fish, but that we're weakening the fish because it's a tough environment to go through, … water with logs in it. Russ – That isn't the question we're talking about … bypass is affecting the fish or selecting weaker fish – that is the management question that I want to know.

Barbara – So to get at that, is the Corps or anybody doing research to look at the SARs of fish that went through bypass versus … Rebecca - … we did a study … we found that fish that go through the bypass system had several … can't hear … not so much Lower Granite or Little Goose … lower than expected adult return rate compared to all the other fish, so it's not just … we did not definitively say that … can't hear … If we didn't look at how that relationship between detection or collection probability and … we can go back and take a look and see if there's any strong … Matt? – Or pre-RSW.

Matt – With the PIT-tagging program that's been implemented for so many years, is there any data that could be used for fish that are detected … The other thing about that collection system is, I think it was in the mid to late 1980s, when Maul et al. did that work on cumulative stress effects of going through bypass. I think it was at McNary. What they showed is that definitely, each step of going through the bypass added to the stress … of the fish. If they're doing that 8 times, or 6 times … you can use your imagination. They didn't really come to any conclusions about whether this was a really super bad thing, but the responses that they did see were reasonably severe. Bill – But unfortunately they weren't able to sample fish that went through the spillway to see … Matt – Correct, that's something that could be, that's a dated study. The technology exists to do that now. Geoff – Tens of thousands of JSATS-tagged fish going through three dams … look at the size of fish that … Bill? – We've done it with radio-tagged fish … and the smaller ones are going through the bypass. Matt – Was it Diane Elliott in Pasco early on, I thought they did some stuff with BKD … about whether sick fish were being selected for … the bypass system, but I can't remember … Bill – They found a slight increase in BKD in fish … but the sample sizes were really small. …

Kenneth – Those are good contributions. I'd like to try this again. Look at this framework and see – are there things on this framework that are miscategorized, that are ranked inappropriately, that should be moved around in terms of their important or their uncertainty? Have we got this right or have we got it wrong? Al – Number 10 up there, adult straying, what's the rationale for putting that up there …, and are you talking about Chinook or steelhead? Jennifer – We were thinking that … found that there was a 10 percent greater straying in barged fish compared to ROR migrants. We were also thinking that at some stage, 10 percent could be pretty high. But keep in mind that this is 10 percent of the straying rate. So say straying rates are 6 percent, 10 percent of that is only .6, so it's not much, so we were thinking of moving that down from highly important to moderate. But that's looking at Chinook. For steelhead, there are higher rates of straying … alternative barging strategy, but we're still waiting for adult returns of that study. We were also thinking about producing a table like this for each species, hatchery versus wild. This is a generalized table, and it would be great to get comments from everyone on how to improve things … looking at spring/summer Chinook, fall Chinook …

Al – It seems like the adult straying would only be an issue if the fish strayed to an area where they weren't detected … was that the case? Jennifer – Most of the straying … down to John Day … that's mostly for steelhead. For Chinook, I can't remember off the top of my head. … Bill – The conversion rate from Bonneville to Granite … if you're measuring effect. Frank - … .6 percent doesn't sound like a lot, but … .3 to .6 can increase the *D* ratio from 1 to 1.5, 1.8. I'm all in favor of leaving it in the high category, particularly because this is clearly, even though the percentage is small, protecting the adult population is something that has low uncertainty because …

?? – There's also a difference between wild and hatchery fish in straying … hatchery fish stray at a higher rate … it seems to be a differential between … can't hear … Russ – I would say on that issue, as far as the importance on *D*, I think it's relatively low. For example, if all of our transported hatchery steelhead, which are the brood fish, shows the greatest straying, converted to Lower Granite dam at the same rate as the in-river fish, by my recollection that would change *D* pretty small. Of the overall adult returns, the impact of straying reducing their conversion to Granite is relatively small, and so it's important for *D*. I agree with moving adult straying down. As far as conservation of wild steelhead in the John Day, it may be a whole different matter. But for *D* I think it's relatively low. Of these, one thing that I respectfully disagree with, I think fish length should be down, physiology and disease should be up, as far as effects on *D*. You can go up there and yes, smaller fish are more likely to fit in the gap of those … predator, but predators don't just eat everything that they can fit in their mouth. They're wanting to intake more energy than it takes to capture that energy. I've been a bass fisherman for a long time, I guarantee if you're going out for a small amount of bass, you throw a little bitty fish out there, you're less likely to get them to strike than if you throw one that's a good meal for them. We know cormorants and terns like certain sizes of fish, and it's the middle size, not the smaller sizes, that they go for. I think that: 1) the difference we see in length isn't that dramatic, and 2) there's going to be pluses and cons as far as predation on that. I don't think that's what we're seeing. The length is not the big one. What we're seeing, and I really believe this, is that the early transported fish are smaller, but I think they're not smolted, and they're spending this longer time, which then increases their count rate with predators. I also have really bought into this idea that has been proposed that some of the disease outbreaks that they die from, when they hold up and take time migrating through that lower river, are worse on them, and increases their mortality, whereas late in the season, when they get through that lower river quickly, they get to saltwater, which seems to drop those down. I think that fish length should be dropped down to moderate, and fish physiology-disease should be up. That's just my opinion, this is a workshop.

