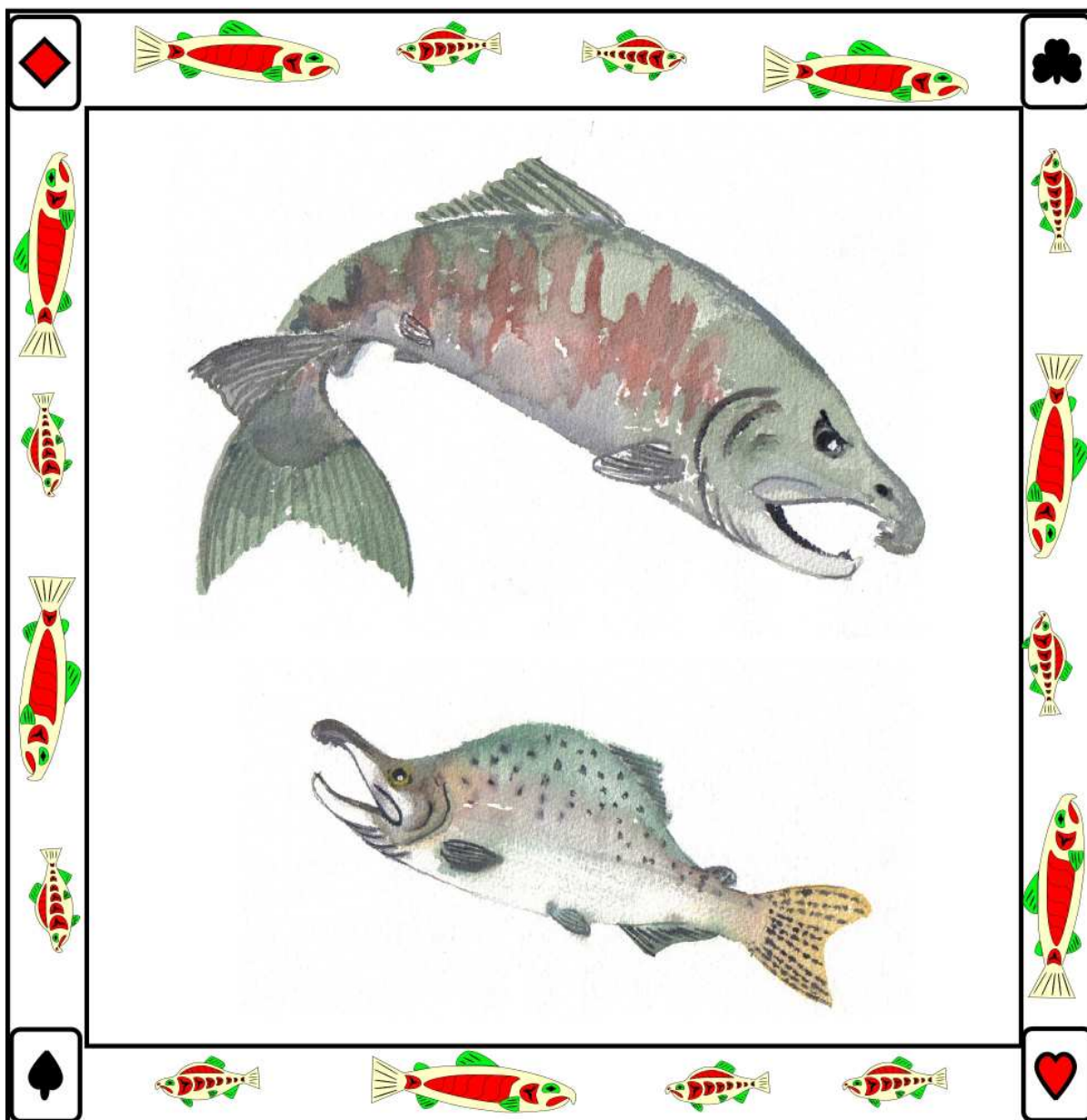


Proceedings of the 23rd Northeast Pacific Pink and Chum Salmon Workshop



February 19-21, 2008

Bellingham, Washington

Rapporteurs:

*Kathleen Neely Orlay Johnson Jeffrey Hard
Laurie Weitkamp Kyle Adicks*

**Proceedings of the 23rd Northeast Pacific Pink and Chum Salmon
Workshop**

**February 19-21, 2008
Bellingham, Washington**

**Steering Committee
Kathleen Neely
Orlay Johnson
Jeffrey Hard
National Marine Fisheries Service
2725 Montlake Blvd. E.
Seattle WA 98112**

**Laurie Weitkamp
National Marine Fisheries Service
Newport Research Station - Bldg. 955
2032 S.E. OSU Drive
Newport, OR 97365-5275**

**Kyle Adicks
Washington Department of Fish and Wildlife
600 Capitol Way N. • Olympia, WA • 98501-1091**

Proceedings of the 23rd Northeast Pacific Pink and Chum Salmon Workshop

Keynote Speaker

Presented by Richard J. Beamish

Is changing capacity of the Strait of Georgia to produce more pink and chum salmon and less coho and chinook salmon an indication of a similar trend throughout the subarctic Pacific?

Dr. Richard Beamish, O.B.C., C.M., Ph.D., F.R.S*, is the Senior Scientist at the Pacific Biological Station in Nanaimo, B.C. Dick Beamish finished his Ph.D. at the University of Toronto in 1970 and went directly to Woods Hole Oceanographic Institute for a Post Doctoral Fellowship with Dick Backus. He then worked at the Freshwater Institute in Winnipeg for a few years, ending up at the Pacific Biological Station in Nanaimo, British Columbia in the mid-1970s. He was the Head of the Groundfish Section from 1977-1979 and Director from 1980-1993.

He is an Editor for Transactions of the American Fisheries Society, a member of the Science Panel for the North Pacific Research Board, Chairman of the Scientific Steering Committee for the North Pacific Anadromous Fish Commission, an active member of PICES, a member of the Committee for Scientific Cooperation for the Pacific Salmon Commission, the Department's representative on the Pacific Fisheries Resource Conservation Council, one of two scientists on the Deputy Ministers' Science Management Board, a former Canadian Commissioner for the International Pacific Halibut Commission and a Professor at Vancouver Island University.

Dr. Beamish has been honoured with a number of awards including the Order of Canada and the Order of British Columbia. He was made a Fellow of the Royal Society of Canada and recently became the first foreign scientist to be made an honorary member of the fisheries laboratory TINRO in Vladivostok, Russia. He has published over 350 articles with about half in peer reviewed journals.

His research interests have included the discovery of acid rain, age determination and the discovery of the longevity of some of our Pacific fish species, the identification of new lamprey species and the evolutionary relationship between these species, and the effects of climate on fish populations. He was one of the first scientists to write about climate regimes and regime shifts.

Banquet Speaker

Presented by Robert R. Fuerstenberg

A Science of the Long View: Thoughts on Fishery Science for an Uncertain World

Sr. Ecologist, King County Department of Natural Resources and Parks
Seattle, Washington

Robert Fuerstenberg is a Senior Ecologist with the King County Department of Natural Resources and Parks in Seattle, Washington, a position he has held for some 23 years. During that time, he has been involved with programs and projects ranging from investigating the effects of urban development on salmonid ecosystems to the design of stream and wetland restoration projects. For the last decade, his attention has been focused on salmon recovery in King County and throughout the Puget Sound region. He was a member of the Puget Sound Technical Recovery Team, a group of 8 scientists responsible for developing the biological and ecological criteria for chinook and chum recovery in the Puget

Sound. Working with the Shared Strategy for Puget Sound, the PSTRT helped craft the Puget Sound Chinook Recovery Plan, a ground-breaking collaboration of citizens, agencies and scientists. His most recent work involves crafting a biodiversity strategy for King County and investigating the effects of landscape change and climate change on regional biodiversity in collaboration with scientists from the US Geologic Survey and The National Marine Fisheries Service.

Foreword

The 23rd Pink and Chum salmon workshop continued the tradition of illuminating current research being conducted with not only these two species but on the ecosystems that support these and many other species. This workshop examined ocean ecology, population enhancement by hatcheries, projects by Global Ocean Ecosystem Dynamics (GLOBEC) and reports from international biologists outside the United States and British Columbia. This workshop also continued the liaison between the Northwest Fisheries Science Center (NWFSC) in Seattle, Washington and the Northwest Indian College (NWIC). Representatives from the NWIC presented the workshop with a dynamic opening ceremony including a traditional Native prayer and dance while showcasing their scientific endeavors as part of the GLOBEC and International session and with a poster.

As in previous proceedings, all abstracts and materials in this documented are not considered peer reviewed and have only undergone minimal format editing to present a cohesive document. Any reference to work published in these proceedings should be approved by the author of the abstract.

Session Leaders

Session I. Ocean Ecology. Alex Wertheimer, Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska.

Session II. Enhancement. Kyle Adicks, Washington Department of Fish and Wildlife, Olympia, Washington.

Session III. Southern Populations. Orlay Johnson, Northwest Fisheries Science Center, Seattle, Washington.

Session IV. GLOBEC and International. Katherine Myers, University of Washington, School of Aquatic and Fishery Sciences.

Session IV. A. Northwest Indian College, Bellingham, Washington.

Session V. Northern Populations. Laurie Weitkamp, Northwest Fisheries Science Center, Newport, Oregon.

Session VI. Contributed papers. Jamal Moss, Alaska Fisheries Science Center, Auke Bay Laboratory, Juneau, Alaska.

Acknowledgments

The steering committee thanks all of the session leaders for their diligence in setting up talks. We also thank Richard Beamish and Robert R. Fuerstenberg for their keynote and banquet talks, respectively. These speakers were not only highly informative, but captivating in their presentation. We would also like to thank Linda Barsalou, the Catering and Sales Coordinator, and the Silver Reef Conference Center in Bellingham Washington for their commitment to making our workshop a success.

Table of Contents

Oral Presentations

	Page
Is changing capacity of the Strait of Georgia to produce more pink and chum salmon and less coho and chinook salmon an indication of a similar trend throughout the subarctic Pacific?	1
Richard J. Beamish, R.M. Sweeting, C.M. Neville and K. Lange	
Chum salmon migration patterns in the lower Columbia River	2
G. Curtis Roegner	
Ocean ecology of juvenile pink and chum salmon in the Northern California Current	2
Laurie Weitkamp and Paul Bentley	
Distribution, migration, and growth of juvenile pink and chum salmon off British Columbia and southeast Alaska	8
Marc Trudel	
Field and laboratory observations of salmon lice (<i>Lepeophtheirus salmonis</i>) infections on juvenile pink salmon (<i>Oncorhynchus gorbuscha</i>) indicate a stable host - parasite system in coastal British Columbia	9
Simon R. M. Jones	
Trophic Interactions among Wild and Hatchery Juvenile Chum Salmon in Taku Inlet, Southeastern Alaska	9
M. Sturdevant, E. Fergusson, C. Reese, A. Wertheimer, N. Hillgruber, W. Smoker, and J. Orsi	
Effects of Starvation on Energy Density of Juvenile Chum Salmon Captured in the Marine Waters of Southeastern Alaska	17
Emily A. Fergusson, Joseph A. Orsi, and Molly V. Sturdevant	
Interactions of Hatchery Chum Salmon with Juvenile Chum and Pink Salmon in the Marine Waters of Southeastern Alaska	20
Joseph. A. Orsi, Alex C. Wertheimer, Emily A. Fergusson, and Molly. V. Sturdevant	
Kuskokwim Bay juvenile chum salmon: An overview	25
Nicola Hillgruber, Sean E. Burrill, Christian E. Zimmerman	
Melting of arctic sea-ice and utilization of the Chukchi Sea by juvenile pink and chum salmon during 2007.	26
James M. Murphy, Jamal H. Moss, Lisa B. Eisner, Ellen C. Martinson, Edward V. Farley	

Hatchery Pink and Chum in Alaska: Supplementing or Supplanting Wild Stock Production?	27
Benjamin W. Van Alen	
Implementation and Operation of an ESA-listed Hood Canal Summer Chum Recovery Project: The Nuts and Bolts	27
Ed Jouper	
Fluctuations in Abundance of North American Pink Salmon (<i>Oncorhynchus gorbuscha</i>) Populations.	28
Bill Waknitz	
ESA-listed Hood Canal Summer Chum Salmon: A brief update on supplementation programs, natural-origin vs. supplementation-origin returns, and recovery	28
Thom H. Johnson, Kyle Adicks, Chris Weller, and Tim J. Tynan	
Hatchery Chum Salmon Straying into Southeast Alaska Streams	41
Andrew W. Piston	
Population changes and genetics of chum salmon in the southern portion of their range (California, Oregon, and Columbia River) and possible impacts of climate and other changes.	45
Orlay W. Johnson, Anna Elz, and Jeffrey J. Hard	
Estimates of genetic introgression into North Creek chum salmon from historic Hood Canal-origin chum salmon supplementation using microsatellites and single nucleotide polymorphisms	45
Denise K. Hawkins, Scott M. Blankenship, Sewall F. Young, Jennifer Von Bargen, Cherril Bowman, and Kenneth I. Warheit	
Lower Columbia River chum salmon genetic population structure estimates using microsatellites and single nucleotide polymorphisms	46
Sewall F. Young, Maureen P. Small, Jennifer Von Bargen, Denise K. Hawkins, and Kenneth I. Warheit	
Morphological development and molecular expression of the olfactory organ in chum salmon (<i>Oncorhynchus keta</i>)	47
Hideaki Kudo, Masakazu Shinto and Masahide Kaeriyama	
Modeling the feeding and growth potential of juvenile pink salmon in the Gulf of Alaska	49
Michael M. Mazur	
Winter Distribution of chum salmon in the central Gulf of Alaska	50
Shigehiko Urawa*, Shunpei Sato, Toshiki Kaga, Masaya Takahashi, Bev Agler, Ron Josephson, Terry Beacham, and Masa-aki Fukuwaka	

Marine habitat use and its effect on Growth and Condition of Juvenile Pink Salmon in the Northern Gulf of Alaska	50
Lewis Haldorson, Milo Adkison, Jack Piccolo, Jennifer Boldt, Steve Moffitt, Jamal Moss	
Interannual and Spatial Feeding Patterns of Hatchery and Wild Juvenile Pink Salmon in the Gulf of Alaska in Years of Low and High Survival.	51
Janet L. Armstrong, Katherine W. Myers, David A. Beauchamp, Nancy D. Davis, Robert V. Walker	
Scale Measurements Indicate Size-Selective Mortality in Prince William Sound Pink Salmon	52
R.V. Walker and J.A. Armstrong	
Interannual Patterns in Stage-Specific Feeding, Growth, and Survival of Pink Salmon in the Gulf of Alaska	53
Dave Beauchamp, Kate Myers, Jan Armstrong, Mike Mazur, Trey Walker, Nancy Davis, Jamal Moss, Ed Cokelet , and Peggy Sullivan	
A Science of the Long View Thoughts on Fishery Science for an Uncertain World	54
Robert R. Fuerstenberg	
Spatial distribution and dynamics of pink (<i>Oncorhynchus gorbuscha</i>), chum salmon (<i>O. keta</i>), and Chinook salmon (<i>O. tshawytscha</i>) in streams dominated by sockeye salmon (<i>O. nerka</i>): insights into the processes of straying and colonization	60
G.R. Pess, T. Quinn, D. Schindler, L. Rogers, and P. Westley	
Straying of Hatchery Chum Salmon (<i>Oncorhynchus keta</i>) in Select Prince William Sound Streams, 2004-2007	61
Rich Brenner, Steve Moffitt, Rick Merizon, Dayna Norris	
Straying of hatchery pink salmon in Prince William Sound – a geospatial analysis.	67
Steve Moffitt	
Impacts of Food Supply and Predators on Juvenile Pink Salmon Survival in Prince William Sound	68
Richard E. Thorne	
Review of Recent Pink and Chum Salmon Investigations in the Central Bering Sea Conducted Onboard the R/V Wakatake maru	68
Nancy D. Davis, Masa-aki Fukuwaka, and Robert V. Walker	
Pink Salmon Stock Status in Southeast Alaska	73
Steven C. Heinl	

The influence of population dynamics and landscape condition on Pink salmon (<i>Oncorhynchus gorbuscha</i>) re-colonization in the Fraser River, British Columbia, Canada.	79
G.R. Pess , T. Quinn, R. Hilborn, and K. Kloehn	

Nondestructive Field Estimation of Fat Content of Yukon River Salmon	80
F. Joseph Margraf, Kyle J. Hartman, M. Keith Cox	

Forecasting Pink Salmon in Southeast Alaska Revisited: Efficacy of Predicting Harvest from Indices of Juvenile Salmon Abundance	81
Alex C. Wertheimer, J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson	

Pacific salmon population extinctions with an emphasis on lost diversity among pink and chum salmon	81
Rick Gustafson, Robin Waples, Jim Myers, Laurie Weitkamp, Greg Bryant, Orlay Johnson, and Jeff Hard	

POSTERS

	Page
Juvenile Pink and Chum Salmon Food Habits and Associated Prey Fields in the Bering and Chukchi Seas	82
Jamal H. Moss, James M. Murphy, Edward V. Farley Jr., Lisa B. Eisner, Kristin D. Cieciel, and Anatoly Volkov	
Tracking of chum salmon fingerling in stream and coastal areas off the Korean Peninsula	82
S. Kang, S. Kim, and J.K. Kim	
Diet of fish-eating “southern resident” killer whales: the use of fish remains, fecal samples, and genetic techniques to determine prey species and stocks	83
Jennifer Hempelmann, M. Bradley Hanson, Robin W. Baird, Candice Emmons, Gregory S. Schorr , John Sneva, Don Van Doornik, Katherine Ayres, Samuel K.	
Multi- user analytical laboratory at Northwest Indian College	84
Charlotte Clausing	
Seasonal patterns in diel feeding, gastric evacuation, and energy density of juvenile chum salmon in Icy Strait, Southeast Alaska, 2001	85
M.V. Sturdevant, E.A. Fergusson, J.A. Orsi, and A.C. Wertheimer	

KEYNOTE

Is changing capacity of the Strait of Georgia to produce more pink and chum salmon and less coho and chinook salmon an indication of a similar trend throughout the subarctic Pacific?

Richard J. Beamish, R.M. Sweeting, C.M. Neville and K. Lange

Fisheries and Oceans Canada, Pacific Biological Station, 3190 Hammond Bay Rd., Nanaimo, B.C. V9T 6N7, Canada.

Tel: 250-756-7029, email: beamishr@pac.dfo-mpo.gc.ca.

Pink salmon returns to the Fraser River probably are at historic high levels. It is difficult to be confident that the accuracy of recent escapement estimates is similar to past estimates. However, we do know that the recent escapements are at least a magnitude larger than anything recorded since the 1950s when reliable records started. The recent large escapements result in large numbers of juvenile pink salmon rearing in the Strait of Georgia in even-numbered years. Our research shows that there are ecosystem impacts of these large abundances of juvenile pink salmon. For example, the early marine survival of coho salmon is lower in even-numbered years, but the impact is greater for hatchery coho salmon than wild coho salmon. We speculate that pink salmon are surviving better than in the past because the production of prey in their early marine period is more stable and perhaps larger. We also know that the total production of pink salmon by all countries is at historic high levels. It is possible that one of the impacts of a changing climate and a warmer ocean is that the capacity of the subarctic Pacific to produce pink salmon will continue to increase. If this is true, the greatly expanding Russian hatchery program will result in a rapid increase in the total abundance of pink salmon. There are currently 33 pink salmon hatcheries on the Sakhalin and Kuril Islands with 10 more planned to be in operation within five years. By 2010 it is expected that hatcheries in this region will release about 1.8 billion pink and chum fry per year. We propose that it is time to have a coordinated, International research plan to determine how climate is affecting the ocean carrying capacity for pink and chum salmon and what the consequences are for other species of Pacific salmon.

OCEAN ECOLOGY
Chair: Alex Wertheimer

Chum salmon migration patterns in the lower Columbia River

G. Curtis Roegner

Point Adams Field Station, Northwest Fisheries Science Center, NOAA Fisheries, 520 Heceta Place, Hammond, OR 97121. Curtis.Roegner@noaa.gov

Chum salmon spawning habitat in the Columbia River has been dramatically reduced from historical levels. Viable chum populations are found only in the Chinook and Grays rivers in Washington and at the Ives Island Complex below Bonneville Dam, although scattered adult returns have been recorded elsewhere. Most chum spawning population in Oregon have been expatriated. We have been monitoring juvenile chum abundance and size at selected sites in the lower Columbia River and estuary from 2002-2007. We have also been studying chum habitat use in restoration sites within the Grays River. In the mainstem river, chum abundance is relatively low in tidal freshwater sites and increases in estuarine water; CPUE from beach seines made on opposite sides of the river are similar despite the large migrant source emanating from Chinook and Grays rivers (Washington side). Chum have a short temporal signal (Feb-May) compared to Chinook salmon (found year-round) and are generally < 70 mm when exiting the river. Many chum exit at < 50 mm. In the Grays River, we monitored chum, Chinook, and coho distribution in restored wetland and reference sites during 2005-2007. The Grays River hatchery released 130-146 K fish in 2006 and 2007. Chum were abundant in restored wetlands the run year following tidal reconnection. Abundance was sharply punctuated (at 2 wk sampling interval) with a synchronous distribution in wetland and reference sites, and outmigration was mostly complete by 1 May. Based on reported sizes at hatchery release, most chum were of natural origin and measured just 30-40 mm FL. Diet analysis of a limited number of individuals indicated food included insect prey derived from the marsh. Conversely, chum were preyed upon by yearling coho in restored wetlands.

Ocean ecology of juvenile pink and chum salmon in the Northern California Current

Laurie Weitkamp¹ and Paul Bentley²

¹Newport Research Station, Northwest Fisheries Science Center, National Marine Fisheries Service, 2032 SE OSU Drive, Newport, OR 97365. laurie.weitkamp@noaa.gov

²Point Adams Field Station, Northwest Fisheries Science Center, National Marine Fisheries Service, 520 Heceta Place, Hammond, OR 97121. paul.bentley@noaa.gov

Pacific salmon research programs currently occur in oceanic waters from San Francisco Bay to the Bering Sea (Grimes et al. 2007). The objective of these programs is to understand the ecology of juvenile Pacific salmon during their first summer in the ocean and therefore the factors affecting their survival at a time when most marine mortality is thought to occur. These programs employ surface rope trawls to collect juvenile salmon, with concurrent measures of physical (e.g., temperature and salinity profiles, nutrients) and biological (e.g., zooplankton samples, chlorophyll *a* concentrations) characteristics at each sampling station (Fisher et al. 2007). Two of these studies are conducted in the Northern

California Current (NCC), off the coasts of Washington and Oregon, by the Northwest Fisheries Science Center: the Columbia Plume study and the Predator study (Emmett et al. 2005, Fisher et al. 2007). The Columbia Plume study samples a series of transects from Cape Flattery to Newport, Oregon (Fig. 1), during daylight in late May, June, and September. The Predator study samples just two transects (Columbia and Willapa Bay; Fig. 1) at night (when most piscivorous predators are near the surface) at biweekly intervals from mid April until August (Emmett et al. 2005).

Although catches of juvenile salmon by these studies are dominated by Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) originating from the Columbia River (Teel et al. 2003, Orsi et al. 2007), they also catch juvenile chum and pink salmon. However, both chum and pink salmon are minor members of the juvenile salmon community caught by the Plume study, representing only 12% ($n = 1875$) and 2% ($n = 267$), respectively, of all juvenile salmon caught off the Washington and Oregon coasts during summers of 1998-2007 ($n = 15,548$; Table 1). Few subadult or adult pink ($n = 18$) or chum salmon ($n = 11$) were caught in the Plume study during the 10 year period.

In the Plume study, the density of juvenile chum salmon (mean = 15.5 fish/km²) was nearly an order of magnitude higher than that of pink salmon (1.9 fish/km²). However, their distributions in September were quite similar: both species were primarily caught in the extreme northern end of the sampling area, with few fish caught south of the Queets River transect (Fig. 1). During this period, mean density of juvenile pink salmon caught in the plume study (5.2 fish/km²) was nearly twice that of chum salmon (2.8 fish/km²; Fig. 2). By contrast, in early summer (late May and June), pink salmon are effectively absent from the Plume study area (mean density = 0.03 fish/km²) while juvenile chum salmon are widely dispersed throughout the study area (mean density = 24.5 fish/km²; Fig. 1). Catches of juvenile chum salmon were also quite high in the Predator study through the middle of July then decreased by late summer (Fig 2). No pink salmon were caught in the Predator study.

In addition to these seasonal and distributional differences in abundance between juvenile pink and chum salmon, there are also differences at finer scales. For example, chum salmon caught in the Plume study were typically in slightly deeper water (124 vs. 109 m, respectively) and further from shore (26.6 vs. 15.8 km, respectively) than pink salmon (Table 1). Chum salmon were also caught in waters that are slightly warmer (13.2°C) and less salty (31.1 ppt) than pink salmon (11.4°C and 32.3 ppt, respectively; Table 1).

Both studies also indicated rapid growth of juvenile chum salmon throughout the summer. Juvenile chum salmon caught by the Predator and Plume studies were similar sized by date, with fish averaging 92 and 94 mm FL in late May, respectively, and 127 and 125 mm in late June, respectively (Fig. 3). By September, the mean size of juvenile chum salmon caught in the Plume study (172 mm FL) was somewhat larger than that of pink salmon (150 mm FL; Fig. 3). Growth rates estimated from changes in the mean size of fish during the summer suggest growth rates for juvenile chum salmon of approximately 1.0 mm/day in the early summer (May- mid July) and 0.7 mm/d for the entire summer (May - September).

The marked distributional differences observed between juvenile pink and chum salmon in early summer (i.e., pink salmon effectively absent and chum salmon found throughout the study area) likely reflect geographic differences in source populations and migratory behavior for the two species. Chum salmon populations exist in most basins along the Washington and northern Oregon Coasts as far south as the Yaquina River (just south of the Newport transect; ODFW 2005). Juvenile chum salmon appear to occupy coastal marine

habitats early in the summer, but have largely dispersed by late summer. By contrast, no pink salmon populations exist on the Washington and Oregon coasts, although extremely large populations occur in protected waters of Puget Sound and the Strait of Georgia. Juvenile pink salmon caught in our study area likely originated from these large “inside” populations and enter our study area after exiting the Strait of Juan de Fuca. Although salmon research in the NCC is focused on juvenile Chinook and coho salmon, these programs can be used to increase our understanding of the ocean ecology of juvenile chum salmon at the southern end of their range.

References

- Emmett, R. L., G. K. Krutzikowsky, and P. Bentley. 2005. 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. *Prog. Oceanogr.* 68:1-26.
- Fisher, J., M. Trudel, A. Ammann, J. A. Orsi, J. Piccolo, C. Bucher, E. Casillas, J. A. Harding, B. MacFarlane, R. D. Brodeur, J. F. Morris, and D. W. Welch. 2007. Comparisons of the coastal distributions and abundances of juvenile Pacific salmon from Central California to the Northern Gulf of Alaska. *Am. Fish. Soc. Symp.* 57:31-80.
- Grimes, C. B., R. Brodeur, S. M. McKinnell, and L. Haldorson, 2007. An introduction to the ecology of juvenile salmon in the Northeast Pacific ocean: regional comparisons. *Am. Fish. Soc. Symp.* 57:1-6.
- Oregon Department of Fish and Wildlife (ODFW). 2005. 2005 Oregon native fish status report. ODFW, Salem, OR. Available online at www.dfw.state.or.us.
- Teel, D. J., D. M. Van Doornik, D. Kuligowski, and W. S. Grant. 2003. Genetic analysis of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington reveals few Columbia River wild fish. *Fish Bull., U.S.* 101:640-652.

Table 1. Number, density, and mean location (depth and distance offshore) and physical parameters (surface temperature and salinity) of catches of juvenile pink and chum salmon caught off the Washington and Oregon coasts by the Plume study, during summers of 1998-2007.

Characteristic	Chum salmon	Pink salmon
No. caught (1998-2007)	1875	267
Mean no./km ²	15.5	1.9
Mean depth (m)	124.3	109.4
Mean distance (km)	26.6	15.8
Surface temperature (°C)	13.2	11.4
Surface salinity (ppt)	31.1	32.3

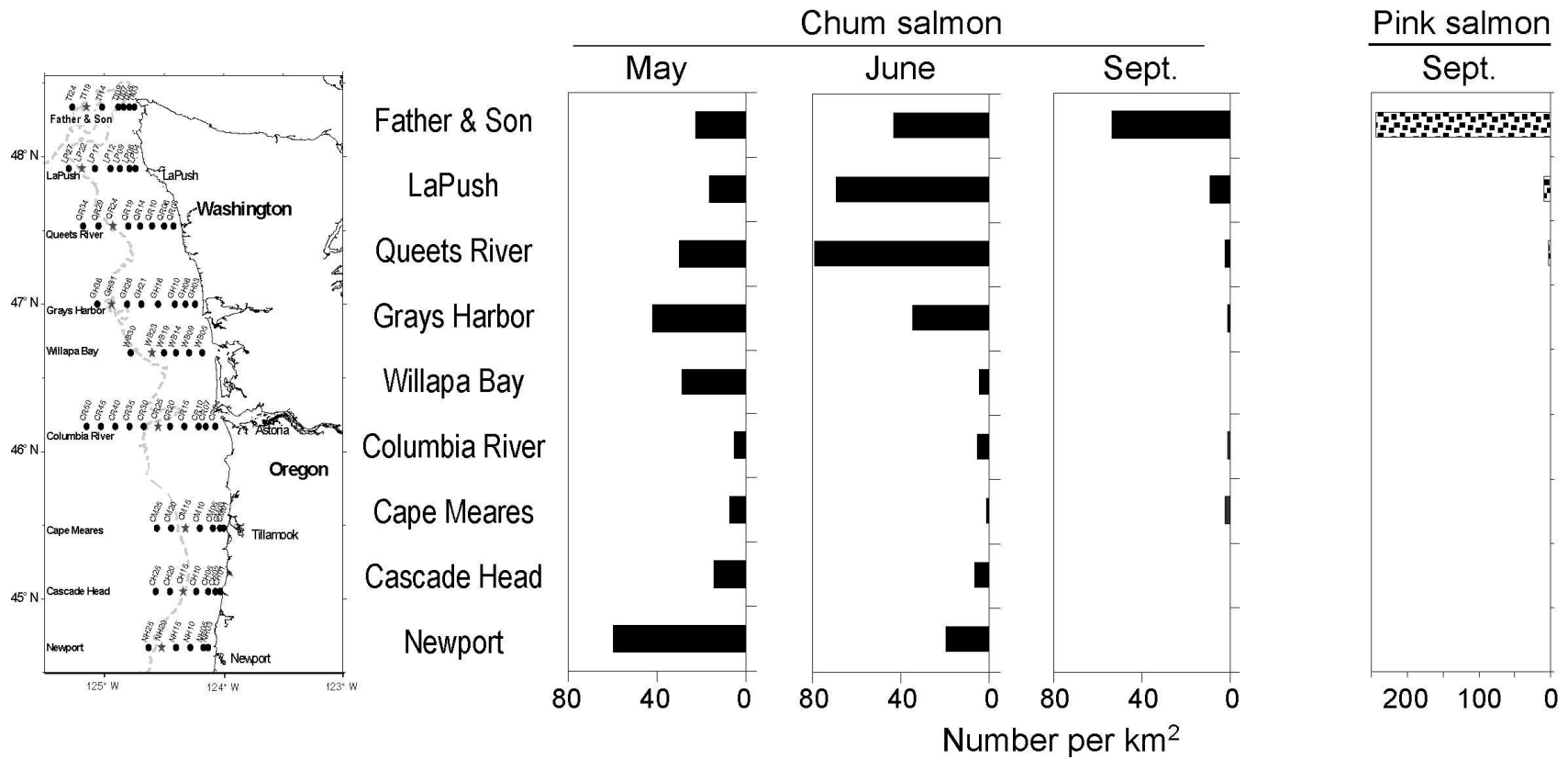


Figure 1. Mean densities (no./km²) of juvenile pink and chum salmon by transect in the Plume study for years 1998-2007. Illustrated are densities of juvenile chum salmon in late May, June and September, and densities of pink salmon in September (pink densities in May and June are extremely low [< 0.1 fish/km²] and are not shown).

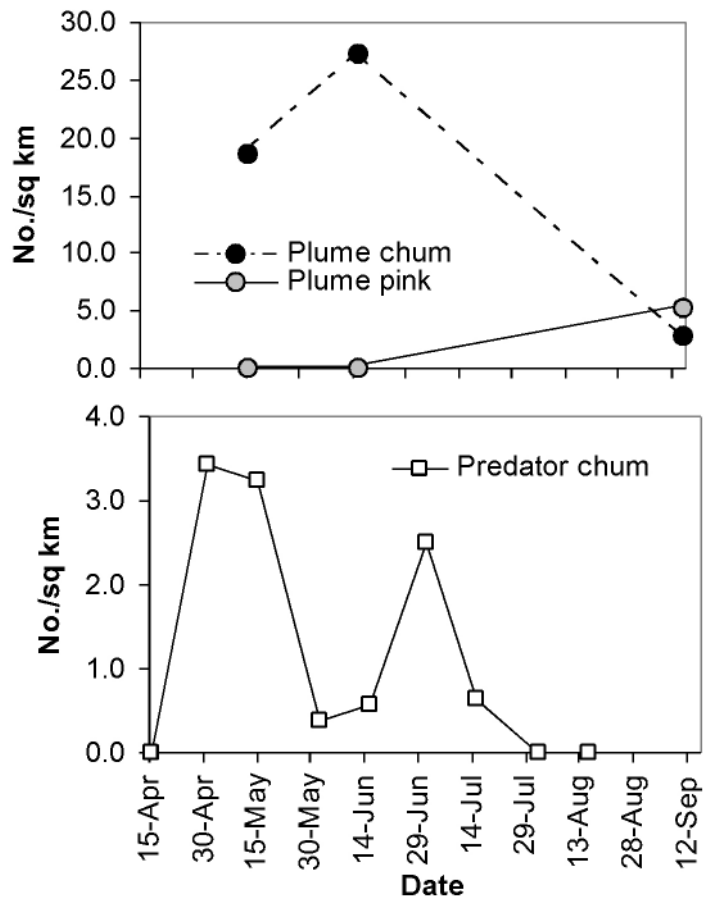


Figure 2. Mean densities (no./km²) of juvenile pink and chum salmon by the Plume (top) and Predator (bottom) studies by sampling date, averaged across years 1998-2007.

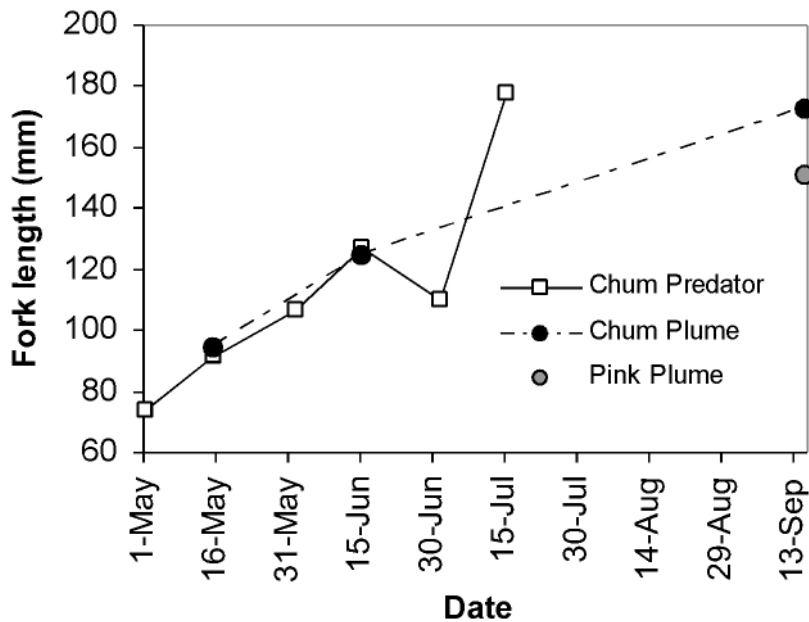


Figure 3. Mean size of juvenile pink and chum salmon by sampling date in the Predator and Plume studies, averaged over years 1998-2007.

