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NPAFC Science Plan 2006–2010: A US Review

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NPAFC Science Plan 2006-2010: A US Review

Scientists from the United States have actively participated within the North Pacific Anadromous Fish Commission to address the goals and objectives of the Commission in regards to status and trends in production of anadromous stocks in ocean ecosystems. Each year, the US provides statistics and updates on salmon genetic baselines (NPAFC Docs. 1027, 1138), salmon bycatch within the US groundfish fisheries (NPAFC Docs. 1104, 1174), the number of hatchery salmon released into the North Pacific Ocean (NPAFC Docs. 1052,1062,1134,1135,1198) and associated otolith thermal marks on hatchery released fish (NPAFC Docs. 1090, 1091), as well as documents on coded wire tag salmon captured in the NPO and those salmon tagged with disc and recording tags released during ocean research surveys (NPAFC Doc. 1038).

The US conducted annual surveys of juvenile salmon ecology in coastal ecosystems from the California current to the Arctic during spring through fall. These surveys are used to assess ecosystem productivity and to determine relative abundance and overall health of juvenile salmon during their first year at sea. Surveys reported annually to the NPAFC include those conducted by the Alaska Fisheries Science Center (AFSC) that take place in southeast Alaska (NPAFC Docs. 937, 1015, 1094, 1153) and the eastern Bering Sea (NPAFC Docs. 941, 1023, 1024, 1093, 1156). Cruise reports for southeast Alaska coastal monitoring (SECM) are reported annually to NPAFC (NPAFC Docs. 1057, 1110, 1181). During 2009, the NPAFC accepted BASIS Phase II research plan to continue international research related to the effect of climate change and variability on anadromous stocks and related nekton (NPAFC Doc. 1164).

To address salmon ecology in the Gulf of Alaska and Bering Sea, the AFSC takes measurements on the physical and biological oceanographic characteristics and collects fish samples using a rope trawl rigged to fish near-surface waters. Random samples of fish collected from the trawl are measured (fork length (mm) and weight (g)), and analyzed for diet composition, age and growth, and energetic status. Distribution and migration pathways for juvenile salmon are inferred based on the survey design and from genetic stock identification.

Abstracts of published research related to the 2006 – 2010 NPAFC Science plan are presented for each objective. However, objectives 1 and 3 were combined as much of the research conducted in the Gulf of Alaska is on juvenile salmon.

1 & 3) Juvenile Anadromous Stocks in Ocean Ecosystems/Gulf of Alaska

Brodeur, R., E. A. Daly, M. V. Sturdevant, T. W. Miller, J. H. Moss, M. E. Thiess, M. Trudel, L. A. Weitkamp, J. Armstrong, and E. Norton. 2007. Regional comparisons of juvenile salmon feeding ecology in coastal marine waters off the west coast of North America. American Fisheries Society Symposium 57:183-203.

Abstract.—Upon entering marine waters, juvenile Pacific salmon *Oncorhynchus* spp. depend on feeding at high and sustained levels to achieve growth necessary for survival. In the last decade, several concurrent studies have been examining the food habits and feeding intensity of juvenile Pacific salmon in the shelf regions from California to the northern Gulf of Alaska. In this paper, we compared results from feeding studies for all five species of juvenile salmon (Chinook salmon *O. tshawytscha*, coho salmon *O. kisutch*, chum salmon *O. keta*, sockeye salmon *O. nerka*, and pink salmon *O. gorbuscha*) between 2000 and 2002, years when these regions were sampled extensively. Within these years, we temporally stratified our samples to include early (May–July) and late (August–October) periods of ocean migration. Coho and Chinook salmon diets were most similar due to a high consumption of fish prey, whereas pink, chum, and sockeye salmon diets were more variable with no consistently dominant prey taxa. Salmon diets varied more spatially (by oceanographic and regional factors) than temporally (by season or year) in terms of percentage weight or volume of major prey categories. We also examined regional variations in feeding intensity based on stomach fullness (expressed as percent body weight) and percent of empty or overly full stomachs. Stomach fullness tended to be greater off Alaska than off the west coast of the United States, but the data were highly variable. Results from these comparisons provide a large-scale picture of juvenile salmon feeding in coastal waters throughout much of their range, allowing for comparison with available prey resources, growth, and survival patterns associated with the different regions.

Fergusson E. A., M. V. Sturdevant, and J. A. Orsi. 2010. Effects of starvation on energy density of juvenile chum salmon (*Oncorhynchus keta*) captured in marine waters of Southeastern Alaska. Fish. Bull. 108: 218-225.

Abstract. —We conducted laboratory starvation experiments on juvenile chum salmon (*Oncorhynchus keta*) captured in the neritic marine waters of northern Southeast Alaska in June and July 2003. Temporal changes in fish energy density (whole body energy content [WBEC], cal/g dry weight), percent moisture content, wet weight (g), length (mm), and size-related condition residuals were measured in the laboratory and were then compared to long-term field data. Laboratory water temperatures and salinities averaged 9°C and 32 psu in both months. Trends in response variables were similar for both experimental groups, although sampling intervals were limited in July because fewer fish were available (n=54) than in June (n=101). Overall, for June (45-d, 9 intervals), WBEC, wet weight, and condition residuals decreased and percent moisture content increased, while fork length did not change. For July (20-d, 5 intervals), WBEC and condition residuals decreased, percent moisture content and fork length increased, and wet weight did not change. WBEC, percent moisture content, and condition residuals fell outside the norm of long-term data ranges within 10–15 days of starvation, and may be more useful than fork length and wet weight in detecting fish condition responses to suboptimal environments.