Bill – I agree with some of what Russ said. I think it's rather telling, I think one of the introductory presentations yesterday morning showed the range of Ds that we see in different species. I think that the average shown for wild Chinook was about .6 or something, for hatchery Chinook it was approaching 1, and for steelhead it was over 1. If you think about it, that's sort of the same way as their average length is. So we really don't have delayed mortality for … big fish, we only have it for very small fish. Frank – But also a lot of times when you do the hatchery versus wild comparison, they're also … can't hear …

Kenneth – I'm going to have to jump in here. We're getting a lot of different things to talk about at the same time. We didn't decide on adult straying, and I'd like to do that before we move on, then let's get into additional fish physiology. David – Can I ask a question, then? Adult straying can actually have a big effect on *D*, could that be the cause of hatchery Ds being different than wild fish? Bill – If you look at the straying rates, they're almost the same in hatchery … We had a meeting on straying a week or two ago, and the … rates are actually pretty high in … steelhead … in barge studies they were actually higher … There are some hatcheries that are worse than others. Chris – Yes, there is some hatchery dependence, be aware of that. David? – It would sure be nice … Bill – There are definitely some hatcheries that have higher stray rates. Surprisingly the wild steelhead are straying … as much or more than the hatchery. Chinook. It's not a concern for fall Chinook, but for spring Chinook … David – So the bottom line is … we don't think … Bill - … but how far down in importance do we want to move that? I think it could be moved down about as far as you could go. … Al – I think I'd leave it where it is until someone organized it a little better, with rationale and tables … Bill – I think Russ hit the nail on the head, though … It's a concern through John Day, but it … doesn't affect *D* very much.

Kenneth – I'm going to put as a comment that there was some argument that number 10 could be reduced in the report. The next thing we're talking about is fish length. There's some argument that that might also be lower than high importance to *D*. Frank – Can I put out an alternative … which is the role fish physiology, disease, and fish length in the wrong category called fish health … you can break it out in how you list it, and have different categories … there's three categories that show it being important, but they're obviously related and there are probably other measures you can make to categorize health. I don't think we should restrict health to just those three. From what I've heard, we all kind of collectively agree … Al - … length was a measure of health? Frank – Basically, yes. Barbara – It may be a covariate … Al – I would leave length separately, Frank. ?? - ... Mr. Ledgerwood was showing, … get in the estuary … get some idea of what kinds of conditions those survivors are in … both groups, and how much they grew. Frank - … can't hear …

Matt – It might be better characterized by, and I kind of agree with Frank's idea, but it might be better characterized instead of fish health, maybe fish performance. Length impacts some of the mechanisms we've been talking about, like swimming performance, predator avoidance, burst swimming speed, all that kind of stuff is correlated with length. From a fish performance perspective, and how the fish deals with the challenges that it's facing, those three categories could go into a single category like fish performance. I know that Schreck would like that. Jim – I disagree, because steelhead, hatchery fish, and wild fish have different lengths, but they can all be healthy or unhealthy. So by … we're losing that important … we might understand this more in terms of fish length than species. I think it's important to separate them. Kenneth – … I think you lose something when you talk about everything … that's very fish-centric … fish-centric measures, and these others are more environment. …

Barbara – I'm not seeing anything on genetics. We touched on it briefly. Genetics plays a role in physiology, disease resistance, adult straying, growth rate. I'm just throwing this out there; what do people think? ?? – The genetic composition would be the same … between two populations in the barged versus not barged … I would assume the population of barged fish, that the genetic composition of those be the same as the population of unbarged fish … the assumption … Barbara – If they were taken at the same time and place, yes. Geoff – Not necessarily. The bypass is selecting for smaller fish … can't hear … Barbara – Also, from that one graph this morning, I'm just fixated on that. It was apparent that the barged and ROR fish are experiencing not just different mortality rates, but different causes for sources of mortality. So ultimately that will have genetic impacts on populations. If you are bypassing the natural selection process, and those are smolts that should have died … Now you're cheating that selection on the smolts, and they come back as adults, and ultimately how is that going to affect fitness in the population? And that's just one factor.

Matt – I think you left the room after your comment, but Maureen disagreed, and now she's gone. Al – I think what she said was … can't hear … Matt – I think she was making the point that whatever fish health … that disease or pathogen is usually a positive benefit for the fish. That goes a little bit against what we're saying. Barbara – But BKD is a bacterial … can't hear … also the genetics of resistance aren't very well documented for a lot of parasitic diseases … BKD people have been trying to breed for genetic resistance for years, and have not had a great deal of success. … if there was an outbreak of disease … versus an endemic parasite that populations have co-evolved with …

Frank – If we move to a cadre that has this performance, the overarching, … what you just said, and I agree with you, is I think you have to look at fish performance indices carefully for hatchery versus wild fish. And I also think that performance measures are necessary … and they have different profiles, and yet wild fish generally do better in the river than hatchery fish. It's like it's different metrics for good performance for the wild and hatchery fish …