Distribution, migration, and growth of juvenile pink and chum salmon off British Columbia and southeast Alaska

Marc Trudel

Fisheries and Oceans Canada, Nanaimo, Canada, trudelm@pac.dfo-mpo.gc.ca

The dynamics of marine ecosystems are strongly influenced by climate variability on both regional and basin-wide scales. On decadal scales, abrupt climate change can reorganize the structure of marine food webs and lead to drastic declines in fisheries resources. However, the impacts of climate change are difficult to assess on highly migratory species due to the diversity of environmental conditions encountered throughout their migration. Hence, an understanding of migration behaviour is required to determine how climate and ocean conditions regulate the production of highly migratory species. Here we investigate the coastal distribution, migration, and growth of juvenile pink and chum salmon along the west coast of British Columbia and southeast Alaska. We show that a large number of juvenile pink and chum salmon remain in coastal waters of British Columbia and southeast Alaska late in the fall and through the winter. We also show that juvenile pink and chum salmon are generally larger further north suggesting either that ocean conditions are more favourable to growth in southeast Alaska than in British Columbia, or that larger individuals initiate their northward migration earlier than smaller ones. Defining the marine regions subject to poor ocean conditions and the groups of stocks that move to these regions will therefore be important to establish management and conservation strategies for Pacific salmon stocks.

Field and laboratory observations of salmon lice (*Lepeophtheirus salmonis*) infections on juvenile pink salmon (*Oncorhynchus gorbuscha*) indicate a stable host - parasite system in coastal British Columbia

Simon R. M. Jones

Pacific Biological Station, Fisheries and Oceans Canada, 3190 Hammond Bay Road, Nanaimo, British Columbia, V9T 6N7, Canada

The significantly reduced return of pink salmon to streams in the Broughton Archipelago (BA) in 2002, combined with the observation of sea lice on juvenile salmon in 2001 led to the suggestion that sea lice were the causal mechanism. To explore this possibility, intensive research efforts focusing on interactions between salmon farms, sea lice (*L. salmonis* and *Caligus clemensi*) and wild juvenile pink and chum salmon are presently underway. Since 2003, DFO has conducted annual surveys of sea lice on post-emergent pink salmon fry in the BA. These efforts have identified significant interannual, spatial and temporal variations in lice abundance. Surface seawater salinity and temperature appear to be important drivers of some of this variation. The marine stickleback (*Gasterosteus aculeatus*) and juvenile chum salmon (*O. keta*) were also shown to be abundant hosts of the salmon louse in the BA. A controlled laboratory infection model using healthy naïve salmon has been used to understand the effects of lice infections. Juvenile pink salmon showed few if any clinical signs of infection and no mortality. This innate resistance to the salmon louse was shown to be developed in fish as small as 0.7g and to function despite feed deprivation. The resistance appears to be based on the ability of pink salmon to mount a rapid inflammatory response in the skin. The presentation will summarize these studies and argue that *L. salmonis* and juvenile pink salmon in the BA represent a well adapted and relatively stable host – parasite system.

Trophic Interactions among Wild and Hatchery Juvenile Chum Salmon in Taku Inlet, Southeastern Alaska

M. Sturdevant¹, E. Fergusson¹, C. Reese², A. Wertheimer¹, N. Hillgruber², W. Smoker², and J. Orsi¹

¹Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA Fisheries

Ted Stevens Marine Research Institute

17109 Pt. Lena Loop Rd.

Juneau, Alaska 99801 USA

Phone: (907) 789-6041 Email: molly.sturdevant@noaa.gov

²Juneau Center, School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 11120 Glacier Highway, Juneau, Alaska 99801 USA

This study was conducted to examine trophic interactions as a potential cause for the decline in harvests of wild, fall run, chum salmon (*Oncorhynchus keta*) in Taku Inlet, southeastern Alaska. Large scale hatchery production of chum and pink (*O. gorbuscha*) salmon began near Taku Inlet in the late 1970's, peaked at about 100 million releases in the early 1990's, and is now steady at about 50 million chum only. As hatchery production increased, declines in the wild harvest were observed. This stimulated interest in the potential for negative stock interactions during early marine residency, when

mortality of Pacific salmon is highest and may be related to competition for food. Thus, we examined the diet and energetic condition of wild and hatchery chum salmon juveniles throughout the spring and summer period of out-migration. This cooperative investigation by NOAA Auke Bay Laboratories, the University of Alaska, the Alaska Department of Fish and Game, and Douglas Island Pink and Chum Hatchery (DIPAC) was supported by the Southeast Sustainable Salmon Fund (Pacific Salmon Commission).

In 2004 and 2005, juvenile chum salmon were caught weekly in nearshore beach seines and townets at stations in Inner, Middle, and Outer Taku Inlet from late April to June, and were caught monthly in epipelagic Nordic trawl hauls in Icy Strait in June and July (Figure 1). Samples representing initial condition of hatchery fish were also collected from netpens throughout the release period (early May to early June). Fish were frozen for energy condition analyses or preserved for stomach analyses. In the laboratory, all fish were measured (fork length, FL, mm) and weighed (wet weight, WW, g) and otoliths were extracted to examine for hatchery thermal marks. Subsamples representing wild and hatchery stocks were then processed to compare their trophic status and condition from time of release throughout residency in Taku Inlet and migration westward through Icy Strait en route to the Gulf of Alaska.

Measures of condition on frozen fish included dry weight (DW, g), moisture content (%), whole body energy content (WBEC, cal/g WW), stomach content percent body weight (%BW), and index of stomach volume (%fullness), in addition to FL and weight. Univariate graphics were used to examine trends in condition measures by stock and location over time. Multivariate analyses (Primer software) were used to examine patterns and test for differences in mean condition, using all seven measures. These measures were either $\log(x+1)$ transformed or square root transformed, then a Bray-Curtis similarity matrix was computed on the data, followed by non-metric dimensional scaling (nMDS) and Analysis of Similarities (ANOSIM).

For diet analyses, prey were counted and identified to species, then grouped into 18 taxonomic categories; these categories were then assigned to three broad prey communities including epibenthic prey (e.g., harpacticoid copepods, gammarid amphipods, and cumaceans); drift prey (e.g., adult and larval chironomid insects); and pelagic prey (e.g., calanoid copepods, barnacle, crab, and euphausiid larvae, hyperiid amphipods, pteropods, and larvaceans). We calculated the mean percent weight (%W), mean percent number (%N), and percent frequency of occurrence (%FO) of each category and for each prey community. Univariate graphics were used to examine trends at both levels: prey composition by stock and location over time, and overall prey community utilization of the stocks by location. Multivariate analyses were used to examine overall patterns and test for differences in diet, using the three measures on all 18 prey categories for fish grouped by stock, location, and week. The Bray-Curtis similarity matrix was computed on square root transformed data, followed by nMDS ordination and ANOSIM.

Wild chum salmon were captured throughout Taku Inlet from earliest sampling in mid-April in both years, prior to hatchery releases; peak of abundance of wild fry coincided with the first hatchery releases in early May, but most wild fry disappeared from the estuary by the time late hatchery fry were released in early June. Hatchery fry were rare in the inner inlet in both years but outnumbered wild fry 20:1 in the outer inlet, where residence overlapped most. Both stocks showed size-related movement off shore, but most

hatchery chum passed through Icy Strait in June, while wild chum of unknown origin continued to migrate through the strait into late summer.

We analyzed the condition of 718 and 970 juvenile chum salmon in 2004 and 2005, respectively. Univariate graphs of chum salmon grouped by wild vs. hatchery stock, sample week, and sample location indicated that hatchery fish initially had greater energy content (Figure 2), but were larger and had lower moisture content than wild fish. Condition of wild fish improved over the weeks in Taku Inlet (energy content increased and moisture content decreased), while condition of hatchery fish declined. However, feeding indices were similarly high and increased for both wild and hatchery fish, indicating that both stocks fed successfully. Multivariate analysis of overall condition in 2004 showed strong separation among the groups, with a low stress value (0.07) from the nMDS ordination (Figure 3). Overall wild and hatchery condition differed significantly (ANOSIM, $R = 0.258$; $P < 0.001$); paired comparisons indicated significant differences ($P < 0.05$) between the stocks at all inlet locations, but no difference in condition between stocks captured in Icy Strait, thus confirming univariate graphical trends.

We analyzed diets of 554 and 881 juvenile chum salmon in 2004 and 2005, respectively. Wild and hatchery chum salmon generally partitioned use of prey communities at locations in Taku Inlet; use of pelagic prey increased for both stocks in the outer inlet, and diets were indistinguishable by the time they reached Icy Strait (Figure 4). Multivariate analysis of 2004 diets showed moderate separation of the groups (nMDS stress = 0.15; Figure 5). Overall diets of wild and hatchery fish differed significantly (ANOSIM, $R = 0.573$; $P < 0.001$); paired comparisons indicated significant differences ($P < 0.058$) between the stocks at all inlet locations, but no difference in Icy Strait, thus confirming univariate graphical trends.

Based on graphical analysis of both 2004 and 2005 data and multivariate analysis of 2004 data, prey partitioning in Taku Inlet did not necessarily indicate competition between wild and hatchery chum salmon. Inverse trends in condition over time were observed for wild and hatchery (fed) fish, which initially showed low and high condition, respectively. Both diet and condition converged by the time fish reached epipelagic strait habitat approximately two months later. If density-dependent interactions affect wild chum salmon in Taku Inlet, the negative effects must occur very rapidly because juvenile survivors enter the GOA with no apparent disadvantage. Analysis of 2005 data is in progress to validate these patterns.

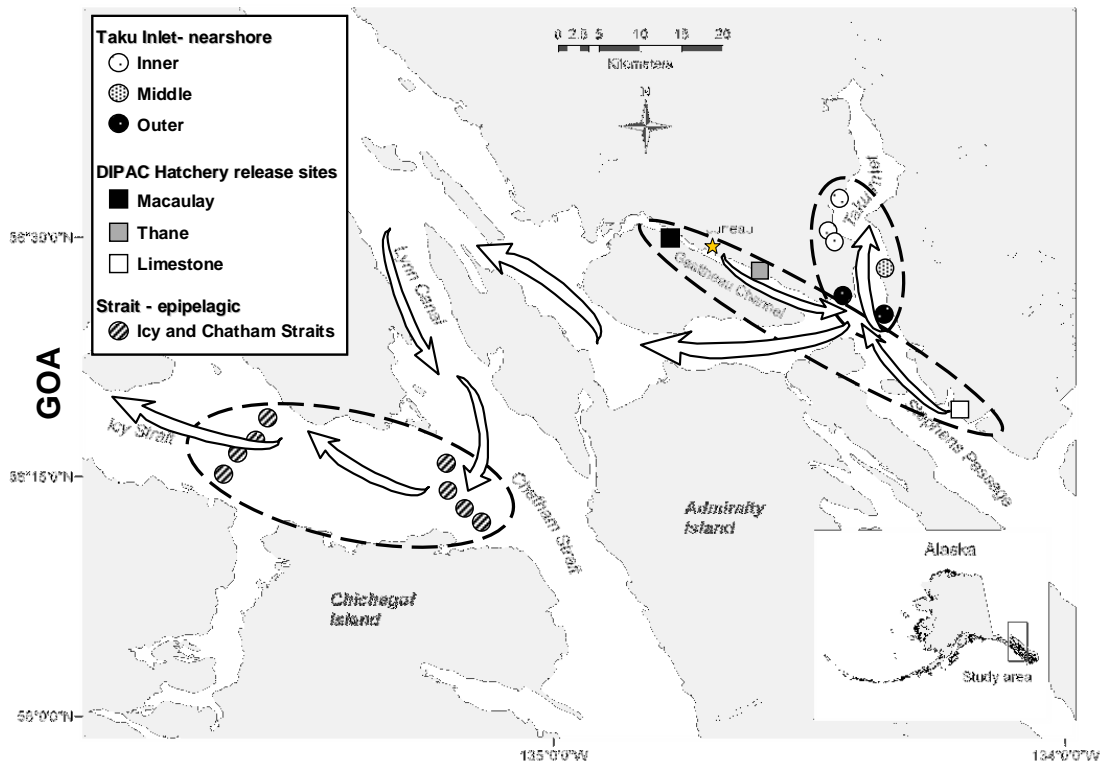


Figure 1. Sampling locations for hatchery and wild juvenile chum salmon at hatchery release sites, in Taku Inlet, and in Icy and Upper Chatham Straits, northern Southeast Alaska, in 2004 and 2005. The migration route of hatchery and wild chum salmon from inside passages of Southeast Alaska through Icy Strait to the Gulf of Alaska, a distance of approximately 200 km, is indicated by arrows.

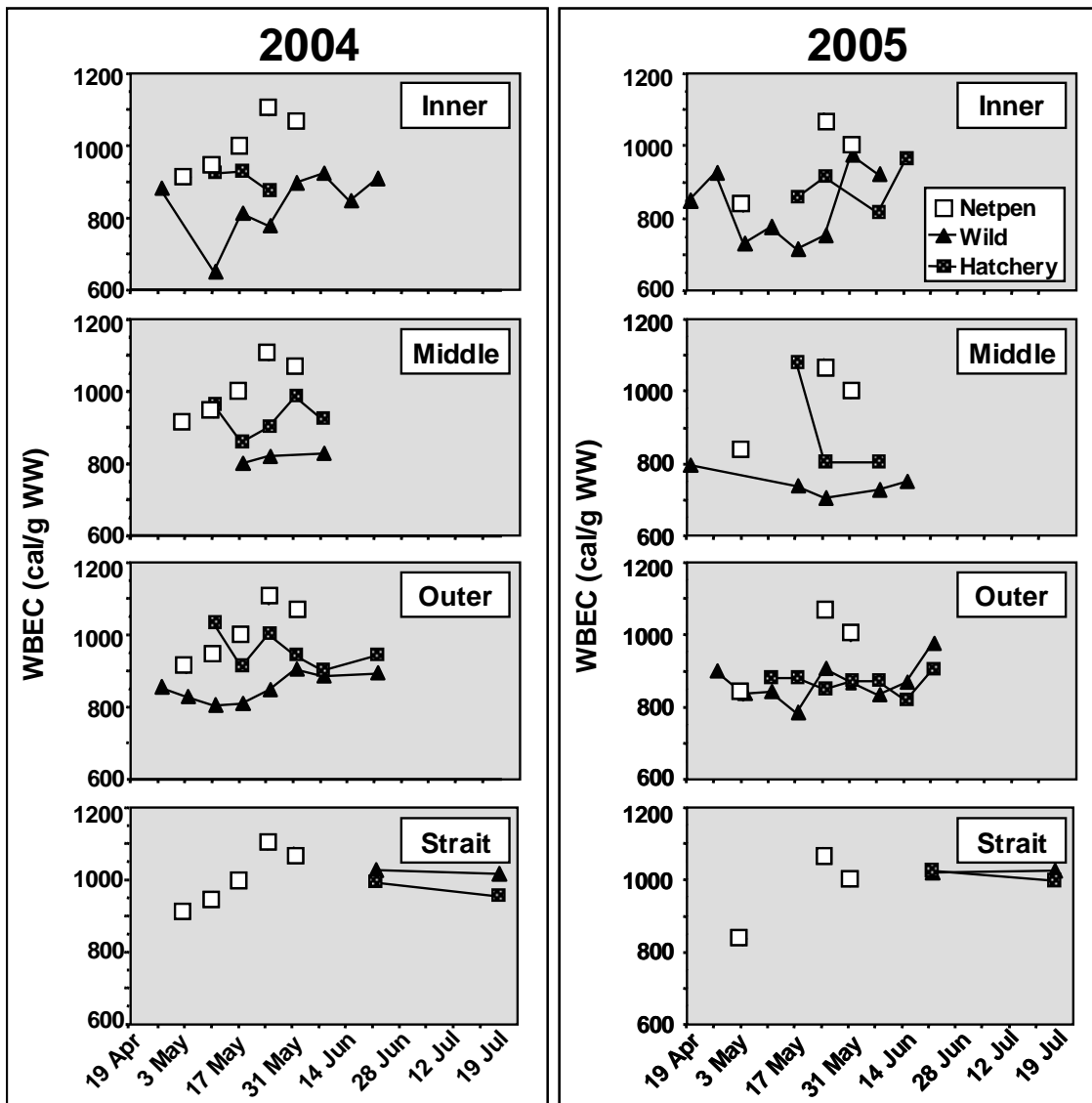


Figure 2. Hatchery and wild chum salmon energy density at locations in Inner, Middle and Outer Taku Inlet and Icy-Chatham Straits from April to July in 2004 and 2005. Data points for netpen samples serve as the baseline hatchery fish condition and represent discrete releases, which are therefore not connected by lines; earliest hatchery releases were fed the longest, while late releases were fed for the shortest period.

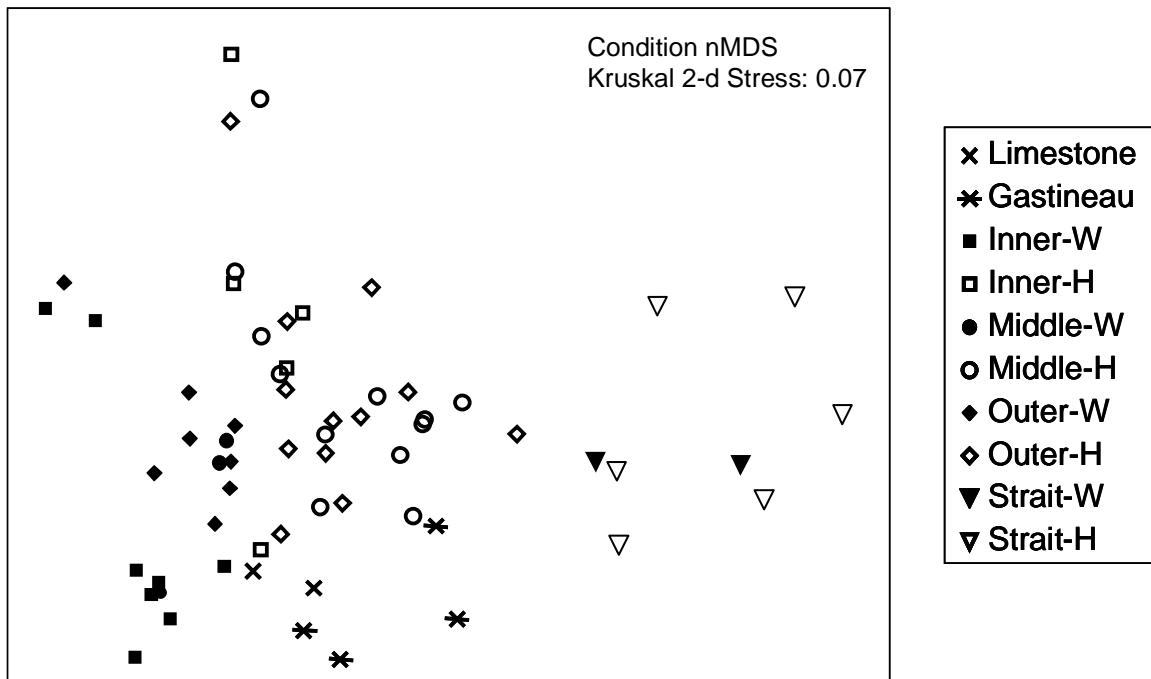


Figure 3. Multivariate non-metric dimensional scaling of hatchery (open symbols with 'H' and asterisks) and wild (closed symbols with 'W') juvenile chum salmon condition measures near Taku Inlet, southeastern Alaska, from April to July 2004. Symbol shape represents location and each symbol represents one sample week for each of 62 hatchery or wild sample groups. Locations include net pen release sites near Juneau (Limestone and Gastineau Channel), at Inner, Middle, and Outer Taku Inlet, and at Icy and Chatham Straits.

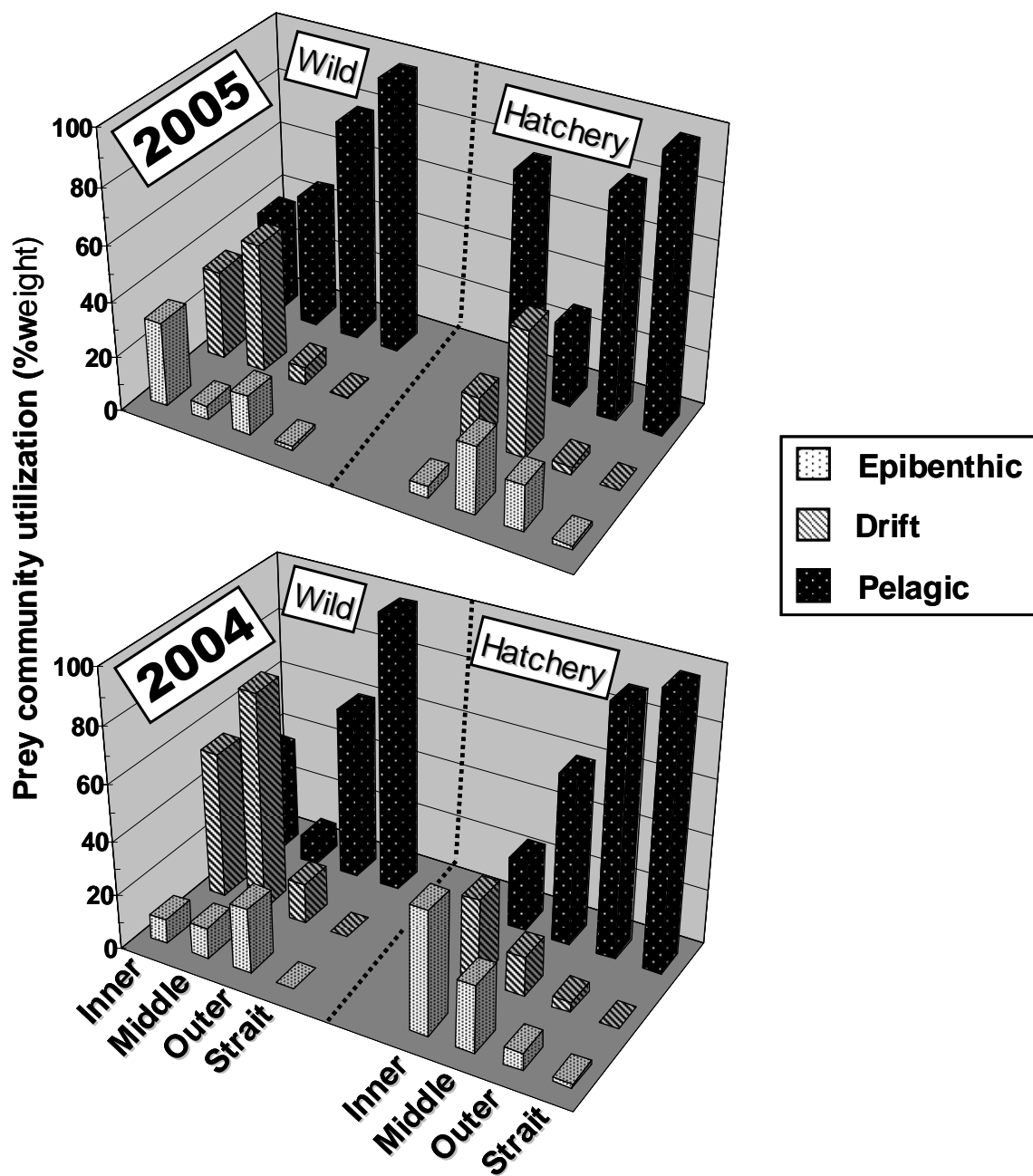


Figure 4. Hatchery and wild juvenile chum salmon utilization of epibenthic, drift, and pelagic prey communities in Inner, Middle and Outer Taku Inlet and Icy-Chatham Straits, April to July, 2004 and 2005. Data are pooled across sample weeks and prey categories to show overall patterns by stock and location.

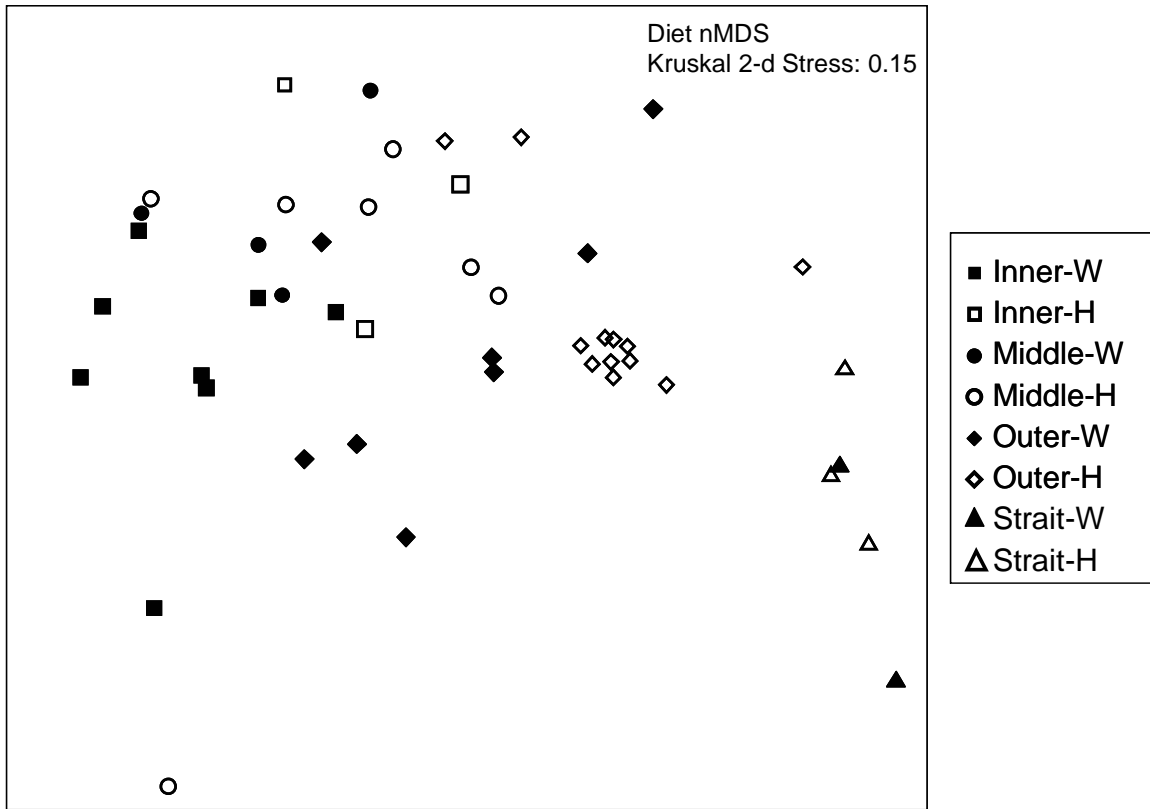


Figure 5. Multivariate non-metric dimensional scaling of hatchery (open symbols with 'H') and wild (closed symbols with 'W') juvenile chum salmon diet measures near Taku Inlet, southeastern Alaska, from April to July 2004. Symbol shape represents location and each symbol represents one sample week for each of 47 hatchery or wild sample groups. Locations include Inner, Middle, and Outer Taku Inlet, and at Icy and Upper Chatham Straits.

Effects of Starvation on Energy Density of Juvenile Chum Salmon Captured in the Marine Waters of Southeastern Alaska

Emily A. Fergusson, Joseph A. Orsi, and Molly V. Sturdevant

Alaska Fisheries Science Center, NOAA Fisheries

Auke Bay Laboratories, Ted Stevens Marine Research Institute

17109 Point Lena Loop Road, Juneau, Alaska 99801-8626 USA

Tel: (907) 789-6613; e-mail: emily.fergusson@noaa.gov

Abstract

We conducted two laboratory starvation experiments on juvenile chum salmon (*Oncorhynchus keta*) captured in the neritic marine waters of the northern region of southeastern Alaska in June and July of 2003. Fish were held in flow-through live tanks of ambient temperatures. Up to 10 fish were randomly selected at 5-10 day intervals. Laboratory water temperatures averaged approximately 9°C in June and July, and were 3-4°C lower than field temperatures. Fewer fish were available in July than in June ($n = 54$ vs. 101), thus limiting the duration and intervals of the July experimental group. Measurements taken for each fish included: fork length (mm); wet weight (WW; g); and dry weight (g; DW). Three measures of condition calculated for each fish included: energy density (whole body energy content, WBEC, cal/g WW), moisture content (%; $(1 - DW/WW) \times 100$), and size condition residuals (CR) from a length-weight regression. Changes in fish condition were compared from initial capture across sacrifice time intervals. Over the 45-day experimental period in June, average WBEC and CR decreased by 40% and 300%, respectively, while average moisture content increased by 8% ($P < 0.01$) (Figures 1-3). Over the 20-day experimental period in July, average WBEC and CR decreased by 11% and 200%, respectively, while average moisture content increased by 2% ($P < 0.01$). Our study validates that WBEC and percent moisture content are appropriate measures of condition when identifying changes in juvenile chum salmon condition in response to variations in habitat quality due to temperature, food availability, and competitive interactions; and that use of CR can account for size bias in subsampling intervals.

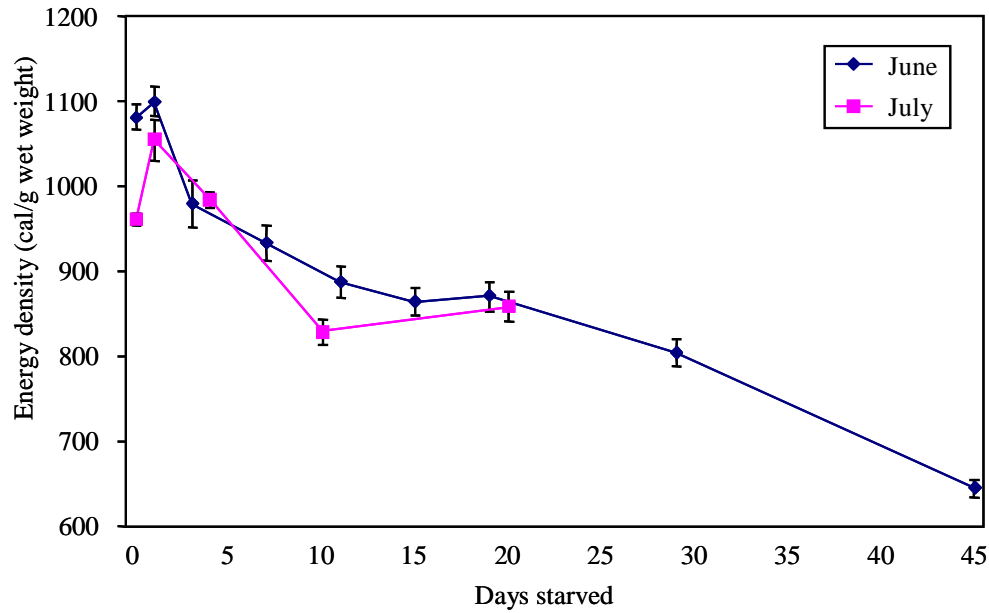


Figure 1. Average whole body energy content (cal/g wet weight) and one standard error about the mean of juvenile chum salmon starved in the laboratory after being captured in the marine waters of Icy Strait and Upper Chatham Strait in the northern region of southeastern Alaska, June and July 2003.

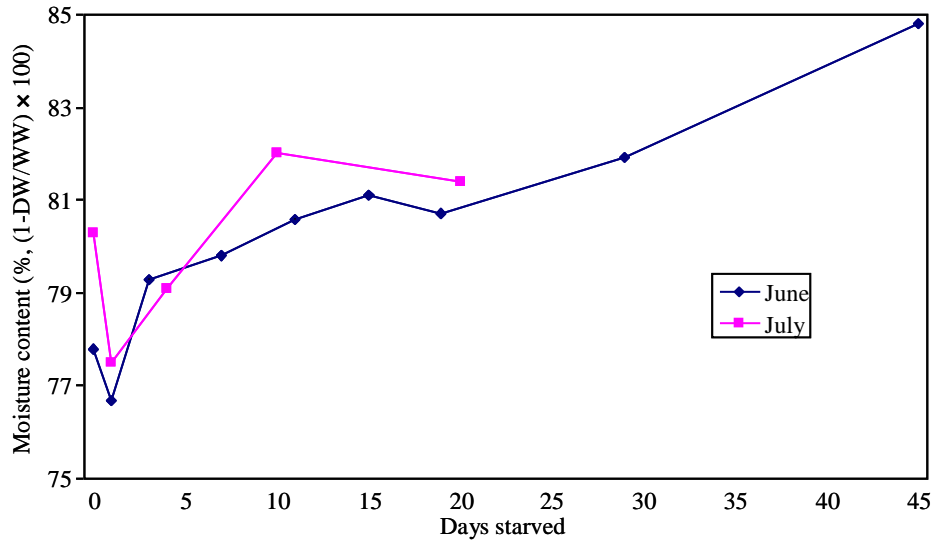


Figure 2. Average moisture content (%; (1-dry weight (g, DW)/wet weight (g, WW)) × 100) and one standard error about the mean of juvenile chum salmon starved in the laboratory after being captured in the marine waters of Icy Strait and Upper Chatham Strait in the northern region of southeastern Alaska, June and July 2003.

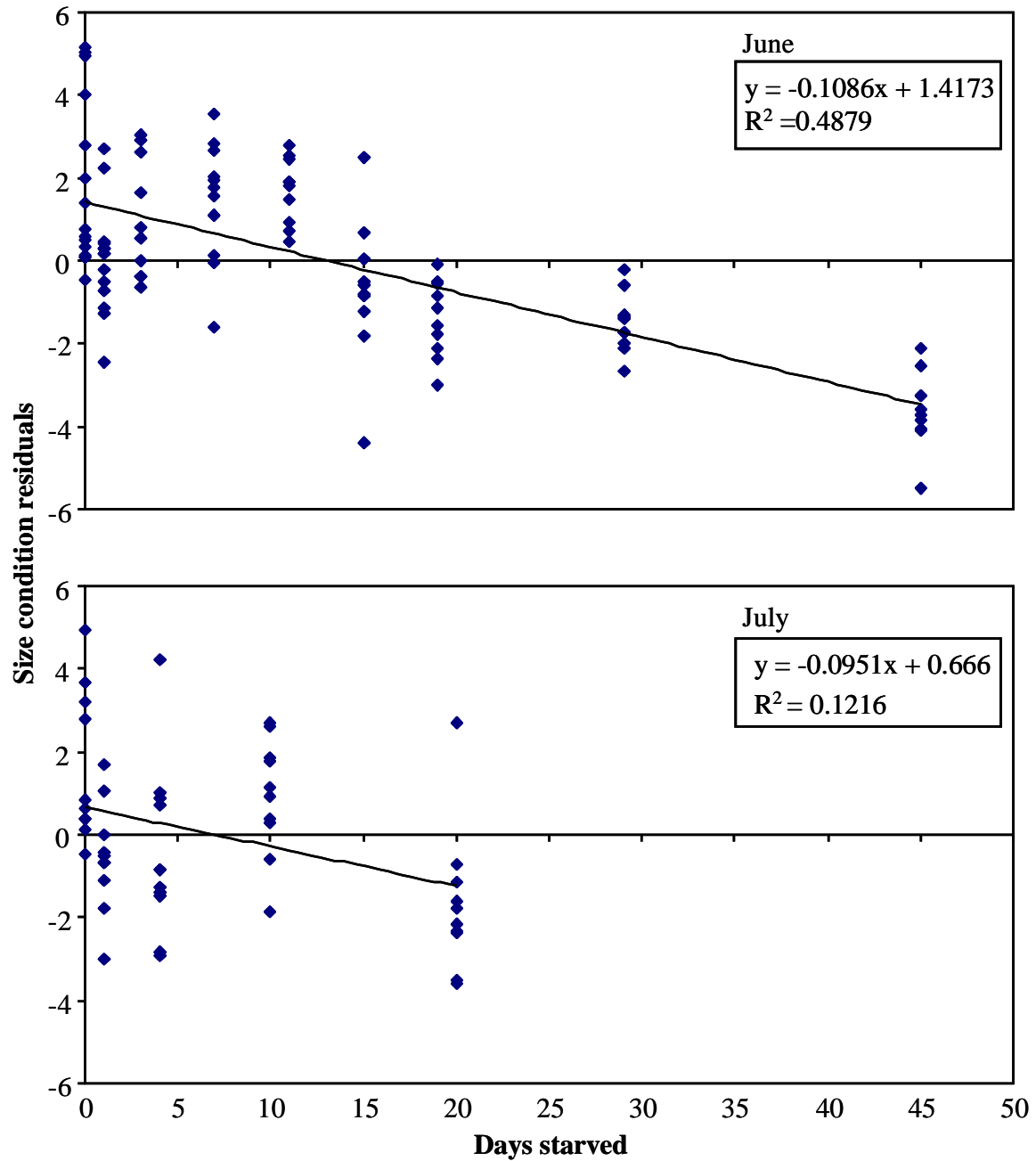


Figure 3.—Size condition residuals from length-weight regressions of juvenile chum salmon starved in the laboratory after being captured in the marine waters of Icy Strait and Upper Chatham Strait in the northern region of southeastern Alaska, June and July 2003.