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. T. 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. Pages 31-80 *In:* G. Churchill, R. Brodeur, L. Haldorson, and S. McKinnell, editors. Ecology of Juvenile Salmon in the Northeast Pacific Ocean: Regional Comparisons. American Fisheries Society, Symposium 57, Bethesda, Maryland.

Abstract.—In this chapter, we describe the distributions and abundances of juvenile Chinook salmon *Oncorhynchus tshawytscha*, coho salmon *O. kisutch*, chum salmon *O. keta*, pink salmon *O. gorbuscha*, and sockeye salmon *O. nerka* in six regions along the west coast of North America from central California to the northern Gulf of Alaska during the early summer (June and July) and late summer–fall (August–November) of 2000, 2002, and 2004. We also describe fish abundance in relation to bottom depth and to the average temperature and salinity of the upper water column. Salmon were collected in rope trawls from the upper 15–20 m over the open coastal shelf. Catch per unit effort was standardized across the different regions. Subyearling Chinook salmon were found only from central California to British Columbia. Yearling Chinook salmon were widespread, but were most abundant between Oregon and Vancouver Island. Juvenile coho salmon were widespread from northern California to the northern Gulf of Alaska, whereas chum, sockeye, and pink salmon were only abundant from Vancouver Island north into the Gulf of Alaska. Generally, the juveniles of the different salmon species were most abundant at, or north of, the latitudes at which the adults spawn. Abundances were particularly high near major exit corridors for fish migrating from freshwater or protected marine waters onto the open shelf. Seasonal latitudinal shifts in abundance of the juvenile salmon were generally consistent with the counterclockwise migration model of Hartt and Dell (1986). Subyearling Chinook salmon were associated with the high salinity environment found off California and Oregon, whereas chum, sockeye, and pink salmon were associated with the lower salinity environment in the Gulf of Alaska. However, within regions, evidence for strong temperature or salinity preferences among the different species

was lacking. Subyearling Chinook salmon were most abundant in shallow, nearshore water.

LaCroix J. J., A. C. Wertheimer, J. A. Orsi, M. V. Sturdevant, E. A. Fergusson, and N. A.. Bond. 2009. A top-down survival mechanism during early marine residency explains coho salmon year-class strength in southeast Alaska. Deep–Sea Research II (2009), doi:10.1016/j.dsr2.2009.03.006.

Abstract.—Coho salmon (*Oncorhynchus kisutch*) are a vital component in the southeast Alaska marine ecosystem and are an important regional fishery resource; consequently, understanding mechanisms affecting their year- class strength is necessary from both scientific and management perspectives. We examined correlations among juvenile coho salmon indices, associated biophysical variables, and adult coho salmon harvest data from southeast Alaska over the years1997–2006. We found no relationship between summer indices of juvenile coho salmon growth, condition, or abundance with subsequent harvest of adult coho salmon in the region. However, using stepwise regression, we found that variation in adult coho salmon harvest was largely explained by indices of juvenile pink salmon (*Oncorhynchus gorbuscha*) abundance (67%) and zooplankton abundance (24%). To determine if high juvenile pink salmon abundance indicates favorable ‘‘bottom-up’’ lower trophic level environmental conditions for juvenile coho salmon, we plotted abundance of juvenile pink salmon against growth and condition of juvenile coho salmon. No change in growth or condition of juvenile coho salmon was observed in relation to the abundance index for juvenile pink salmon. Therefore, we hypothesize that coho salmon year-class strength in southeast Alaska is influenced by a‘‘top-down’’predator control mechanism that results from more abundant juvenile pink salmon, which serve as a predator buffer during early marine residency.

Morris, J. F. T., M. Trudel, M. E. Thiess, R. M. Sweeting, J. Fisher, S. A. Hinton, E. A. Fergusson J. A. Orsi, E.V. Farley, Jr., , and D. W. Welch. 2007. Stock-specific migrations of juvenile coho salmon derived from coded-wire tag recoveries on the continental shelf of western North America. Pages 81-104 *In:* G. Churchill, R. Brodeur, L. Haldorson, and S. McKinnell, editors. Ecology of Juvenile Salmon in the Northeast Pacific Ocean: Regional Comparisons. American Fisheries Society, Symposium 57, Bethesda, Maryland

Abstract.—A conceptual model of juvenile coho salmon *Oncorhynchus kisutch* migration from Oregon, Washington, the Columbia–Snake River system, British Columbia, and southeast Alaska was derived using coded-wire-tag data from juvenile salmon surveys conducted between 1995 and 2004. Over this 10-year period, 914 coded-wire-tagged (CWT) juvenile coho salmon were recovered. In general, the migratory behavior of juvenile coho salmon observed in this study was consistent with previous studies showing that juvenile salmon generally undertake a northward migration and utilize the continental shelf as a migration highway. However, this study also revealed that both regional and specific river stocks of coho salmon from all parts of the North American coast are composed of fast components that take a rapid and direct migration in the summer to as far west as Kodiak Island, Alaska and slow components that migrate over a relatively short distance from their natal rivers and reside over winter on the shelf. The Columbia–Snake River system, coastal Oregon, and coastal Washington had the highest proportion of fast CWT migrants among regions. Furthermore, specific stocks within the lower Columbia River had the highest proportion of fast CWT migrants both within the Columbia–Snake River watershed and along the entire west coast of North America. Distances migrated along the shelf were positively correlated to size at capture during the summer for almost all regional stocks, indicating that fast-migrating juvenile coho salmon have faster growth rates. The widespread dispersion along the continental shelf as a consequence of a mix of slow and fast migrants and the subsequent offshore migration into different regions of the Gulf of Alaska may have been selected over evolutionary time scales. This strategy would have ensured the long-term survival of individual stocks by spreading the risk of mortality among oceanic regions.