Kenneth – We talked about some possible modifications here. What about the low importance of *D*? Are these things that we can safely ignore, or should we be moving those back up into the higher importance level? The ones listed further down as low importance to *D* are lower river conditions and predators, barging conditions, and pre-hydrosystem conditions. Paul Wagner? – I think lower river conditions are fairly important. I think the conditions drive a lot of what actually ends up being a success. For the early barged fish it may be a low turbidity issue that's limiting their success as much as it is their physiology. Since one is easily measurable … and what if we knew more about … do a better job in transport management, if that really is a key driver of success. … I think I've drawn a tentative conclusion that the early barged fish, while we barge them down they may not physiologically be up to speed. But usually the flows are low early in the year. Their traveling times are long, turbidity is clear, so they're just set up for a problem. And they don't have a lot of friends, so they're just out of their towns … When we get into May, flows are generally higher, turbidity is higher, and the fish's motors are turned on, so they're not so susceptible when they enter in the lower river. So barging then works. But we're using a date as a surrogate for a lot of things - … river flows, turbidity, predator prevalence. I still think a key one is some aspect of ocean conditions, and I'm hung up on chlorophyll, because it's easy to measure … But it's passive, almost. Once you have your program where you can get the data and you're good to go, and there are times when I think we should be transporting, probably in May … it's another one of providing … is it a turbidity surrogate in the ocean? When they get out there and it's clear blue, you're toast. If it's soupy green, you have a better chance. It varies. In 2005, which was the year that we chose to transport everything. Production in the ocean was terrible, and they may have been better in the river getting delayed. 2010 may have been a similar situation, where we delayed transport, conditions came on very strong in the ocean, all the fish that didn't get there early, they got there at a good time. Or we'll see how it plays out. Let's ask for tools if we can …

Kenneth – Can I ask you to move over to the right hand side and say what would it mean to move forward in that area? Is there a key uncertainty, or is that a data gap that would allow you to move forward? … Paul – It's a data gap … There could be data for the lower river, more literature … maybe Bonneville's fish ladder as our turbidity measure for the lower river. The data gap in terms of chlorophyll sort of depicting what it is, we have one paper. It's one of those that would not be that difficult to fill in the missing years and correlate that with more recent … Geoff – He wants to move 7 up the list. Kenneth – I have a note for modifications to the framework … for lower river conditions possibly increase importance.

Jim - … there's a separate factor for estuary conditions and predators. … The lower river is really before you get to the estuary, and we put it low because the original data that Carl Schreck produced showed no difference between transport of in-river fish down to the freshwater area. So we want to keep that part low, and then put our emphasis down in the estuary, and I think that's what you're referring to, is that right? Paul – The lower river, I would think, from Bonneville dam to Astoria and beyond … Jim - … Our lower river in this graph goes down to about river kilometer 70. The estuary is there on down. Geoff – Survival is usually very high for all fish down to river kilometer 70 … Jim – That's why we put that as a lower category. Our intent is to get these things separated so they don't all end up in the same box. Derek – I would say as long as the lower river conditions doesn't include that lower 18 kilometers where we see all the mortality … lower river survival studies … it does leave that section lower in my mind. If we start including more of the estuary, that thing's going to shoot up to the top of your list. Jim – That's number 8. Kenneth – And it is at the top of the list, and it's on the high uncertainty side, so there's work to do there. Jim – But I think you bring out a real interesting point, linking transportation decisions with projected ogee conditions and estuary conditions. We don't have that here, and that seems like a dynamite thing to do for management and research. …

Ken – I think a lot of what we have seen in modeling results is that *D* or SARs is correlated to some things we can measure. … correlated with things you can't measure, or that we haven't measured, because we don't have those data sets to work with. … a lot of the work that we've done is sort of stuck. We can't tell what the disease level was of the fish for the past 10 years, even though you have a 10-year data set with PIT-tags, you can't correlate it. I think there are a lot of data gaps that we've experienced in trying to evaluate this data …

Russ – On the disease thing, since the mid to late 1990s, Idaho Fish and Game went into a very aggressive fish health program, at our anadromous hatcheries especially, and I do think that there is a lot of disease profile information associated with releases for the past 10 years. It may not have been looked at, but we have that data, we have a very aggressive program. The problem is that there's probably a lot of information, there will be some years where we do have disease outbreaks in the hatcheries, and they're released with a higher load profile after … going in. Does that correlate with any change you see? One thing that Jim Anderson brought up that I've been thinking about a lot is that for wild Chinook we see the lowest Ds, but there's a lot of variation there for a good … is there a difference, just looking relative to adult return rates, in *D*? Does that have an effect? Then the other thing that we should look at is, does *D* vary depending on the probability of turbine passing, bypass, for the in-river fish. In years when we have a lot of spill, less passage, is *D* different than when we had a low spill, 2005-2004 type year? Does that change *D* and help improve our understanding of *D*? I thought that that's one of the things we need to look at, is overall SARs, and then in-stream management decisions – can we identify something? One of the things I've always been surprised that no one's ever really talked about is that we see these consistent low Ds for wild Chinook. In 2001 we culled a hell of a lot of fish, and look what they got down at Bonneville for the in-river fish. … *D* was an outlier and much higher than we've seen in all the other years, in that year. So there's something going on. These things are relative. The more we improve transportation, *D* is going to go up. But the more we improve in-river condition, *D* is going to go down. So a low *D* is not necessarily a bad thing, if we get there because we improve in-river conditions. I want to make that clear.

Frank – In terms of modifications to the framework, … lumping (things that have to do with timing), and again, you could break them out, you have sub-bullets, but hydrosystem arrival, and estuary conditions and predators, and ocean conditions and upwelling – they all kind of seem to be related to timing. It's the concept of a trigger, and understanding what that trigger is. Kenneth – I wonder if by keeping them apart we're more likely to find the trigger than if you lump them all together as timing. Russ – I propose that we move disease and fish physiology up to the high importance. Does anyone object to that? Al - … fish are delivered to you, they're already bearing disease, they already have a certain condition every year. In terms of what you would decide to do in your management strategy …Russ? – You have fish length up there, what are you going to about fish length? It's a high importance as far it affects *D*. Al – If it's for understanding what processes might be driving it, I can see that you might want to elevate it to look at … Russ – I think that we could do more with disease and physiology than we can do with length … but because disease, if there is lateral transmission in the barge, and disease is causing it, but we find out that by starting transportation later we help reduce that, we've addressed a factor, we've improved fish performance, and we've increased *D*, which are all good things. Al – That could be what we're doing right now. … maybe a potential agent that could explain … Russ – And we could do something about it, we've made a management decision based on that. What are you going to do about length?