Interactions of Hatchery Chum Salmon with Juvenile Chum and Pink Salmon in the Marine Waters of Southeastern Alaska

Joseph. A. Orsi, Alex C. Wertheimer, Emily A. Fergusson, and Molly. V. Sturdevant
Auke Bay Laboratories, Alaska Fisheries Science Center, NOAA Fisheries,
Ted Stevens Marine Research Institute, 17109 Point Lena Loop Road, Juneau, AK 99801
(907) 789-6034 joe.orsi@noaa.gov

Hatchery chum salmon (*Oncorhynchus keta*) comprise an economically important harvest component of commercial salmon fisheries in southeastern Alaska (SEAK), yet little is known of how these fish interact as juveniles with wild chum and pink salmon (*O. gorbuscha*) in the marine environment. Because the early marine period is often identified as critical one for the survival of salmon, understanding early marine interactions of these species in ecosystems may give insight to mechanisms governing year class strength. In June and July of 2005, surface trawling was conducted to examine these interactions in strait habitats of the northern and southern regions of SEAK (Figure 1). A bioenergetics model was used, with juvenile salmon data and associated biophysical parameters (temperature, fish growth, predator and prey energy density, and prey fields), to estimate the consumption of zooplankton and compare it to the available standing crop. Species and hatchery stock group densities were highest in both regions during June (391 to 2,313 fish · km⁻²) (Table 1), and the modeled zooplankton consumption was highest during this period by all stock groups (2.8 to 3.2 kg zooplankton · km⁻² · d⁻¹) (Table 2). Salmon diet and energy density varied between species and time periods. However, of the available standing crop of zooplankton measured in each region and time period (25 to 145 MT zooplankton · km⁻²), simulations indicate juvenile salmon only consumed a small fraction (<2%) (Table 3). These results suggest hatchery chum stocks interact with juvenile chum and pink salmon in strait habitats of SEAK, particularly in June, but only a small percentage of the available zooplankton was consumed by both species and stock groups.

Table 1.—Average CPUE (catch per haul) of juvenile chum salmon and pink salmon stock groups in Icy Strait and Clarence Strait, southeastern Alaska, June and July 2005. Stock groups are UM=Unmarked fish, MC= Macaulay, HF=Hidden Falls, and NB=Neets Bay. Trawl catch ability was assumed to be 100%. Densities of juvenile salmon (fish/km²) were based on a trawl area swept of 36,000 m² and a conversion factor of CPUE/0.036.

Region	Strait habitat	Salmon species	Stock group	June			July		
				Trawl hauls	CPUE	Density (fish/km ²)	Trawl hauls	CPUE	Density (fish/km ²)
Northern	Icy	Chum	UM	20	21.05	585	23	2.79	77
	Icy	Chum	MC	20	31.64	879	23	0.27	7
	Icy	Chum	HF	20	29.81	828	23	1.86	51
	Icy	Pink	UM	20	24.75	688	23	5.17	144
Southern	Clarence	Chum	UM	20	14.07	391	20	2.95	82
	Clarence	Chum	NB	20	19.98	555	20	4.40	122
	Clarence	Pink	UM	20	83.25	2,313	20	4.30	119

Table 2.—Zooplankton consumption rates of juvenile pink and chum salmon stock groups calculated from 28 bioenergetics model runs based on biophysical parameters in Icy Strait and Clarence Strait, southeastern Alaska in June and July, 2005. Stock groups are UM=Unmarked fish, MC= Macaulay, HF=Hidden Falls, and NB=Neets Bay. The two temperature simulations used to model consumption (3 m depth and 20 m integrated) rates are shown in Table 2.

Region	Strait habitat	Salmon species	Stock group	Consumption rates of zooplankton (g of prey/ g of predator/ d)			
				June temperature simulations		July temperature simulations	
				3 m	20 m integrated	3 m	20 m integrated
Northern	Icy	Chum	UM	0.049302	0.042376	0.046044	0.040637
	Icy	Chum	MC	0.084087	0.074917	0.069012	0.063129
	Icy	Chum	HF	0.085867	0.074488	0.074348	0.066227
	Icy	Pink	UM	0.092518	0.081109	0.079236	0.071326
Southern	Clarence	Chum	UM	0.121122	0.113258	0.096114	0.091469
	Clarence	Chum	NB	0.104449	0.096849	0.088040	0.083078
	Clarence	Pink	UM	0.141971	0.133533	0.111062	0.106315

Table 3.—The percentage of available zooplankton consumed by juvenile pink salmon and chum salmon stock groups calculated from 28 bioenergetics model runs based on biophysical parameters in Icy Strait and Clarence Strait, southeastern Alaska in June and July, 2005. Stock groups are UM=Unmarked fish, MC= Macaulay, HF=Hidden Falls, and NB=Neets Bay. The percent consumed shown here is based on the 3 m temperature simulation that yielded the highest consumption rates shown in Table 2. The percentage consumption is also determined for two of zooplankton sample measurements (333 μ mesh and 505 μ mesh) and two metrics (surface area km² and cubic km³).

Region	Strait habitat	Salmon species	Stock group	Consumption km ²				Consumption km ³			
				June		July		June		July	
				333	505	333	505	333	505	333	505
Northern	Icy	Chum	UM	0.000	0.000	0.000	0.000	0.003	0.003	0.001	0.001
	Icy	Chum	MC	0.001	0.001	0.000	0.000	0.008	0.010	0.000	0.000
	Icy	Chum	HF	0.001	0.001	0.000	0.000	0.006	0.008	0.001	0.001
	Icy	Pink	UM	0.001	0.001	0.000	0.000	0.005	0.006	0.004	0.005
	Total			0.002	0.003	0.001	0.001	0.021	0.027	0.006	0.007
Southern	Clarence	Chum	UM	0.001	0.001	0.000	0.000	0.008	0.015	0.005	0.004
	Clarence	Chum	NB	0.001	0.002	0.001	0.000	0.012	0.023	0.006	0.005
	Clarence	Pink	UM	0.005	0.008	0.001	0.001	0.051	0.093	0.007	0.006
	Total			0.006	0.012	0.002	0.001	0.072	0.131	0.018	0.015

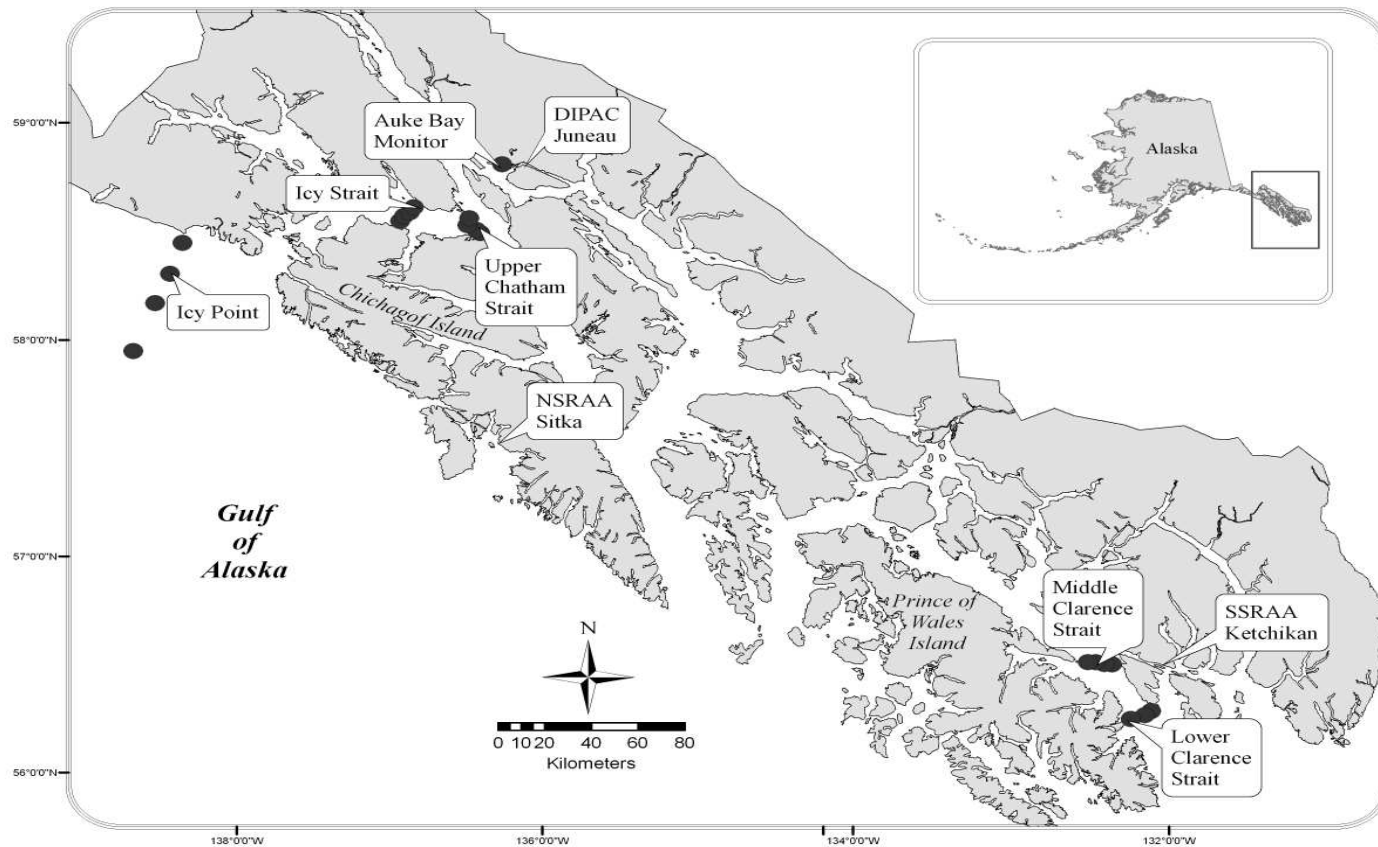


Figure 1.—Stations sampled for juvenile salmon and associated biophysical parameters in Icy Strait and Clarence Strait in the northern and southern regions of southeastern Alaska, June and July 2005. Also identified are the bases of operation and associated towns of the principal chum salmon hatcheries (DIPAC, NSRAA, and SSRAA) and in the region.

Kuskokwim Bay juvenile chum salmon: An overview

Nicola Hillgruber*¹, Sean E. Burrill², Christian E. Zimmerman²

¹School of Fisheries and Ocean Sciences

University of Alaska Fairbanks

11120 Glacier Highway, Juneau, AK 99801

n.hillgruber@uaf.edu

²USGS Alaska Science Center

4230 University Dr., Suite 201

Anchorage, AK 99508

ABSTRACT

Little is known about the estuarine residence of juvenile chum salmon (*Oncorhynchus keta*) in western Alaska. It is at this stage, however, that juveniles might experience high mortality rates that may ultimately determine year class strength. Recent fluctuations in the abundance of chum salmon in the Kuskokwim River have demonstrated a need for more information on chum salmon life history, but particularly on factors impacting the critical estuarine life stage. Here we present results on spatial and temporal patterns of estuarine distribution, diet, and condition of chum salmon juveniles in 2003 and 2004 in Kuskokwim Bay. Juvenile chum salmon were collected in two years with a modified Kvichak surface trawl. Chum salmon were caught in the estuary the middle of May until late July; no chum salmon were caught in August. Environmental conditions, particularly sea surface temperature (SST) changed remarkably during the juvenile outmigration, with uniformly low temperatures of 7°C in May, increasing to SST as high as 15.6°C in June. In May, distribution of juvenile chum salmon was confined primarily to the waters of the river plume, with fish leaving the plume towards the later part of their outmigration, indicating that they were using the river plume as a staging area to adjust to higher salinity water and possibly as a nursery area to protect them from visual predators.

Juvenile chum salmon feeding success was variable and differed with size, season, salinity, and year. Feeding incidence increased significantly with size and season. Feeding incidence and intensity were lowest for those juvenile chum salmon of the smallest size class that were collected early in the season. Prey composition was similar between years. Drift insects and small calanoid (< 2.5mm) and harpacticoid copepods were the primary prey items for juvenile chum salmon within the bay. Calanoids and insects combined made up > 50% of all prey consumed and > 80% of the overall prey biomass for all size classes and sampling weeks.

Mean energy content of chum salmon increased significantly from 2003 to 2004. In 2004, energy density decreased significantly from 5,371 cal/g in mid-May to 4,932 cal/g in mid-June. The decrease in energy densities from May to June was apparent in all size classes, except for the ≥ 60 mm class. The observed decrease in energy content with season and fish size might suggest that juvenile chum salmon were allocating the majority of their energy into growth, rather than the storage of lipids. The significantly lower energy content of chum salmon of similar sizes outmigrating into the bay in June in comparison to May might be the result of higher metabolic costs, possibly due to higher sea surface temperatures.

Age and duration of residence in saltwater habitats of juvenile chum salmon was examined using otolith microstructure and microchemistry. Juvenile chum salmon were captured from stations distributed throughout the bay and across a salinity gradient from 0 to

26. Post-emergence ages ranged from 12 to 44 d and were weakly correlated with standard length ($r^2 = 0.31$, $n = 192$, $p < 0.001$). Dates of emergence ranged from 19 April to 24 May with a median date of 6 May. Otolith strontium-to-calcium ratios were examined to determine the timing of saltwater entry. Duration of estuarine residence was estimated for 8 fishes and ranged from 8 to 18 d. Identification of the freshwater to saltwater transition was not possible for 42 otoliths, most likely due to the interference from maternally inherited effects and short freshwater residence.

Our study represents the first research effort on the estuarine ecology of juvenile chum salmon in Kuskokwim Bay. Our results indicate that timing of outmigration may be of essential importance for condition, growth, and subsequent survival probability of juvenile chum salmon. A more thorough understanding of this critical period in the life of juvenile salmonids may provide some information on mechanisms responsible for regulating chum salmon population size and on the role of environmental variation, which may be of particular importance in light of changing climatic condition as recently observed in the Bering Sea.

Melting of arctic sea-ice and utilization of the Chukchi Sea by juvenile pink and chum salmon during 2007.

James M. Murphy, Jamal H. Moss, Lisa B. Eisner, Ellen C. Martinson, Edward V. Farley
NOAA Fisheries, Auke Bay Laboratories
Ted Stevens Marine Research Institute
17109 Pt Lena Loop Road
Juneau AK, 99801-8344

The arctic has been losing sea-ice at rate of 1% each year; however the loss of sea-ice during the summer melting season in 2007 was extensive. By September (the end of the summer melting season) the ice extent reached a record low, shattering the previous minimum extent set in 2005 by 23%. The United States Bering-Aleutian Salmon International Survey was extended into the Chukchi Sea in September, 2007 to provide insight into how juvenile salmon and associated epipelagic fish species are responding to the loss of sea ice. Juvenile pink and chum salmon were found in significant numbers throughout the survey area in the Chukchi Sea and their average size was larger in the Chukchi Sea than the eastern Bering Sea shelf. The combination of longer day-length associated with high latitude regions (longer feeding period) and the anomalously warm sea surface temperatures (11.0°C) associated with the loss of sea ice may have resulted in higher growth potential in the Chukchi Sea. However, larger size does not necessarily imply higher growth rates as timing of ocean entry can also have a significant impact on juvenile size. Scale-circuli spacing and counts are used to provide insight into the relative effect of growth rate and ocean entry timing on the size of juvenile salmon in the Chukchi Sea.

ENHANCEMENT
Chair: Kyle Adicks

Hatchery Pink and Chum in Alaska: Supplementing or Supplanting Wild Stock Production?

Benjamin W. Van Alen

U.S. Forest Service, Juneau Ranger District, 8510 Mendenhall Loop Road, Juneau, AK, 99801, bvanalen@fs.fed.us, 907-789-6257

In Alaska, circumstances of poor runs (escapements), an overly competitive fishing industry, can-do technically savvy hatchery biologists, traditional use of hatcheries, and oil money led to financing “ocean ranching” hatchery programs in the 1970s. Meanwhile, projects to estimate and manage for wild stock escapements remained chronically under funded. Is the hatchery effort boosting salmon production, a wise investment, needed, and natural? Or are we simply operating hatcheries because we can? For pink salmon in southeast Alaska, the management focus since Statehood (1959) has been to rebuild wild stock escapements and returns are now at historical high levels. Return-per-spawner relationships show that wild fish are filling the ocean’s carrying capacity for pink salmon production. In contrast, in Prince William Sound, the rebuilding of wild stock escapements and returns has been superceded by production releases of hatchery fish. The commercial fishery is now dependent on hatchery fish, an ironic situation given the near pristine habitat and the tremendous cost of hatcheries. This is nearly the same situation for chum fisheries in southeast Alaska and Prince William Sound. This paper questions the biological assumptions and financial investment behind the ocean ranching program. I’ll conclude that the production of wild and hatchery salmon is ultimately dependent on the carrying capacity of shared freshwater and marine habitats and that we are best able to fully seed available rearing habitat by maintaining the natural distribution and abundance of wild stock escapements. Each hatchery fish released increases competition, increases straying, decreases fitness, decreases growth, increases predation, decreases survivals, decreases management precision, and increases harvest pressure on wild fish. Our limited funds are best spent on the assessment and management of wild stocks.

Implementation and Operation of an ESA-listed Hood Canal Summer Chum Recovery Project: The Nuts and Bolts

Ed Jouper

Washington Department of Fish and Wildlife, 40 W. Skokomish Valley Rd., Shelton, WA 98584

In March of 1999, the National Marine Fisheries Service (NMFS) determined that the summer chum originating from Hood Canal and the Strait of Juan de Fuca represented an Evolutionarily Significant Unit (ESU), and formally listed these fish under the Endangered Species Act (ESA) as a threatened species. In August of 1999, the Summer Chum Salmon Conservation Initiative (SCSCI) identified Tahuya River summer chum as one of four extirpated stocks in the Hood Canal summer chum ESU and as a potential future candidate

for a summer chum reintroduction project. The Union River Supplementation/ Tahuya River Reintroduction Project was implemented in June of 2000 as a cooperative project between Washington Department of Fish and Wildlife (WDFW) and the Hood Canal Salmon Enhancement Group (HCSEG). The following is a discussion of what is entailed in implementing and operating a summer chum recovery project in compliance with the protocols set forth in the SCSCI and the Union/Tahuya River Hatchery and Genetic Management Plan (HGMP).

Fluctuations in Abundance of North American Pink Salmon (*Oncorhynchus gorbuscha*) Populations.

Bill Waknitz

Research Fisheries Biologist

P. O. Box 130 Manchester, WA 98353

1-360-871-8322 bill.waknitz@noaa.gov

Pink salmon populations are known to experience large inter-annual variations in abundance. Increases or declines of 90%+ from one generation to the next are not uncommon. Recently, artificial propagation programs in North America have been correlated with or hypothesized for generational population variability among some pink salmon populations in Alaska, British Columbia, and Washington. However, before the impacts of artificial propagation on pink salmon populations can be evaluated, it is important to first describe normal annual average run size and variation from the mean. This paper will present long-term abundance data for several North American pink salmon populations.

ESA-listed Hood Canal Summer Chum Salmon: A brief update on supplementation programs, natural-origin vs. supplementation-origin returns, and recovery

Thom H. Johnson¹, Kyle Adicks², Chris Weller³, and Tim J. Tynan⁴

¹Washington Department of Fish & Wildlife, Hood Canal District, 283286 Highway 101, Port Townsend, WA 98368

²Washington Department of Fish & Wildlife, 600 Capitol Way North, Olympia, WA 98501-1091, USA

³Point No Point Treaty Council, 7999 NE Salish Lane, Kingston, WA 98346

⁴NOAA Fisheries Service, Salmon Recovery Division, 510 Desmond Drive, Suite 103, Lacey, WA 98503

Abstract

Hood Canal summer chum (including the eastern Strait of Juan de Fuca) were listed as threatened under the Endangered Species Act in 1999. Recovery planning and implementation were underway prior to the listing, with harvest reductions and supplementation programs enacted in the early 1990's. The Washington Department of Fish and Wildlife and Point No Point Treaty Tribes distributed the Summer Chum Salmon Conservation Initiative (SCSCI) in April 2000. The initiative described a comprehensive plan for the implementation of summer chum salmon recovery in Hood Canal and eastern Strait of Juan de Fuca. The Summer Chum Recovery Plan, prepared by the Hood Canal

Coordinating Council, incorporated the harvest and artificial production management provisions of the SCSCI and also addressed habitat protection and restoration. The Recovery Plan was formally adopted by National Marine Fisheries Service (NMFS) under rule 4(f) of the Endangered Species Act in March 2007.

Run sizes of summer chum have been on the rise since the mid-1990's, with some of the highest returns on record occurring in recent years. Supplementation programs have succeeded in reducing the extinction risk of several stocks that were at critically low levels prior to supplementation and these stocks have demonstrated strong returns of both supplementation-origin and natural-origin fish in recent years. Reintroduction programs also appear to be succeeding, with natural-origin spawners returning to three streams where summer chum had been extinct for more than 10 years.

Interim recovery goals for summer chum have been developed by the Washington Department of Fish and Wildlife and the Point No Point Treaty Tribes – the fish resource co-managers in the summer chum region - based on historic population sizes, and include abundance, escapement, productivity, and diversity targets. Summer chum populations are not yet meeting the Co-managers' abundance-based recovery goals, due in part to the requirement that all stocks must meet recovery abundance thresholds over a period of 12 years. The outlook for summer chum, however, is much brighter than it was just 10 years ago, based on recent increased abundances and other indicators.

Introduction and Background

Summer chum in Hood Canal and the Strait of Juan de Fuca experienced a severe decline in abundance in the 1980's, extending into the early 1990s. Abundances reached record lows in 1989 and 1990, with less than 1,000 spawners escaping to the region each year. By 1991, seven of the sixteen recognized summer chum stocks were considered extinct, eight stocks were at high risk of extinction, and one stock was at moderate risk of extinction. In 1992, the state and tribal Co-managers implemented harvest reductions aimed at protecting summer chum, and together with the U.S. Fish and Wildlife Service and local citizen groups, initiated three hatchery supplementation programs utilizing native brood stocks. In 1999, the Hood Canal summer chum Evolutionarily Significant Unit (ESU) (including the Strait of Juan de Fuca), was listed as threatened under the Endangered Species Act. The Washington Department of Fish and Wildlife and Point No Point Treaty Tribes distributed the Summer Chum Salmon Conservation Initiative (SCSCI) in April 2000 (WDFW and PNPTT 2000). The initiative described a comprehensive plan for the implementation of summer chum salmon recovery in Hood Canal and eastern Strait of Juan de Fuca. The harvest and artificial production components of the SCSCI were subsequently approved by the National Marine Fisheries Service (NMFS) under Limits 6 and 5, respectively, of the Endangered Species Act 4(d) rule (NMFS 2001, 2002). Since then, the SCSCI hatchery (supplementation) programs have been reviewed favorably by the Hatchery Scientific Review Group (HSRG 2002, 2004) and by the Recovery Science Review Panel (RSRP 2004). The SCSCI's harvest and artificial production management provisions were also incorporated into the Summer Chum Recovery Plan prepared by the Hood Canal Coordinating Council (HCCC 2005). A key premise of the SCSCI is that "commensurate, timely improvements in the condition of habitat critical for summer chum salmon survival are necessary to recover the listed populations to healthy levels". The HCCC Recovery Plan, which also addressed habitat protection and restoration, was formally adopted by NMFS as

an acceptable plan to recover the listed summer chum ESU under section 4(f) of the Endangered Species Act in March, 2007 (NMFS 2007a, 2007b).

Since recovery efforts for Hood Canal summer chum were initiated, six conservation-directed supplementation and three reintroduction programs have been undertaken. Harvest rates on summer chum have been severely curtailed, and are currently managed under the risk averse harvest management plan described by the SCSCI. Harvest rates were decreased from an average of ~49% prior to implementation of protective harvest measures (1974-1991) to an average of <5% after the measures were applied (1992-2006). A variety of habitat restoration and protection projects have also been implemented by local, state and federal governmental entities and non-governmental cooperative groups on summer chum streams and in critical estuarine areas. Reports covering stock assessment, management, and supplementation activities from 2000-2006 have been completed (WDFW and PNPTT 2001, 2003; WDFW and PNPTC 2004, 2005, 2006, 2007a, 2007b), and the Co-managers have identified interim recovery goals for summer chum (PNPTT and WDFW 2003).

This paper gives general updates on population trends, supplementation programs, and achievement of SCSCI performance standards meant to measure progress toward recovery of the Hood Canal summer chum ESU. For more detailed information, consult the five-year report on progress of the SCSCI (WDFW and PNPTT 2007b) available on the Washington Department of Fish and Wildlife (WDFW) website (<http://wdfw.wa.gov/fish/chum/chum.htm>).

Abundance Trends and Extinction Risk

Abundances of summer chum in Hood Canal declined from the late 1970's through the early 1990's (Figure 1). All stocks of summer chum in Hood Canal except the Union River suffered declines in abundance during this period. In the Strait of Juan de Fuca, the decline started approximately 10 years later, with a noticeable and lasting drop in abundance in 1989. Populations rebounded to higher levels quickly in the mid-1990's, after the initiation of harvest reductions and several supplementation programs. Larger escapements were seen from 1995-1997 for the major streams entering the west side of Hood Canal. Abundances were down again in 1998 and 1999 (although still five times higher than abundances just prior to recovery efforts), but began to increase in 2000. The 2003 and 2004 escapements were the largest on record, with a total of over 79,000 fish escaping to the region in 2004. However, 2004 is the peak return year in a strong 4-year production cycle and, as expected, production declined in 2005 as the run cycled down from the high year. Overall, the average total annual escapement has increased from 2,367 fish in 1988-1991 to 38,353 fish in 2004-2007.

Extinction risks for all stocks have decreased since the onset of recovery activities, with increases in population sizes, and effective population sizes per generation greater than 500 for all but two stocks (Adicks et al. 2005, WDFW and PNPTT 2007b). In addition, three stocks have been reintroduced into watersheds where the indigenous stock was extinct, further reducing the extinction risk for the donor stocks and reinitiating natural summer chum production in these streams.

Supplementation Programs

Artificial production was identified as an important tool for use in recovery of summer chum salmon, and supplementation programs were initiated early in the recovery process. Supplementation as a salmon recovery tool has been the subject of much debate, in

part due to differing application of the term supplementation itself. Supplementation, as defined by the SCSCI, is “The use of artificial propagation to maintain or increase natural production while maintaining the long-term fitness of the target population, and keeping the ecological and genetic impacts to non-target populations within specified biological limits.” Implicit in this definition is the intent to halt supplementation when the wild population has recovered.

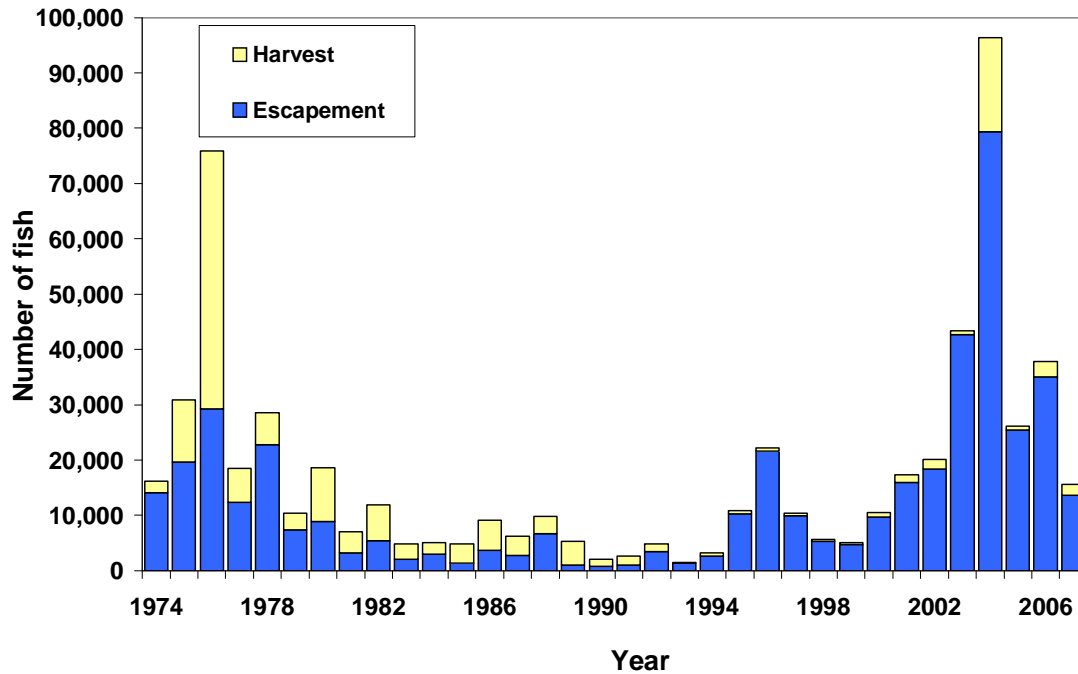


Figure 1. Total escapement and harvest of summer chum salmon returning to Hood Canal and Strait of Juan de Fuca, 1974-2007.

The controversy surrounding the use of artificial production techniques to supplement depressed wild salmon populations is based on the uncertainty of whether this type of intervention would lead to irreversible losses of fitness and genetic diversity, and a concern that the hatchery programs would continue indefinitely to enhance fishing opportunities. Because of past chum salmon supplementation successes (Ames and Adicks 2003), the Co-managers were confident that well-founded hatchery programs would result in rapid increases in the numbers of returning fish and a corresponding reduction in extinction risk. The primary challenge facing the Co-managers was to develop a set of protocols that would minimize the risk of deleterious hatchery-related effects on supplemented stocks.

The definition of supplementation used in the SCSCI is central to the strict criteria and standards used for selecting and conducting supplementation programs for Hood Canal summer chum. Supplementation is to be used only when a summer chum stock is at risk of extinction, or to develop a broodstock in support of a program to reintroduce summer chum to previously occupied habitats. Tynan et al. (2003) summarized the strict standards guiding supplementation programs set forth by the SCSCI. These standards included strategies for

minimizing potential deleterious effects of supplementation, and requirements for monitoring and evaluation of supplementation programs. Schroder and Ames (2004) further detail specific protocols to be followed during artificial production to insure the SCSCI standards are met. Early results of monitoring and evaluation of supplementation programs are presented in WDFW and PNPTT (2001, 2003, 2007b) and Johnson and Weller (2003).

Table 1 lists the supplementation (and reintroduction) programs undertaken to date for Hood Canal summer chum and Figure 2 shows the distribution of the programs in the ESU. Four of the programs have been terminated after either reaching the three chum generation (12-year) maximum program duration limit specified by the SCSCI (Quilcene and Salmon), or because adult return targets were being met before the three generation limit was reached (Chimacum and Union).

Table 1. Listing of summer chum supplementation and reintroduction programs, including brood years when programs began and brood years when mass marking (otolith marking or adipose clipping) was initiated. Also shown are the first year of marked adult returns and, where applicable, the last brood year before program termination.

Supplementation/ reintroduction program	Brood year program initiated	Brood year mass marking initiated	First year marked adults to return ¹	Brood year program terminated
Salmon Creek	1992	1993	1996	2003
Big Quilcene River ²	1992	1997	2000	2003
Lilliwaup Creek ³	1998	1997	2000	
Chimacum Creek (reintro.)	1996	1999	2002	2003
Big Beef Creek (reintro.)	1996	1998	2001	2004
Hamma Hamma River	1997	1997	2000	
Jimmycomelately Creek	1999	1999	2002	
Union River	2000	2000	2003	2003
Tahuya River (reintro.)	2003	2003	2006	

¹ First year of returning age 3 fish is shown. Most adults return at ages 3 and 4, with perhaps a few at ages 2 and 5.

² Adipose clip.

³ Attempts to initiate supplementation efforts at Lilliwaup began in 1992, but broodstock collection efforts were largely unsuccessful until the 1998 brood, when a functional trap was first installed on the creek.

Natural-origin vs. supplementation-origin returns: Since 1997, all supplementation program-origin fish have been mass marked with adipose clips (Quilcene) or with program-unique otolith marks (all other programs). This means that beginning with the 2001 return, the vast majority of supplementation origin recruits were identifiable as supplementation fish, and also to their program of origin. Reintroduction fish were not necessarily marked for the first few years of the program, since the streams selected for reintroduction did not have extant summer chum populations, and all returns were assumed to be of supplementation origin.

HOOD CANAL SUMMER CHUM SALMON ESU

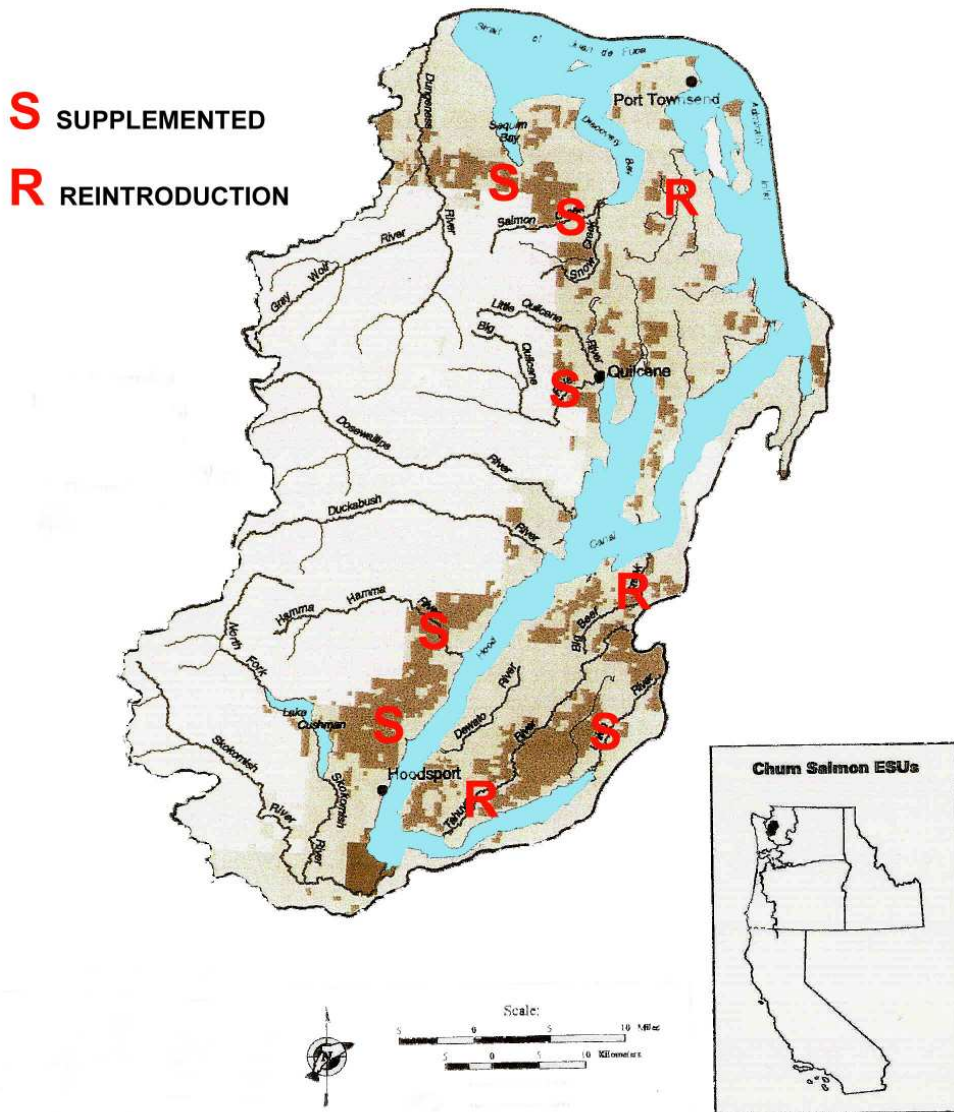


Figure 2. Map of Hood Canal summer chum salmon ESU, showing locations of supplementation and reintroduction projects.