Orsi, J.A., A. C. Wertheimer, E.A. Fergusson, and M. V. Sturdevant. 2008. Interactions of hatchery chum salmon with juvenile chum and pink salmon in the marine waters of southeastern Alaska. Pgs. 20-24 *In:* O. Johnson and K. Neeley, eds. 23rd NE Pacific Pink and chum Salmon Workshop. (.). February 19-21, 2008, Bellingham, WA.

Abstract.—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 a 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.

Orsi, J., E. Fergusson, M. Sturdevant, R. Focht, C. Blair, S. Doherty, and S. Heinl. 2010. Juvenile chum salmon biophysical parameters in Southeast Alaska: Examining relationships to survival and harvest.

Abstract.—Chum salmon (*Oncorhynchus keta*) are an economically important resource in the commercial salmon fisheries of Southeast Alaska (SEAK), where marked hatchery stocks comprise the majority of the harvest. Detailed regional information exists on chum salmon, both for hatchery marine survivals and for annual harvests of wild and hatchery stocks. In addition, high marking rates of hatchery stocks from the three major enhancement facilities in SEAK permit stock-specific metrics, such as growth and catch, to be determined from juvenile chum salmon caught at sea. From 1997 to 2005, the Southeast Alaska Coastal Monitoring project sampled juvenile chum salmon during summer in seaward migration corridors of SEAK. A full suite of biophysical parameters was developed from field sampling and laboratory analyses (e.g., temperature, zooplankton measures, chum salmon energy density). These data were combined with information from thermal marks to examine stock-specific relationships of chum salmon and biophysical parameters to marine survival and harvest over a nine year period. The goals of this study are to better understand chum salmon survival mechanisms and to identify potential forecast model parameters for this species in SEAK.

Orsi J., A. Wertheimer, M. Sturdevant, E. Fergusson, and B. Wing. 2009. Insights From a 12-Year Biophysical Time Series of Juvenile Pacific Salmon in Southeast Alaska: the Southeast Alaska Coastal Monitoring Project (SECM). NOAA, AFSC, Research Feature Article. 8 p. http://www.afsc.noaa.gov/Quarterly/jas2009/JAS09feature.pdf

Abstract.—Pacific salmon (*Oncorhynchus* spp.) occur throughout Alaska waters and have important linkages among freshwater, estuarine, and oceanic ecosystems. Although salmon in Alaska waters are primarily managed by the state of Alaska, the National Oceanic and Atmospheric Administration (NOAA)'s 2006-2011 Strategic Plan addresses many issues related to salmon, such as their marine essential fish habitat, the migration of endangered stocks, the interactions of wild and hatchery stocks with respect to ocean carrying capacity, and the ecological interactions of salmonids with other species within the context of climate change. Moreover, Under Secretary of Commerce for Oceans and Atmosphere and NOAA Administrator Dr. Jane Lubchenco, in her May 2009 Message from the Under Secretary, stated "Rapid climate change is one of our nation's greatest challenges…Decision makers from the government and the private sector are searching for science-based data, information and knowledge that are critical for us to adapt, plan for, and respond to rapid changes in climate." Since 1997, the Alaska Fisheries Science Center's (AFSC) Auke Bay Laboratories have maintained a study, the Southeast Alaska Coastal Monitoring (SECM) project, to develop time series of the biophysical data associated with juvenile salmon and their coastal ocean environment within Southeast Alaska and into the Gulf of Alaska. This time series enables ecosystem change to be measured and compared to variability in juvenile salmon dynamics and their subsequent year-class strength. This article describes the SECM research approach and presents key findings from this 12-year effort.

Orsi, J. A., J. A. Harding, S. S. Pool, R. D. Brodeur, L. J. Haldorson, J. M. Murphy, J. H. Moss, E. V. Farley Jr., R. M. Sweeting, J. F. T. Morris, M. Trudel, R. J. Beamish, R. L. Emmett, and E. A. Fergusson. 2007. Epipelagic fish assemblages associated with juvenile Pacific salmon in neritic waters of the California Current and the Alaska Current. Pages 105-155 *In:* G. Churchill, R. Brodeur, L. Haldorson, and S. McKinnell, eds. Ecology of Juvenile Salmon in the Northeast Pacific Ocean: Regional Comparisons. American Fisheries Society, Symposium 57, Bethesda, Maryland.