Dave Marvin – We have a data gap. We don't know the length. We had this assumption … that potential collection effects may be due to smaller, weaker fish. We have a data gap because we don't know what the actual length of these fish are as they arrive at the collection facilities, in this case when they arrive at Lower Granite. Since all of our work is done with large fish, and all of these fish have PIT-tags in them, we have PIT-tag data from … those lengths are 3 or 4 months old by the time they get down to Lower Granite. Since all of those PIT-tagged fish have the ability to be segregated from the general population … we now have lower densities of those fish going through there. It makes it very easy, in my opinion, and this is something I've been proposing for 10 years, do video monitoring on those fish, and we could essentially get the lengths of known fish going through these facilities – no handling, no secondary handling, no MS-222. … little additional tag effect or collection effect to obtaining those lengths.

Dave Marvin - We also have a data gap in the fish condition, physiology, disease susceptibility with these fish. At Lower Granite, at Little Goose, at McNary, at John Day, at Bonneville, we have the ability to collect specific PIT-tagged fish, do some subset of these tagged fish. Then we'll be able to look at the condition factor, look at lipid content, be able to measure ATP levels, measure BKD prevalence, or whatever marker for actual disease expression are necessary. If you want to measure that condition at Lower Granite, before fish go on the barge, and then that gives you your control to be able to measure that change on any of those fish … I think that we have data gaps, and as far as specific actions we can take, we can set up and establish a long-term concerted monitoring effort, looking at length of fish coming downstream. And not only for … that feeds into necessary information for numerous other studies for which these fish are initially PIT-tagged. As far as the condition, disease, physiology, we've already got an independent research … My suggestion is, let's come up with a concerted effort that we can use across the board to address questions of *D* as well as other management questions, and establish some kind of systematic monitoring for those barged groups …

Bill – One negative of the … fish … that's going to be a smaller and smaller portion of fish. … (Frank has to leave). Dave - In the case of the general population, yes, you can have all these caveats about being able to extrapolate that out to the general population, and you're always going to have those caveats, you always have those assumptions that need to be addressed, and rightfully so. Specific to *D*, if you're looking at the condition of ROR fish versus bypassed fish, or bypassed fish versus transported fish, you have the opportunity and the mechanism to be able to obtain that now. And rather than speculating, I think that we should just go ahead and implement that monitoring program to be able to look at the condition of those fish …

Geoff – My comment is that in Dick's presentation he said the quality of the length information is just as good as those who are tagging 18,000 fish a day with PIT-tags … I don't have high confidence that we're looking for possible differences in the 2, 3, or 4 millimeter range, and you're going to get the signal out of them … you're going to have to make a concerted effort to recognize the quality of the input data, not just the data you're starting with, but to do the length and the time of the tagging, whether it's at granite at a hatchery, the precision of the video monitoring for length. We see differences in survival of … In the fish that we tag, we probably make mistakes also, but we're not handling tens of thousands a day. Our fish are processed more slowly. But on the order of 3 or 4 millimeters difference, the fish that are surviving to East Sand Island on average are 3 to 4 millimeters larger than the fish we tag. The differences are fairly small … Dave – And as your measurement is biased, your precision is … not only at time of barging, but with any of these … passing through hatcheries.

Kenneth – I haven't put anything here in the specific actions, because … actions that may affect *D*, where something is going to change *D* or adult returns. I'm putting the monitoring and research up here, and then the next category up … learn what to do … Does anybody have any other data gaps that could maybe be filled?

Bob – It seems to me we should consider a little bit more the lower river conditions … The reason I say that is because we found that there's quite a bit of difference in survival of barged fish versus in-river fish at Bonneville. So at that point in-river groups already exhibited or experienced the culling (?)… Then after that point, when we barge fish, they experience the culling that the in-river group had experienced. I think there's a lot that's happening in the lower river, when you start talking about avian predation and so forth. But there's a section, and I know Dick and I feel similar about, unless it's a seagull, you don't get a lot of Caspian tern or cormorant predation above river kilometer 50, 60, 70. So between that point and Bonneville dam, it's a big section of river where I think the barged fish are most likely experiencing, or going through that culling process. Is that a result of the river condition or something else? I think instead of just saying it's a 2, … fish shoot straight through there on their way to the estuary, and there's no impacts. That might be a little bit off. There may be something going on that …

Derek – So your argument is for the lower river category being moved up from the low category? Bob – Yes, I am, I think that is where the culling is occurring for the barged fish. If there was some way to evaluate that … Russ – Actually that's a good point, then. To counter that, we have a lot of research. We saw some presented today. In that first 70 miles, there's not that dramatic a difference in survival. Bob – I appreciate that. Russ – And another thing is that if culling was a big factor in this effect, is that in-river fish are getting culled between Lower Granite and Lower Monumental dams. If this *D* is because we're transporting weaker fish from Lower Granite dam, that in-river fish are getting culled out, some of that culling occurs. And the biggest one, of just purely weak fish, should occur between Lower Granite and Lower Monumental dam. If culling was a significant factor, SARs of fish collected and transported from Lower Monumental dam should be higher than fish collected at Lower Granite dam. Yet what we see in adult return rate, and it's highly variable, if sample sizes are small at LoMo, generally LoMo does worst than Granite. So if you take those two pieces, it doesn't appear that culling …