Summer chum adults returning to Hood Canal streams are sampled for marks as a part of broodstock collection, and on the spawning grounds. This allows determination of natural-origin and supplementation-origin returns, and evaluation of return rates and straying of supplementation-origin fish. Scales are also sampled, allowing analysis, by brood year, of age structure and productivity for natural-origin fish and of contributions of supplementation-origin fish. For the years 1999 to 2006, summer chum from most of the spawning

aggregations within each population were sampled for age, mark, and genetic composition. Sample sizes meet or exceed goal collection levels each year, with generally well over 100 fish sampled per stream, and from 300-1000 fish for the Strait of Juan de Fuca population and 300-3000 for the Hood Canal population (WDFW and PNPTT 2000, 2001, 2003; WDFW and PNPTC 2004, 2005, 2006).

In the Strait of Juan de Fuca region, total supplementation-origin recruits accounted for 19% to 74% of annual summer chum returns from 1999 to 2006 (Table 2). In the Discovery Bay and Chimacum management units, supplementation programs were discontinued after brood year 2003 and the proportion of supplementation-origin fish declined as summer chum populations returned to primarily natural production. For example, mark data indicates that 4,909 (89%) and 1,480 (73%) of the fish returning in 2006 to Discovery Bay and Chimacum, respectively, were of natural origin, indicating that success of the programs in increasing spawner abundances has not been limited to supplementation-origin fish.

Table 2. Estimates of natural-origin and supplementation-origin runsize for Strait of Juan de Fuca summer chum management units from 1999 through 2007.										
Management Unit (MU)	Origin		Return year							
			1999	2000	2001	2002	2003	2004	2005	2006
Sequim Bay	Nat. origin	No.	7	55	253	2	69	614	496	346
		%	100%	100%	97%	5%	15%	37%	38%	48%
	Supp. origin	No.	0	0	9	40	381	1,051	821	382
		%	0%	0%	3%	95%	85%	63%	62%	52%
Discovery Bay	Nat. origin	No.	141	460	1,230	4,100	4,021	4,402	4,656	4,909
		%	27%	52%	44%	68%	67%	68%	66%	89%
	Supp. origin	No.	391	419	1,581	1,972	1,983	2,028	2,356	605
		%	73%	48%	56%	32%	33%	32%	34%	11%
Chimacum	Nat. origin	No.	0	0	0	129	229	593	894	1480
		%	0%	0%	0%	15%	41%	52%	64%	73%
	Supp. origin	No.	38	52	909	738	334	548	510	554
		%	100%	100%	100%	85%	59%	48%	36%	27%
SJFuca total	Nat. origin	No.	148	515	1,483	4,231	4,319	5,609	6,046	6,735
		%	26%	52%	37%	61%	62%	60%	62%	81%
	Supp. Origin	No.	429	471	2,499	2,750	2,698	3,627	3,687	1,541
		%	74%	48%	63%	39%	38%	39%	38%	19%
	Total		577	986	3,982	6,981	7,017	9,359	9,735	8,279

In the Hood Canal region, total supplementation-origin recruits accounted for 12% to 41% of annual summer chum returns from 2001 to 2006 (Table 3). Supplementation programs were discontinued after brood year 2003 in the Big Quilcene River (Quilcene/Dabob Bays management unit) and the Union River (Southeast Hood Canal management unit), but the reintroduction program in the Tahuya River (also in the Southeast Hood Canal management unit) is ongoing. Again, the proportion of supplementation-origin fish declined as summer

chum populations returned to primarily natural production. For example, mark data indicates that 13,093 (92%) and 1,747 (48%) of the fish returning in 2006 to Quilcene and Southeast Hood Canal, respectively, were of natural origin.

Table 3. Estimates of natural-origin and supplementation-origin runsize for Hood Canal summer chum management units from 2000 through 2006.

Management Unit (MU)	Origin		Return year						
			2000	2001	2002	2003	2004	2005	2006
Quilcene/Dabob Bays	Nat. origin	No.	--	3,632	4,330	10,850	59,333	6,231	13,093
		%	--	48%	72%	84%	94%	89%	92%
	Supp. origin	No.	6,704	3,964	1,720	2,013	3,833	792	1,198
		%	--	52%	28%	16%	6%	11%	8%
Mainstem Hood Canal	Nat. origin	No.	2,035	2,696	2,832	8,748	20,905	4,767	8,928
		%	--	63%	46%	79%	81%	67%	78%
	Supp. origin	No.	--	1,552	3,388	2,394	4,984	2,360	2,497
		%	--	37%	54%	21%	19%	33%	22%
SE Hood Canal	Nat. origin	No.	757	1,517	890	7,974	3,611	709	1,747
		%	100%	100%	100%	66%	60%	35%	48%
	Supp. origin	No.	0	0	0	4,045	2,386	1,293	1,883
		%	0%	0%	0%	34%	40%	65%	52%
Hood Canal total	Nat. origin	No.	--	7,845	8,052	27,572	83,849	11,707	23,768
		%	--	59%	61%	77%	88%	72%	81%
	Supp. origin	No.	--	5,516	5,108	8,452	11,203	4,445	5,578
		%	--	41%	39%	23%	12%	28%	19%
	Total		9,542	13,361	13,160	36,024	95,062	16,152	29,346

Reintroduction programs also appear to be succeeding. Hatchery-origin summer chum adults originating from stock reintroduction programs on Chimacum Creek, Big Beef Creek, and the Tahuya River returned in high numbers to the watersheds to spawn naturally. As a result, natural-origin spawners are now returning again to Chimacum and Big Beef Creeks, streams where summer chum had been extinct for more than 10 years (WDFW and PNPTC 2004, 2005, 2006, 2007a); the first natural-origin recruits in the Tahuya River are expected in 2009.

SCSCI Performance Standards

The SCSCI describes performance standards “meant to provide immediate criteria upon which to measure progress toward recovery of summer chum populations”. The standards, described for abundance, escapement, productivity and management actions, are evaluated in the five year review of the SCSCI (WDFW and PNPTC 2007). Following is a brief overview of how well some of the standards have been met.

One standard is that annual abundance should be stable or increasing and the five year mean abundance must be higher than the critical abundance threshold. Post season abundance estimates for the five years, 2000 through 2004, are provided in Table 4 for the

ESU, each population (region), and each management unit. The ESU and the Hood Canal population exceeded the abundance critical thresholds each year and exceeded the recovery threshold several times; the Strait of Juan de Fuca population exceeded the recovery threshold in 4 of 5 years, but was lower than the critical threshold in 2000. Similarly, each management unit has generally exceeded the critical thresholds, the exceptions being Sequim Bay in 2000 and 2002 and Mainstem Hood Canal in 2000.

Table 4. Abundance thresholds and post-season runsize estimates for Hood Canal and Strait of Juan de Fuca summer chum, 2000-2004.

Unit	Abundance Thresholds		Post Season Estimates				
	Critical	Recovery	2000	2001	2002	2003	2004
H. Canal - SJFuca ESU	5,590	22,760	10,483	17,342	20,141	43,040	104,289
Strait of Juan de Fuca	1,010	2,080	987	3,982	6,981	7,016	9,236
Sequim	220	520	55	262	42	450	1,665
Discovery	790	1,560	879	2,811	6,072	6,004	6,430
Chimacum	na	na	52	909	867	563	1,141
Hood Canal	4,580	20,680	9,496	13,360	13,160	36,024	95,053
Quilcene	1,260	4,570	6,704	7,595	6,050	12,863	63,167
Mainstem Hood Canal	2,980	15,560	2,035	4,248	6,220	11,142	25,889
SE Hood Canal	340	550	757	1,516	890	12,019	5,997

Note: Boxed entries indicate abundance below critical threshold. Bolded entries indicate abundance above recovery threshold.

Another standard is that natural-origin escapement should be stable or increasing and the five year mean escapements must be higher than the critical abundance thresholds. The natural-origin escapements have been estimated for management units and stocks beginning with 2001, the first year when the vast majority of returning supplementation fish were marked and the ongoing sampling of spawners would accommodate separating natural-origin from hatchery-origin for all stocks. Table 5 shows that the four year mean natural-origin recruit (NOR) escapement exceeded the critical threshold for all management units, that annual escapements generally exceeded the critical thresholds, and that, excepting Lilliwaup, the management units and stocks show increasing trends over the four years.

A third standard is that the five-year mean productivity should be greater than 1.2 natural-origin recruits per spawner. As shown in Table 6, mean productivity for the five brood years, 1996 through 2000 (or for available years as indicated), has ranged from 3.22 to 6.89 natural-origin recruits per spawner for the stocks or management units. The table results are based on analysis of collected mark and age data for adult return years 1999 through 2004.

Table 5. Thresholds, actual annual, and mean NOR escapement estimates for Hood Canal summer chum, 2001-2004.						
Management Unit / Stock	Critical Thresh./Flag ¹	2001	2002	2003	2004	Mean
Sequim Bay	200	251	7	68	613	235
Discovery Bay	720	1,222	4,085	3,986	4,392	3,421
Quilcene	1,110	3,048	3,211	10,740	35,838	13,209
Mainstem H.C. ²	2,660	2,616	2,755	8,672	20,720	8,691
Dosewallips	736	757	1,313	6,510	10,325	4,726
Duckabush	700	662	355	1,600	7,850	2,617
Hamma	1042	1,155	1,050	535	2,409	1,287
Lilliwaup	182	41	36	27	136	60
S.E. Hood Canal	300	1,491	872	7,923	3,603	3,472
¹ Shown are critical thresholds that apply to management units and minimum escapement flags that apply to stocks within the Mainstem Hood Canal management unit (WDFW and PNPTT 2000). Values that fall below the applicable threshold/flag are shown with bold and italicized font.						

Table 6. Mean productivity of management units and stocks, brood years 1996-2000	
Management Unit / Stock	1996-2000 Mean Productivity (natural-origin recruits/spawner)
Sequim Bay Jimmycomelately	5.83
Discovery Bay Salmon/Snow	4.23
Port Townsend Chimacum	5.52 ¹
Quilcene/Dabob Bays Big/Little Quilcene	3.22 ²
Mainstem Hood Canal Dosewallips	5.05
Duckabush	6.13
Hamma Hamma	5.68
Lilliwaup	6.45
SE Hood Canal Union	6.89 ³
¹ Applies to only two brood years, 1999 and 2000.	
² Applies to only four brood years, 1997 through 2000.	
³ Applies only to two brood years, 1997 and 1998.	

Recovery Goals

In 2003, the co-managers identified interim recovery goals for individual summer chum stocks that addressed annual abundance (run size) and escapement, productivity, and

diversity (PNPTT and WDFW 2003). The goals were developed with the information available at that time, with the expectation that the recovery standards will be reviewed and revised as more is learned about the population dynamics of Hood Canal summer chum. The recovery goals were based on historic (pre-decline) population sizes and also specified criteria for meeting the thresholds.

More recently, the Puget Sound Technical Recovery Team (PSTRT 2007) identified two independent summer chum populations (Strait of Juan de Fuca and Hood Canal) within the ESU. The PSTRT also identified viable salmonid population criteria providing for low extinction risk for these two populations. The PSTRT supports managing for recovery at the level of the co-managers' individual stocks (or what may be described as sub-populations of the PSTRT's two independent populations) as compatible with and a reasonable intermediate step toward the PSTRT's long-term population viability criteria.

Despite recent abundant returns of Hood Canal summer chum, it will be some time before stocks can meet recovery thresholds over the period of twelve years required by the recovery goals (WDFW and PNPTC 2007b). These interim goals will be revisited as more is learned about summer chum population dynamics and productivity. One important issue remaining involves how to include reintroduced summer chum populations in recovery goal setting.

Conclusion

The overall goal of the SCSCI is "To protect, restore and enhance the productivity, production, and diversity of Hood Canal summer chum salmon and their ecosystems to provide surplus production sufficient to allow future directed and incidental harvests of summer chum salmon." The SCSCI acknowledged that both short-term and long-term measures would be necessary to meet that goal. Recent returns of summer chum to Hood Canal indicated that the short-term measures have been highly successful. Harvest reductions and supplementation programs, along with favorable freshwater and marine conditions are all believed to have contributed to the recent success in recovering the summer chum populations. The total abundance and escapement of summer chum in 2004 were the largest on record for Hood Canal and returns in 2005 and 2006 have been good. Although summer chum stocks are not yet meeting the Co-managers' recovery targets, recent returns are a positive sign that the goals can be met.

The true measure of success of recovery efforts must be viewed over the longer term, as supplementation programs are discontinued, and as summer chum potentially face less favorable freshwater and marine survival regimes. There is good reason to be optimistic that summer chum can remain at abundances higher than pre-supplementation levels even after supplementation is stopped, as has happened with South Puget Sound summer chum (Ames and Adicks 2003). Continued monitoring of escapement and abundances, careful management of harvest rates, and commensurate protection and/or restoration of habitat critical to Hood Canal summer chum are all imperative if the goal of the SCSCI is to be met. On-going data collection will contribute to better understanding of the population dynamics of Hood Canal summer chum, and will help to focus long-term management actions to maximize benefits to summer chum.

References

- Adicks, K., J. Ames, and T.H. Johnson. 2005. ESA-listed Hood Canal Summer Chum Salmon: A brief update on supplementation programs, extinction risk, and recovery goals. Pages 161-172 in Proceedings of the 22nd Northeast Pacific Pink and Chum Salmon Workshop. Ketchikan, Alaska. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Allendorf, F.W., D. Bayles, D.L. Bottom, K.P. Currens, C.A. Frissell, D. Hankin, J.A. Lichatowich, W. Nehlsen, P.C. Trotter, and T.H. Williams. 1997. Prioritizing Pacific salmon stocks for conservation. *Conservation Biology* Vol. 11. No. 1. p. 140-152.
- Ames, J. and K. Adicks. 2003. Chum salmon supplementation: Bane or Boon? Proceedings of the 21st Northeast Pacific Pink and Chum Salmon Workshop. Department of Fisheries and Oceans. Vancouver, B.C. Canada. p. 168-184. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Hatchery Scientific Review Group (HSRG)—Lars Mobrand (chair), John Barr, Lee Blankenship, Don Campton, Trevor Evelyn, Conrad Mahnken, Paul Seidel, Lisa Seeb and Bill Smoker. March 2002. Hatchery Reform Recommendations for the Puget Sound and Coastal Washington Hatchery Reform Project: Eastern Strait of Juan de Fuca, South Puget Sound, Stillaguamish and Snohomish rivers. 161 p. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101 (available from www.hatcheryreform.org).
- Hatchery Scientific Review Group (HSRG)—Lars Mobrand (chair), John Barr, Lee Blankenship, Don Campton, Trevor Evelyn, Conrad Mahnken, Paul Seidel, Lisa Seeb and Bill Smoker. March 2004. Hatchery Reform Recommendations for the Puget Sound and Coastal Washington Hatchery Reform Project: Hood Canal, Willapa Bay, North Coast, Grays Harbor. 291 p. Long Live the Kings, 1305 Fourth Avenue, Suite 810, Seattle, WA 98101 (available from www.hatcheryreform.org).
- Hood Canal Coordinating Council (HCCC). 2005. Hood Canal and Eastern Strait of Juan de Fuca Summer Chum Salmon Recovery Plan. Hood Canal Coordinating Council. 334 p. plus eight appendices. Available at <http://hccc.wa.gov/SalmonRecovery/>
- Johnson, T.H. and C. Weller. 2003. On-going supplementation programs for summer chum salmon in the Hood Canal and Strait of Juan de Fuca regions of Washington State. Proceedings of the 21st Northeast Pacific Pink and Chum Salmon Workshop. Department of Fisheries and Oceans. Vancouver, B.C. Canada. p. 201-217. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- National Marine Fisheries Service (NMFS). 2001. Determination that Washington Dept. of Fish and Wildlife and Point No Point Treaty Tribes harvest resource management plan meets the requirements of Limit 6 under the ESA 4(d) rule. Federal Register Notice. Vol. 66, No. 113, pp. 31600-31603.
- NMFS. 2002. Decision Memorandums stating Hatchery and Genetic Management Plans submitted by Washington Dept. of Fish and Wildlife and U.S. Fish and Wildlife meet the requirements of Limit 5 under the ESA 4(d) rule. Two memorandums by Robert Lohn dated February 26, 2002. 8p. and 5p.
- NMFS. 2007a. Recovery Plan for the Hood Canal and Eastern Strait of Juan de Fuca Summer Chum Salmon (*Oncorhynchus keta*) National Marine Fisheries Service, Northwest Region. Portland, OR. 53 p. Available at

- http://www.nwr.noaa.gov/Salmon-Recovery-Planning/Recovery-Domains/Puget-Sound/upload/HCC_Supplement.pdf
- NMFS. 2007b. Adoption of ESA Recovery Plan for the Hood Canal and Eastern Strait of Juan de Fuca Summer Chum Salmon ESU. Federal Register Notice. Vol. 72, No. 100, pp. 29121-29126. Available at <http://www.nwr.noaa.gov/Publications/FR-Notices/2007/upload/72FR29121.pdf>
- Point No Point Treaty Tribes (PNPTT) and Washington Department of Fish and Wildlife (WDFW). 2003. Interim summer chum salmon recovery goals. Supplemental Report No. 5, Summer Chum Salmon Conservation Initiative – An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca. Wash. Dept. of Fish and Wildlife. Olympia, WA. 33 p. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Puget Sound Technical Recovery Team (PSTRT). 2007. Dawgz ‘N the Hood: The Hood Canal Summer Chum Salmon ESU. Part 1. Identification of independent populations within the Hood Canal summer chum ESU. Part II. Viability criteria for the Hood Canal summer chum ESU and populations. 2/28/07 DRAFT. 64 p. Draft report available at following web site address: http://www.nwfsc.noaa.gov/trt/trt_documents/hood_canal_summer_chum_se-su280207final-1corr.pdf.
- Recovery Science Review Panel (RSRP). 2004. Report for meeting held August 30-September 2, 2004. 17 p. Northwest Fisheries Science Center, Seattle, Washington. (available at http://www.nwfsc.noaa.gov/trt/rsrp_docs/rsrpreportsept30_2004e.pdf)
- Schroder, S. and J. Ames. 2004. Protocols for summer chum salmon supplementation recovery projects. Supplemental Report No. 6, Summer Chum Salmon Conservation Initiative – An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca. Wash. Dept. of Fish and Wildlife. Olympia, WA. 36 p. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Tynan, T.J., C. Weller, and T.H. Johnson. 2003. Supplementation standards for recovering ESA-listed threatened summer-run chum populations in the Hood Canal and Strait of Juan de Fuca regions of Washington. Proceedings of the 21st Northeast Pacific Pink and Chum Salmon Workshop. Department of Fisheries and Oceans. Vancouver, B.C. Canada. p. 185-200. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty (PNPT) Tribes. 2000. Summer Chum Salmon Conservation Initiative - An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca Region. Wash. Dept. of Fish and Wildlife. Olympia, WA. 800 p. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty (PNPT) Tribes. 2001. Annual report for the 2000 summer chum salmon return to the Hood Canal and Strait of Juan de Fuca region. Supplemental Report No. 3, Summer Chum Salmon Conservation Initiative - An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca Region. December 2001. Wash. Dept. of Fish and Wildlife. Olympia, WA. 123 p. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).

- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty (PNPT) Tribes. 2003. Report on summer chum salmon stock assessment and management activities for 2001 and 2002. Supplemental Report No. 4, Summer Chum Salmon Conservation Initiative – An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca. October 2003. Wash. Dept. of Fish and Wildlife. Olympia, WA. 219 p. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).
- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty Council (PNPTC). 2004. 2003 Progress report on Hood Canal summer chum salmon. Memorandum dated September 9, 2004. 22 p. Available at <http://wdfw.wa.gov/fish/chum/library/>.
- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty Council (PNPTC). 2005. 2004 Progress report on Hood Canal summer chum salmon. Memorandum dated February 10, 2005. 15 p. Available at <http://wdfw.wa.gov/fish/chum/library/>.
- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty Council (PNPTC). 2006. 2005 Progress report on Hood Canal summer chum salmon. Memorandum dated March 1, 2006. 18 p. Available at <http://wdfw.wa.gov/fish/chum/library/>.
- Washington Department of Fish and Wildlife (WDFW) and Point No Point Treaty Council (PNPTC). 2007a. 2006 Progress report on Hood Canal summer chum salmon. Memorandum dated May 31, 2007. 26 p. Available at <http://wdfw.wa.gov/fish/chum/library/>.
- Washington Department of Fish and Wildlife and Point No Point Treaty Tribes. 2007b. Five-year review of the Summer Chum Salmon Conservation Initiative: Supplemental Report No. 7, Summer Chum Salmon Conservation Initiative – An Implementation Plan to Recover Summer Chum in the Hood Canal and Strait of Juan de Fuca Region. December, 2007. Wash. Dept. Fish and Wildlife. Olympia, WA. 235 p., including Appendices. Available at the WDFW website (<http://wdfw.wa.gov/fish/chum/library/>).

Hatchery Chum Salmon Straying into Southeast Alaska Streams

Andrew W. Piston

Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 205, Ketchikan, AK 99901, (907) 225-9677, andrew.piston@alaska.gov

Hatchery production of chum salmon in Southeast Alaska increased dramatically over the last two decades, from 8.7 million fry released at eight locations in 1980, to 367 million fry released at 16 locations in 2006. Hatchery fish accounted for an average of 75% of the commercial harvest of chum salmon—94 million fish—over the 10 years, 1995–2004 (Heinl 2005). In 2006, the estimated proportion of hatchery-produced chum salmon in the Southeast Alaska commercial fisheries was almost 85% (White 2007). Although the Alaska Department of Fish and Game (ADF&G) is concerned about straying of all species released from hatcheries, the scale of the chum salmon releases makes this one of the most important species to monitor in Southeast Alaska. In 2008, we will be conducting the initial season of a

study designed to estimate the fraction of hatchery chum salmon strays in wild stock index streams in Southeast Alaska.

Alaska's Sustainable Salmon Policy states that "wild salmon stocks and fisheries on those stocks should be protected from adverse impacts from artificial propagation and enhancement efforts (5 AAC 39.222)." High rates of straying would make it difficult for fisheries managers to monitor chum salmon populations through standard survey techniques, and greatly reduce the department's ability to formulate meaningful escapement goals and test whether those goals are being met for wild chum salmon populations as required by the Sustainable Salmon Fisheries Policy. Although ADF&G has implicitly assumed that hatchery-reared chum, coho, sockeye, and Chinook salmon successfully home to their release site, there have been no organized, region-wide studies to assess the rate of straying of hatchery salmon in Southeast Alaska, nor studies to assess the effect of this straying on wild populations.

The Alaska Department of Fish and Game currently tracks wild salmon escapements in Southeast Alaska by different means, using species-specific programs that developed over time. For pink salmon, Heintz and Geiger (2005) described an abundance index derived from a series of aerial peak counts using 718 streams annually surveyed in Southeast Alaska. This escapement measure is not a measure of total abundance, but rather it is a time series intended to show the relative trends in escapement size going back to 1960. Heintz (2005) developed an index for chum salmon, similar to the pink salmon index, using 82 streams distributed across the Southeast region (increased to 89 streams in 2007). This index for wild chum salmon escapements has shown a slight upward trend over the past two decades. An obvious criticism of this approach is that this index may have increased because of an increase in hatchery strays, while the actual wild-stock escapements did not increase, or could have even declined.

From 1995 to 2002, ADF&G collected otolith samples from 15 summer chum salmon streams, primarily near Juneau, in northern Southeast Alaska (Table 1). Nearly all of the streams sampled were within 50 km of the nearest hatchery release site. Although many of the samples were small and not representative of run-timing within each system, they indicate that a significant number of hatchery strays were present in the summer chum salmon systems that were examined. The four Juneau area chum salmon index streams that were sampled (Berners River, Fish Creek, Peterson Creek, and Sawmill Creek) had a very high proportion of hatchery strays. Approximately 60% of the fish sampled in these index systems were hatchery strays from local release sites (Table 1). Non-index streams that were sampled in the Juneau area (Cowee Creeks, Gilkey River, Gold Creek, Salmon Creek, Ralphs Creek, Lawson Creek, Eagle River, Slocum Creek, Lace River) also had a relatively high proportion of hatchery strays. In contrast to summer chum salmon streams, samples collected from three large fall chum salmon systems in the northern Southeast Alaska (the Taku, Chilkat, and Alsek rivers) showed virtually no evidence of hatchery straying, which would be expected given that there are no large-scale fall chum salmon release sites in northern Southeast Alaska.

Table 1. Chum salmon streams sampled for otoliths in Southeast Alaska, 1995-2002.

Stream Name	ADF&G Stream Number	Sample Date	Year	Wild Chum Salmon	Hatchery Marked Chum Salmon	Number Sampled	Proportion of Strays
Alsek River	182-30-010	13-Oct	2000	50	0	50	0%
Berners River	115-20-010	August	1996	1	11	12	92%
Berners River	115-20-010	6-Aug	2000	21	9	30	30%
Berners River	115-20-010	15-Aug	2001	17	2	19	11%
Chilkat River	115-32-025	24-Jul	2000	20	1	21	5%
Chilkat River (24 Mile Channel)	115-32-025	Sept - Oct	2000	126	1	127	1%
Chilkat River (Herman Creek)	115-32-048	Aug - Oct	2000	112	0	112	0%
Chilkat River (Klehini River)	115-32-046	28-Sep	2000	43	0	43	0%
Chilkoot River	115-33-030	24-Jul	2000	6	16	22	73%
Cowee Creek	115-20-062	17-Aug	1996	4	20	24	83%
Eagle River	111-40-092	14-Aug	1995	12	6	18	33%
Fish Creek	111-50-069	July - August	1995	28	17	45	38%
Fish Creek	111-50-069	1-Aug	1996	15	51	66	77%
Gilkey River	115-20-030	9-Aug	1996	27	2	29	7%
Gold Creek	111-40-020	6-Aug	1996	67	3	70	4%
Cowee Creek	111-40-090	17-Aug	1996	35	13	48	27%
Lace River	115-20-020	8-Aug	1996	33	9	42	21%
Lawson Creek	111-40-089	17-Aug	1995	5	0	5	0%
Lawson Creek	111-40-089	8-Aug	1996	51	8	59	14%
Peterson Creek	111-50-010	August	1995	12	10	22	45%
Peterson Creek	111-50-010	6-Aug	1996	0	50	50	100%
Ralphs Creek	112-21-006	31-Jul	2002	59	1	60	2%
Salmon Creek	111-40-015	August	1995	63	8	71	11%
Salmon Creek	111-40-015	August	1996	35	38	73	52%
Sawmill Creek	115-20-052	18-Aug	1995	21	2	23	9%
Sawmill Creek	115-20-052	17-Aug	1996	5	18	23	78%
Slocum Creek	111-32-099	14-Aug	1996	10	40	50	80%
Taku River	111-32-032	6-Jul	1996	4	2	6	33%
Taku River	111-32-032	August	1998	10	0	10	0%
Taku River	111-32-032	4-Oct	2000	43	0	43	0%
Summer Chum Total				527	334	861	38.8%
Fall Chum Total ¹				404	2	406	0.5%

¹ Six fish sampled at Taku River on 6 July 1996 not included in fall chum totals

In 2006, we collected otolith samples from chum salmon carcasses at Traitors Creek (ADF&G Stream Number 101-90-029), located in the next bay south of Neets Bay hatchery in southern Southeast Alaska. The creek mouth is approximately 35 km by water from the release site in Neets Bay. Traitors Creek was historically an important producer of wild chum salmon (e.g., chum escapement of 32,000 in 1962). We collected 192 otolith samples on three separate sampling events from early to late August; 87% of the samples had hatchery marks, primarily from Neets Bay hatchery. This otolith sampling indicates that recent wild-stock escapement estimates in this system have been inflated by large numbers of hatchery strays.

In 2007, we collected otolith samples from chum salmon carcasses at Fish Creek (ADF&G Stream Number 101-15-085), a chum salmon index stream near Hyder, Alaska. The nearest hatchery release site to Fish Creek is located approximately 180 km south in

Nakat Inlet. We collected 148 otolith samples on two sampling events conducted 13 and 27 August 2007, and found no otolith marked fish.

Without implementing a program to sample chum salmon for otolith marks in streams at varying distances to hatchery chum salmon release sites, we have no way of knowing if the region-wide upward trend in our wild chum salmon stocks reflects increased wild chum salmon abundance, or if it is simply a result of increased hatchery chum salmon production over the past two decades. Currently, most of the information we have concerning chum salmon straying is for streams located relatively close to hatchery release sites. The limited sampling conducted to this point indicates that aerial escapement estimates for streams within 50 km of a hatchery release site (distance by water) are likely to be biased high to some degree by the presence of hatchery chum salmon strays. Outside of the Fish Creek sample (ADF&G stream number 101-30-085), we have little information concerning hatchery straying into streams located greater than 50 km from hatchery release sites. In addition, almost all of the samples collected have been from the Juneau and Ketchikan areas and large regions of Southeast Alaska have not been sampled at all.

In 2008, ADF&G will conduct a study to look at straying by hatchery chum salmon into wild stock chum salmon index streams in Southeast Alaska. Our purpose with this study is to estimate the fraction of hatchery strays in the chum salmon wild-stock escapement index for each management area in Southeast Alaska. In the initial year of this study, we will be sampling streams in the Ketchikan and Sitka management areas, as well as streams in and around Tenakee Inlet in the Juneau management area. Under the assumption that some release strategies may make returning hatchery fish more prone to straying, we will develop a list of all hatchery chum salmon release groups with major age classes returning during the study period. Each release will be classified as to (1) remote release or not, (2) early release or late release, (3) and other categories to be defined later. We will use this information to evaluate the relationship between hatchery release strategies and straying rates in hatchery produced chum salmon.

References

- Heinl, S. C. 2005. Chum salmon stock status and escapement goals in Southeast Alaska 2005 [in] J. A. Der Hovanisian and H. J. Geiger, editors. Stock status and escapement goals for salmon stocks in Southeast Alaska 2005. Alaska Department of Fish and Game, Special Publication No. 05-22, Anchorage.
- Heinl, S.C. and H.J. Geiger. 2005. Pink salmon stock status and escapement goals in Southeast Alaska 2005 [in] J. A. Der Hovanisian, and H. J. Geiger, editors. Stock status and escapement goals for salmon stocks in Southeast Alaska 2005. Alaska Department of Fish and Game, Special Publication No. 05-22, Anchorage.
- White, B. 2007. Alaska salmon enhancement program 2006 annual report. Alaska Department of Fish and Game, Fishery Management Report No. 07-04, Anchorage.

SOUTHERN POPULATIONS

Chair: Orlay Johnson

Population changes and genetics of chum salmon in the southern portion of their range (California, Oregon, and Columbia River) and possible impacts of climate and other changes.

Orlay W. Johnson, Anna Elz, and Jeffrey J. Hard

NOAA, National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Blvd. East, Seattle, WA 98112. 206-860-3253 orlay.johnson@noaa.gov

Spawning populations of chum salmon historically extended as far south as the San Lorenzo River in California and 322 km upstream in the Sacramento River. In 1905-06 chum salmon juveniles were the most abundant salmon species in streams surveyed between the Sacramento and Columbia rivers. Today, these populations have greatly declined, and in the Columbia River are now listed under the ESA as a threatened species. Little life history, genetic, or other biological information has been developed on these fish. This information is important as southern populations may represent remnants of historical populations with characteristics essential to the successful restoration of depleted present day populations.

Information developed in conjunction with ODFW, WDFW, and USFWS includes demographic, genetic, and life history data, such as presence or absence of spawning populations, age structure, and timing of migrations. Preliminary microsatellite genetic data indicate population structure among coastal populations and differences from interior and Puget Sound runs. Coastal populations may also contain unique genotypes and adaptations which may be important as increasingly rapid changes in climate, pollution impacts, and development expose salmonids to pressures beyond their ability to adapt, forcing further declines and even extinction.

Estimates of genetic introgression into North Creek chum salmon from historic Hood Canal-origin chum salmon supplementation using microsatellites and single nucleotide polymorphisms

Denise K. Hawkins, Scott M. Blankenship, Sewall F. Young, Jennifer Von Bargen, Cherril Bowman, and Kenneth I. Warheit

Washington Department of Fish and Wildlife, Molecular Genetics Laboratory

Contact: hawkidkh@dfw.wa.gov

During the 1970s and 1980s, south Puget Sound streams received chum salmon outplants with Hood Canal ancestry. North Creek, a tributary to Gig Harbor received some of those fish by-way-of Minter Creek Hatchery, which is on Carr Inlet. Washington Department of Fish and Wildlife (WDFW) established a goal of removing Hood Canal genes from South Puget Sound chum salmon populations and set an upper threshold on introgression of Hood Canal chum salmon genes at 5%. A regional enhancement group wants to collect and spawn chum at North Creek, and incubate the eggs on-site for release into the stream, but can do so only if estimates of Hood Canal ancestry are below that 5% threshold for 5 consecutive years. WDFW's Genetics laboratory has estimated introgression levels in the North Creek chum population using allozyme and microsatellite markers. Here

we use single nucleotide polymorphism (SNP) assays that were developed with ascertainment panels that focused on separating western Alaskan populations, to make a parallel assessment of introgression in the North Creek population. We assess the relative power of our chum salmon microsatellite panel and the SNP markers that were developed with an Alaskan ascertainment bias, and we examine the concordance of the two sets of estimates.

Lower Columbia River chum salmon genetic population structure estimates using microsatellites and single nucleotide polymorphisms

Sewall F. Young, Maureen P. Small, Jennifer Von Bargen, Denise K. Hawkins, and Kenneth I. Warheit

Washington Department of Fish and Wildlife, Molecular Genetics Laboratory

Contact: youngsfy@dfw.wa.gov

Historic records suggest that chum salmon once may have spawned in the Columbia River basin as far inland as the Walla Walla River, over 500 km from the Pacific Ocean. Typical run sizes were likely one million or more returning adults. By the late 1950s, chum salmon returns to the Columbia basin had decreased to several hundred fish per year, spawning in the Columbia River and its tributaries below Bonneville Dam. We used a suite of 17 microsatellite loci to characterize chum populations from three ecoregions in the lower Columbia basin and found significant heterogeneity in genotypic distributions between samples collected in the three regions. We analyzed the same groups with a panel of single nucleotide polymorphism (SNP) assays that were developed to distinguish western Alaskan chum populations to evaluate their power for population discrimination at the southern end of the eastern Pacific range of chum salmon. We also used the SNP panel to characterize samples from the Abishiri River on Hokkaido in Japan to look for evidence of genetic introgression from over one million fry planted into the Elochoman River in the 1970s.

