Juvenile Pacific Salmon Use of Knik Arm Estuaries: A Literature Review

Estuaries are known to provide several important functions for juvenile Pacific salmon. They act as a refuge from predators, an area for salinity adjustment, and a nursery for feeding and growth. The level of a juvenile salmon's dependency on an estuary is determined by several factors including; the species, the size upon entry into the estuarine environment, the amount of available food within the estuary, the amount of available food within other associated nursery habitats, and the physical conditions of the estuary (Healy, 1982).

The Knik Arm is a dynamic tidal estuary that supports five species of Pacific salmon. It is characterized by strong currents, large tidal flats, high suspended sediment loads, and seasonal ice substrate scouring (Prevel- Ramos et al. 2012). Previous research has been conducted within the lower portion of the Knik Arm (Dames and Moore 1983, and Houghton et al. 2005) as well as within the greater Cook Inlet (Abookire et. al., Blackburn, 1978, Moulton 1997, Nemeth et al. 2007, and Wolf et al. 1983) These studies have revealed some important information as to how the different species utilize the Cook Inlet and Knik Arm estuary.

Temporal and Spatial Use

Studies throughout the Pacific Northwest compiled and compared by Healy (1982) have revealed some general trends as to the temporal and special use of estuaries by juvenile salmon. Pink and chum salmon have been found to migrate as fry early in the spring soon after emergence. Pink salmon only reside in inner estuaries for a day or two before moving to rear in outer estuaries or moving directly to sea. Chum juveniles are more likely to spend time rearing in the inner estuary, sometimes up to three weeks as was found in the Nanaimo and Fraser River estuaries. Chum are usually gone from the estuarine environment by mid-July with the larger fish moving seaward before the smaller. The majority of sockeye smolt migrate into estuaries at age 1+ and do not spend more than a few days within the inner estuary, however a minority of sockeye that migrate as fry may spend an entire summer within the river plume rearing before moving out to sea. Chinook have the most varied life history patterns and therefore the most varied utilization of estuaries. Some systems support Chinook that migrate mostly as fry exhibiting behavior similar to chum while others have Chinook that migrate as age 1+ and move directly to the outer estuary or to sea. In general, coho are the last to migrate into estuaries and spend a short amount of time rearing within both inner and outer estuary environments (Healy 1982).

Although Healy's compilation revealed some useful general trends the literature on salmon estuary use is highly variable by region. For example Healy (1982) found that coho smolts typically arrive in the Nanaimo estuary (British Columbia) as age 1+, later in the season than Chinook, chum and pink and spend relatively little time rearing within the estuary. However Drucker (1979) found that coho smolts were not migrating into the Karluk estuary (Kodiak Island, AK) until age 2+ or 3+. Also, all along the

Pacific coast a percentage of coho populations migrate into estuaries as age 0+ fry and may spend a year or more moving between estuarine and freshwater habitats (Koski 2009).

Similar type variances occur for the other species of salmon. In general it has been found that Chinook rely most heavily on estuaries because they reside there the longest and exhibit the most growth (Dunford 1975, Korman et al. and Healy 1980), however some studies have found that a large percentage of seasonal cohorts are age 1+ Chinook that move through the estuaries quickly not showing much dependence on them for growth (Kjelson et al. 1982). Within the Northern Cook Inlet, Moulton (1997) found that coho may have a longer residency within estuaries than other species, being the last salmon species present into the fall.

Within the Knik Arm, juvenile salmon sampling with beach seine and tow net revealed some baseline spatial and temporal use by each species. Chum salmon in the Knik Arm were found to be all age 0+ fry between 21 and 60mm in length (Houghton et al. 2005). They arrive in arm in April and have a single peak abundance in late May or early June (Dames and Moore 1983). Studies in 2004 and 2005 concluded that the vast majority of chum juveniles had outmigrated out of the Knik Arm by July (Houghton et al. 2005).

Coho juveniles that migrate through the Knik Arm have several different life-history adaptions. Both Dames and Moore (1983) and Houghton et al. (2005) noted the presence of many different size cohorts ranging from 30 to 140mm. Coho abundances peaked in July but presence was noted by Houghton (2005) into November.

Sockeye within the Knik Arm are divided between two age classes, age 0+ fry and age 1+. They were the only species to show strong spatial variation, having higher abundances in the inner arm near the mouth of Fire Creek and the North entrance to Eagle Bay. The highest abundances were in June with a sharp decline in abundance in September (Houghton et al. 2005).

The majority of Chinook juveniles were found to be age 1+ with a peak abundance in the arm in late June-July with substantial decreases in August. However there was a presence of smaller age 0+ migrants that were present in the arm in April. Moulton (1997) also noted the presences of two age classes within the Northern Cook Inlet. Chinook were more often caught near-shore than in open water.

Very few pink salmon were caught in studies within the Knik Arm (Dames and Moore 1983 and Houghton 2005). The 33 pinks caught by Houghton et al. (2005) were all young-of-the-year fry and occurred during the spring months. Caught per effort within the Northern Cook Inlet (Moulton 1997) was much higher than that in the Knik Arm, pinks being the most common salmon species in the spring months.