Russ - The third piece is, early in my research career, and trying to estimate mortality per river kilometer from release to Lower Granite dam for both hatchery and wild fish collected at … traps, is that if you did it on the pure river kilometer for wild fish from the smolt trap to Lower Granite dam, … to the ocean, they're dead before they get there. But the best model for both hatchery and wild fish was to try to come up in a given year with an initial mortality, and then a mortality per … It worked out pretty dang well for both wild and hatchery fish. Depending on the year, there's a pretty significant initial mortality from release from trapping and tagging at a trap, but then it gets pretty consistent. So all those things seem to take turns culling them. We know if you release a hatchery fish … just above a dam, they get a lot of pretty weak fish collected at that dam. You do see that when you're releasing very close … but I think once you get down a ways, I don't see evidence that culling is still going on and is a significant factor in what we're seeing here. Bill – A few of the Idaho hatcheries are more like 100 kilometers upstream from Lower Granite.

Derek – I have a comment on that. Where did you draw the line on where culling has to stop? I can't see anywhere you can say, OK, LoMo is where we culled them, and now we have the healthy fish. I think if you look at SARs for the fish that survived in-river all the way to Bonneville, then you're more likely to have culled … than if you pick LoMo. So I'm not sure that I agree with your assessment that they should be culled by LoMo, and yet we don't see any SARs there. Russ – That culling should be greater early and then decline. Derek/Russ … Al – I don't agree that it's linear after … Derek – No. Russ – I think there's an initial high, and then I think mortality does go down in-river into a fairly constant rate per kilometer. Geoff – We've looked at it in the lower 10 or 35 kilometers and it is not constant. We see the lowest survival in the lowest 50 kilometers, so per kilometer … Russ – I understand that, but that's not a culling effect, that's something else going on. Derek – The survival rate is worse in the lower Columbia than it is in the Snake. … Steve – Russ's point doesn't depend on culling having been all above or all below, and I think the point is if there's any culling at all that would occur between Granite and LoMo, then the prediction would be that the fish you picked up at LoMo and transport would be a higher quality group of fish, it should have a higher SAR. It doesn't matter whether that's all other, or whether all the culling has happened by then. That would be the prediction anytime.

Kenneth – We're talking a lot about culling. Is there some uncertainty or data gap that needs to be filled there? Russ – Obviously there's some uncertainty from folks. Geoff - … quality of the fish in that case may be different, maybe the bypasses collect different segments of the population … collects weaker fish. Derek – Correct me if I'm wrong, but the sample sizes for SAR categorization for LoMo are pretty small. … We've had that as a question on our 1-pagers as a research objective, is to get a better evaluation from SAR data for fish transport.

Dave M – For my clarification, what's the definition of culling? … Barbara – I've got natural selection. Russ – Weaker fish that are going to die no matter what we do to them. My understanding of the thinking is that we're transporting a lot of fish, and no matter what we do to them they're going to die anyway, whereas the in-river fish, those fish that are going to die anyway die before they get down there. Once again, the question is, why would culling be much bigger on wild Chinook and is reversed on steelhead? Steelhead Ds are generally above 1. In the data set that we have these Ds above 1, we cull more steelhead because their in-river survival is lower than Chinook. There is too much data, and I know it's complex – but when I look at this I keep seeing stuff, and culling just doesn't seem to be a significant factor here. Bill – I would also add that there's a discussion on culling in the CSS workshop on delayed mortality in 2004 … Jim – And we have a large section on how to approach culling … tools that we need … Dave M – So the intrinsic components of that I assume would be disease, predation, size selectivity, those are all contributors that can't be extricated and addressed independently? Jim – Possibly they can … There's a large section on culling in the report … ?? – I guess you could look at it in terms that culling, if you looked at it objectively, maybe there is something as far as condition in the lower river. … that might be …

Kenneth – We haven't really covered much about areas of future research and monitoring. Hearing what we've talked about the past couple of days, it seems like there ought to be more. What areas of future research look promising in answering some of these management questions? David – I know that Jim Anderson is right that delayed mortality does exist for smaller fish. Jim – And David is right in showing it doesn't exist for large fish.

Russ – I would like to have research that looks at the relationship of *D* and ocean productivity. Jim – Yes, that's really … Russ – That's a big one. Then also as the proportion of in-river fish changes, does *D* change? ?? – Would you measure that just from the fish passing the dams and the numbers going through the bypass? Russ – Yes, we have pretty good estimates of the proportion that we're transporting. Jim – So Bonneville release of fish and its effect on *D* of river fish. … post-Bonneville hatchery releases … Bill? – When we get done releasing those fish … transport effect? … Dave M – Aren't you really talking about post-Ice Harbor hatchery releases, rather than post-Bonneville? … Those fish that are transported really don't experience any of the influence of fish that stay below … So the in-river fish, once they come down into the Columbia, are then mixing with all of your other populations of hatchery and wild fish coming out of the mid-Columbia, coming out of the Yakima, coming down the river. And your transported fish don't experience any of that, until they rejoin the river system below Bonneville. Jim – We have a low estimate of how many total fish smolts pass Bonneville, but I don't know of any numbers for how many other fish … But you're right, there's a whole other component. Any hatchery below the hydrosystem that is putting fish in the estuary … both populations. … Jim – We have an estimate of all fish passing Bonneville … missing data gap, could probably be filled in …

Dick – I think we ought to look at species composition coming through the lower river, not just tagged fish, but within the context of the coho and the fall Chinook and the other groups that were released in there that provide alternative prey, particularly early in the season. We ought to look at the frequencies of fish that do make it, and not just individuals, but we need to have enough sample to establish some sort of … frequency … find out what their growth rates are in-river, and how that might compare to the delayed frequency groups of transported fish that we might want to compare those to, and how they fit into that other context. We have some … we're really lacking now, is that we really don't understand very much about the temporal changes of lower river contribution on fish.