**GLOBEC and International
Chair: Katherine Myers**

Morphological development and molecular expression of the olfactory organ in chum salmon (*Oncorhynchus keta*)

Hideaki Kudo, Masakazu Shinto and Masahide Kaeriyama
Laboratory of Strategic Studies on Marine Bioresource Conservation and Management,
Graduate School of Fisheries Sciences, Hokkaido University,
3-1-1, Minato-cho, Hakodate 041-8611, Japan
(tel & fax: 81 138 40 5602, e-mail: hidea-k@fish.hokudai.ac.jp)

It is generally accepted that anadromous salmonids imprint some odorants of their natal streams at the seaward migration, and use their olfaction for discriminating those streams during spawning migration. Despite the importance of the olfactory organ for the olfactory imprinting, developmental process of this organ is not well understood in Pacific salmon (*Oncorhynchus* spp.). Olfactory stimuli are transmitted to the brain through two cell types (ciliated and microvillus) of the olfactory receptor cells in olfactory organ. We analyzed the morphological developments of olfactory organs in chum salmon (*O. keta*) during the period of their life history. In addition, we performed molecular morphological observation in order to identify cell types of the olfactory receptor cells. Number of olfactory lamellae in one side of the olfactory organ indicated about 4.5 lamellae in the fry stage, and reached a state of equilibrium at about 18 lamellae after high seas phase (Fig. 1A). Chum salmon had about 370,000 cells in the fry stage and 21 million cells at the maturity in one side of this organ (Fig. 1B). In the immunohistochemistry, the olfactory marker protein (OMP) localized the mature ciliated olfactory receptor cells (Fig. 2B), and glutathione S-transferase (GST) localized both ciliated and microvillus olfactory receptor cells (Fig. 2C). Expressions of OMP and GST in the olfactory receptor cells could distinguish both cell types. Our results provide the first quantitative analysis of number of the olfactory receptor cells and the method for distinction of two the olfactory receptor cell types in Pacific salmon.

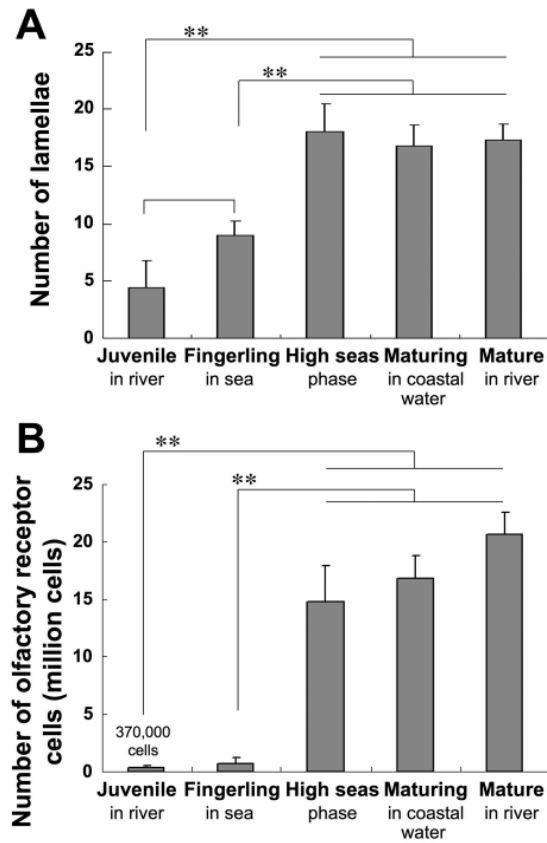


Figure 1. Changes in number of olfactory lamellae and receptor cells on each side of chum salmon olfactory rosettes. A, Number of olfactory lamellae. B, Number of olfactory receptor cells. **, $p < 0.01$

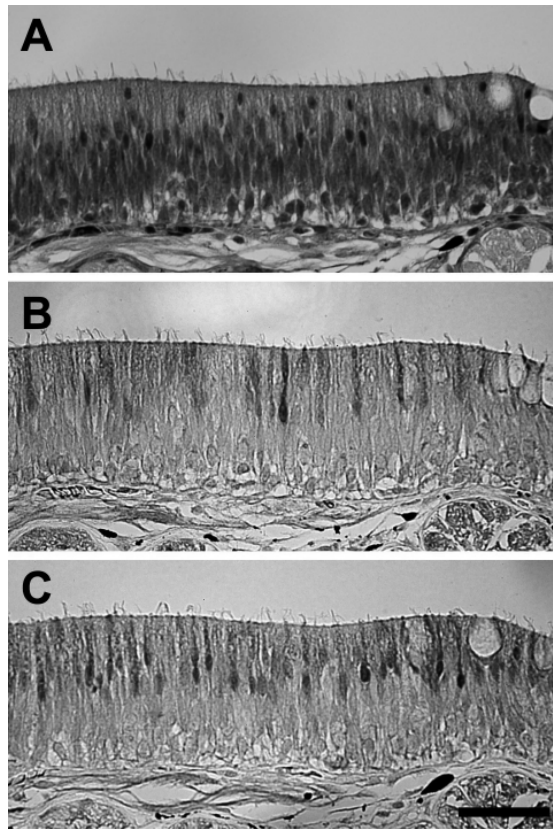


Figure 2 Protein expressions of OMP and GST in the chum salmon olfactory epithelium. **A.** Hematoxylin and eosin staining. **B.** Immunohistochemistry of OMP. **C.** Immunohistochemistry of GST. Scale bar indicates 50 μ m.

Modeling the feeding and growth potential of juvenile pink salmon in the Gulf of Alaska

Michael M. Mazur

School of Aquatic and Fisheries Sciences, University of Washington

Box 355020, Seattle, WA, 98195-5020, USA

(206) 616-3660 mazurm@u.washington.edu

A bioenergetics-based light-dependent foraging model for juvenile pink salmon (*Oncorhynchus gorbuscha*) was integrated within a spatially-explicit framework to investigate the influence of temperature, prey quality, and prey quantity on the size-specific growth potential of age-0 pink salmon during the fall of 2004. The quality of pelagic habitat in terms of the volumetric proportion of the Coastal Gulf of Alaska offering positive growth to a juvenile salmon was quantified and used to identify potential spatial and temporal periods of growth limitation for juvenile pink salmon. The bioenergetics-based light-dependent foraging model provided a reliable, predictive approach for evaluating the spatio-temporal trade-offs between food types, feeding, temperature, and growth. Similarly, the model was able to account for the non-linear influences of fish body size, and water temperature critical to the feeding and growth process of juvenile salmon. These results

support the utility of these models for quantifying the availability of growth habitat for pelagic fishes and illustrate their potential as a predictive tool for fisheries management.

Winter Distribution of chum salmon in the central Gulf of Alaska

Shigehiko Urawa*, Shunpei Sato, Toshiki Kaga, Masaya Takahashi, Bev Agler, Ron Josephson, Terry Beacham, and Masa-aki Fukuwaka

*North Pacific Anadromous Fish Commission, Suite 502, 889 West Pender St., Vancouver, B.C., Canada V6C 3B2; phone: 604-775-5550; e-mail: urawa@npafc.org

Winter is believed to be a crucial period for marine salmon survival, but little biological data exists to support this hypothesis. In mid February 2006, a winter research cruise was conducted to examine the spatial distribution and biological status of salmon in the central Gulf of Alaska. A total of 535 chum salmon were caught at 7 stations (48-54°N, 145°W) by surface trawl. The water temperature (4.5- 6.5°C) of their winter habitat was apparently lower than that of the summer habitat. Ocean age 2 and 3 fish were dominant at all sampling stations, and young fish (ocean age 1) were distributed in the warmer southern waters. The samples included 46 otolith marked fish released from hatcheries in Prince William Sound (PWS, n=7), southeast Alaska (n=37), British Columbia (n=1), and Japan (n=1). The stock composition of chum salmon biomass estimated by 14 microsatellite loci markers was 11.1% western Alaska/Peninsula, 10.9% PWS, 15.9% southeast Alaska, 5.6% northern BC, 16.7% southern BC, 1.7% Washington, 17.5% Russian, and 19.8% Japanese stocks. All young fish (ocean age 1) were North American origin (mostly PWS, southeast Alaska and southern BC), while the proportion of Asian stocks increased with the ocean ages. Asian and Alaskan chum salmon were relatively abundant between 48°N and 51°N, while BC stocks were abundant in the northern water (50-53°N). The results confirmed that the Gulf of Alaska is an important winter habitat for various chum salmon stocks of North American and Asian origins. Our trophic analysis suggests that young fish are extremely undernourished during winter. Further winter surveys should be beneficial to understand the marine mortality of salmon.

Marine habitat use and its effect on Growth and Condition of Juvenile Pink Salmon in the Northern Gulf of Alaska

Lewis Haldorson¹, Milo Adkison¹, Jack Piccolo¹, Jennifer Boldt¹, Steve Moffitt², Jamal Moss³

¹School of Fisheries and Ocean Sciences
University of Alaska Fairbanks, Juneau

²Alaska Dept. of Fish & Game, Cordova AK

³NMFS, NOAA, Auke Bay Laboratory, Juneau

Juvenile pink salmon released from hatcheries in Prince William Sound (PWS) sequentially occupy three distinctly different habitats during summer: PWS, the Alaska Coastal Current (ACC) and shelf water seaward of the ACC front (SHELF). PWS is a large estuary (9000 km²) that has a relatively fresh mixed-layer during the summer due to large amounts of freshwater input. The ACC is a fast-flowing coastal current that typically

extends 30 – 40 km from the shore. SHELF water seaward of the ACC front is notably more saline than the ACC. In 2001 – 2004 juvenile pink salmon were sampled as they migrated through the three habitats. Growth and condition were estimated for fish from each hatchery, based on an exponential growth model and residuals from weight - length regression. Growth was consistently fastest in fish sampled in SHELF water, especially compared to those from the ACC habitat. Fish from the SHELF habitat were also consistently in better condition (than those found elsewhere). There were also differences among years in both growth and condition, with fastest growth and better condition found in fish sampled in 2002 and 2004. Interannual variation in growth and condition, especially among fish from the SHELF habitat, appears to be related to survival of hatchery pink salmon.

Interannual and Spatial Feeding Patterns of Hatchery and Wild Juvenile Pink Salmon in the Gulf of Alaska in Years of Low and High Survival.

Janet L. Armstrong*, Katherine W. Myers, David A. Beauchamp,
Nancy D. Davis, Robert V. Walker
School of Aquatic and Fishery Sciences
University of Washington Box 355020 Seattle, WA 98195-5020

To improve understanding of mechanisms affecting growth and survival, we evaluated summer diets and feeding patterns (prey composition, energy density, stomach fullness) of large and small, hatchery and wild juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound (PWS), Alaska, and in three different habitat regions of the northern coastal Gulf of Alaska (CGOA). Our 6-yr study (1999-2004) included two years each of low (~ 3%), mid (~5%), and high (~8-9%) survival of PWS hatchery pink salmon. Since variation in diet of juvenile pink salmon should affect growth and ultimately survival, we expected variation in diet, growth and survival to be correlated. Diet composition and gut fullness in July and August, but not September was significantly different among years, but we could not identify any consistent differences composition or gut fullness between low- and high-survival years. Within years, no significant differences were found in diet composition or gut fullness between hatchery and wild fish or among the four PWS hatchery stocks. Diets varied by water mass (habitat) as juveniles moved from PWS to progressively more saline habitats in the CGOA. In July, when juveniles were most abundant in PWS, their diets were dominated by pteropods and hyperiid amphipods. Once fish moved to inner-shelf (least saline) habitat in the CGOA in July, their diets were dominated by larvaceans in low-survival years or pteropods in high-survival years. Diet quality was higher in CGOA habitats than in PWS in July but had no consistent relationship to annual survival. In August, fish moved to the more productive outer-shelf (most saline) CGOA, where large copepods and pteropods were dominant prey. Our results indicate that spatial variation in diets of juvenile pink salmon in July and migration to the inner-shelf CGOA play a critical role in marine growth and survival.

Scale Measurements Indicate Size-Selective Mortality in Prince William Sound Pink Salmon

R.V. Walker and J.A. Armstrong

School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020

Use of thermal otolith marks and scale growth measurements allows comparison of size-at-age between juvenile pink salmon released from Prince William Sound hatcheries and surviving adults that returned to the same hatcheries the following year. A previous analysis of scales from 2001 release groups showed that faster-growing fish during their first summer in the ocean had higher survival rates than slower-growing fish (Moss et al. 2005). Comparisons were made at similar landmarks (circulus number) on scales of juveniles and surviving adults of the same cohort for growth during the first summer.

The analysis was extended to juveniles and adults from 2002-2004 release groups (Cross et al. in press). Hatchery juveniles were significantly larger during 2002 and 2004 (years of higher survival) than during 2001 and 2003 (years of lower survival). In all four years surviving fish began growing faster than the average juvenile in mid-summer (determined from scales of returning adults), and scale size distributions of surviving fish and all juveniles diverge as summer progresses (Cross et al. in press). This demonstrates that larger, faster-growing juveniles experienced higher survival, and significant size-selective mortality occurs after the first growing season.

These results support the “critical size – critical period” hypothesis, which postulates that in addition to an early period of predation-based mortality, salmon year class strength is also influenced by a later physiologically-based mortality (Beamish and Mahnken 2001). “Juvenile salmon that fail to reach a critical size by the end of their first marine summer do not survive the following winter.”

We updated the previous studies with scales from hatchery returns in subsequent years and from open-ocean sampling in earlier years. Scales from adults returning from 2005-2006 releases showed a similar tendency, with less scale growth in late summer in a year with poor survival, and better growth in a year with higher survival. No sampling for juvenile pink salmon in late summer has been conducted since 2004, preventing further comparisons of growth of average juveniles with those that survive.

In contrast, summer scale growth from unmarked (origins unknown) pink salmon caught in 1994-2002 in the Gulf of Alaska by the training ship *Oshoro maru* showed no relation to survival rates. However, these samples (from 52°-56°N along longitude 145°W in early July) include a number of stocks (such as Kodiak, Cook Inlet, and other areas of south central and southeastern Alaska) in addition to Prince William Sound fish. The lack of an overall relationship to Prince William Sound hatchery survival indicates that summer growth influencing survival may differ from region to region, even in geographically contiguous areas. Monitoring growth of Prince William Sound pink salmon in late summer may provide a useful predictor of survivorship the following year.

References

Beamish, R.J. and C. Mahnken. 2001. Prog. Oceanography 49: 423-437.

- Cross, A.D., D.A. Beauchamp, K.W. Myers, and J.H. Moss. In Press. Early marine growth of pink salmon in Prince William Sound and the coastal Gulf of Alaska during years of low and high survival. *Transactions Am. Fish. Soc.*
- Moss, J.H., D.A. Beauchamp, A.D. Cross, K.W. Myers, E.V. Farley, Jr., J.M. Murphy, and J.H. Helle. 2005. Evidence for size-selective mortality after the first summer of ocean growth by pink salmon. *Transactions Am. Fish. Soc.* 134: 1313-1322.

Interannual Patterns in Stage-Specific Feeding, Growth, and Survival of Pink Salmon in the Gulf of Alaska

Dave Beauchamp¹, Kate Myers¹, Jan Armstrong¹, Mike Mazur¹, Trey Walker¹, Nancy Davis¹, Jamal Moss², and Ed Cokelet³, and Peggy Sullivan^{1,4}

¹ University of Washington, School of Aquatic & Fishery Sciences, Box 355020
Seattle, WA 98195-5020

² NOAA Fisheries, Auke Bay Lab

³ Pacific Marine Environmental Lab., 7600 Sand Point Way NE, Seattle, WA 98115

⁴ Joint Institute for the Study of the Atmosphere and Ocean
3737 Brooklyn Ave NE, University of Washington, Box 355672, Seattle, WA 98195

The goals of the U.S. GLOBEC (Global Ocean Ecosystems Dynamics) program are to understand and predict how populations of marine animals (holozooplankton, fish, and benthic invertebrates) respond to global climate changes. The focal species of fish in the GLOBEC coastal Gulf of Alaska (CGOA) program is pink salmon. This paper provides a brief overview of our GLOBEC CGOA research on stage-specific feeding, growth and survival of juvenile pink salmon. Our objectives are (1) to relate inter-annual growth variation in juveniles to adult survival, (2) to determine timing and relative magnitude of stage-specific, size-selective mortality, (3) to determine inter-annual variation in summer distribution, diet, and thermal experience, (4) to estimate inter-annual variation in monthly feeding rate of pink salmon during their first summer, and (5) to determine the relative importance of temperature, feeding rate, and prey quality for influencing inter-annual growth and survival. To date, our major results and conclusions are, as follows:

- Ocean survival is related to juvenile size and growth
- Significant size-selective mortality occurs after the first summer and is correlated with higher overall marine survival
- High ocean survival is correlated with:
 - Higher juvenile feeding and growth rates
 - Growth of survivors diverged from “average” during July-August
 - Broader spatial distribution during the first summer
- Climate effects on growth and survival
 - Minor direct thermal effects on summer growth metabolism
 - Major bottom-up effects on prey composition and availability
 - Feeding rate influences summer pink salmon growth more than temperature or prey quality in CGOA
 - Non-crustacean zooplankton prey are very important in pink salmon diets

BANQUET PRESENTATION

A Science of the Long View

Thoughts on Fishery Science for an Uncertain World

Robert R. Fuerstenberg

Sr. Ecologist, King County Department of Natural Resources and Parks

Seattle, Washington

Introduction

I owe two debts for the subject of this address: the first to Peter Schwartz and his outstanding book “The Art of the Long View”, which introduced me to important concepts of strategic thinking for an uncertain world; and the second to Lance Gunderson and Carl Folke of the Resilience Alliance who have taken an obscure ecological concept and enlarged it for the work of science and society. You will hear echoes of these works throughout this address. Just what is the *long view* that I refer to here? This view would have us integrate across long time and large spatial scales in order to accommodate uncertainty about the future. The long view has three components:

1. The consideration of slow, broad variables: the long, deep climatic cycles that are context for environmental variation, for example, or evolutionary pathways with origins in the deep past;
2. Attention to fast, specific variables such as year to year productivity and abundance; and
3. An understanding of key uncertainties in both knowledge and our ability to predict future events.

For us, as fishery scientists, it means considering time scales from decades to centuries, spatial scales from habitats to bioregions, biological structure from genes to meta-populations, and the recognition that some ecological and evolutionary processes play out slowly, often far more slowly than our patience allows or our management strategies accommodate.

The objective of the *long view* is to craft scenarios, modes of action that are robust to the uncertain future. Peter Schwartz calls this work of scenario-building an “art”; I think, in this, we can do him one better. We can, if we set our minds to it, create and employ concepts and modes of thought robust to scale and time, manage for uncertainty, and establish principles of practice that can accommodate the change we will experience in the future. Who better, than those of us in the natural sciences, in fisheries and ecology, which confront our imperfect knowledge almost every day, to take on this task? An important component of the long view is that of civic engagement. The crafting of scenarios robust to the uncertain future requires the effective use of knowledge, experience, and skill—all attributes of our work as fishery scientists. An important question, then, is “How can we participate in this work?” We have powerful tools—concepts, approaches, methods—and the experience working with the natural world. We are, I believe, well suited for this work.

Things Change

“We have entered an era of unsurpassed uncertainty. The modes of the past may be no guide to the future.”

The evidence of change—significant change at our doorstep—is too compelling to ignore. The human population of Puget Sound and the Georgia Basin is increasing quickly. The region may accommodate an additional 2 million people by 2020; important components of biodiversity in the region are imperiled: Chinook, summer chum, steelhead and Bull Trout have been listed as threatened, the southern population of killer whales as endangered; climate change is likely to have profound and far-reaching effects on populations and ecosystems; even the relationship between science and society appears to be changing. In resource management, for example, we have witnessed a shift from the mode of sole professional management to a much more democratic form of management with considerable public influence. Almost all areas of scientific endeavor, but especially the biological sciences, are being scrutinized and influenced by society more strongly now than in my recent memory. These and other changes bring increasing pressure and uncertainty to our work as scientists and managers and present us with many challenges:

- What should the goals of our work be?
 - Sustainability?
 - Minimum viable populations?
 - Triage?
 - Increased resource exploitation?
- Who will (and should) set these goals?
- How should we as scientists engage with society when setting goals and implementing them?
- How do we act ethically and professionally, and maintain scientific integrity in the face of societal pressures?
- How should we address and communicate the uncertainty associated with our knowledge and management?

We have the knowledge and acumen to meet these challenges. But it will require some, if not all, of us to move beyond our comfort zones a bit—for some of us, quite a bit. Here's how I think we can do this as fishery scientists.

Meeting the challenges in an uncertain world

I have three guiding principles, rules of engagement, really, for us as scientists in this uncertain world. I believe they are useful to keep in mind as we do our work, and necessary if our work is to have the influence we wish it to have.

First, *we must develop and maintain a broad, integrative perspective*. We must always place our work in perspective, in the larger context of other species and communities, and, fundamentally, in larger spatial and longer temporal frames, always larger, longer, more inclusive.

Second, *investigate and apply novel concepts and approaches*. Many of our current scientific and management strategies are likely to be inadequate to the uncertainty and variation we expect. We should seek out and develop new approaches and concepts that will help us apply the *long view* to our work. Some of these concepts may come from other professions or from a broader view of nature itself.

Third, and most difficult for many of us as professional scientists, is to *engage more fully with scientific issues in the public domain*. To do so will require us to use our experience and knowledge to communicate and engage with our extended, non-scientific community. This is the essence of civic science.

We are all ecologists now

Integrating and broadening our perspective requires, at least in my view, ecological and evolutionary perspectives, and an ecosystem approach to implementing the perspectives.

The ecological perspective has several components:

- It is relationship-based—environment to organism, organism to organism, the relationships described by food webs and ecological communities, and the linkages among process, structure and function in ecosystems;
- It accounts for the contingent nature of ecological patterns, that is, the present bears the imprint of the past;
- It reflects multiple scales of space and time, and the hierarchical structure of ecosystems.

The evolutionary perspective is a necessary complement to the ecological one. It, too, has many elements:

- The importance of long time frames;
- Past events shape current and future responses;
- Selection is always occurring;
- Management strategies usually have distinct evolutionary consequences.

The ecosystem approach may be more familiar to most of us. It has been described in a variety of publications over the years but a few of its salient features bear repeating here. It is based on a few important features of ecosystems, namely that ecosystems are complex, functional entities that can be described and mapped; components within an ecosystem are more closely linked to each other than to components outside the ecosystem; and ecosystems are embedded in larger systems and linked to adjacent ecosystems. The approach calls for us to recognize the following in our management activities:

- *Hierarchical context.* A focus on a single level of the biodiversity hierarchy (genes, species, populations, ecosystems, landscapes) is insufficient to address an ecological problem.
- *Ecological boundaries.* Since ecosystems are a component of larger and smaller ecological units, it is critical to describe the boundaries and scale of the ecosystem appropriate to the question being asked.
- *Ecological integrity.* Protecting native diversity and the ecological patterns and processes that produce and maintain that diversity is fundamental to sustainable ecosystem function.

“The first rule of intelligent tinkering is to save all the pieces...”

The investigation and use of novel concepts and approaches reflects the spirit of scientific curiosity and inquiry, one of many attributes of the scientific endeavor that gives it such strength and durability. In the novel ecosystems that are likely to emerge in the future, some concepts and approaches are likely to be more robust than others. We must be open to the possibility, no, the probability, that there are ideas, concepts, and approaches that we have not investigated thoroughly or applied diligently, or have yet to develop. That some of these concepts and approaches may derive from areas outside of our common scientific experience should not be an excuse to ignore them. We have four such concepts and approaches that, I believe, have much merit and should be applied more explicitly in fishery

science: the precautionary principle, the adaptive principle, the use of emerging resilience concepts, and a renewal of a conservation ethic among practitioners.

The *precautionary principle* may be familiar to many of us and is a straightforward expression of the relationship between uncertainty and action. Briefly, one form of the principle states that the lack of knowledge should not become an excuse for not taking conservation actions. If one of our main fishery goals is sustainability, and if environmental conditions in the future are likely to be both highly variable and increasingly unpredictable, then we should act carefully to err on the side of species and ecosystem conservation as a hedge against unforeseen outcomes.

The *adaptive principle* has taken many forms over the past decade; the latest is called adaptive management and has, by overuse, become almost meaningless to many of us. But at its core, this principle reflects an intentional attempt to learn from our management actions and apply that knowledge to improving the next generation of actions. In many ways we have been adaptive, but not explicitly so. In general we have been conducting a long-term experiment with fish populations—particularly salmon—and with their ecosystems. We have intended our management strategies and actions to produce some change in populations or ecosystems but we have often been less than clear about the potential outcomes. Recognizing this, we should construct strategies and actions as explicit hypotheses and evaluations that we can and should be testing.

New concepts and frameworks will be necessary to cope with anticipated large-scale change and uncertainty. The notion of *resilience* is a set of emerging concepts that has much promise as such a framework or organizing model. Derived from ecological theory and ecosystem studies, C.S. Holling made the concept more explicit in his 1973 book on adaptive environmental management. Since then, the concept has steadily gained credibility and influence in understanding both ecological and social systems and exploring the linkages between them. Resilience is a measure of the disturbance or disruption a (ecological or social) system can undergo before it changes “state” and is subject to a new set of controlling variables. An “emergent” property of ecological and social systems, resilience is the focus of considerable research on just what attributes of these systems lends them resilience. The interaction of system structure—including biological structure—with system processes (demographic and physical processes, for instance) seems to be key to understanding system resilience.

A bit distinct from the first three principles but critical to our work is to embed it, or set it upon, an ethical foundation that can provide a touchstone for right and wrong action. I believe that a conservation ethic, as Aldo Leopold described it in *A Sand County Almanac*, is an appropriate foundation. It seems to me, as an ecologist, that our fundamental obligation as scientists, but especially as biologists, is to treat with our subjects, whether species or ecosystems, as members and “plain citizens” of the ecological community of which we are a part. This is a renewal of Leopold’s Land Ethic taken into the water. Perhaps our ecological knowledge—our awareness of the relationships that are critical to the sustainability of ecosystems and populations—places a higher demand on us than it does on an ordinary citizen unaware of such inter-dependencies. Despite the years since Leopold first described the ethic, it has yet to take widespread hold. We are in a unique position to contribute to this renewal and we should accept the responsibility to do so.

Science and Society

In the uncertain future, how can we, as fishery scientists, engage with the rest of society in constructive rather than destructive ways? How can we use our knowledge, our methods, and our experience to meet the expectations of society; even when those expectations seem to be at cross purposes? How can we help establish those expectations? Science and scientists have, for many years, enjoyed an esteemed place in society, although at times during public debates about harvest rates, or hatchery operations, or habitat protection, or endangered species, it may not seem like that is true. At times like these, I find myself asking “What is it that society wants from us, anyway?” Is it reassurance—we have the problem under control—or some acceptable and perfect answer that will send everyone away nodding in agreement? And more to the point, what can, or should, we provide when such questions are raised?

We have some tricks, some standard responses that I suspect we have all used at one time or another. We can successfully avoid the question: “We’ll get back to you on that” or “That’s not really a scientific question” or “We don’t have enough information to answer that”, which may be true as far as it goes. We sometimes provide an answer by invoking the objective, collective of science: “Science tells us...” or “The data shows...” More rarely, and a good example of civic engagement by scientists is to use the question to open a thoughtful dialogue with non-scientists, to use the opportunity to probe the question further, to describe the state of knowledge and uncertainty, to explain the logic and context of the strategies we employ. It may be rare, but it can be an opportunity to educate and engage our community around the issues we face each day. This engagement of scientists with the public in an open and honest fashion, with our knowledge, methods, and experience in the service of clarifying the debates around natural resources—especially fisheries here in the Northwest—is the essence of civic science.

Civic Science

“It is an unfulfilled civic duty of scientists...to engage themselves more fully and actively in public debate and action on important issues.”

--D. N. Langenberg, 1991
American Association for the
Advancement of Science

“Conservation biologists have a social obligation to participate in the public debate about the nature of ecosystem health...this responsibility must be accepted squarely...”

--Bryan Norton

For many of us, this is a perilous path, especially in regard to our reputations and our standing among our peers. We fear loss of objectivity, bias, mistrust, and a descent into advocacy. But, I submit, in this world of increasing and competing demands on living resources, of rapidly changing ecosystems, and unparalleled uncertainty about our ecologic future, we must engage in these important discussions using our knowledge and experience, our methods, and our skills—all the scientific tools at our command. We have looked at powerful concepts and approaches that can aid the debate; our experience with the natural world is without equal, our dedication is unquestioned. How do we go about this important

work without risking our scientific integrity? Perhaps we should be asking how we use our scientific integrity to participate in the debates. As civic scientists we can engage in the debates in a variety of ways and remain true to our standing as scientists.

First, we can be generous with our knowledge, open and honest about that which we know, that which we do not, and where the uncertainty lies; we can aid in clarifying assumptions and context, help create a common understanding; we can bring tested and novel concepts and approaches to bear on the issues; we can ask the difficult questions that others may avoid; we can assist the public in learning explicitly and systematically, use the logic and methods of science to refine goals and objectives, and evaluate alternatives; we can insist on intellectual rigor and honesty; we can avoid simplistic answers to complex questions; and we can demonstrate the value and power of working collaboratively. We can accomplish this important work with honesty and integrity if we keep in mind a very few simple rules: Distinguish scientific questions from questions of value; Don't allow advocacy to create bias; Distinguish personal bias from scientific judgment; and last, practice humility and respect, something most of us are familiar with in our dealings with the natural world. In the words of the Unknown Fishery Biologist,

"In a world beset by the widespread loss of biodiversity, our obligation does not end in the field or laboratory, in the classroom or in the pages of a journal. The study of ecosystems carries a responsibility to society to tell what we understand as truthfully and openly as we can and, if need be, advocate for the living world."

Thank you.

Readings

- Berkes, F. J. Colding, and C. Folke. 2003. Navigating Social-Ecological Systems.
Gunderson, L., C.S. Holling, and S.L. Light, eds. 1995. Barriers and Bridges to the Renewal of Ecosystems and Institutions.
Holling, C.S. 1978. Adaptive Environmental Assessment and Management.
Leopold, Aldo. 1946. A Sand County Almanac.
Norton, Bryan. 2005. Sustainability: A Philosophy of Adaptive Ecosystem Management.
Schwartz, Peter. 1996. The Art of the Long View: Planning for the Future in an Uncertain World.

NORTHERN POPULATIONS

Chair: Laurie Weitkamp

Spatial distribution and dynamics of pink (*Oncorhynchus gorbuscha*), chum salmon (*O. keta*), and Chinook salmon (*O. tshawytscha*) in streams dominated by sockeye salmon (*O. nerka*): insights into the processes of straying and colonization

G.R. Pess^{1,2}, T. Quinn², D. Schindler², L. Rogers², and P. Westley²

¹United States Department of Commerce (DOC)

National Oceanic and Atmospheric Administration (NOAA)

National Marine Fisheries Service (NMFS), Northwest Fisheries Science Center (NWFS),

2725 Montlake Blvd East, Seattle, WA, U.S.A. 98112

george.pess@noaa.gov

²University of Washington

School of Aquatic and Fishery Sciences (SAFS)

Box 355020 Seattle, WA, U.S.A. 98195-5020

Salmonids can quickly colonize new habitats and establish self-sustaining populations, and have done so repeatedly over the evolution of the species. Successful colonization is influenced by several factors including, but not limited to, straying, characteristics of the newly available habitat, local adaptations of the colonists, and competition with other salmonids in newly opened habitat. We examine the correlation between the occurrence of small salmonid spawning aggregates of several salmon species, habitat characteristics, and competing, numerically dominant sockeye salmon at the stream reach and watershed scale in 20 different streams in the Wood River system, Alaska. We hypothesized that the occurrence of non-dominant salmonids will be greatest where habitat conditions for spawning are most suitable, and competition with dominant adult spawning sockeye is lowest. We used pink, chum, and Chinook salmon occurrence as an indicator of salmon colonists because their populations are relatively low in the streams throughout the Wood River system, yet they have been documented for over 35 years by the University of Washington's Fisheries Research Institute (FRI) program. We found considerable variation in historic occurrence of pink and chums across Wood River streams. However wider and deeper streams tended to have a higher occurrence of pink and Chinook salmon, and to a lesser extent chum salmon. Specifically, streams with a drainage area greater than 20 km² consistently had pink and chum salmon occurrence, whereas watersheds less than 6 km² are typically devoid of pink, Chinook, and chum. In addition sockeye density was negatively correlated with both pink and chum occurrence. Multiple linear regression, Principal Components Analysis (PCA), and model averaging techniques indicates that variables related to stream depth, in-stream cover, and competition are the best predictors of occurrence and abundance of pink, Chinook, chum, and sockeye salmon in the Wood River system.

Straying of Hatchery Chum Salmon (*Oncorhynchus keta*) in Select Prince William Sound Streams, 2004-2007

Rich Brenner¹, Steve Moffitt¹, Rick Merizon², Dayna Norris¹

¹Alaska Department of Fish and Game, Division of Commercial Fisheries, PO Box 669, Cordova, AK. 99574. phone: 907-424-3212, email: richard.brenner@alaska.gov

²Alaska Department of Fish and Game, Division of Sport Fisheries, 1800 Glenn Hwy., Suite 4, Palmer, AK, 99645. phone: 907-746-6321

Abstract:

During 2002 and 2003, the Alaska Department of Fish and Game found that >87% of the chum salmon (*Oncorhynchus keta*) collected at Eshamy Creek weir in western PWS originated from PWSAC hatcheries. Following the remote releases of chum salmon fry, unusually large escapements of chum salmon (up to 130,000/year) were observed in streams surrounding hatchery release sites, where few chum salmon had been observed during the past several decades. In 2004, we initiated a study to quantify the straying of hatchery chum salmon into PWS streams. In general, streams were selected for sampling if they had an historical average escapement of >1,000 chum salmon. Otoliths from chum salmon carcasses collected within streams (n=13 to 34 streams/year) were analyzed for hatchery thermal marks. During 2004-2007, the vast majority of streams sampled contained chum salmon of hatchery origin, with the percentage of hatchery chum salmon strays in historically significant chum salmon spawning streams as high as 63%. The percentage of hatchery chum salmon in streams within 15 km of hatchery release sites ranged from 90-100%. Annually, 2.5-10% of all the chum salmon carcasses sampled throughout PWS were of hatchery origin. Our findings reveal serious concerns about the potential for deleterious impacts to wild stocks of salmon and with the primary assumptions regarding estimated wild stock escapement and inseason management of chum salmon in PWS.

Introduction

A number of studies and reviews have highlighted concerns about the harmful impacts that salmon enhancement programs can have on wild stocks of salmon (Araki 2007; Naish 2007; Myers et al. 2007; Mobrand 2005; Aprahamian et al. 2003; Hilborn and Eggers 2001, 2000). Despite their wild origin, in only a few generations hatchery breeding, feeding, care, and release methods can result in domestication, alteration in gene frequencies and phenotypic differences from their wild counterparts (Wang et al. 2002; Berejikian et al. 2001) that can be passed on to the progeny of hatchery-wild mating (Ford et al. 2006; Wessel et al. 2006; McClelland 2005). As such, the supportive breeding of captive salmon and subsequent hybridization of captive and wild salmon stocks can result in a decrease in the fitness of wild salmon populations, even with relatively low rates of introgression (Ford 2002).