Abstract.—We compared epipelagic fish assemblages associated with juvenile (ocean-age 0) Pacific salmon *Oncorhynchus* spp. from neritic waters of the California Current and Alaska Current regions in the spring–summer and summer–fall periods of 2000–2004. Catches originated from rope trawl surveys conducted between latitudes 37°N and 60°N and spanned more than 1,100 km in the coastal and inshore habitats of each region. Catch data were used from the epipelagic sampling of waters from near surface to depths of about 18 m, primarily over the continental shelf. Catch composition, frequency of occurrence, and density were evaluated between regions and habitats for day sampling. Diel (night and day) catch comparisons were also made at a few localities in each region. In day catches from both regions, a total of 1.69 million fish and squid representing 52 fish families and 118 fish species were sampled from 2,390 trawl hauls. Ninety-seven percent of the daytime catch was composed of 11 fish families and squid in coastal and inshore habitats of each region: clupeids dominated catches in the California Current (72% and 76% of catch, respectively), and salmonids dominated catches in the Alaska Current (46% and 62% of catch, respectively). Juveniles comprised 81–99% of salmon sampled in both coastal and inshore habitats of each region. Frequencies of occurrence were highest for juvenile salmon in both regions, but average densities were highest for Pacific herring *Clupea pallasii* and Pacific sardine *Sardinops sagax* in the California Current region. Cluster analyses revealed distinct geographic breakpoints in coastal species assemblages off central Vancouver Island and in inshore species assemblages in southeastern Alaska. Species were found to cluster into six groups from coastal localities and four groups from inshore localities. Indicator species analysis and nonmetric multidimensional scaling revealed that most species of juvenile salmonids were located in northern localities. Although juvenile salmon had the most uniform distribution of any species group, their densities relative to associated species were dramatically lower in the California Current, suggesting a higher degree of interactions between juvenile salmon and other species in this region. Diel comparisons in both regions indicated substantially higher catches at night, particularly of clupeids, osmerids, and gadids. Salmonids were a relatively minor component of the night catch in both regions due to dramatic diel shifts in community structure. Additional study of diel interactions of juvenile salmon and associated species is needed to quantify habitat utilization dynamics in marine ecosystems.

Reese, C., N. Hillgruber, M. Sturdevant, A. Wertheimer, W. Smoker, and R. Focht. 2009. Spatial and temporal distribution and the potential for estuarine interactions between wild and hatchery chum salmon (*Oncorhynchus keta*) in Taku Inlet, Alaska. Fish. Bull 107(4):433–450.

Abstract.—We investigated estuarine spatial and temporal overlap of wild and marked hatchery chum salmon (*Oncorhynchus keta*) fry; the latter included two distinct size groups released near the Taku River estuary (Taku Inlet) in Southeast Alaska (early May releases of ~ 1.9 g and late May releases of ~ 3.9 g wet weight). Our objectives were to compare abundance, body size, and condition of wild chum salmon fry and hatchery chum salmon fry raised under early and late rearing strategies in different habitats of Taku Inlet and to document environmental factors that could potentially explain the distribution, size, and abundance of these chum salmon fry. We used a sampling design stratified into inner and outer inlet and neritic and littoral habitats. Hatchery fry were rare in the inner estuary in both years but outnumbered wild fry 20:1 in the outer estuary. Hatchery fry were significantly larger than wild fry in both littoral and neritic samples. Abundances of wild and hatchery fry were positively correlated in the outer inlet, indicating the formation of mixed schools of hatchery and wild fry. Spatial and temporal overlap was greatest between wild and early hatchery fry in the outer inlet in both habitats. The early hatchery release coincided with peak abundances of wild fry in the outer inlet, and the distribution of wild and early hatchery fry overlapped for about three weeks. Our results demonstrate that the timing of release of hatchery fry may affect interactions with wild fry.

Sturdevant, M. V., E. A. Fergusson, J. A. Orsi, and A. C. Wertheimer. 2008. Seasonal patterns in diel feeding, gastric evacuation, and energy density of juvenile chum salmon in Icy Strait, Southeast Alaska, 2001. Pgs. 85-95 *In:* O. Johnson and K. Neeley, eds. 23rd NE Pacific Pink and chum Salmon Workshop. February 19-21, 2008, Bellingham, WA.

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-µm 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.

Sturdevant, M., E. Fergusson, C. Reese, A. Wertheimer, N. Hillgruber, W. Smoker, and J. Orsi. 2008. Trophic Interactions among wild and hatchery juvenile chum salmon in Taku Inlet, Southeastern Alaska. Pgs. 9-16 *In:* O. Johnson and K. Neeley, eds. 23rd NE Pacific Pink and chum Salmon Workshop. February 19-21, 2008. Bellingham, WA.

Abstract.—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).

Sturdevant, M. V., M. F. Sigler, and J. A. Orsi. 2009. Sablefish predation on juvenile salmon in the coastal marine waters of Southeast Alaska in 1999. Trans. Am. Fish. Soc. 138:675–691.

Abstract.—At-sea observations of age-1+ sablefish (*Anoplopoma fimbria*) predation on juvenile salmon (*Oncorhynchus* spp.) were combined with laboratory studies to determine gastric evacuation rates and used to estimate summer predation impact in the northern region of Southeast Alaska. In June and July 1999, up to 63% of sablefish examined from trawl catches in strait habitat had each consumed one to four juvenile pink (*O. gorbuscha*), chum (*O. keta*), or sockeye (*O. nerka*) salmon. In two laboratory experiments, field-captured sablefish were acclimated without food in compartmentalized flow through tanks with conditions manipulated to reflect the photoperiod and temperature regimes of summer. These predators were offered one whole, pre-weighed juvenile chum salmon, consumption events were observed, and then predators were sacrificed at predetermined time intervals. Prey biomass remaining in the stomach of each predator was weighed, and an exponential model of the decline in percent biomass over time yielded instantaneous evacuation rates of r = 0.049 at 12°C and r = 0.027 at 7°C, respectively. From field data combined with model-derived estimates of meal frequency, we estimated that 0.8-6.0 million juvenile salmon were consumed by age-1+ sablefish in the 500 km^2 area of Icy Strait in a 33-day period. Moreover, a 10-year time series of catches indicated that 1999 was a year of unusually high abundance for age-1+ sablefish and relatively low juvenile salmon abundance. We speculate that sablefish predation in 1999 could have impacted abundance of out-migrating juveniles and contributed to low harvests of returning adult pink salmon in 2000 and adult chum salmon in 2002. Our results suggest that sablefish predation on juvenile salmon can occur during episodic, strong year classes of sablefish and may affect adult salmon returns.