Kenneth – It seems like we should broaden that out. We heard a lot about the value of getting your hands on fish further and further downstream, … do we measure that? Dick – I believe so, and I think getting your hands on the fish with known migration history is extremely important. I think equally important is the context in which they go through the estuary. We tend to think of fish that come from way upstream coming through in a vacuum, and they mix in with a whole different suite of fish that we really don't know much about anymore. There's some … seining going on every couple of weeks, but I think we have the potential to look at that on a very steady basis, and I think it might be quite revealing. What are the alternatives to the very large bird populations just downstream?

Geoff – I think health is the big one there … Kenneth – Because we're talking about this in terms of following a cohort, some of the things you talked about don't have to do with PIT-tagged fish. ... I'm focusing on getting your hands back on the fish that you have some history on. You're going to need to re-tag those … I have health and length, and I'm not sure what else to add there …

Kenneth – Before it gets too late, I want to try and extract some specific actions. If we could learn these things and know what to do, what actions would we take if you're trying to learn whether, when, or why we want to transport fish that increase their adult returns? What actions would you take if you knew that you were going to affect adult returns, or what actions do you think would affect those returns? David – Can I phrase it a little differently first? How much do you have to improve adult returns before you justify … biologically or under the ESA … you have to do everything. But how much you have to do, or small does *D* have to be before you saw it's not worth barging. That tells us something about what we're trying to measure. … David/Geoff – How much do you have to improve adult returns to justify continuing to barge fish? … ?? - … the effect size is 1.1 to 1 right now … ratios, it's that small … can't hear …

Barbara - … there's a lot of variation … Derek – We generally don't look at an annual rate like that, … look at seasonal SARs … David – So there's the trigger, really, which is when is the TIR high enough that you can start barging? Russ – One of the things I was going to say is that TIR is what we base the decision to transport on. We know that the best decision with that season and that decision on transporting overall as far as our ASA, … range of ocean productivity, more adults back to Goose … As we saw in 2001, we can have great Ds and TIRs, but that's not what we want to do on a regular basis. If that was our goal, to get the highest Ds and TIRs we can, I can do that. But it's not likely the best management decision for adult return rates, so it is very complex. As far as what I would do as a manager, I don't make any decisions, I just try and influence decisions – that's my management role. If I'm trying to figure out from the past data and the conditions we face in a given year, and weighing improving adult return rates and gaining more information to make long-term decisions down the road, how to come up with right … extremely complex.

Kenneth – It seems like we're not really capturing the depth of what's possible. … whether to barge, when to barge, … Russ – And where to barge – McNary, John Day? And who to barge? Kenneth – I'm not sure all of these are actionable, … trying to get something in here that we can think about. Derek – I would put how to barge in there too. Jim – We want to put how we need to be monitoring the ocean and the estuary, to give us information on what, where, why … Kenneth – That's what I was thinking here. If those gaps can be filled, will it help us take … actions? Jim – So what information we're getting … barging predictions … Kenneth – So not only when to barge, but can we do that within season?

Steve – As a product of a *D* workshop and a *D* report, it seems like right now all of our specific action questions are all answered with T:I and not *D*. Kenneth – Is that appropriate? Steve – I don't know. *D* is a ratio of two things that are changing constantly. But to answer these questions, as far as actions, do we want actions that have to do with *D* per se? To answer these questions, it doesn't really matter what *D* is, it's just one of the things in the box that gives us the ultimate answer. Jim – If you have some control over the … of survival, and it's going to be some demands … that you're going to have a lower in-river survival … that again becomes critical to the balance … what *D* will be according to … ocean conditions, and this is what in-river survival is going to be according to other demands on the system. Then we would need separate … Steve – So I would say if the answer is a result of the workshop, if the nature of the answer is, this is how *D* comes into this, this is why you would consider *D* while you're answering this question, then yes, that's appropriate. Kenneth – We could take out arguments at the next level of … can't hear … In some sense, T:I might not be the best measure either. If you can improve river conditions and keep transport conditions the same, you still gain something … whether the numbers go in the wrong direction in terms of transport, you still gain something in terms of the fish. We're barge-focused … this workshop ... Steve – Isn't this an issue … unless you're in the condition where the in-river can never be brought up to as high as the transport, then you should transport everything, right? Kenneth – Some would argue.