The Alaska Department of Fish and Game (ADF&G) finfish genetics policy states that, "Gene flow from hatchery fish straying and intermingling with wild stocks may have significant detrimental effects on wild stocks. First priority will be given to protection of wild stocks from possible harmful interactions with introduced stocks." (Davis 1985). Towards this end, ADF&G, in association with the PWSAC created the Prince William Sound/Copper River Comprehensive Salmon Plan agreement. This plan stresses the protection of wild stocks in management and hatchery practices and states that, ".....the proportion of hatchery

salmon straying into wild-stock streams must remain below 2% of the wild-stock escapement over the long term.”

The Prince William Sound Aquaculture Corporation (PWSAC) currently release ~134 million chum salmon (*Oncorhynchus keta*) into PWS each year (White 2007). Average annual returns to PWS are currently ~2.6 million chum salmon (Hollowell et al. 2007).

The Alaska Department of Fish and Game became concerned about the straying of hatchery chum salmon into PWS streams around the year 2000 when aerial surveys revealed that the combined annual escapement of chum salmon within streams of the Montague and Southwest districts to be more than 130,000 chum salmon. In contrast, the annual chum salmon escapements in these districts had not exceeded 6,000 chum salmon prior to hatchery chum salmon releases. The increased escapement of chum salmon in these districts seemed to coincide with remote releases of hatchery chum salmon at Port Chalmers, which began during 1994. Also during 2000, weir crews at Eshamy Creek noted unusually large numbers of chum salmon in the creek. The weir crews collected chum salmon otoliths during 2002 and 2003 at Eshamy Creek, and, based on hatchery thermal marks, ADF&G concluded that 92% and 87%, respectively, of these chum salmon originated from hatcheries within PWS. From these results, ADF&G decided to begin an investigation of hatchery chum salmon straying within PWS streams.

The objectives of this study were to: 1) Quantify the proportion of sexually mature hatchery chum salmon in historically-significant chum salmon spawning locations in PWS, and, 2) Determine the spatial and temporal extent of chum salmon straying throughout PWS.

Materials and Methods

Sample sites

Streams sampled for chum salmon otoliths during this study were located throughout PWS, in southcentral Alaska. In order to accomplish our first study objective, streams were first chosen for sampling if they had an historical average annual escapement of >1000 chum salmon. Annual escapements were estimated from aerial surveys of ~215 index streams that have been surveyed by ADF&G biologists from May – October for the past several decades (corrected for observer efficiency). When possible, chum salmon otoliths were also sampled at the Eshamy and Coghill Rivers. In 2007, seven streams surrounding the AFK and Port Chalmers release sites (not considered to be historically significant chum salmon spawning locations) were opportunistically sampled after ADF&G biologists observed large masses of chum salmon during aerial surveys.

Chum salmon otolith collections

Otolith sampling was conducted by walking along the stream corridors and sampling every chum salmon that was encountered until the desired sample size of 96 chum salmon was reached. After 2004, many of the streams were also re-sampled one or more times. Except for the Eshamy and Coghill weirs, where chum salmon were sacrificed during sampling, all otoliths were collected from dead chum salmon that appeared to be sexually mature. After slicing off the top portion of the head, otoliths were removed using tweezers and placed into a 96-well sampling tray. The sex and approximate location of the fish within the stream corridor (intertidal or upstream and/or GPS location) was recorded. Otoliths were analyzed for hatchery-specific thermal marks at the Otolith Analysis Laboratory within the ADF&G office in Cordova, Alaska.

Results and Discussion

Below we present what are essentially the raw results from the first four years of this investigation. All results are based on analyses of thermally marked otoliths by personnel at the Otolith Laboratory in Cordova, Alaska. For the 2004 pilot study we sampled a total of 916 chum salmon carcasses from 15 streams, mostly in the north and northwest PWS (Figure 1). We determined that 83 (9.1%) of these chum salmon were of hatchery origin. The average stream contained 8.8% hatchery chum salmon when calculated for streams from which more than 50 samples were collected.

During 2005 we greatly expanded the spatial and temporal extent of our sampling. We collected a total of 2,295 chum salmon carcasses from 17 streams spread throughout PWS (Figure 1) and many of these streams were sampled multiple times from late July through September (Merizon and Moffitt, In Review). We determined that 204 (8.9%) of these chum salmon were of hatchery origin. The average stream contained 9.4% hatchery chum salmon when calculated for streams from which more than 50 samples were collected. A total of 227 chum salmon were sampled at the Eshamy weir, of these 222 (97.8%) were of hatchery origin. A total of 61 chum salmon were sampled at the Coghill River weir, of these 57 (93.4%) were of hatchery origin.

For 2006, adverse weather greatly curtailed our sampling schedule. A total of 1,576 chum salmon carcasses were sampled from 13 streams. We determined that 40 (2.5%) of these chum salmon were of hatchery origin. The average stream contained 2.8% hatchery chum salmon when calculated for streams from which more than 50 samples were collected. A total of 160 chum salmon were sampled at the Eshamy weir, of these 159 (99.4%) were of hatchery origin. A total of 25 chum salmon were sampled at the Coghill River weir, of these, 12 (48%) were of hatchery origin.

During 2007 we again expanded the extent of our sampling and collected otoliths from 4,950 chum salmon carcasses from 31 streams. We determined that 513 (10.4%) of these chum salmon were of hatchery origin. The average stream contained 17.9% hatchery chum salmon when calculated for streams from which more than 50 samples were collected. A total of 199 chum salmon were sampled at the Eshamy weir, of these 197 (98.9%) were of hatchery origin. A total of 13 chum salmon were sampled at the Coghill River weir, of these 8 (61.5%) were of hatchery origin.

For approximately 70% of the sampled streams, there was at least one year during which the average percentage of hatchery chum salmon that was above the 2% threshold recommended within the Prince William Sound/Copper River Comprehensive Salmon Plan (Figure 1). Although streams within 1-10 km of hatchery release sites generally had large numbers of hatchery strays (Figure 1; PC and AFK release sites), our results also indicate a relatively high proportion of hatchery chum salmon (31-63%) within historically significant chum salmon spawning locations that are considerably farther (15-40 km) from release sites (Figure 1; Siwash, Long and Swanson spawning locations). Thus, our findings reveal serious concerns about the potential for deleterious impacts to wild stocks of salmon and concerns with the primary assumptions regarding estimated wild stock escapement and inseason management of chum salmon in PWS.

As shown in Figure 2, the highest straying percentages for individual collection trips were found to occur during the early portion of our sampling season, from July to early August. This is likely because the original hatchery broodstock was made up of chum salmon from the early returning chum salmon into the Wells River and Beartrap Creek. In the near

future we hope to add this temporal data to our existing model of the spatial extent of chum salmon straying within PWS (Moffitt and Raborn, 2007) in order to better understand, predict and control chum salmon straying in this region.

Acknowledgments

This research was funded by the Alaska Department of Fish and Game. We would like to thank a number of people for helping to collect and process chum salmon otoliths and provide assistance with the study design: Anton Antonovich, Dan Ashe, Judy Berger, Jeremy Botz, Jim Edmundson, David Evans, Lowell Fair, Dan Gray, Chris Habicht, Glenn Hollowell, Bert Lewis, Dan Moore, Jeff Regnart, James Seeb, Jan Bullock, Brittany Blain, Chris Clark, Nancy Del Pesco, Kris Kartchner, Matthew Kampshoff, Jim O'Rourke, Melanie O'Rourke, Lauren Padawer, Justin Priest, Eric Quilty, Georgia Rodgers and Justin Stoltzfus.

References

- Aprahamian, M. W., Smith, K. M., McGinnity, P., McKelvey, S., and Taylor, J. 2003. Restocking of Salmonids--Opportunities and Limitations. *Fisheries Research* 62: 211-227.
- Araki, H., Cooper, B., and Blouin, M. S. 2007. Genetic Effects of Captive Breeding Cause a Rapid, Cumulative Fitness Decline in the Wild. *Science* 318: 100-103.
- Berejikian, B. A., Tezak, E. P., Park, L., LaHood, E., Schroder, S. L. and Beall, E.. 2001. Male Competition and Breeding Success in Captively Reared and Wild Coho Salmon (*Oncorhynchus kisutch*). *Canadian Journal of Fisheries and Aquatic Science* 58: 804-810.
- Davis, R. 1985. State of Alaska Finfish Genetics Policy. Alaska Department of Fish and Game, Division of Commercial Fisheries, Gene Conservation Laboratory. <http://www.genetics.cf.adfg.state.ak.us/policy/finfish.php>
- Ford, M. J., Fuss, H., Boelts, B., LaHood, E., Hard, J. and Miller, J. 2006. Changes in Run Timing and Natural Smolt Production in a Naturally Spawning Coho Salmon (*Oncorhynchus kisutch*) Population after 60 Years of Intensive Hatchery Supplementation. *Canadian Journal of Fisheries and Aquatic Science* 63: 2343-2355.
- Ford, M. J. 2002. Selection in Captivity during Supportive Breeding May Reduce Fitness in the Wild. *Conservation Biology* 16(3): 815-825.
- Hilborn, R., and Eggers D. 2001. A review of the hatchery programs for pink salmon in Prince William Sound and Kodiak Island, Alaska: response to comment. *Transactions of the American Fisheries Society* 130:720-724.
- Hilborn, R. and Eggers, D. 2000. A Review of the Hatchery Programs for Pink Salmon in Prince William Sound and Kodiak Island, Alaska. *Transactions of the American Fisheries Society* 129: 333-350.
- Hollowell, G., Lewis, B, Merizon, R., and Moffitt, S. 2007. Fishery Management Report No. 07-33. 2005 Prince William Sound Area Finfish Management Report. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries. <http://www.sf.adfg.state.ak.us/FedAidPDFs/fmr07-33.pdf>
- McClelland, E. K., Myers, J. M., Hard, J. J., Park, L. K. and Naish, K. A. (2005). Two Generations of Outbreeding in Coho Salmon (*Oncorhynchus Kisutch*): Effects on Size and Growth. *Canadian Journal of Fisheries and Aquatic Science* 62: 2538-2547.

- Merizon R. M. and Moffitt S. D. In Review. Straying rates of hatchery chum salmon in select Prince William Sound streams, 2005. Fishery Data Series No. YY-XX. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.
- Mobrand, L. E., Barr, J., Blankenship, L., Campton, D. E., Evelyn, T. T. P., Flagg, T. A., Mahnken, C. V. W., Seeb, L. W., Seidel, P. R. and Smoker, W. W. 2005. Hatchery Reform in Washington State: Principles and Emerging Issues. *Fisheries* 30(6): 11-39.
- Moffitt, S. and Raborn, S. 2007. Hatchery Releases in Prince William Sound and Published Threshold Straying Rates: How Do They Match Up? Annual Meeting of the Alaska Chapter of the American Fisheries Society, Ketchikan, Alaska.
- Myers, R. A., Levin, S. A., Lande, R., James, F. C, Murdoch, W. W., and Paine, R. T. 2007. Hatcheries and Endangered Salmon. *Science* 303: 1980.
- Naish, K. A., Taylor, III., J. E. Levin, P. S. Quinn, T. P. Winton, J. R., Huppert, D., and Hilborn, R.. 2007. An Evaluation of the Effects of Conservation and Fishery Enhancement Hatcheries on Wild Populations of Salmon. *Advances in Marine Biology* 53: 61-194.
- Wang, S., Hard, J., and Utter, F. 2002. Salmonid Inbreeding: A Review. *Reviews in Fish Biology and Fisheries* 11: 301-319.
- Wessel, M. L, Smoker., W. W. Fagen, , R. M. and Joyce, J. 2006. Variation of Agonistic Behavior among Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) of Hatchery, Hybrid, and Wild Origin. *Canadian Journal of Fisheries and Aquatic Science* 63: 438-447.
- White, B. 2007. Fishery Management Report No. 07-04. "Alaska Salmon Enhancement Program 2006 Annual Report. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries.
<http://www.sf.adfg.state.ak.us/FedAidPDFs/fmr07-04.pdf>

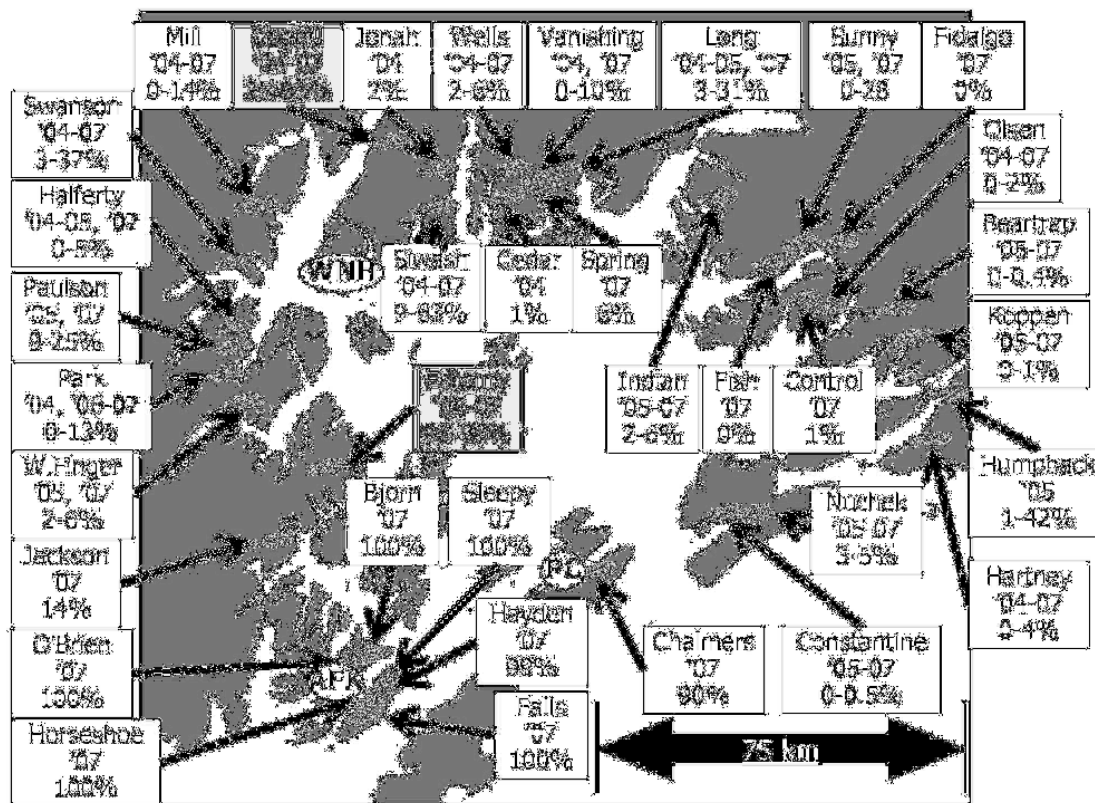


Figure 1. Individual boxes contain the common stream name, years sampled, and the range of percentages of hatchery chum salmon found in these Prince William Sound streams from 2004-2007. The Coghill and Eshamy weirs are shaded because these fish were sacrificed during sampling. All other percentages were determined from chum salmon carcasses found within stream corridors. WNH = Wally Noeremburg rearing and release facility, PC = Port Chalmers remote release site and AFK = Armin F. Koernig remote release site.

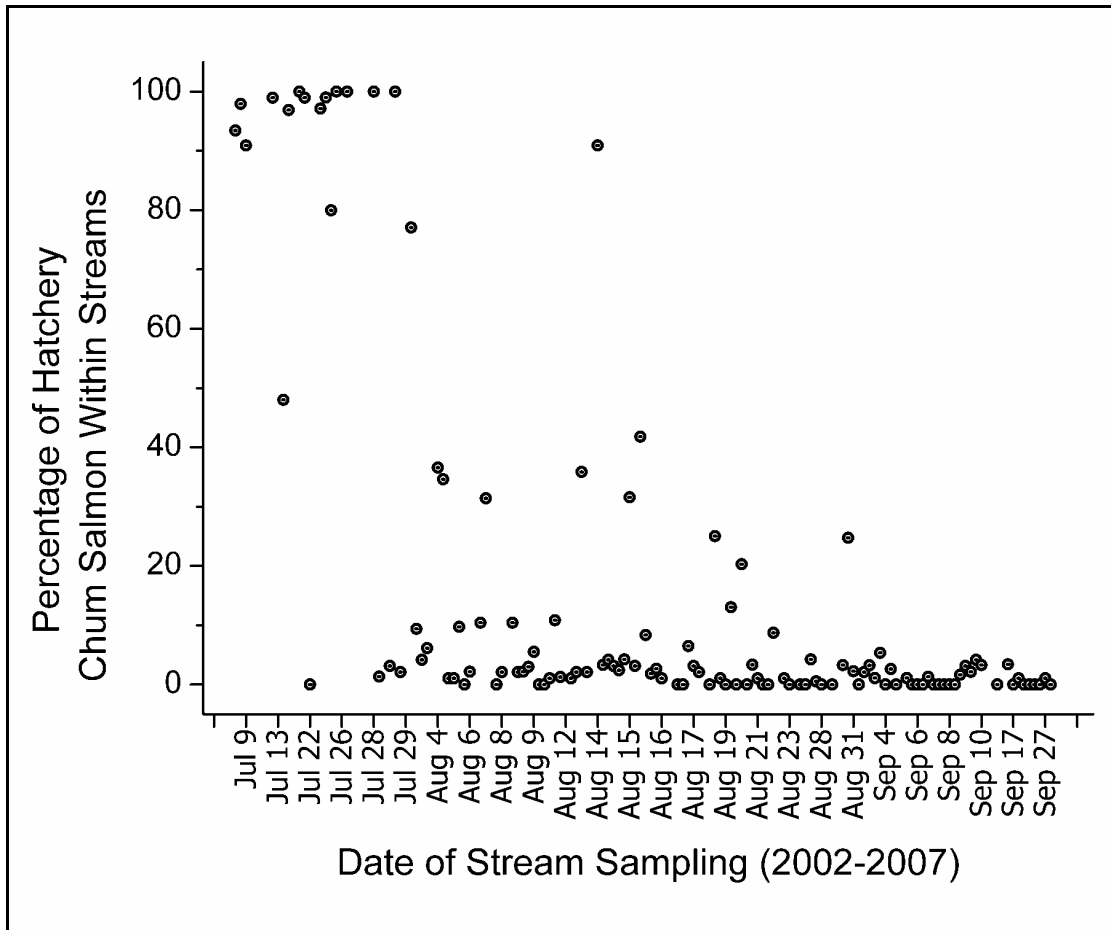


Figure 2. The percentage of hatchery chum salmon within Prince William Sound streams from individual sampling trips (7 July to 29 September; 2002-2007). Shown are streams from which the otoliths of more than 20 chum salmon were sampled.

Straying of hatchery pink salmon in Prince William Sound – a geospatial analysis.

Steve Moffitt (Steve.moffitt@alaska.gov)

Alaska Department of Fish and Game, Division of Commercial Fisheries, 401 Railroad Avenue, Cordova, Alaska 99574-0669. 907-424-3212

Hatcheries in Prince William Sound (PWS) released an average of ~ 585 million pink, from 1997-2006. If hatchery strays successfully interbreed with wild salmon, the genetic variability of wild fish could be reduced. Subsequently, the resilience of stocks to change, e.g., climate change or disease, may be reduced. Several threshold levels of hatchery straying have been suggested to minimize the possible genetic impacts to wild salmon (Copper River/PWS Phase 3 plan - 2%; Washington Hatchery Reform group - 5%; Ford (2002) – 10%). Alaska Department of Fish and Game staff collected otoliths from pink salmon carcasses in streams to estimate the proportion of hatchery fish in 1997-1999. All hatchery pink salmon returning to PWS had thermal marks applied to their otoliths beginning

in brood year 1995. The proportion of hatchery fish in the streams was negatively correlated with the distance from release site for several facilities and years. The relationship between hatchery proportion and distance from release site was used to estimate 1) the proportion of the escapement index streams and 2) the proportion of the total escapement index that included hatchery fish proportions that exceeded the threshold levels. The 1997 and 1998 data indicated the western side of PWS had a significant number of streams that exceeded the threshold levels.

Impacts of Food Supply and Predators on Juvenile Pink Salmon Survival in Prince William Sound

Richard E. Thorne

Prince William Sound Science Center, P.O. Box 705, Cordova, AK 99574

Tel: (907) 424-5800 X226; email: rthorne@pwssc.org

Research during the mid-1990s indicated that juvenile pink salmon (*Oncorhynchus gorbuscha*) survival in Prince William Sound was positively correlated with the abundance of large-bodied copepods of the genus *Neocalanus*, and negatively correlated with the abundance of walleye pollock (*Theragra chalcogramma*). The Prince William Sound Science Center conducted annual monitoring of the spring abundance and distribution of both macrozooplankton and fish predator populations from 2000 to 2006. Fish predators exhibited a progressive inshore movement during years of poor nursery conditions, consistent with prey-switching from large zooplankton to small near-shore fishes, including pink salmon fry. The correlation between adult returns and large copepod abundance in nursery years was high after the first four years of monitoring, but weakened with the subsequent three years. The dominant factor in returns over the seven-year period is a two-year oscillation. The basis of the two-year cycle is puzzling. These fish are primarily of hatchery origin, and annual releases are similar in magnitude. A two-year oscillation did not exist prior to the 2001 return. It may be that the four-year period of alternating high and low zooplankton abundance initiated an ecological mechanism, such as cannibalism, that has continued the two-year oscillation even though the original forcing function no longer matches.

Review of Recent Pink and Chum Salmon Investigations in the Central Bering Sea Conducted Onboard the R/V Wakatake maru

Nancy D. Davis¹, Masa-aki Fukuwaka², and Robert V. Walker¹

¹School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA USA 98125-5020

²Hokkaido National Fisheries Research Institute, Fisheries Research Agency, 116 Katsurakoi, Kushiro, Japan, 085-0802

Since 1991 a high seas salmon research vessel, Wakatake maru, has returned in June through July to the central North Pacific and the central Bering Sea in the vicinity of 180° longitude (40°N to 58°N latitude) to monitor the stock condition of salmon and steelhead in the survey area (Fukuwaka et al. 2007). We review biological characteristics of chum and

pink salmon caught in the central Bering Sea portion of that survey. The results include catch per unit of effort (CPUE; number of fish caught per 1500 m of gillnet), body size at age, food habits, and some results from archival data tag recoveries.

Chum salmon abundance varies year to year, but does not show a trend over the time period (Fig. 1). Chum CPUE is higher in even-numbered years than odd-numbered years when pink salmon are abundant in this area. Chum salmon ocean ages range from 1 to 4, with ocean age- 2 and -3 the dominant age groups. No juvenile chum salmon are caught in this area in July. Juveniles may not have migrated far enough offshore to be present in the survey area in mid-summer. In 1992, 1996, 1997, and 2006 relatively large pulses of ocean age-1 fish were caught in this area. There is no distinct trend in size at age changing over the time series. (Fukuwaka et al. 2007). During summer, chum salmon caught in the survey area of the central Bering Sea are composed of Japanese, Russian, and Alaskan stocks (Seeb et al. 2004)

Examination of chum salmon stomach contents collected from the central Bering Sea during summer indicates changes in diet composition as the fish grow (Fig. 2). Stomach contents of 0.1 immature chum salmon contain more hyperiid amphipods than do stomachs of older fish, and the proportion of gelatinous animals (medusae and ctenophores) increases in older, maturing chum salmon. The potential disadvantage of consuming prey of low energy density may be compensated for by high rates of consumption and digestion, and high prey availability. Diet shift by age affects the potential for salmon inter-specific interactions.

All pink salmon caught during the survey are maturing fish. The abundance of pink salmon in odd-numbered years is about 35 times more abundant than in even-numbered years (Fig. 3). Abundance of odd-year pink salmon was high in 1991, 1997, and 1999, and has been increasing from a low in 2001. Abundance in even-numbered years was particularly high in 1994 and 2004. There is no particular trend in pink salmon fork length over the time period (Fukuwaka et al. 2007). Pink salmon stocks in this area are composed of Russian and Alaskan stocks, with stocks from eastern Kamchatka predominating in odd years when the catches of pink salmon are higher (Myers et al. 1996).

Pink salmon diet in odd-numbered years is more taxonomically diverse than in even-numbered years when pink salmon abundance is low (Fig. 4). Pink salmon food habits data were grouped into small, medium, and large sized fish based on quartiles of fish body weight. Small pink salmon are those in the lowest 25% body weight (<1061 g BW). Medium-sized fish are in the 25% to 75% grouping, and the largest fish are in the top quartile weighing more than 1460 g. In even-numbered years the largest fish consume the least diverse diet, one composed almost exclusively of euphausiids, copepods, squid, and fish, of which euphausiids, squid, and fish are the most calorically-rich salmon prey (Davis et al. 1998).

During the Wakatake maru survey and on other vessels of opportunity, all species of salmon are tagged and released with disk tags, and some are also tagged with archival data tags, which record environmental conditions the salmon experiences (most often temperature and depth; Walker et al. 2006). For more information on the tag recovery program, please see http://www.npafc.org/new/science_fishtag.html and <http://www.fish.washington.edu/research/highseas/tagging.html>. Thus far, all recovered archival tag data from chum and pink salmon are from maturing fish released in the summer and recovered in the fall. In general, depth and temperature records from these tags show that, except for Chinook salmon, all salmon display a diel pattern of vertical distribution moving between shallow and deep water during the day and remaining near the surface at

night (Walker et al 1999, 2003, 2006). The diel pattern is strongest in chum and pink salmon. Pink salmon have an average depth of 10 m and an average daily maximum depth of 37 m. Chum salmon have a deeper vertical distribution, with an average depth of 16 m and an average daily maximum depth of 58 m (Walker et al. 2006). In the oceanic portion of the data, the depth range recorded from tags placed on pink and chum salmon consistently indicates a narrow depth range (approximately 0 to 50 m) of vertical movement, whereas the daily temperature range experienced by these fish varies widely (approximately 1° to 15°C), depending on the water mass the fish traverses. Therefore, chum and pink salmon may choose a particular depth range rather than a particular temperature range, which could be linked to their foraging behavior.

We thank the Fisheries Agency of Japan for its long term support of the Wakatake maru surveys and we are grateful to the Washington Sea Grant, Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative, North Pacific Research Board, and NOAA for their financial support.

References

- Davis, N.D., K.W. Myers and Y. Ishida. 1998. Caloric value of high-seas salmon prey organisms and simulated salmon ocean growth and prey consumption. *N. Pac. Anadr. Fish Comm. Bull.* 1:146-162.
- Fukuwaka, F., N. Davis, M. Kuwaki, S. Imai, and K. Toge. 2007. International salmon research aboard the R/V Wakatake maru in the central North Pacific Ocean and Bering Sea during the summer of 2007. *N. Pac. Anadr. Fish Comm. Doc.* 1046:19 p.
- Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler, and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956-1995. *N. Pac. Anadr. Fish Comm. Doc.* 192:231 p.
- Seeb, L.W., P.A. Crane, C.M. Kondzela, R.L. Wilmont, S. Urawa, N.V. Varnavskaya, and J.E. Seeb. 2004. Migration of Pacific Rim chum salmon on the high seas: insights from genetic data. *Environ. Biol. Fish.* 69:21-36.
- Walker, R.V, N.D. Davis, K.W. Myers, and M. Fukuwaka. 2003. Releases and recoveries of U.S. salmonid data storage tags, and recoveries of high seas tags in North America, 2003. *N. Pac. Anadr. Fish Comm. Doc.* 722:14 p.
- Walker, R.V, J.H. Helle, K.W. Myers, N.D. Davis, J.M. Murphy, S. Urawa, O.S. Temnkyh, V.V. Sviridov, and V.G. Fedorenko. 2006. NPAFC Salmon Tagging. *N. Pac. Res. Board Proj. 204 Final Report.* 42 pp.
- Walker, R.V, K.W. Myers, N.D. Davis, H.R. Carlson, and K.D. Friedland. 1999. U.S. releases and recoveries of salmonid data storage tags and disk tags in the North Pacific Ocean and Bering Sea, 1999. *N. Pac. Anadr. Fish Comm. Doc.* 412:20 p.

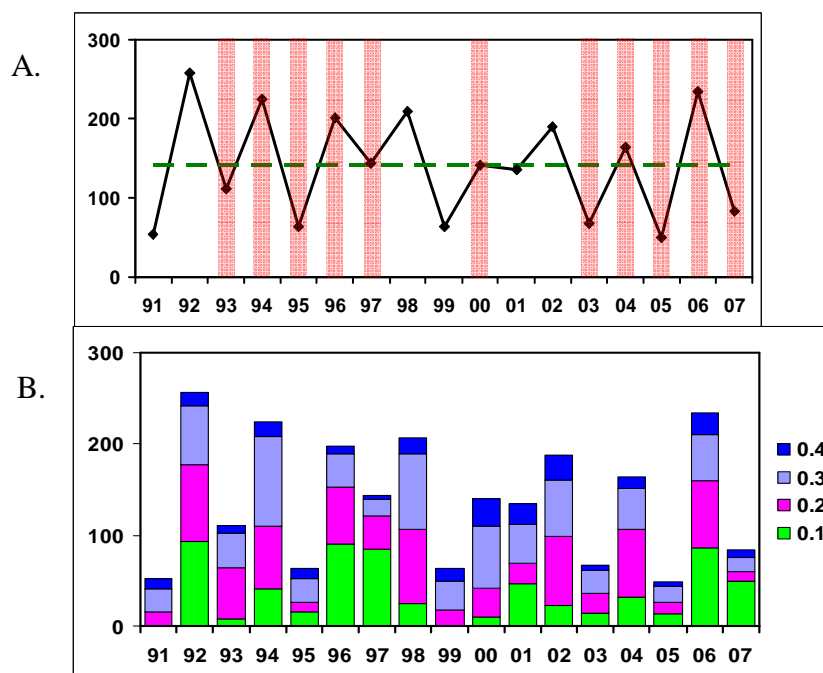


Figure 1. A. Chum salmon annual and mean CPUE in the central Bering Sea (no./1500 m gillnet). Bars indicate warm anomalies (NOAA/NESDIS;1985-1993 climatology) in the time/area of fishing. Other time periods are average conditions. B. Estimates of CPUE represented by age group.

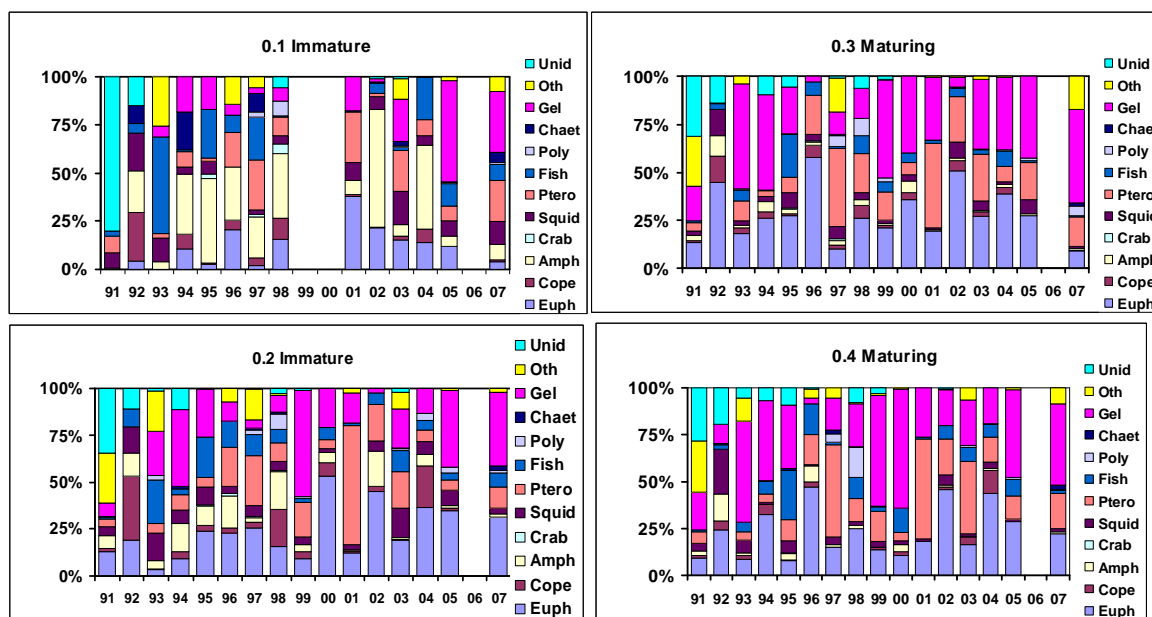


Figure 2. Chum salmon food habits in the central Bering Sea by age-maturity group. Percentages represent average proportions (by weight) per year standardized to 100%. Samples from 2006 are not yet analyzed. Euph=euphausiids, Cope=copepods, Amph=amphipods, Ptero=pteropods, Poly=polychaetes, Chaet=chaetognaths, Gel=gelatinous (medusae, ctenophores, salps), Oth=other groups, and Unid=unidentified.

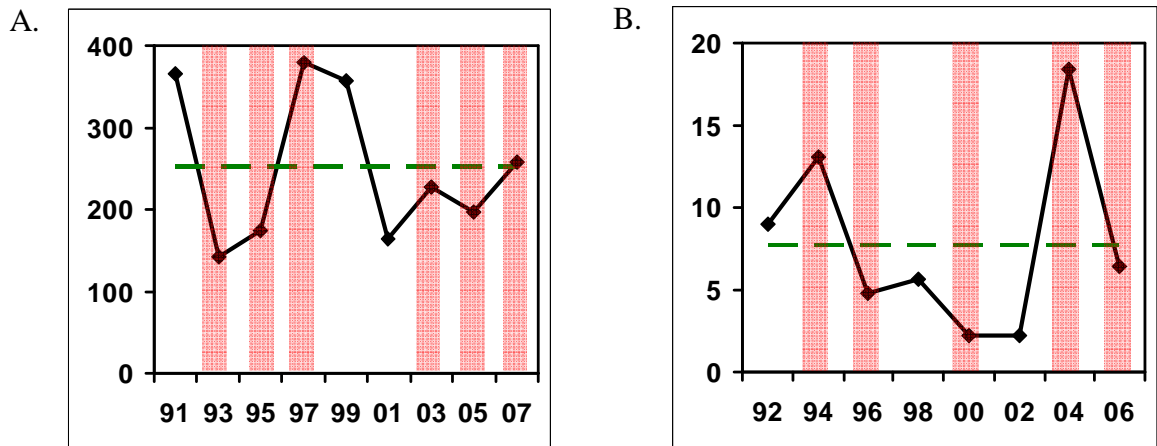


Figure 3. Pink salmon (maturing, age-0.1) annual and mean CPUE in the central Bering Sea (no./1500 m gillnet) in odd- (panel A) and even-numbered years (panel B). Bars are the same as described in Fig. 1

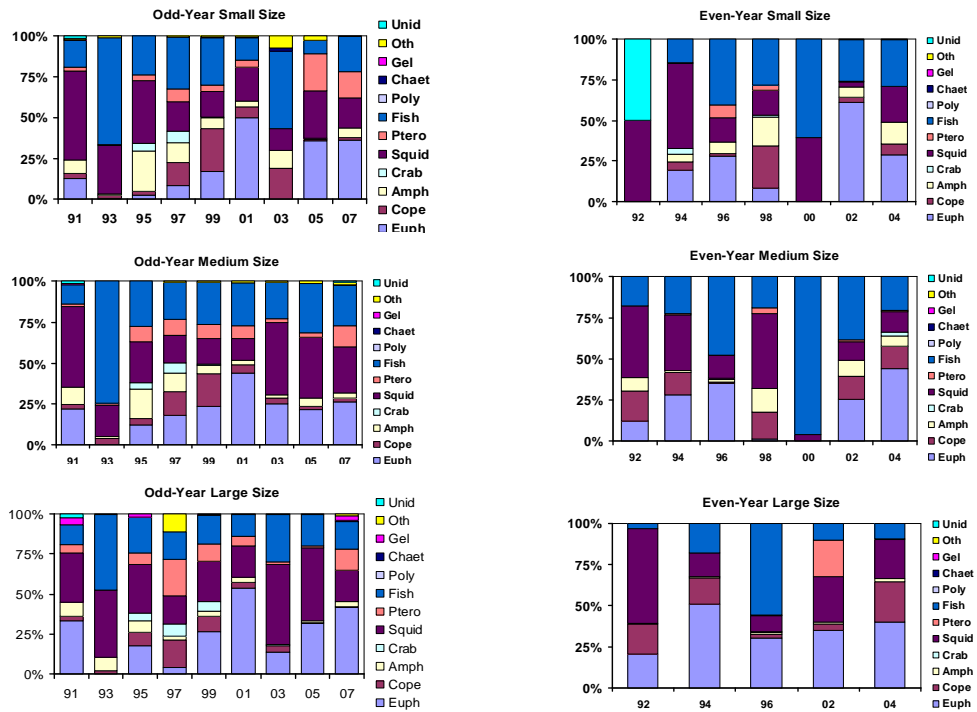


Figure 4. Pink salmon (maturing, age-0.1) food habits in the central Bering Sea by body size and odd- and even-numbered years. Small size fish=lowest 25% in body weight (<1061 g), medium size fish= middle 25% to 75%, large size fish=top quartile weighing (>1460 g). Percentages and prey groups are the same as described in Fig. 2.