Trudel, M., J. Fisher, J. A. Orsi, J. F. T. Morris, M. E. Thiess, R. M. Sweeting, S. Hinton, E. A. Fergusson, and D. W. Welch. 2009. Distribution and Migration of Juvenile Chinook Salmon Derived from Coded Wire Tag Recoveries along the Continental Shelf of Western North America. Trans. Amer. Fish. Soc. 138:1369–1391.

Abstract.—The effects of ocean conditions on highly migratory species such as salmon are difficult to assess owing to the diversity of environments they encounter during their marine life. In this study, we reconstructed the initial ocean migration routes of juvenile Chinook salmon *Oncorhynchus tshawytscha* originating from Oregon to Southeast Alaska using coded wire tag recovery data from Canadian Department of Fisheries and Oceans and National Marine Fisheries Service research surveys conducted between 1995 and 2006. Over this 12-year period, 1,862 coded-wire-tagged juvenile Chinook salmon were recovered along the coasts of Oregon, Washington, British Columbia, and Alaska from March to November. Except for those from the Columbia River, most juvenile Chinook salmon remained within 100–200 km of their natal rivers until their second year at sea, irrespective of their freshwater history and adult run timing. Northward migration of most coastal stocks was initiated during their second or possibly third year at sea, whereas the Strait of Georgia and Puget Sound stocks primarily migrated onto the continental shelf after their first year at sea. In contrast, Columbia River Chinook salmon generally undertook a rapid northward migration that varied among life histories and stocks. Columbia River spring Chinook salmon were recovered as far north as Prince William Sound, Alaska, during their first summer at sea, whereas very few Columbia River fall Chinook salmon were recovered north of Vancouver Island. In addition to northern migrants, a fraction of the Columbia River spring and fall Chinook salmon actively migrated south of the Columbia River. The stock-specific initial ocean migration routes described in this study will aid in the identification of the appropriate spatial and temporal scales for assessing the processes regulating Chinook salmon recruitment in the marine environment.

Weitkamp, L., and M. V. Sturdevant. 2008. Food habits and marine survival of juvenile Chinook and coho salmon from marine waters of Southeast Alaska. Fish. Oceanog. 17:380–395.

Abstract.—Little is known about the food habits of juvenile Chinook (*Oncorhynchus tshawytscha*) and coho (*O. kisutch*) salmon in marine environments of Alaska, or whether their diets may have contributed to extremely high marine survival rates for coho salmon from Southeast Alaska and much more modest survival rates for Alaskan Chinook salmon. To address these issues, we documented the spatial and temporal variability of diets of both species collected from marine waters of Southeast Alaska during summers of 1997-2000. Food habits were similar: major prey items of both species included fishes, crab larvae, hyperiid amphipods, insects, and euphausiids. Multivariate analyses of diet composition indicated that the most distinct groups were formed at the smallest spatial and temporal scales (the haul), although groups also formed at larger scales, such as by month or habitat type. Our expectations for how food habits would influence survival were only partially supported. As predicted, coho salmon had more prey in their stomachs overall (1.8% of body weight [BW]) and proportionally far fewer empty stomachs (0.7%) than either Alaskan Chinook (1.4% BW, 5.1% empty) or coho salmon from other regions. Contrary to our expectations, however, coho salmon diets contained surprisingly few fish (49% by weight). Apparently, Alaskan coho salmon achieved extremely high marine survival rates despite a diet consisting largely of small, less energetically-efficient crustacean prey. Our results suggest that diet quantity (how much is eaten) rather than diet quality (what is eaten) is important to marine survival.

Obj 2) Anadromous stocks in the Bering Sea Ecosystem (BASIS)

The NPAFC completed a five year review of BASIS at the 2009 annual meeting in Seattle, Washington. The review was published in Bulletin 5. New information in relation to salmon and Bering Sea ecosystems from the US Party include:

New information on Distribution/Migration

- Most of the juvenile chum salmon caught in the Bering Strait were from populations of the Anadyr-Kanchalan river system of northeastern Russia and the majority of fish collected in the Chukchi Sea site were from populations of northwestern Alaska (Kondzela et al. 2009).
- Juvenile Chinook salmon were distributed within water depths less than 50 m and their highest densities were found close to river mouths of primary Chinook salmon-producing rivers in the eastern Bering Sea (Yukon, Kuskokwim, and Nushagak rivers) through their first summer at sea. This reflects a later marine dispersal from freshwater entry points than typically found in Gulf of Alaska stream-type Chinook salmon and resulted in the presence of juvenile Chinook salmon in shallow, non-trawlable habitats during the surveys. Juvenile Chinook salmon stock proportions in the northern shelf region (north of 60°N) were: 44% Upper Yukon, 24% Middle Yukon, 31% Coastal Western Alaska, and 1% other western Alaska stock groups. Juvenile Chinook salmon stock proportions present in the southern shelf region (south of 60°N) were: 95% Coastal Western Alaska, 1% Upper Yukon, and 4% other western Alaska stock groups (Murphy et al 2009)