Russ – As far as the future of research, Paul Wagner mentioned that he wanted to look at, does *D* change in a year when we transport early fish, but low river flows are high during that early transport. Does river flow below Bonneville affect the performance of early transported fish? When flows are higher, turbidity is up, do they migrate faster and have lower predation, and so *D* is lower for early migrating fish in the high early flows … Yes, Kenneth mentioned … in-river fish without changing transport is a good thing overall, and that's right. But we're focusing here at the *D* workshop, we're trying to figure out what we can do to improve the performance of transported fish. We're not focusing on trying to figure out what to do for overall SARs. It ties in with this piece. We're trying to figure out, looking at *D*, does that give us some ideas on actions we can take to improve the performance of transported fish without hurting the in-river fish. It's can we really improve transport performance under a set condition …

Geoff – As long as everybody's performance … timing of releases with barged releases, to see if you could do this using existing data, and see how well that slug of barged fish stays together. Dave has some data from PIT-tags, and we have some new acoustic tags. Look at that and see whether you could possibly alter the barge release timing at the normal locations … you get them to pass the river at night. Dave M - … Geoff mentioned earlier that they are … to look at the tidal and diel passage patterns at those estuary arrays. It seems to me that that's … we need that information in order to be able to measure the performance of any changes in barge releases. Kenneth – So … detection of active tags … Dave M – I would say globally through the hydrosystem. We want that information for the lower river and estuary. Steve? – Specific to *D*, we want in the lower river and estuary.

?? – With respect to whether to barge fish and when to start barging, is anyone considering the effect of artificial selection of the effect of barging … migration timing of smolts … River-run fish that are migrating late have lower SARs than those that migrate earlier. … Those that are being put in the barges and speeded-up … that's basically artificial selection, maintain any genetic basis for … migration time … Is that a good thing or not? … can't hear … Kenneth - … artificial selection due to the timing of barging on genetic characteristics. Geoff – I think that may come into play pretty heavily on latencies (?) and sub-yearling Chinook that are passing the dams in the Snake, and they may elect to rear over the winter in the reservoirs, and may do very well there if they are allowed to do that. But if they show up and get collected … nobody really knows … Kenneth - … early in the barging season, or late? ?? – I guess it could be different for different life histories, but I was thinking in terms of because of the reservoir … migration now … late … migration was not as successful as early migration. Natural selection would tend to move those out and get earlier migration in the longer haul, which might be good if you're going to keep dams around. But by barging those guys, you allow the genes to do well, and you maintain the diversity in the population … can't hear … which might be bad if you don't want to do barging, but on the other hand it may be good if your ultimate goal is to get rid of dams and maintain diversity. It's a consideration.

Kenneth – I'd like to add some kind of a note on this as to how we might approach that. Is this something that would have to do with the genetics of those fish? … ?? – It would have to do with the hereditability of migration timing. … potential artificial selection … Dick? – Under specific actions, … if we wonder when to start, we also wonder when to stop.

Kenneth – I want to be respectful to your schedules, so if there are any last ones here, let's go ahead and add them. Then we'll wrap things up here. Does anybody else want to put something on here? We can always accept things, and we'd like for you to turn in your handouts if you have thoughts or suggestions for us. You can get in touch with us after the fact if that's of value. Derek – If you don't have those filled out yet, you can take them back to your office. If you want to jot down some changes to how we put this thing together, please fill it out and send it to David or me and we'll get it to Kenneth to be considered for inclusion into this. Please give us feedback. Kenneth – We'd rather have them now than having comments on the next draft of the report, because then everybody else doesn't get to see the comments until later.

Dave M – I do have one last comment. I'd like to offer my compliments to you. This is the best job of cat-herding I've seen in years. I think everybody stayed on task, and you did a great job organizing … Kenneth – Thanks to Jenn, she did a lot of the organization – (applause for Jenn!). Derek – Thank you for your participation, and a special thanks to the presenters as well. We appreciate you taking the time. I know this is a tough time of year to break away. … Watch for the next round of our draft report.

Appendix G

Differential Delayed Mortality Survey

Appendix G

Differential Delayed Mortality Survey

The following survey was distributed electronically and as paper copies before and during the workshop.

Differential Delayed Mortality Workshop Survey

1. Below is a list of potential factors affecting differential delayed mortality. Please identify any other factors not included in the list.

A. Pre-hydrosystem conditions
B. Hydrosystem arrival time and travel time
C. Fish physiology
D. Fish disease
E. Dam operations
F. Barging conditions
G. Lower Columbia River conditions and predators
H. Estuarine conditions and predators
I. Oceanic conditions
J. Straying and fallback
K. Tag burden
L. ________________________
M. ________________________
N. ________________________

2. Please rank the potential factors from Question 1 by their degree of influence on differential delayed mortality by writing each factor's identifying letter in one of the boxes below.

High effect on D:

Moderate effect on D:

Low effect on D:

3. Which three factors are most worthy of additional research?

1. ____

2. ____

3. ____

Survey Results

Question 1

Other factors of *D* to consider:

- Routes of dam passage in conjunction with dam operations
- Hatchery versus wild rearing types

Question 2

The potential factors of *D* were scored as 1 for low, 2 for medium, and 3 for high. By descending order, the potential factors thought to influence *D* were as follows:

- Hydrosystem arrival time and travel time (20 points)
- Estuary conditions and predation (20 points)
- Ocean conditions (19 points)
- Fish physiology (15 points)
- Dam operations (15 points)
- Lower River conditions and predation (14 points)
- Barging conditions (13 points)
- Straying and fallback (12 points)
- Tagging effect (12 points)
- Fish disease (11 points)
- Prehydrosystem conditions (10 points)

Question 3

Each time a factor was chosen, it was scored 1 point. The potential factors of *D* most worthy of research were, in descending order:

- Estuary conditions and predation (6 points)
- Ocean conditions (5 points)
- Hydrosystem arrival time and travel time (3 points)
- Dam operations (2 points)
- Barging conditions (2 points)
- Lower Columbia River conditions and predation (2 points)
- Fish physiology (1 point)

Appendix H

Comparison with the 2004 Comparative Survival Study Workshop

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Comparison with the 2004 Comparative Survival Study Workshop

The 2004 Comparative Survival Study (CSS) Workshop (Marmorek et al. 2004) documented and assessed evidence of factors affecting survival over different life-history stages. The study considered issues related to latent mortality and differential delayed mortality. Latent mortality considers passage route-specific post-hydrosystem survival and is not informative regarding the differential impacts of the hydrosystem and transportation on post-hydrosystem mortality. The differential delayed mortality (*D*) hypotheses considered in the workshop overlapped with the material and conclusions reached in the review reported in this document. Below we note linkages between the two reports. The 2004 CSS Workshop hypotheses 2.2, 2.3, 2.4, and 2.5 are listed below along with the sections in our report where the equivalent topics are discussed.