Pink Salmon Stock Status in Southeast Alaska

Steven C. Heinl

Alaska Department of Fish and Game, 2030 Sea Level Drive, Suite 205

Ketchikan, AK 99901, (907) 225-9677, steve.heinl@alaska.gov

Abstract

The Alaska Department of Fish and Game annually monitors, via aerial surveys, 718 pink salmon spawning streams in Southeast Alaska. These streams are divided into 45 stock groups in three sub-regions (Southern Southeast, Northern Southeast Inside, and Northern Southeast Outside). Forty (89%) of 45 stock groups were stable or exhibited an increasing trend over the past 21 years, whereas five (11%) stock groups exhibited declining trends. These declines were small and these stocks are considered to be functionally stable. Escapement goals based on broad sub-regions have been met or exceeded annually for more than 11 years.

Introduction

Wild pink salmon *Oncorhynchus gorbuscha* spawn in approximately 2,500 short, coastal streams throughout Southeast Alaska and support a large and valuable commercial fishing industry. Recent pink salmon harvests in Southeast Alaska have been at the highest levels since record keeping began at the onset of the 20th century. The annual harvest of pink salmon averaged 47 million fish a year over the past 10 years, and fluctuated between 12 million and a historical high of 78 million fish (1999; Figure 1). Over that same time period, the ex-vessel value of pink salmon averaged \$20.4 million a year. More than 96% of the pink salmon harvest in Southeast Alaska is of wild origin (White 2008, and previous reports in that series). Pink salmon stocks in Southeast Alaska are managed through extensive inseason monitoring of harvests, fishing effort, and developing escapements (Van Alen 2000, Zadina et al. 2004). Pink salmon escapements during the past two decades have been at the highest levels since monitoring began in 1960 (Heinl and Geiger 2005; Figure 1).

A 1996 American Fisheries Society sponsored study of salmon stocks at risk found pink salmon populations to be increasing or stable in over 96% of the spawning aggregations they examined in Southeast Alaska (Baker et al. 1996). Van Alen (2000) also noted a general upward trend in pink salmon abundance (only one of the 652 streams he examined showed a downward trend between 1960 and 1996). A more recent analysis of trends in pink salmon escapement survey data showed that seven of 45 pink salmon stock groups in Southeast Alaska exhibited declines in escapement survey measures between 1984 and 2004, and declines were so small that those stocks were considered functionally stable (Heinl and Geiger 2005). Here I provide a brief update in trends of pink salmon escapements in Southeast Alaska, based on the most recent 21 years of survey data, 1987–2007.

Methods

Area management biologists annually estimate salmon spawning stock size for 718 pink salmon index streams via aerial surveys, conducted at intervals, during most of the migration period. Peak survey counts are identified for each stream at the end of the season, and compiled into various indices of abundance (Zadina et al. 2003). For example, Southeast Alaska is divided into three broad sub-regions for the purposes of pink salmon stock assessment (Figure 2). Numerous tagging studies (e.g., Rich 1927, Nakatani et al. 1975)

demonstrated that the commercial fisheries in each sub-region generally target pink salmon that ultimately spawn in that sub-region; therefore, Southeast Alaska pink salmon escapement goals were developed at this broad level (Zadina et al. 2003). Index streams are further grouped into 45 smaller, management “stock groups,” that are useful for assessing the distribution of the pink salmon escapement across the region. Each stock group represents a collection of streams that support pink salmon runs with similar migration routes and run timing, are managed as a unit, and are assumed to share similar productivity and exploitation rates (Van Alen 2000).

I used a non-parametric approach described by Geiger and Zhang (2002), to assess trends over the most recent 21 years of pink salmon escapement survey data for each of the 45 pink salmon stock groups. This method provides a robust estimate of a stock’s increase or decline over a given time series, by fitting a resistant regression trend line to the data. The regression line is then used to back-cast to an estimate of an escapement at year zero, the “year-zero reference point,” and the slope of the line is a robust estimate of the stock’s decline (or increase). Geiger and Zhang (2002) suggested that a decline be considered “biologically meaningful” when the estimated underlying annual decline was more than 3% of the back-cast year-zero reference point; a decline that would result in an overall decline of more than 60% over a 21-year period. I used rank index values for this analysis, rather than raw survey counts; i.e., annual values for each stock group were ranked from lowest to highest, and the ranked values were used for the trend analysis. This transformation eliminated some of the noise inherent in the survey data, and placed all of the index values on the same scale for easy comparison.

Results and Discussion

Biological escapement goals for pink salmon in southeast Alaska were met, or exceeded, for the two largest sub-regions since the late 1980s, and for all three sub-regions since 1994 (Figures 3–5). Pink salmon escapements continue to be well distributed across southeast Alaska. Of the 45 pink salmon stock groups, 40 (89%) exhibited stable or increasing trends over the most recent 21 years of survey data, 1987–2007, while five stock groups (11%) exhibited declines. Only one of the 17 stock groups in the Southern Southeast sub-region exhibited a declining trend in survey data over the past 21 years (Figure 6), and four of the 18 stock groups in the Northern Southeast Inside sub-region exhibited declining trends in survey data (Figure 7). All seven of the pink salmon stock groups in the Northern Outside sub-region exhibited strong increasing trends in survey data over the past 21 years (Figure 6); a trend that coincided with a large increase in pink salmon runs in this area over the last 15 years (Figure 5).

Although five stock groups exhibited recent declines, the declines did not qualify as “biologically meaningful” as defined by Geiger and Zhang (2002). Escapement indices for these stocks have generally been recorded within established escapement management targets, and these stocks could be considered functionally stable. The four pink salmon stock groups in the Northern Southeast Inside sub-region that exhibited declining trends in this analysis are located in central southeast Alaska, in Frederick Sound and lower Stephens Passage (Figure 2). These are early-run stocks and some of the first fish to arrive on the spawning grounds (Sheridan 1962). These fish also enter southeast Alaska waters early in the fishing season (Nakatani 1975). Pink salmon spawning in Frederick Sound and lower Stephens Passage migrate a relatively long distance through inside waters: they enter through

Icy Strait, move south through Chatham Strait, then east into Frederick Sound and Stephens Passage (Nakatani et al. 1975). Again, escapement management targets for these stock groups have largely been met over the past decade, and recent small declines compared to other stock groups simply suggests that these stocks are more fully utilized than other stocks that exhibited recent increasing trends in escapement.

In summary, pink salmon escapements have been at or above escapement goals and well distributed throughout southeast Alaska and no stocks can currently be considered “stocks of concern” under the State of Alaska’s formal Sustainable Salmon Fisheries Policy. More information on pink salmon stock assessment in Southeast Alaska can be found in Zadina et al. (2003), and Heinl and Geiger (2005).

References:

- Baker, T. T., A. C. Wertheimer, R. D. Burkett, R. Dunlap, D. M. Eggers, E. I. Fritts, A. J. Gharrett, R. A. Holmes, and R. L. Wilmot. 1996. Status of Pacific salmon and steelhead escapements in Southern Alaska. *Fisheries* 21(10) 6-18.
- Geiger, H. J., and X. Zhang. 2002. A simple procedure to evaluate salmon escapement trends that emphasizes biological meaning over statistical significance. *Alaska Fishery Research Bulletin* 9:128-134.
- Heinl, S. C., and H. J. Geiger. 2005. Pink salmon stock status and escapement goals in Southeast Alaska and Yakutat [*in*] Stock status and escapement goals for salmon stocks in Southeast Alaska 2005. Der Hovanisian, J. A., and H. J. Geiger [*eds.*] Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Special Publication No. 05-22, Anchorage.
- Nakatani, R. E., G. J. Paulik, and R. Van Cleve. 1975. Pink salmon (*Oncorhynchus gorbuscha*), tagging experiments in Southeastern Alaska, 1938-42, and 1945. NOAA Tech. Rep. NMFS SSRF-686.
- Sheridan, W. L. 1962. Relation of stream temperatures to timing of pink salmon escapements in Southeast Alaska. P. 87-102. *In*: N. J. Wlimovsky (ed.), Symposium on Pink Salmon. H.R. MacMillan Lect. Fish., Inst. Fish., Univ. B. C., Vancouver.
- Rich, W. H. 1927. Salmon-tagging experiments in Alaska, 1924 and 1925. U.S. Bur. Fish., Bull. 42:109–146.
- Van Alen, B. W. 2000. Status and stewardship of salmon stocks in Southeast Alaska. [*In*] pp. 161- 194. E. E Knudsen, C. R. Steward, D. D. McDonald, J. E. Williams, D. W. Reiser [*eds.*] Sustainable Fisheries Management: Pacific salmon. CRC Press. Boca Raton, Florida.
- White, B. 2008. Alaska salmon enhancement program 2007 annual report. Alaska Department of Fish and Game, Fishery Management Report No. 08-03, Anchorage.
- Zadina, T. P., S. C Heinl, H. J. Geiger, and A. J. McGregor. 2003. Pink salmon stock status and escapement goals in Southeast Alaska and Yakutat. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 1J03-, Juneau.

Figures:

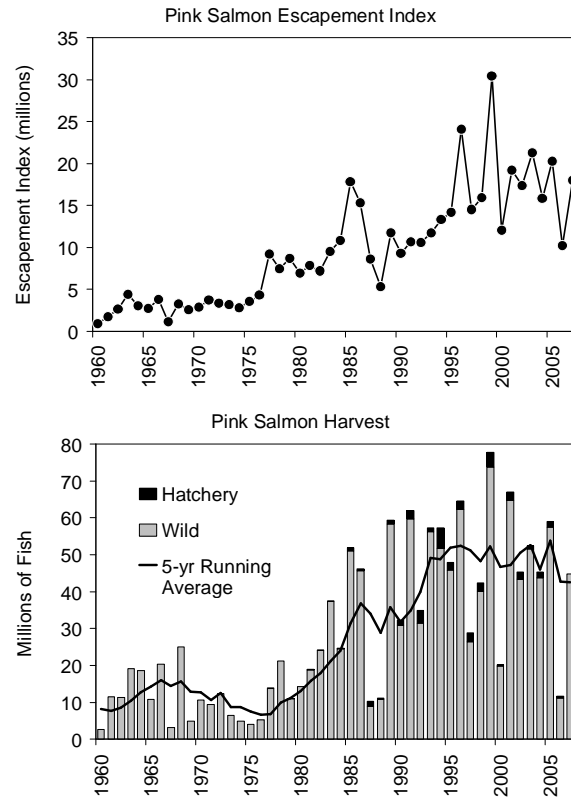


Figure 1. Annual escapement index, and harvest of wild and hatchery-produced pink salmon, in southeast Alaska, 1960–2007.



Figure 2. Three sub-regions delineated for pink salmon stock assessment in Southeast Alaska: Southern Southeast (all waters from Sumner Strait south to Dixon

Entrance), Northern Southeast Inside (all inside waters north of Sumner Strait), and Northern Southeast Outside (all waters off outside coast of Baranof and Chichagof islands).

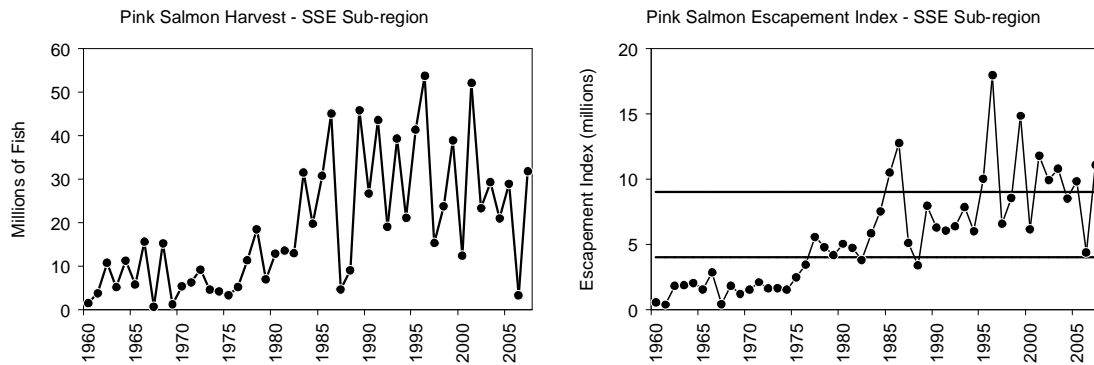


Figure 3. Annual pink salmon harvest and escapement index for the Southern Southeast sub-region, 1960–2007. Horizontal lines show the escapement goal range of 4.0 million to 9.0 million index spawners.

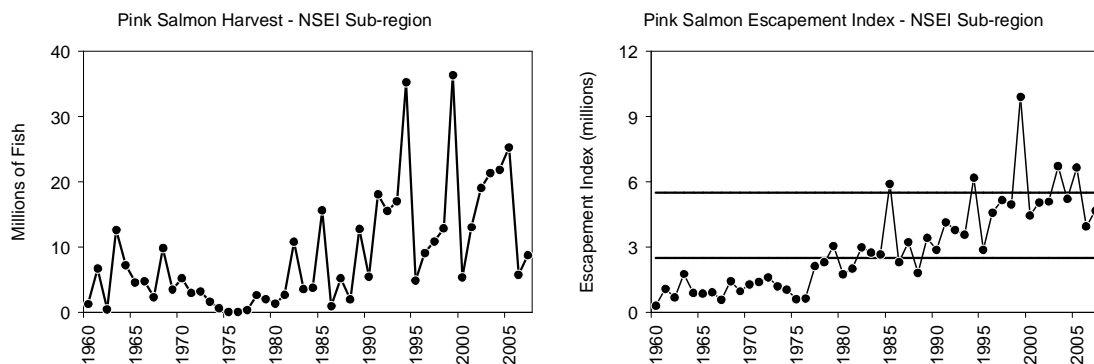


Figure 4. Annual pink salmon harvest and escapement index for the Northern Southeast Inside sub-region, 1960–2007. Horizontal lines show the escapement goal range of 2.5 million to 5.5 million index spawners.

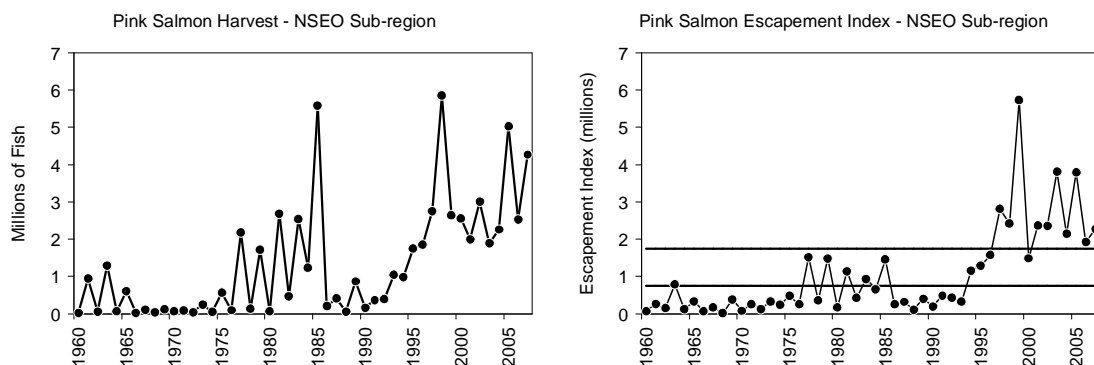


Figure 5. Annual pink salmon harvest and escapement index for the Northern Southeast Outside sub-region, 1960–2007. Horizontal lines show the escapement goal range of 0.75 million to 1.75 million index spawners.

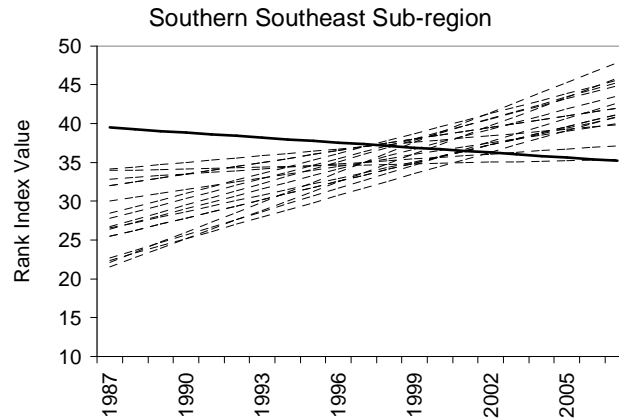


Figure 6. Resistant-regression trend lines of survey data on time for the 17 pink salmon stock groups in the Southern Southeast sub-region of southeast Alaska, 1987–2007. Dashed lines show stock groups that were stable or exhibited increasing trends over the past 21 years; solid bold line shows one stock group that exhibited a declining trend.

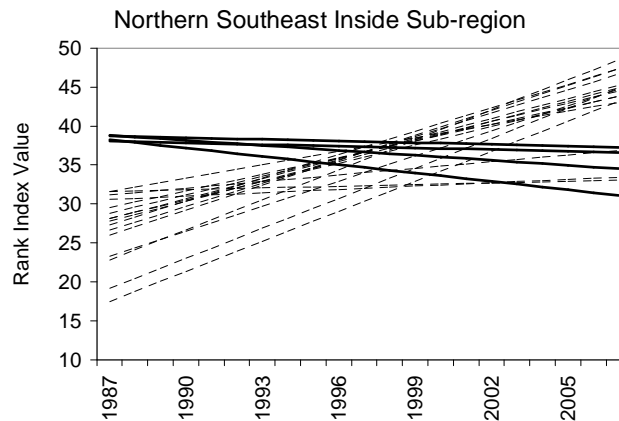


Figure 7. Resistant-regression trend lines of survey data on time for the 18 pink salmon stock groups in the Northern Southeast Inside sub-region of southeast Alaska, 1987–2007. Dashed lines show stock groups that were stable or exhibited increasing trends over the past 21 years; solid bold lines show four stock groups that exhibited declining trends.

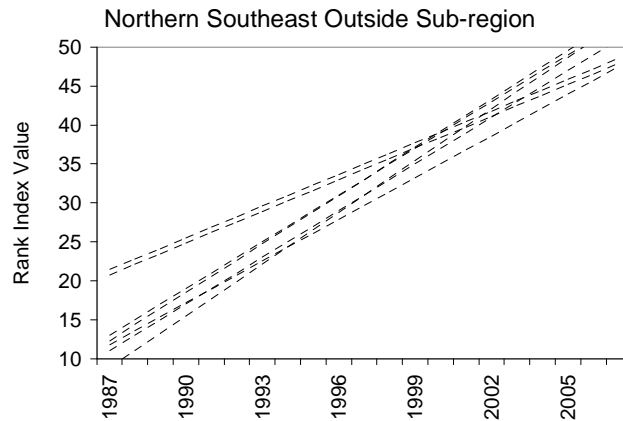


Figure 8. Resistant-regression trend lines of survey data on time for the seven pink salmon stock groups in the Northern Southeast Outside sub-region of southeast Alaska, 1987–2007. All stock groups exhibited increasing trends over the past 21 years.

CONTRIBUTED
Chair: Jamal Moss

The influence of population dynamics and landscape condition on Pink salmon (*Oncorhynchus gorbuscha*) re-colonization in the Fraser River, British Columbia, Canada.

G.R. Pess^{1,2}, T. Quinn², R. Hilborn², and K. Kloehn¹

¹NOAA Fisheries, Northwest Fisheries Science Center

2725 Montlake Blvd East, Seattle, WA, U.S.A. 98112

george.pess@noaa.gov

²University of Washington, School of Aquatic and Fishery Sciences

Box 355020, Seattle, WA, U.S.A. 98195-5020

We investigate how the establishment of pink salmon (*Oncorhynchus gorbuscha*) populations in the Fraser River, British Columbia, Canada in newly reopened habitats is related to specific life history variation and landscape conditions. Pink salmon in the Fraser River were cut off from most of the watershed between 1913 and the 1940s due to a rockslide at Rkm 209 that altered flow conditions and made adult fish passage impossible. Local spawning populations above the slide area disappeared. Fish passage facilities developed in the 1940s allowed adult pinks to migrate past the flow barrier and re-colonize the Upper Fraser. We hypothesize self-sustaining populations of colonists can be established when the population growth rate of the colonizing population is greater than one. This occurs when specific population and landscape factors are met. We developed a general population model with multiple parameters to fit observed spawning population growth for each watershed above the historic barrier. We use maximum likelihood techniques to estimate each of the parameters, and likelihood ratios to compare each of the models to determine the one which best fit the observed data. We found that self-sustaining spawning populations of pink salmon can be established within 10 to 30 years of habitat being reopened to access. However, a self-sustaining population in the uppermost watershed was not established during

the dataset time period, and instead became a sink population for two of the nearest spawning populations. Differences in colonization rates between the self-sustaining and non self-sustaining populations were related to distance from source population, population growth rate, habitat area, and annual relative population size. The results suggest that the combination of distance from source population, habitat suitability, natural barriers, and population dynamics helped determine the spatial and temporal patterns of Fraser River pink salmon re-colonization.

Nondestructive Field Estimation of Fat Content of Yukon River Salmon

F. Joseph Margraf¹, Kyle J. Hartman², M. Keith Cox³

¹US Geological Survey, Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska Fairbanks, Fairbanks, AK 99775-7020 USA

(tel: 907-474-6044, fax: 907-474-7872, e-mail: joe.margraf@uaf.edu)

²Wildlife & Fisheries Resources Program, Division of Forestry and Natural Resources, Davis College of Agriculture, Forestry, and Consumer Sciences, West Virginia University, Morgantown, WV 26506-6125 USA (e-mail: hartman@wvu.edu)

³Sheldon Jackson College, 801 Lincoln Street, Sitka, AK 99835 USA
(e-mail: kcox@sj-alaska.edu)

Field measurement of the ecological condition of fish has been greatly constrained by the lack of a means to directly determine in vivo energy density or fat (lipid) content. Knowledge of the amount of fat (energy) available to Pacific salmon during their upriver spawning migration is a critical need for understanding and predicting the consequences of fisheries management practices, human development activities, and global climate change. Fortunately, recent developments of Bioelectrical Impedance Analysis (BIA) promise a simple, nondestructive means of estimating proximate composition (e.g. fat, protein, water content) for field applications with fish. In this study we demonstrate the utility of BIA for estimating the proximate composition of Chinook and chum salmon on their spawning migration in the Yukon River, Alaska. From a sample of 134 fish, we were able to estimate fat content using BIA with 90% accuracy relative to the amount of fat measured by standard laboratory proximate analysis. Similar results were obtained for protein, water, and energy density. While some minor refinements in field technique are still needed, we now have a reliable and accurate means of estimating proximate composition and energy density of live fish that can be used in a variety of research or management contexts.

Forecasting Pink Salmon in Southeast Alaska Revisited: Efficacy of Predicting Harvest from Indices of Juvenile Salmon Abundance

Alex C. Wertheimer, J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson
National Marine Fisheries Service Auke Bay Laboratory, 11305 Glacier Highway
Juneau, Alaska 99801-8626 USA
email: Alex.Wertheimer@noaa.gov

A time series of indices of juvenile salmon abundance and associated biophysical data has been collected by Auke Bay Laboratories' Southeast Alaska Coastal Monitoring (SECM) project in neritic marine habitats of the northern region of Southeast Alaska (SEAK) from 1997-2007. Beginning in 2004, SECM data have been used to forecast pink salmon harvests in SEAK. Linear models based on juvenile pink salmon catch per unit effort (CPUE) and associated environmental data have provided forecasts within 15% of the actual harvests for the 2004, 2005, and 2007 returns. However, the harvest was only 30% of the forecast in 2006, when the return was the weakest since 1988. Potential problems with using juvenile pink salmon indices for forecasting include: 1) the geographic and temporal representation of the juvenile sampling may not adequately represent the entire Southeast region, and 2) periods of major mortality occurring in the ocean subsequent to the sampling period. Adding environmental data to the forecast model may improve the accuracy of the forecast, but may also reduce its precision. In 2007, juvenile pink salmon CPUE was the lowest observed since the inception of SECM, indicating another poor even-year return in 2008. The 2008 return will thus be an important test of the use of the juvenile pink salmon indices for forecasting SEAK pink salmon harvest.

Pacific salmon population extinctions with an emphasis on lost diversity among pink and chum salmon

Rick Gustafson, Robin Waples, Jim Myers, Laurie Weitkamp, Greg Bryant, Orlay Johnson, and Jeff Hard
National Marine Fisheries Service, Northwest Fisheries Science Center,
Conservation Biology Division, 2725 Montlake Blvd E, Seattle, Washington 98112-2097, USA (tel: 206 860 3372, fax: 206 860 3335, e-mail: rick.gustafson@noaa.gov)

We report the first attempt to systematically enumerate extinct Pacific salmon populations and characterize lost ecological, genetic, and life history diversity types among six species of Pacific salmon (Chinook salmon *O. tshawytscha*, sockeye salmon *O. nerka*, coho salmon *O. kisutch*, chum salmon *O. keta*, pink salmon *O. gorbuscha*), and steelhead *Oncorhynchus mykiss*, from the western contiguous United States. Collectively, nearly 30% of historic populations of these six species have been extirpated in the U. S. Pacific Northwest and California since Euro-American contact; however, pink and chum salmon have seen relatively low levels of population extinction (18–21%) compared to the other four species. The low overall number of pink and chum salmon population extinctions may be due to the fact that the majority of these historical populations occurred in northern coastal portions of our study area, where overall extinction rates were relatively low and to these species' short juvenile residence in freshwater (<1–2 months). We recognized two groupings of both chum and pink salmon that possibly represent extinct ESUs.

POSTERS

Juvenile Pink and Chum Salmon Food Habits and Associated Prey Fields in the Bering and Chukchi Seas

Jamal H. Moss, James M. Murphy, Edward V. Farley Jr., Lisa B. Eisner, Kristin D. Cieciel, and Anatoly Volkov

Auke Bay Laboratories

Alaska Fisheries Science Center, NOAA Fisheries

Ted Stevens Marine Research Institute

17109 Point Lena Loop Road

Juneau, AK 99801

(907) 789-6609 jamal.moss@noaa.gov

The food habits and prey resources of juvenile pink and chum salmon inhabiting the northern Bering and Chukchi Seas were investigated as a first step toward improving our understanding of how climate change may impact pacific salmon ecology in the arctic and subarctic. Juvenile pink and chum salmon were observed in significant numbers throughout the Chukchi Sea, Kotzebue Sound, and Bering Strait during early autumn 2007, and preyed heavily on larval pricklebacks (*Lumpenus fabricii*) in the Chukchi Sea and primarily on zooplankton in Kotzebue Sound the northern Bering Sea. Euphausiids were abundant in the water column of all regions and in the diets of both species. Decapods were a favored prey item of pink salmon while chum salmon preyed heavily upon tunicates and coelenterates. Decapods, tunicates, and coelenterates were rarely observed in the water column and may be highly selected for by juvenile salmon and other pelagic fishes. Fish prey commonly has greater energy content than zooplankton prey, and the potential for fish growth in the Chukchi Sea may be higher relative to more southerly regions due to a preponderance of larval pricklebacks. Future investigations should focus on quantifying the quality of marine habitat in the Arctic in terms of the potential for supporting fish growth.

Tracking of chum salmon fingerling in stream and coastal areas off the Korean Peninsula

S. Kang, S. Kim, and J.K. Kim

Though the catches of chum salmon have more than doubled during the past 20 years due to favorable oceanic conditions and artificial enhancement programs, there is a conspicuous low survival rate among Korean chum salmon compared to other stocks. To evaluate the environmental effects on chum salmon survival in Korean waters, a series of larval/juvenile surveys were conducted in Namdae Stream after they were released in 2005~2007. Six locations in the stream were chosen, and fry were collected approximately every 10 days during March through May. Also, 10~12 ocean stations were sampled for juveniles with about 2~3 week interval in late spring. In stream, fry seemed to be transported toward the estuary in March. The highest densities in April and May, however, were found in upper stream. Fork length and weight were increased with time, but those parameters decreased at mid May as fast growing fry moved downstream. In ocean, chum salmon

juveniles stayed mostly closed to the coastal areas, and showed tendency of northward distribution with time. Furthermore, negative correlation between sea surface temperature near the coastal area and return rate of spawners to natal stream three years later was found ($p < 0.01$).

Diet of fish-eating “southern resident” killer whales: the use of fish remains, fecal samples, and genetic techniques to determine prey species and stocks

Jennifer Hempelmann¹, M. Bradley Hanson¹, Robin W. Baird², Candice Emmons¹, Gregory S. Schorr², John Sneva³, Don Van Doornik⁴, Katherine Ayres⁵, Samuel K. Wasser⁵, Kenneth C. Balcomb⁶, Kelley Balcomb-Bartok⁶, and Michael J. Ford¹

¹Northwest Fisheries Science Center, National Marine Fisheries Service
2725 Montlake Boulevard East, Seattle, WA 98112

²Cascadia Research Collective

218 ½ West Fourth Avenue, Olympia, WA 98501

³Washington Department of Fish and Wildlife

600 Capital Way North

Olympia, WA 98501

⁴Northwest Fisheries Science Center, Manchester Research Station,
P.O.Box 130, Manchester, WA 98353

⁵University of Washington, Center for Conservation Biology,
Department of Biology, Box 351800, Seattle, WA 98195

⁶Center for Whale Research

PO Box 1577, Friday Harbor, WA 98250

Recovery plans for endangered “Southern Resident” killer whales (*Orcinus orca*) have identified reduced prey availability as a possible risk to the population. In order to better assess this risk, we initiated a prey selection study in the whales’ San Juan Island and Puget Sound range from 2004 to 2008. Following the whales in a small boat, we collected fish scales and tissue remains from predation events, as well as feces, using a fine mesh net. We identified prey species through scale analysis and molecular genetics. Prey detection from fecal samples provided a new dimension to killer whale diet studies. Fecal samples represent prey consumed over an extended period of time and are therefore expected to be less biased, or at least have different biases, than fish remains collected after a predation event at the surface. Chinook salmon, a relatively rare species, has been identified as the primary prey species consumed during the whales’ San Juan Island summer range (May-September). This finding strongly supports previous studies based on small numbers of samples collected from the surface. Using genetic stock identification methods, we found that most of the Chinook prey items originated from the Fraser River, and relatively few originated from Puget Sound. During the whales’ Puget Sound fall-winter range, Chum salmon appear to be the dominant prey species consumed. However, this data is incomplete as we have relatively small numbers of fall-winter samples and they are geographically limited. In addition to Chinook and Chum salmon, we identified Coho and Steelhead salmon as well as Pacific Halibut, Lingcod, and Rockfish as prey items. Nevertheless, while fecal samples showed more diversity in the whales’ diet, Chinook remains the primary prey item. These results are likely

to be of significant value in guiding management actions to recover the Southern resident killer whale population.

Multi- user analytical laboratory at Northwest Indian College

Charlotte Clausing

Environmental Tech.

Northwest Indian College

2522 Kwina Rd. Bellingham, WA, USA

Activities Associated with the Laboratory

In keeping with the goals of the College to engage in research and provide technical support to tribal governments and organizations and the College, the lab is consistent with using available resources for community needs, including education, research and extension. The laboratory provides the student resources to prepare for a career in natural resources utilization, environmental protection and answers for the extension and outreach programs. The land grant mission of the College, education, research and extension is also consistent with development of this resource.

Research

The analytical equipment provides opportunity for undergraduate students and faculty and technical staff to investigate the usage of analytical techniques and equipment to answer numerous questions in their individual research projects. Some of the potential projects are summarized below:

- Bacteria associated with hydrogen production
- Pesticide analysis to provide impacts on aquatic life and animals
- Analysis of water samples containing various pollutants of concern
- Fatty acid analysis to identify pathogens
- Fatty acid analysis to determine value of algae culture for growth and survival of high health shellfish larvae and seed.

Outfall analysis of industries

- Runoff analysis of agricultural, storm drains and other sources of toxic contamination.
- Identification of unknown chemicals

The accomplishments of a well run and equipped laboratory only begin here. Analysis of well water, foods and other factors related to human health are high priorities for the lab and will be available as this resource is developed.

Teaching

Teaching activities involve various upper level classes to begin utilization of current lab equipment to become familiar with their use. Theory and practice of equipment use and value will be gained through courses and student research projects. Extraction, isolation, and characterization of chemical compounds through hands on use of the equipment provides cutting edge opportunities.

Public Service

Answers to question posed by the public concerning pesticides, plant diseases and identification of microbial organisms that pose a water quality threat to shellfish beds.

Previous Pink and Chum Workshop Proceedings

Seasonal patterns in diel feeding, gastric evacuation, and energy density of juvenile chum salmon in Icy Strait, Southeast Alaska, 2001

M.V. Sturdevant, E.A. Fergusson, J.A. Orsi, and A.C. Wertheimer.

Auke Bay Laboratories, Ted Stevens Marine Research Institute, Alaska Fishery Science Center, NOAA Fisheries, 17109 Point Lena Loop Rd., Juneau, AK 99801-8626, Phone: (907) 789-6041, Email: molly.sturdevant@noaa.gov

Abstract.

We report on the seasonal diel feeding, gastric evacuation rate, and energy density of juvenile chum salmon, *Oncorhynchus keta* (n = 574), in the Icy Strait migration corridor of northern Southeast Alaska, from May-September, 2001. This study is a component of the Southeast Coastal Monitoring Project investigating annual juvenile salmon abundance, distribution, stock composition, and habitat parameters since 1997. We collected fish during seven time periods over 24 hr, with a beach seine near shore in May and a surface trawl offshore from June-September. We sampled surface (2-m) temperature and prey fields (243-, 333- and 505- μ m mesh zooplankton nets, to 20-m depth) concurrently. Surface temperatures and zooplankton biomass and density peaked in June. Seasonal diets of juvenile chum salmon reflected changes in monthly zooplankton composition, and after May, fish selected for larger, less abundant prey. Diel patterns in diet composition varied by month, but prey %BW and numbers generally peaked late in the day along with zooplankton density. Juvenile chum salmon consumption (%BW) was significantly higher in May and June than in later months, although monthly mean stomach fullness (73-87% volume) did not differ. From May to July, evacuation rates increased concurrent with increases in surface temperature and fish size, a change in diet from crustacean to larvacean prey, and an increase in prey numbers. Daily rations ranged from 17-27%BW per month. Mean whole body energy content values, determined by bomb calorimetry, increased significantly from approximately 849 to 1123 cal/g wet weight from May to September, and moisture content declined from 84% to 78%. These results can be applied in bioenergetic models to increase our understanding of carrying capacity of marine ecosystems for juvenile chum salmon and other planktivores.

Introduction.