New information on Food Habits, Trophic Interactions, and Energetic Status of juvenile salmon

- Model results revealed that juvenile pink salmon inhabiting the eastern Bering Sea grew at an average rate of 1.17 mm•day^{-1} and juvenile chum salmon grew at a rate of 1.21 mm•day^{-1}. The U.S. BASIS survey area was expanded northward to include the Chukchi Sea during 2007, where larger juvenile pink and chum salmon were found in higher abundances relative to pink and chum inhabiting the eastern Bering Sea. Food habits analyses revealed that juvenile pink and chum salmon fed upon high energy prey in the Chukchi Sea, and that the majority of chum salmon encountered there were from either Alaskan or Russian stocks. (Moss et al. 2009)
- The BASIS food habits studies of sockeye, chum, pink, and Chinook salmon conducted in 2002–2006 were summarized. These studies identified important (≥ 10% of prey composition by weight) prey taxa of salmon. Salmon diet composition differed between the western region, where diets contained more zooplankton, and the eastern region, where diets contained more ichthyoplankton and nekton. Salmon feeding conditions, growth, and survival in the eastern region were more favorable in relatively warm years, as compared to cool years. However, warmer conditions may not be favorable for all salmon species, such as chum salmon. These studies significantly increased the available information on salmon food habits during the fall in the western, central, and eastern regions. Salmon diet composition shifted from zooplankton to fish and squid, or to larger sizes of fish prey, with increasing salmon body size, age, or maturity. Continued monitoring of salmon food habits will contribute to understanding how future climate changes will affect salmon populations in the Bering Sea (Davis et al. 2009).
- This is the first study of winter diets of Chinook salmon in the eastern Bering Sea. We analyzed Chinook salmon stomach samples collected by U.S. observers on board commercial groundfish trawlers from January to March and July to August, 2007. The proportion of empty stomachs was higher in winter (45%) than summer (8%), suggesting longer time periods between meals in winter. Diversity of squid species in Chinook salmon

diets was higher in winter than summer, when more fish, particularly juvenile walleye pollock, were consumed. All age groups of Chinook salmon collected in winter consumed fish offal, likely generated by fishery catch-processing activities, however, fish offal was not observed in summer samples. In winter, the ratio of euphausiids and fish offal weight to Chinook salmon body weight was significantly higher in samples collected at shallow depths (< 200 m), and the ratio of squid was significantly higher in salmon collected at deeper depths (201–600 m). The ratio of euphausiids to fish body weight was significantly higher in immature than maturing Chinook salmon (Davis et al. 2009).

- Juvenile pink salmon (*Oncorhynchus gorbuscha*) were examined in the eastern Bering Sea from 2004 to 2007 to assess the influence of ocean temperature on whole body energy content (WBEC), length, and diet. Fish were collected during the United States Bering-Aleutian Salmon International Study (U.S. BASIS) surveys in the eastern Bering Sea. Warmer spring and summer sea surface temperatures prevailed from 2004 to 2005 on the eastern Bering Sea shelf, whereas cooler spring and summer sea surface temperatures occurred from 2006 to 2007. Juvenile pink salmon changed diet between the warm and cool years. Walleye pollock *Theragra chalcogramma* dominated the diet (> 50% wet mass) in warm years, while walleye pollock were nearly absent from the diet in cool years. Juvenile pink salmon lengths were significantly longer in warm years but WBEC was significantly lower. We interpret our results to indicate that length is not always a reliable measure of energy status (Andrews et al. 2009).
- We explored possible associations between jellyfish biomass (*Aequorea* spp., *Aurelia labiata*, *Chrysaora melanaster*, and *Cyanea capillata*), juvenile salmon (*Oncorhynchus keta*, *O. nerka*, *O. gorbuscha*, *O. kisutch*, and *O. tshawytscha*) abundance, and oceanographic characteristics (temperature, salinity, chlorophyll-*a*, and bottom depth) during two warm years (2004, 2005) and two cool years (2006, 2007) in the eastern Bering Sea from the annual Bering-Aleutian Salmon International Surveys (US BASIS). A significant difference was observed in the mean relative biomass of the four jellyfish species in response to the various conditions in warm versus cool years. Our results indicated that juvenile *O. tshawytscha* were significantly associated with cooler temperatures in only cool years and shallower bottom depths in all years. Juvenile *O. kisutch* were associated with shallower than average bottom depths for all years and juvenile *O. keta* had only cool-year associations with lower salinities and shallower bottom depths. Similar spatial distributions were seen between jellyfish and juvenile salmon, suggesting the possibility of competition. Immature *O. keta* were significantly associated with the same physical ocean factors as *Aequorea* spp. during fall warm years, indicating a potential for interaction (Cieciel et al. 2009).