- **CSS Hypothesis 2**. "Passage through or around the hydrosystem causes indirect mortality to smolts that may not be expressed until the estuary/ocean life stage. Indirect effects may be expressed differently for hatchery and wild fish."
  – Based on seasonal variations in smolt-to-adult return rate (SAR) and *D* we also concluded the passage experience affects post-hydrosystem survival considered in the section on Patterns of *D* (Section 2.2.2) and in many of the D factors addressed throughout our report. The results of the 2004 CSS Workshop from comparing upstream and downstream stocks are not informative for understanding *D*.
- **CSS Hypothesis 2.1**. "The hydrosystem indirectly affects SARs by causing changes in hydrologic conditions in the estuary."
  – This was considered not relevant to *D* because both in run-of-river (ROR) migrants and transport migrants are affected by estuarine conditions.
- **CSS Hypothesis 2.2a**. "The hydrosystem indirectly affects SARs by delaying (in-river) or accelerating (transport) arrival of smolts in the estuary."
  – This was considered in the sections on Hydrosystem Arrival Time and Travel Time ❶, Estuarine Conditions ⑧, and Oceanic Conditions ⑨.
- **CSS Hypothesis 2.2b**. "The hydrosystem indirectly affects SAR by changing and delaying the smolt development processes, through both altered timing of entry and stress."
  – This was considered in the sections on Fish Physiology ❸, Dam Operations ⑤, and Barging Conditions ⑥.
- **CSS Hypothesis 2.3.1**. "Smolt passage routes through or around the hydrosystem cause various types of stress on smolts that increase vulnerability to mortality factors (2.3.1.1 – 2.3.1.4)."
  – This was considered in the sections on Fish Physiology ❸, Dam Operations ⑤, and Barging Conditions ⑥.

- **CSS Hypothesis 2.3.1.1**. "Amount or extent of passage through or around the hydrosystem increases vulnerability to horizontal transmission of pathogens."
  - This was considered in section on Disease ❹. Limited data were available in 2004. Recent data are variable (Arkoosh et al. 2006; Dietrich et al. 2007; Dietrich et al. 2008; Mesa et al. 2008; Eder et al. 2009a, b), thus illustrating the complex interactions between fish conditions and environmental conditions upstream of, throughout, and downstream of the hydropower system..
- **CSS Hypothesis 2.3.1.2**. "Passage through or around the hydrosystem reduces growth rates or condition of smolts."
  - This was considered in the sections on Fish Length ❷, Fish Physiology ❸, and Barging Conditions ⑥. Limited data were available in 2004. Additional data are available now (Wagner and Congleton 2004; Congleton et al. 2005; Zabel et al. 2005; Muir et al. 2006; Schreck et al. 2006; Mesa et al. 2008), but refinement of exactly how and where growth and condition affect SARs of barged and ROR migrants has not been identified.
- **CSS Hypothesis 2.3.1.3**. "Passage through or around the hydrosystem increases vulnerability to predation."
  - This was considered in the sections on Lower Columbia River Conditions and Predators ⑦ and Estuarine Conditions and Predators ⑧. Several studies available at the time of the 2004 CSS Workshop were conducted and reviewed; many of them were laboratory studies. More recently, studies specific to the lower river estuary environment have been conducted (Mesa et al. 2008; Roby et al. 2008; ICF J&S 2009). Evidence of significant differential rates of predation between ROR and barged fish still have not been identified in the field studies, but predator-prey models have identified substantial reductions in predation with the alternative barging strategy.
- **CSS Hypothesis 2.3.1.4**. "Passage through or around the hydrosystem results in reversal of, or incomplete smoltification."
  - This was considered in the section on Fish Physiology ❸. Currently, gill Na^+/K^+-ATPase activity is the most often measured index of osmoregulation or smoltification. However, this index is not always consistent with saltwater preference tests (Schreck et al. 2005). A lack of a formal definition of smoltification makes this hypothesis difficult to test accurately.
- **CSS Hypothesis 2.4**. "The hydrosystem indirectly affects SARs by shifting the timing of mortality of transported fish to post-Bonneville Dam, based on the hypothesis that fish experience a fixed rate of mortality."
  - A fixed daily rate of mortality was not considered in our report. We provide an alternative culling hypothesis in Section 3.2, Culling Model with Dynamic Processes in Heterogeneity Among Individuals.
- **CSS Hypothesis 2.5**. "The hydrosystem indirectly affects SARs through size selectivity and annual variation in bypass survival."
  - This was considered in the section on Fish Length ❷. Weak support for this hypothesis was determined at the 2004 CSS Workshop. Since then, the Zabel et al. (2005) article was published and shows support for this hypothesis , while Buchanan et al. (2011) provides mixed support.