Fish feeding and condition are important components in studies on trophic relationships, ecosystem carrying capacity, and survival of fish to adulthood. Juvenile salmon (*Oncorhynchus*. spp.) in Alaska are abundant and enjoy high survival rates compared to those in the Pacific Northwest region (Cooney and Brodeur 1998). Fundamental information on seasonal patterns and daily rhythms in what prey are eaten by juvenile salmon, what prey are available, when fish feed most actively during the day, how fast they digest their food and

need to feed again, and how these factors influence their daily ration and nutritional condition, can help to explain regional differences between fish groups. We report on the diel feeding rhythms, gastric evacuation, and nutritional condition of juvenile chum salmon (*O. keta*) in Icy Strait in northern Southeast Alaska, from May–September 2001.

Our objectives were to compare the seasonal prey fields available to seasonal diets of juvenile chum salmon, monitor diel feeding intensity, determine seasonal changes in diel feeding rhythms, monitor the passage of food through fish guts to estimate gastric evacuation rates, compute daily ration, and to relate feeding success to seasonal nutritional condition. While diet measures provide short-term information about feeding success, measures of condition reflect a longer, integrated history of the feeding environment prior to the time of sampling.

Materials and Methods.

Sampling and shipboard experiments were conducted in 2001 in Icy Strait, northern Southeast Alaska, during five, 7-d cruises from May–September aboard the NOAA ship *John N. Cobb* (Orsi et al. 2004). We defined diel periods D1–D7 as 3-hr intervals beginning at 04:00, 07:00, 10:00, 13:00 16:00, 19:00, and 22:00, respectively, sampled over a 48–72 hr period each month, to examine diel feeding periodicity. Sub-samples of large catches were also defined as T_0 when used to initiate timed evacuation experiments. Fish were collected onshore on May 21–23 by beach seining with a 37-m long net (set in round hauls) in Icy Strait in cobble habitat. Summer sampling was accomplished at station ISC, 6.4 km off the northern beach, on June 29–30, July 30–31, August 28–30, and September 28–30. We fished a Nordic 264 rope trawl (20-m deep by 26-m wide mouth opening, 184-m length, 0.8-cm mesh knotless liner in cod end) at the surface, directly astern of the *John N. Cobb*; hauls were 20 min in duration at a speed of 2–3 knots (Orsi et al. 2004). Biophysical oceanographic samples were collected to accompany fish samples. Temperature (°C) and salinity (PSU) data were collected at 3-m depth with a CTD and zooplankton was sampled with three nets in the 20-m surface water column in each diel period every month except May (one at mid-day). We used a NORPAC 50-cm frame, 243- μ m mesh net, hauled vertically, and a BONGO 60-cm frame with 505- and 333- μ m mesh nets, hauled in double-oblique fashion.

After each haul, juvenile chum salmon were sorted from the catch and anesthetized with tricaine methanesulfonate (MS-222). Sub-samples were preserved in 10% formalin-seawater for diet or were frozen for energy density determinations ($n \leq 12$ each). In May and July, approximately 100 additional live fish were immediately transferred to 2.5 m³ tanks of seawater for the evacuation experiment. Seawater was pumped from 3 m below the vessel, filtered to remove potential zooplankton food, and tank temperature was monitored. Fish sub-samples ($n \leq 10$) were sacrificed at nine intervals ranging from 1–32 hours after T_0 and preserved as above for stomach analysis.

In the laboratory, preserved fish for stomach analyses were measured (mm fork length, FL) and weighed (nearest mg) and the stomachs were excised, weighed (nearest mg), and stored in 50% isopropyl alcohol. During stomach analysis, we recorded visual percent fullness (volumetric index in 25% increments) and total content weight (nearest mg), then teased apart, identified and counted prey organisms. Plankton settled volumes (SVs, ml) of NORPAC samples and displacement volumes (DVs, ml) of bongo samples were measured, sub-samples were obtained with a Folsom splitter, then zooplankton taxa were identified and counted by species, sex, stage and size groups, and sample counts were expanded by the split

fraction (Sturdevant et al. 2002). Frozen fish for nutritional condition analyses ($n \leq 12$ per month) were measured and weighed as above, stomachs were excised, contents extracted and weighed, and viscera were replaced in the body cavity. The entire carcass was dried to a constant weight (nearest mg), homogenized into uniform powder, and a pellet sub-sample (~0.150 g) was pressed; the pellet was then combusted in a Parr 1425¹ bomb calorimeter (Parr Inst. Co. 1993) and the energy released recorded as calories/g dry weight (cal/g DW).

Data were analyzed at two temporal scales, seasonal and diel, using ANOVA (Minitab 13.2). For seasonal comparisons, data were averaged across all diel periods per month; for diel comparisons, samples were compared within month by D1-D7 time periods. We summarized size as mean length, diet composition as mean percent numbers of major prey taxa, and feeding intensity as means of percent fullness index, prey percent body weight (%BW, stomach content wet weight divided by fish body weight without stomach contents), and total numbers of prey (Sturdevant et al. 2002). Zooplankton abundance was expressed as density in number $\cdot \text{m}^{-3}$; taxonomic percent composition was computed for comparison to diet percent composition. For fish nutritional condition, percent dry weight (%DW) was calculated using wet and dry body weights; WBEC in cal/g wet weight (cal/g WW) was estimated as (cal/g DW)(%DW/100). Moisture content was calculated as 100-%DW. Seasonal summaries were computed as mean %moisture and WBEC per month. Rates of gastric evacuation (GER) were calculated for May and July from the exponential decline in stomach content mass or prey numbers of fish caught at T_0 through successive intervals of starvation, using the equation $\text{GER}, y = S(e^{-rt})$, where S = prey number or weight, t = time, and r = instantaneous evacuation rate. Daily ration was computed for each month as consumption $\cdot \text{d}^{-1}$, $C = (24) (\text{mean prey \%BW}) \cdot (\text{GER})$ (Adams and Breck 1990; Williams et al. 2001). Direct values were used for May and July, while values in other months were interpolated to adjust for changes in diet composition that affect evacuation rates (Adams and Breck 1990).

Results.

Size and nutritional condition of juvenile chum salmon exhibited clear seasonal patterns (Figure 1). Over the season, length increased significantly ($P = 0.000$) from approximately 40 mm to 200 mm FL (Figure 1a), but June and July fish sizes were not different, probably due to the influx of a mixture of stocks into the area. Moisture content data were not available for the May fish caught at Crist Point; we therefore used DIPAC hatchery juvenile chum salmon vouchers taken on April 30 to compare moisture content and WBEC to fish later in the season (Figure 1b). Wild fish were approximately 10 mm shorter than these hatchery fish in May ($P < 0.001$; Figure 1a), but because their cal/g DW did not differ ($P = 0.075$), and because body size is not correlated with WBEC (Rodgveller et al. 2007), we assumed the hatchery fish were representative. Moisture content declined significantly ($P = 0.000$) from >84% in spring to about 80% in summer to <78% for the September fish ($P = 0.000$); no significant difference among fish was observed across summer months. Seasonal WBEC increased significantly ($P = 0.000$) from 849.2 in May to a peak of 1122.7 in late September, with no significant difference between summer values (Figure 1b).

Juvenile chum salmon fed intensively throughout the summer, and only one empty stomach was observed. Stomach fullness averaged 73-87% from May to September, with significantly ($P = 0.021$) greater fullness only in May compared to August (Figure 2a). Seasonal prey %BW gradually declined from spring over the summer, consistent with

allometric growth patterns, from about 3.5% to about 1.5% BW; prey %BW was significantly ($P = 0.000$) higher in May compared to all later months, and in June compared to August and September (Figure 2b). Prey numbers increased significantly ($P = 0.000$), from 49 prey in May to 1370 in September (Figure 2c), with no significant differences in June-July-August values of 527-644 prey per gut.

Diel patterns of feeding intensity were fairly weak and varied by month (data not shown). The complete diel sample series was available only for June ($n = 68$, vs. 27-61 fish in other months; Sturdevant et al. 2002). Stomach fullness did not differ across diel periods in any month except July, when %fullness was significantly higher ($P = 0.046$) at night (D6) compared to morning (D2). Prey %BW showed a significant ($P \leq 0.003$) drop at mid-day in May compared to earlier and later in the day, and an increasing trend from morning to night in June and July, but no trend ($P \geq 0.129$) in August or September. Prey number was also significantly lower ($P \leq 0.014$) at mid-day in May compared to morning or night, was highest at night (D6) in June and July, showed no significant trend in August, then peaked in the afternoon in September.

The seasonal diet of juvenile chum salmon was principally composed of a variety of crustacean zooplankters, with large numerical contributions of larvaceans in summer (Figure 3). Diet focused on calanoid copepods in May, and included a small proportion of epibenthic harpacticoid copepods; small calanoids were important by number, while large calanoids were important by weight. Juvenile euphausiids and larvaceans composed most of the diet in June, with euphausiids dominant by weight. Hyperiid amphipods appeared in the diet in July, and co-dominated with larvaceans for the rest of the season in percent weight and percent number.

Zooplankton prey size fields also varied seasonally in both density and composition (Sturdevant et al., unpub. data). Density ranged from hundreds of organisms in the 505- μ m mesh, to a few thousand in the 333- μ m mesh, up to nearly 20,000 in the 243- μ m mesh. Seasonally, zooplankton density and biomass usually peaked in June (Sturdevant et al. 2002). The taxonomic composition of prey size fields differed from each other and from juvenile chum salmon diets. The smaller meshes were dominated by small and large calanoid copepods throughout the season, but juvenile chum salmon consumed these prey only in May. In contrast, chum salmon diets were most similar in composition to the 505- μ m prey size field. Small calanoids made up much less of the total in this large mesh, which, consequently, reflected higher percentages of the taxa eaten—euphausiids, hyperiid amphipods and larvaceans—than the smaller meshes did. However, juvenile chum salmon consumed these taxa in greater proportions than they were represented even in the largest prey size field, indicating selective predation.

Diel rhythms in zooplankton abundance showed generally lower densities during the day and higher densities in evening-night (D6-D7) in all prey size fields and all months (data not shown). For example, comparison of diel zooplankton to diel chum diet in June showed that, although principal taxa did not change dramatically over the course of the day, at mid-day the number of prey eaten declined along with zooplankton density and corresponded with a decline in the percentage of euphausiids available.

Instantaneous evacuation rates of juvenile chum salmon in July ($GER = -0.653$; $R^2 = 0.83$) were more rapid than in May ($GER = -0.239$; $R^2 = 0.81$) (Figure 4). Diets at the time of capture were substantially different in both prey composition and prey number in the two months, with low mean numbers (range ≈ 100 -160) of principally crustacean prey in May

fish guts (Figure 4a) and high mean numbers (range \approx 400-800 of principally larvacean prey in July fish guts (Figure 4b). Fish emptied their guts in approximately twelve hrs in May vs. seven hrs in July. Evacuation rates and mean prey numbers and biomass were used to calculate daily ration. Daily ration in prey numbers peaked in June (\sim 20,000), while ration in %BW peaked in September (\sim 27%; Figure 4c).

Discussion.

Food resources may be limited in some habitats at some times during the critical early marine period in salmon life history (e.g., Bailey et al. 1975, Cooney et al. 1981, Perry et al. 1996), and seasonal WBEC values provide insight into habitat use, consistency of feeding intensity, density-dependent feeding, and carrying capacity (Paul 1997). While numerous studies of juvenile chum salmon diet have been published (e.g., Bailey et al. 1975, Karpenko and Nikolaeva 1989, Sturdevant et al. 1996, Landingham et al. 1998), ours represents one of the more complete seasonal studies in the first marine summer, and no information has yet been published on their energetic condition (Orsi et al 2004). A few studies have been published on energetic condition of juvenile pink salmon, which have similar diets and early life history as chum salmon (Paul and Willette 1997, Boldt and Haldorson 2004, Rodgveller et al. 2007).

Juvenile chum salmon in our study in Icy Strait fed continuously over the 24-hr diel period each month from May to September; stomachs averaged approximately 80% full throughout the season. This observation supports the use of a continuous feeding model for juvenile chum salmon (Adams and Breck 1990). Daily ration peaked in early summer, along with seasonal peak zooplankton and temperature, but prey numbers eaten increased seasonally. Juvenile salmon diet and zooplankton composition changed more on a seasonal scale than on a diel scale. Seasonal patterns of feeding intensity were consistent with seasonal changes in prey composition and higher rates of feeding on abundant, smaller prey organisms (larvaceans) even while selection for less abundant, large prey occurred. Diel abundance of zooplankton generally peaked late in the day each month. However, variable diel feeding rhythms also suggested that feeding intensity was influenced by the prey available seasonally and by prey diel rhythms. Thus, the size and/or principal type of prey, such as vertically migrating, heavy-bodied or pigmented euphausiids and hyperiid amphipods, affected measures of feeding intensity in different periods. Further analysis of zooplankton individual taxa, measures of diet-zooplankton similarity, and prey selection indices may elucidate the mechanisms for these patterns (Seki and Shimizu 1998).

Evacuation rate of juvenile chum salmon increased from May to July, resulting in shorter time to empty stomachs and seasonal maintenance of a high daily ration despite utilization of prey with lower body mass. Factors influencing the high GER included a five-fold increase in total number of prey in guts at time of capture (greater number of particles and therefore surface area for digestive enzyme function (MacDonald et al. 1982); increase in fish size (higher caloric requirement); a 5-degree increase in habitat temperature (increased metabolic rate; Brett and Higgs 1970, Adams and Breck 1990); and change in prey from hard-bodied taxa that are relatively mobile to soft-bodied taxa that are less mobile (easier to capture and digest, no indigestible exoskeleton; MacDonald et al. 1982, Arai et al. 2003) without substantial loss in nutritional value and energy content (Davis et al. 1998). These good feeding conditions were reflected over the season by the steadily increasing fish size,

declining moisture content and increasing energy density, all indicating good nutritional condition and growth of juvenile chum salmon.

In Southeast Alaska and other regions, large-scale hatchery production of juvenile salmon may increase the potential for competitive interactions between enhanced and wild stocks of salmon in both near shore, coastal, and oceanic habitats (Wertheimer et al. 2004). The demands of increased hatchery production on the carrying capacity of the marine ecosystem have been assessed with bioenergetic modeling (Boldt and Haldorson 2004, Orsi et al. 2004). However, such studies often rely on input parameters derived for conspecifics or other age classes. The daily ration values we computed empirically for juvenile chum salmon are about five times as high as estimates from bioenergetics modeling for which species-specific physiological parameters were not available (Orsi et al. 2004) and juvenile chum salmon in Icy Strait appear to be thriving. Our results provide model parameters specific to juvenile chum salmon, including information on diel feeding periodicity and gastric evacuation rates that can be used to validate and improve bioenergetic modeling.

References

- Adams, S. and J.E. Breck. 1990. Bioenergetics. pp. 389-415 *In*: C. B. Schreck and P. B. Moyle (eds.). *Methods for Fish Biology*. Bethesda, Maryland: American Fisheries Society.
- Arai, M. N., D.W. Welch, A.L. Dunsmuir, M. Jacobs and A.R. Laduceur. 2003. Digestion of pelagic ctenophora and cnidaria by fish. *Can. J. Fish. Aquat. Sci.* 60:825-829.
- Bailey, J.E., B.L. Wing and C.R. Mattson. 1975. Zooplankton abundance and feeding habits of fry of pink salmon, *Oncorhynchus gorbuscha*, and chum salmon, *Oncorhynchus keta*, in Traitors Cove, Alaska, with speculations on the carrying capacity of the area. *Fishery Bull.* 73(4):846-861.
- Boldt, J.L. and L.J. Haldorson. 2004. Size and condition of wild and hatchery pink salmon juveniles in Prince William Sound, Alaska. *Trans. Amer. Fish. Soc.* 133:173-184.
- Brett, J.R. and D.A. Higgs. 1970. Effect of temperature on the rate of gastric digestion in fingerling sockeye salmon, *Oncorhynchus nerka*. *J. Fish. Res. Bd. Canada.* 27(10):1767-1779.
- Cooney, R.T. and R.D. Brodeur. 1998. Carrying capacity and North Pacific salmon production: stock-enhancement implications. *Bull. Mar. Sci.* 62(2):443-464.
- Davis, N.D., Myers K.W. and Ishida Y. 1998. Caloric value of high-seas salmon prey organisms and simulated salmon ocean growth and prey consumption. *North Pacific Anad. Fish Comm. Bull.* 1:146-162.
- Karpenko, V.I., and E.T. Nikolaeva. 1989. Daily feeding rhythm and rations of juvenile chum salmon, *Oncorhynchus keta*, during river and early marine part of their life cycle. *J. Ichthy.* 29(4):75-82.
- Landingham J.H., M.V. Sturdevant and R.D. Brodeur. 1998. Feeding habits of juvenile Pacific salmon in marine waters of southeastern Alaska and northern British Columbia. *Fishery Bull.* 96:285-302.
- MacDonald, J.S., K.G. Waiwood and R. H. Green. 1982. Rates of digestion of different prey in Atlantic cod (*Gadus morhua*), ocean pout (*Macrozoarces americanus*), winter flounder (*Pseudopleuronectes americanus*) and American plaice (*Hippoglossoides platessoides*). *Can. J. Fish. Aquat. Sci.* 39(5):651-659.

- Orsi, J.A., A.C. Wertheimer, M.V. Sturdevant, E.A. Fergusson, D.G. Mortensen, and B.L. Wing. 2004. Juvenile chum salmon consumption of zooplankton in marine waters of southeastern Alaska: a bioenergetics approach to implications of hatchery stock interactions. *In: Reviews in Fish Biology and Fisheries* 14: 335–359.
- Parr Operating Instruction Manual. Parr Instrument Co. 1993. 1425 Semimicro Bomb Calorimeter No. 280MM. Parr Instrument Co. 21153rd St. Moline, Illinois USA 61265 (<http://www.parrinst.com>).
- Paul, A.J. 1997. The use of bioenergetic measurements to estimate prey consumption, nutritional status and thermal habitat requirements for marine organisms reared in the sea. *Bull. Natl. Res. Inst. Aquac. Suppl.* 3:59-68.
- Paul, A.J. and M. Willette. 1997. Geographical variation in somatic energy content of migrating pink salmon fry from Prince William Sound: A tool to measure nutritional status. pp. 707-720 *In: Forage Fishes in Marine Ecosystems*. Alaska Sea Grant College Program AK-SG-97-01, 816 pp.
- Perry, R.I., B.J. Hargreaves B. Waddell, and D.L. Mackas. 1996. Spatial variations in feeding and condition of juvenile pink and chum salmon off Vancouver Island, British Columbia. *Fisheries Oceanog.* 5(2):73-88.
- Rodgveller, C.A., J.H. Moss, and A.M. Middleton. 2007. The influence of sampling location, timing, and hatching origin on the prediction of energy density in juvenile pink salmon. NOAA Tech. Memo. NMFS-AFSC-170, 27 p.
- Seki, J. and I. Shimizu. 1998. Diel migration of zooplankton and feeding behavior of juvenile chum salmon, in the central Pacific coast of Hokkaido. *Bull. Nat. Salmon Res. Center* 1:13-27.
- Sturdevant, M.V., A.C. Wertheimer, and J.L.Lum. 1996. Diets of juvenile pink and chum salmon in oiled and non-oiled nearshore habitats in Prince William Sound, 1989 and 1990. *American Fish. Soc. Symp.* 18: 578-592.
- Sturdevant, M.V., E.A. Fergusson, J.A. Orsi, and A.C. Wertheimer. 2002. Diel feeding of juvenile pink, chum, and coho salmon in Icy Strait, southeastern Alaska, May–September 2001 (NPAFC Doc. 631). Auke Bay Laboratory, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, U. S. Dept. of Commerce, 11305 Glacier Highway, Juneau, AK 99801 8626, USA, 42 pp.
- Wertheimer, A.C., W.R. Heard and W.W. Smoker. 2004. Effects of hatchery releases and environmental variation on wild-stock productivity: consequences for sea ranching of pink salmon in Prince William Sound, Alaska. pp. 307-326 *In: K.M. Leber, S. Kitada, H.L. Blankenship and T. Svåsand (eds.). Stock Enhancement and Sea Ranching: Developments, Pitfalls and Opportunities*. Blackwell Pub., 562 pp.
- Williams, A., J.A. Koslow, A. Terauds and K. Haskard. 2001. Feeding ecology of five fishes from the mid-slope micronekton community off southern Tasmania, Australia. *Mar. Biol.* 139:1177-1192.

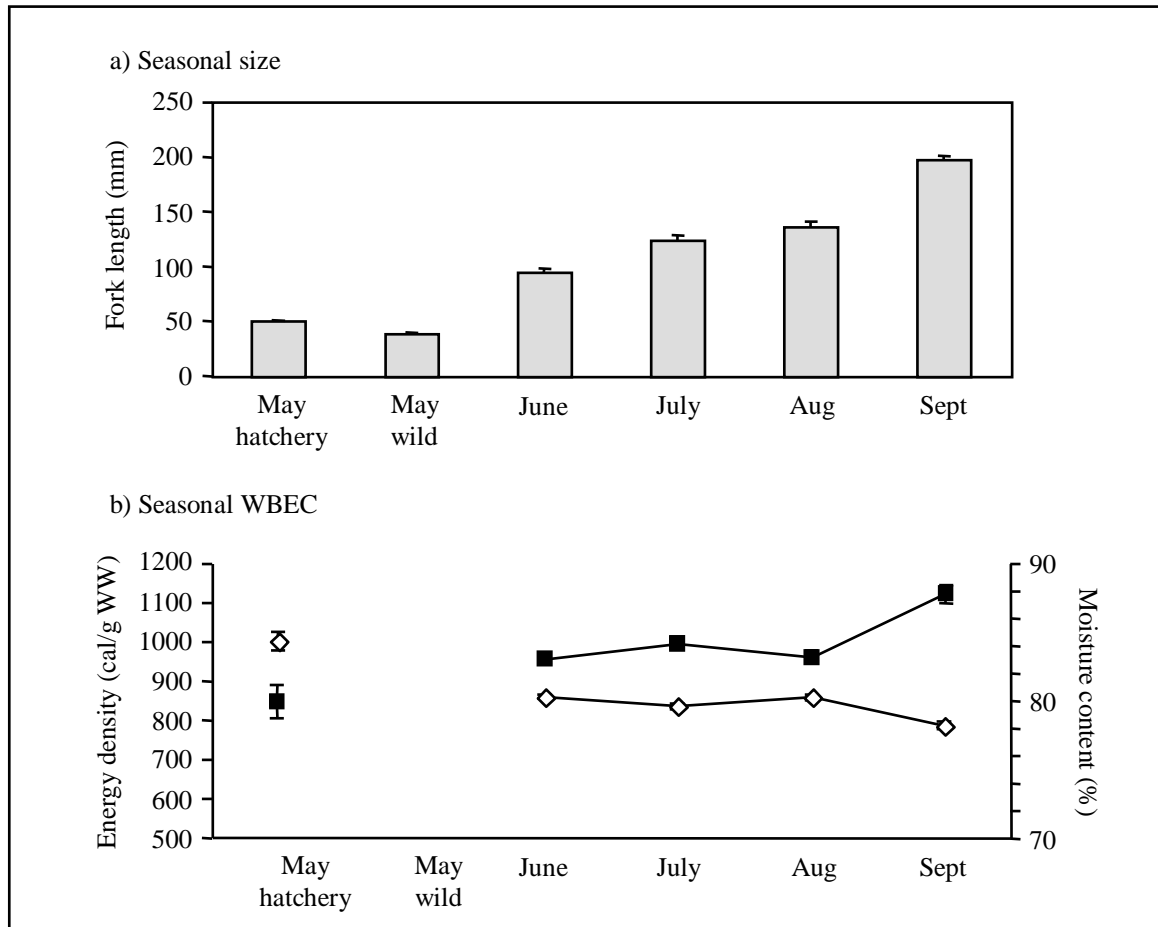


Figure 1. Seasonal size and condition of juvenile chum salmon in Icy Strait, 2001, as (a) mean fork length in mm and (b) mean WBEC in cal/g wet weight (squares) and percent moisture content (diamonds). Standard error bars shown.

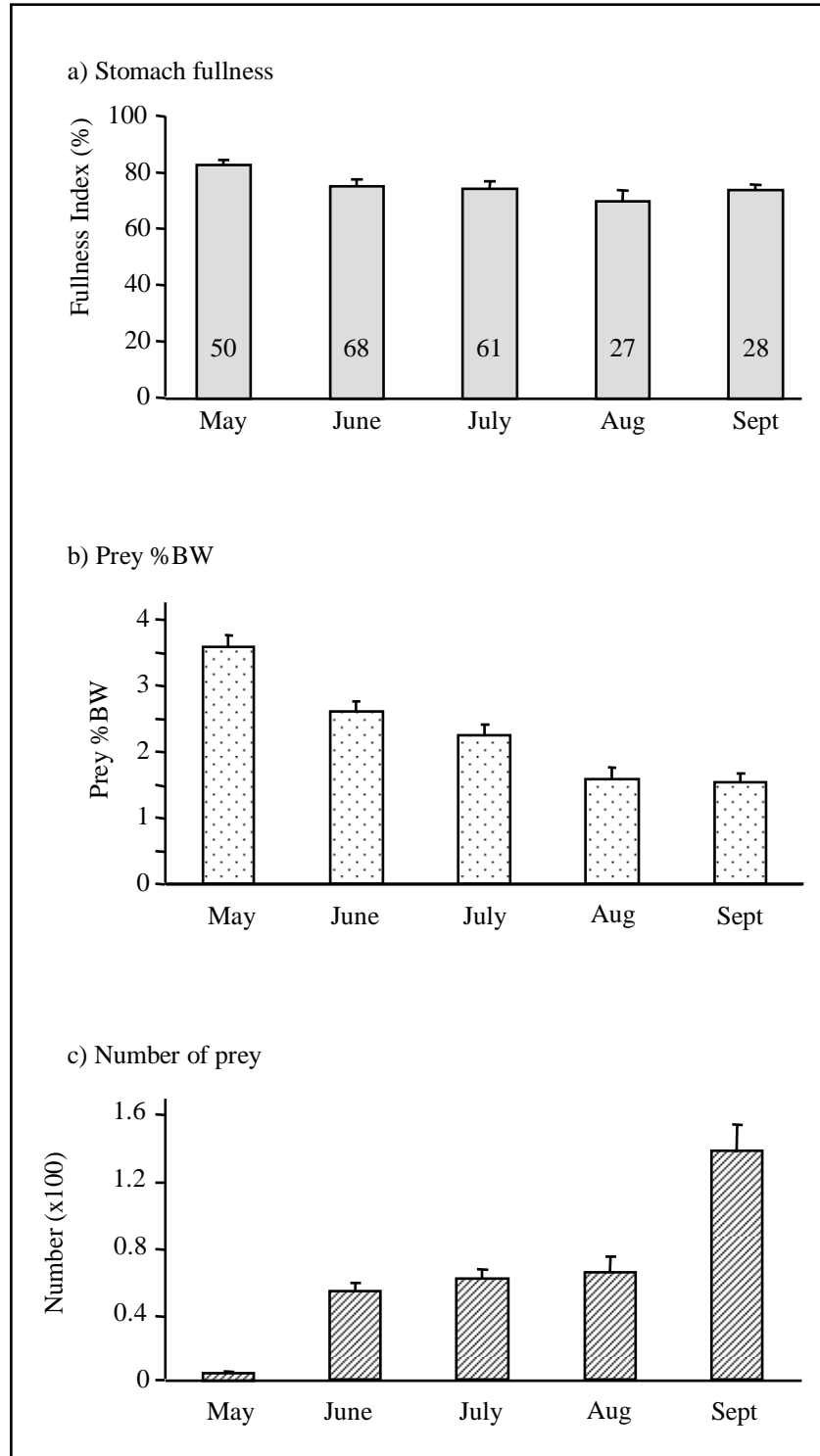


Figure 2. Seasonal feeding intensity of juvenile chum salmon in Icy Strait, 2001, as (a) mean stomach fullness index, (b) mean prey percent body weight (%BW), and (c) mean number of prey eaten. Standard error bars shown.

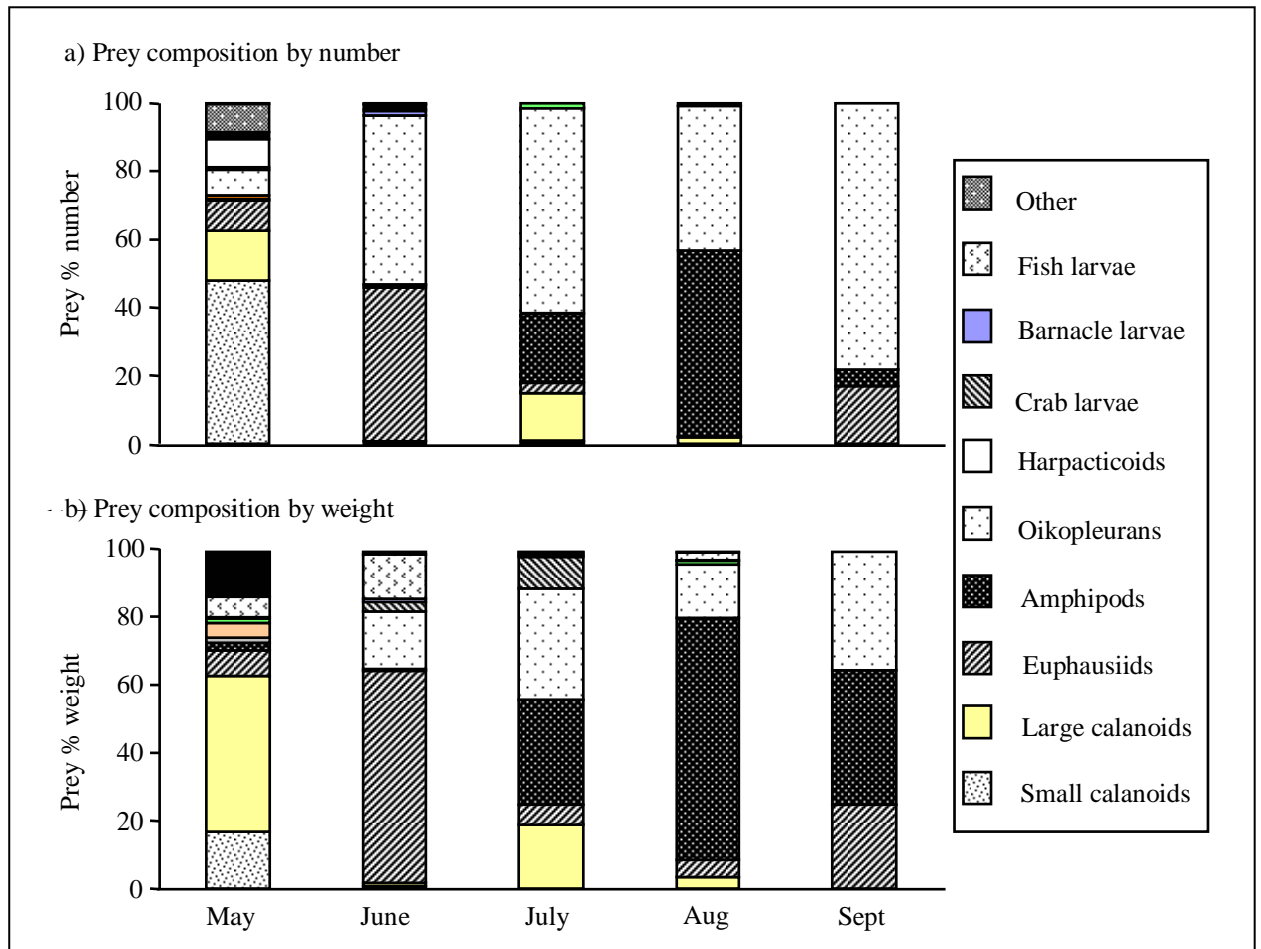


Figure 3. Seasonal prey composition of juvenile chum salmon in Icy Strait, 2001, as (a) mean percent of total prey number and (b) mean percent of total prey weight by prey taxon.

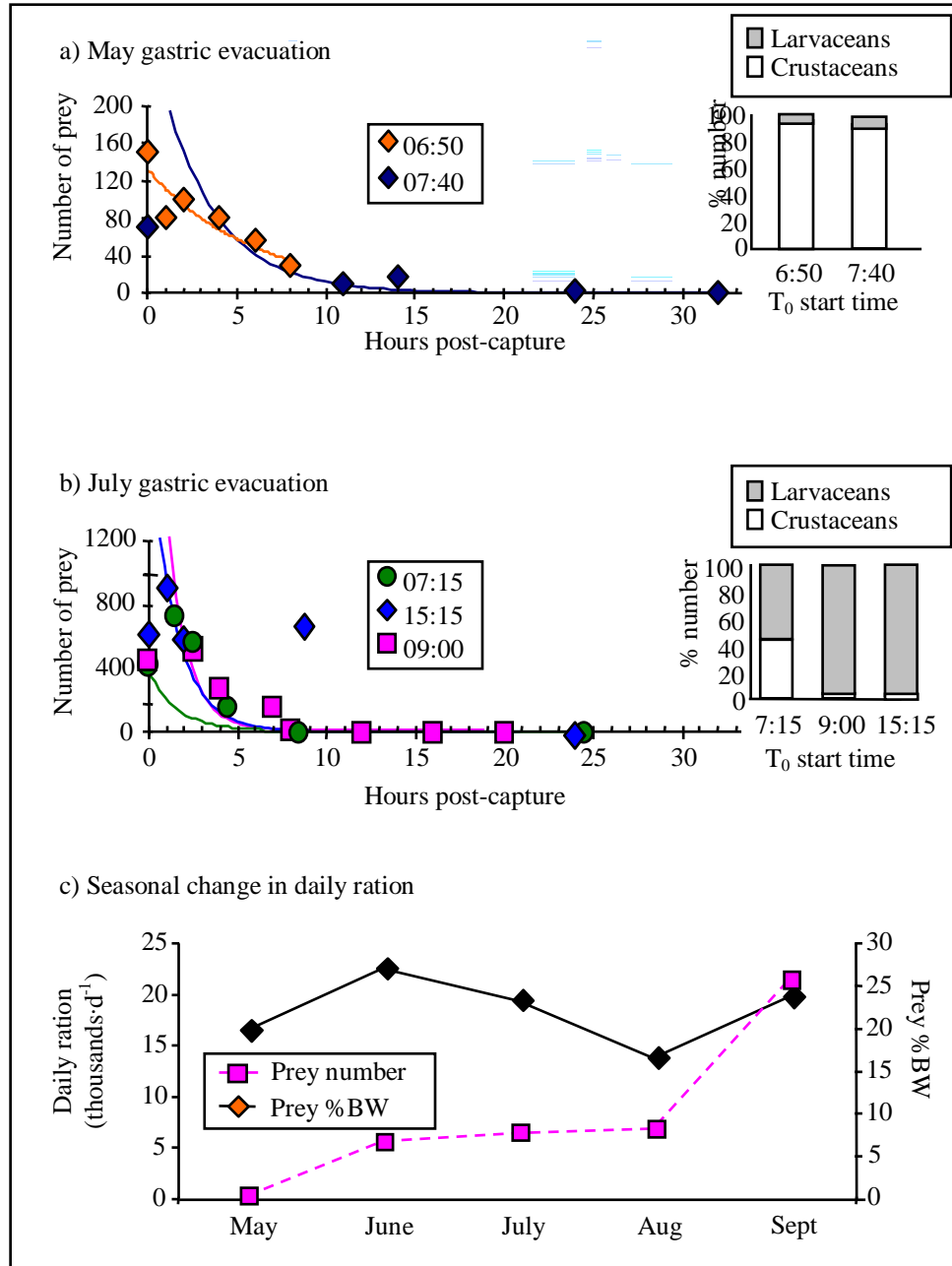


Figure 4. Juvenile chum salmon exponential evacuation rates as numbers of prey declining over time in (a) May and (b) July, with diet composition as percent number of prey at T_0 starting times (right hand inserts), and (c) seasonal daily ration in prey numbers and percent body weight in Icy Strait, 2001.