New Information of Growth Potential and Production Trends

- Spatial and temporal variation in growing conditions for juvenile salmon may determine the survival of salmon after their first year at sea. To assess this aspect of habitat quality, a spatially explicit bioenergetics model was used to predict juvenile chum salmon (*Oncorhynchus keta*) growth rate potential (GRP) on the eastern Bering Sea shelf during years with cold and warm spring sea surface temperatures (SSTs). Annual averages of juvenile chum salmon GRP were generally lower among years and regions with cold spring SSTs. In addition, juvenile chum salmon GRP was generally higher in offshore than in nearshore regions of the eastern Bering Sea shelf during years with warm SSTs; however, the distribution (catch per unit effort) of juvenile chum salmon was not significantly (*P* < 0.05) related to GRP. Shifts from warm to cold SSTs in the northern region do not appear to affect summer abundance of juvenile Yukon River chum salmon, whereas the abundance of juvenile Kuskokwim River chum salmon drops precipitously during years with cold SSTs. From this result, we hypothesize that size-selective predation is highest on juvenile Kuskokwim chum salmon during cold years, but that predation is not as great a factor for juvenile Yukon River chum salmon. Although not addressed in this study, we also hypothesize that the smaller Yukon River chum salmon captured during years with cold SSTs likely incur higher size-selective mortality during winter (Farley and Moss 2009)

- We tested the hypothesis
- that larger juvenile sockeye salmon
- (*Oncorhynchus nerka*) in Br istol Bay, Alaska, have higher marine stage survival rates than smaller juvenile salmon. We used scales from returning adults (33 years of data) and trawl samples of juveniles (*n*= 3572) collected along the eastern Bering Sea shelf during August through September 2000−02. Thesize of juvenile sockeye salmon mirrored indices of their marine-stage sur v iva l rate (e.g., sma ller f ish had lower indices of marine-stage survival rate). However, there was no relationship between the size of sockeye salmon after their first year at sea, as estimated from archived scales, and brood-year survival size was relatively uniform over the time series, possibly indicating size-selective mortality on smaller individuals during their marine residence. Variation in size, relative abundance, and marine-stage survival rate of juvenile sockeye salmon is likely related to ocean conditions affecting their early marine migratory pathways along the eastern Bering Sea shelf (Farley et al. 2007).
- Interannual variations in distribution, size, indices of feeding and condition of juvenile Bristol Bay sockeye salmon Oncorhynchus nerka collected in August to September (2000–2003) during Bering–Aleutian Salmon International Surveys were examined to test possible mechanisms influencing their early marine growth and survival. Juvenile sockeye salmon were mainly distributed within the southern region of the eastern Bering Sea, south of 57°09 N during 2000 and 2001 and farther offshore, south of 58°09 N during 2002 and 2003. In general, juvenile sockeye salmon were significantly larger (P < 0_05) and had significantly higher indices of condition (P < 0_05) during 2002 and 2003 than during 2000 and 2001. The feeding index was generally higher for age 1.0 year sockeye salmon than age 2.0 year during all years. Among-year comparisons suggested that Pacific sand lance Ammodytes hexapterus were important components of the juvenile sockeye salmon diet during 2000 and 2001 (20 to 50% of the mean wet mass) and age 0 year walleye pollock Theragra chalcogramma were important components during 2002 and 2003 (50 to 60% of the mean wet mass). Warmer sea temperatures during spring and summer of 2002 and 2003 probably increased productivity on the eastern Bering Sea shelf, enhancing juvenile sockeye salmon growth (Farley et al. 2007).
- Harvests of Yukon Chinook salmon increased in the mid-1970s, then declined during 1998 to 2007 in response to fewer returning salmon. We examined annual growth of age-1.3 and age-1.4 Yukon Chinook salmon scales, 1965–2004, and tested the hypothesis that shifts in Chinook salmon abundance were related to annual growth at sea. Annual scale growth trends were not significantly correlated with salmon abundance indices, sea surface temperature, or climate indices, although

growth during the first year at sea appeared to have been affected by the 1977 and 1989 ocean regime shifts. Chinook salmon scale growth was dependent on growth during the previous year, a factor that may have confounded detection of relationships among growth, environmental conditions, and abundance. Scale growth during the second year at sea was greater in odd-numbered years compared with even-numbered years, leading to greater adult length of age-1.3 salmon in odd-numbered years. The alternating-year pattern in Chinook salmon growth was opposite that observed in Bristol Bay sockeye salmon, and it may be related to the higher trophic level of Chinook salmon and indirect competition with pink salmon. This finding highlights the need to investigate alternating-year patterns in salmon growth, prey abundance, and factors that influence these patterns, such as pink salmon (Ruggerone et al. 2009).

- During their last season at sea, some chum salmon from North America and Japan are known to forage in the southeast Bering Sea. Body size of mature chum salmon from North America and Japan was compared with sea surface temperatures in the winter, spring, and summer in the southeast Bering Sea during three time periods: pre-regime shift 1960–76, regime shift 1977–94, and post-regime shift 1995–2006. During the 1977–94 time period, mean correlation coefficients between body size and sea surface temperatures were positive and largest during the winter and spring. During the 1960–76 and 1995–2006 time periods, correlation coefficients were usually smaller and often negative. We conclude that chum salmon from many locations around the Pacific Rim were present in the eastern Bering Sea during the winter and spring of 1977–1994. We suggest that differences in oceanographic parameters and population density of salmon during the three time periods may influence migration pathways of salmon in the North Pacific Ocean and Bering Sea. Research on migration patterns of salmon in relation to these factors is necessary to elucidate these issues (Helle and Fukuwaka 2009).
- The Model for Assessing Links Between Ecosystems (MALBEC) is a policy gaming tool with potential to explore the impacts of climate change, harvest policies, hatchery policies, and freshwater habitat capacity changes on salmon at the North Pacific scale. This article provides background information on the MALBEC project, methods, input data, and preliminary results pertaining to (1) hatchery *versus* wild salmon production in the North Pacific Ocean, (2) rearing, movement, and interactions among Pacific salmon populations in marine environments, (3) marine carrying capacities, density-dependent growth, and survival in Pacific salmon stocks, and (4) climate impacts on productivity in salmon habitat domains across the North Pacific. The basic modeling strategy underlying MALBEC follows the full life cycle of salmon and allows for density-dependence at multiple life stages, and it includes spatially explicit ecosystem considerations for both freshwater and marine habitat. The model is supported by a data base including annual run sizes, catches, spawning escapements, and hatchery releases for 146 regional stock groups of hatchery and wild pink, chum, and sockeye salmon around the North Pacific for the period 1952–2006. For this historical period, various hypotheses about density-dependent interactions in the marine environment are evaluated based on the goodness-of-fit between simulated and observed annual run sizes. Based on the information we used to inform our ocean migration table, interactions among stocks that originate from geographically distant regions are greatest in the Bering Sea in summer–fall and in the eastern sub-Arctic in winter–spring. While the model does not reproduce the observed data for some specific stock groups, it does predict the same overall production pattern that was observed by reconstructing run sizes with catch and escapement data

alone. Our preliminary results indicate that simulations that include density-dependent interactions in the ocean yield better fits to the observed run-size data than those simulations without density-dependent interactions in the ocean. This suggests that for any level of ocean productivity, the ocean will only support a certain biomass of fish but that this biomass could consist of different combinations of stocks, stock numbers and individual fish sizes. MALBEC simulations illustrate this point by showing that under scenarios of Pacific-wide reduced hatchery production, the total number of wild Alaskan chum salmon increases, and that such increases are large where density-dependent effects on survival are large and small where they are not. Under scenarios with reduced freshwater carrying capacities for wild stocks, the impacts of density-dependent interactions also lead to relative increases in ocean survival and growth rates for stocks using ocean habitats where density-dependence is large (Mantua et al. 2009).

- Climate regime shifts can alter the community structure of marine species in the North Pacific Ocean. In this study, we use a regime shift detection algorithm to determine whether regime shifts are recorded as shifts in the mean fish length indices at the smolt, juvenile, immature, and mature life stages based on measurements of increments on scales of adult age-2.2 sockeye salmon (*Oncorhynchus nerka*) that returned to the Karluk River, Kodiak Island over a 77-year time period (1924–2000). Fish length was expected to increase with cool-to-warm climate shifts (1926, 1958, 1977, and 1998) and decrease with warm-to-cool climate shifts (1943, 1947, 1971, and 1989). Regime shifts were not consistently observed as statistical shifts in the time series of fish length indices. At contemporaneous lags, shifts in the mean temperature of the North Pacific were detected as shifts in length in 1958 (+), but not in 1926 (+), 1943 (-), 1971 (-), and 1977 (+). Shifts in the atmospheric circulation and sea level pressure of the North Pacific were detected as negative shifts in length in 1989 (-), but not in 1926 (+), 1947 (-), 1977 (+), 1998 (+). Shifts in length indices were associated with the 1957-58 El Niño, the warm-to-cool shift in 1989, and preceded the 1976–77 climate shift in the North Pacific Ocean. Fish length indices from salmon scales may be useful predictors for major and more recent shifts in the status of the ecosystem of the North Pacific Ocean (Martinson et al. 2009).
- A spatially explicit bioenergetics model was used to predict juvenile sockeye salmon *Oncorhynchus nerka* growth rate potential (GRP) on the eastern Bering Sea shelf during years with cooler and warmer spring sea surface temperatures (SSTs). Annual averages of juvenile sockeye salmon GRP were generally lower among years with cooler SSTs and generally higher in offshore than nearshore regions of the eastern Bering Sea shelf during years with warmer SSTs. Juvenile sockeye salmon distribution was significantly ($P < .05$) related to GRP and their prey densities were positively related to spring SST ($P < .05$). Juvenile sockeye salmon GRP was more sensitive to changes in prey density and observed SSTs during years when spring SSTs were warmer (2002, 2003, and 2005). Our results suggest that the pelagic productivity on the eastern Bering Sea shelf was higher during years with warmer spring SSTs and highlight the importance of bottom-up control on the eastern Bering Sea ecosystem (Farley and Trudel 2009).
- In this review, we consider size of juvenile Pacific salmon (*Oncorhynchus* spp.) after the first summer at sea to be the trait on which size-selective mortality operates. The idea is based on the critical size, critical period hypothesis, where those individuals within a cohort that do not reach a critical size during their first summer at sea have higher rates of late fall and over-

winter mortality. The results suggest that early marine growth of juvenile Bristol Bay sockeye (*O. nerka*), Prince William Sound hatchery pink (*O. gorbuscha*), and British Columbia coho (*O. kisutch*) salmon from geographically distinct regions (Bering Sea, northern Gulf of Alaska, coastal British Columbia, respectively) is important and that these salmon must attain sufficient growth during their first summer at sea to survive subsequent years at sea (Farley et al. 2007).