Feeding and Growth

The diet composition of juvenile salmon varies based on what is available in the estuarine environment but also somewhat based on species. A bifurcation exists between the diets of pink and chum versus that of Chinook and coho. Pink and chum have been found to feed primarily on zooplankton (Manzer

1969, and Bailey et al. 1975) while Coho and Chinook, entering estuaries at a potentially larger size feed on benthic invertebrates or other fish (sandlance) or herring larvae (Manzer 1969 and Dunford 1975). Within the Fraser River estuary Dunford (1975) found that chum and Chinook when not in competition select very similar prey but when they are in competition Chinook tend to feed more on larger benthic prey while chum begin to select smaller planktonic prey.

Within the Knik Arm very little stomach content analysis has been performed for juvenile Pacific salmon. Dames and Moore (1983) found that the majority of the juvenile salmon diet is composed of terrestrial insects. Coho and sockeye juveniles were found to have a higher percentage of marine prey within stomachs suggesting they spend more time feeding in the Knik Arm than chum, whose stomach contained very little marine prey. However marine prey never constituted more than 30% of stomach contents for any species. Dames and Moore (1983) use this fact as further evidence that salmon have short residences within the Knik Arm.

Juveniles in the Northern Cook Inlet however, had very diverse diets. In June insects, calanoid copepods, fish larvae and barnacle cyprids were common in all species stomachs. Coho had a higher frequency of fish (probably pink and chum fry). Beginning in July there was significant shift in diet among all species with dipterans/homopterans predominating in all species stomach contents except in pinks (Moulton 1997).

Although Houghton et al. (2005) did not perform stomach content analysis; their data presents evidence of growth within the Knik Arm. Although it was found that chum residency within the arm is fairly brief, length data gives evidence to growth within this short period. Chum growth was also indicated in the Cook Inlet by Moulton (1997). Growth analysis is more difficult for sockeye, Chinook and coho due to the many life-history strategies present within the arm. Apparent growth can result from larger fish moving into the area or smaller fish moving out. Accounting for these possibilities Houghton et al. (2005) saw an apparent growth pattern in coho. It was traced from the May-June cohort with a 40 mm node to the 70-80mm node seen in October.

Similar apparent growth was recognized in Chinook juveniles despite their presence dispersed among several age classes. There was poor survival for the small number of less than 50mm migrants present in April. A cohort of Chinook had a node of 70mm that grew to significantly by August (Houghton et al. 2005).

Data Gap

To date only a few juvenile salmon studies have been conducted in the Knik Arm estuary. These studies have provided useful baseline information for how each species of salmon utilizes the arm during their outmigration, however some critical information still remains unknown. Large areas of the arm have not been sampled due to the difficulty of sampling mainly, stream mouths, mudflats and edge habitat between fresh and saline water. Due to past studies reliance on beach seines that can only be utilized on shorelines, potentially significant habitat has been missed. The composition of diet and exact growth data has not been collected and the relative survival of various age classes within a species is largely unknown. Lastly the influence of pollutant inputs in the Knik Arm has gone unstudied. Estuaries are often popular sites for development and studies have shown that pollutants such as polycyclic aromatic hydrocarbons can have negative impacts on salmonid growth (Meador et al. 2006).

Annotated Bibliography

Abookire, A.A., Piat, J.F. and M.D. Robards. Nearshore fish distributions in an Alaskan estuary in relation to stratification, temperature and salinity. Estuarine, Coastal and Shelf Science 51, 45-59.

Abstract: *Fish were sampled with beach seines and small-meshed beam trawls in nearshore (<1km) and shallow (<25m) habitats on the southern coast of Kachemak Bay, Cook Inlet, Alaska, from June to August, 1996–1998. Fish distributions among habitats were analysed for species composition, catch-per-unit-effort (CPUE) and frequency of occurrence. Two oceanographically distinct areas of Kachemak Bay were sampled and compared: the Outer Bay and the Inner Bay. Outer Kachemak Bay is exposed and receives oceanic, upwelled water from the Gulf of Alaska, whereas the Inner Bay is more estuarine. Thermohaline properties of bottom water in the Outer and Inner Bay were essentially the same, whereas the Inner Bay water-column was stratified with warmer, less saline waters near the surface. Distribution and abundance of pelagic schooling fish corresponded with area differences in stratification, temperature and salinity. The Inner Bay supported more species and higher densities of schooling and demersal fish than the Outer Bay. Schooling fish communities sampled by beach seine differed between the Outer and Inner Bays. Juvenile and adult Pacific sand lance (Ammodytes hexapterus), Pacific herring (Clupea harengus pallasi), osmerids (Osmeridae) and sculpins (Cottidae) were all more abundant in the Inner Bay. Gadids (Gadidae) were the only schooling fish taxa more abundant in the Outer Bay. Thermohaline characteristics of bottom water were similar throughout Kachemak Bay. Correspondingly, bottom fish communities were similar in all areas. Relative abundances (CPUE) were not significantly different between areas for any of the five demersal fish groups: flatfishes (Pleuronectidae), ronquils (Bathymasteridae), sculpins (Cottidae), gadids (Gadidae) and pricklebacks (Stichaeidae).*

This paper presents a small scale fish distribution study on Kachemak Bay. The sampling location was split between the more oceanic, tidally influenced outer bay and the sheltered, warmer, less saline inner bay. The goal was to determine if distribution is influenced by small scale environmental factors such as water stratification, temperature and salinity. Sampling by 44m beach seine was conducted June through August on the southern shore of the bay, south of Homer at 6 locations in the outer bay and 5 in the inner bay. Salmonids made up only 4% of the total 259,811 fish caught in beach seines. They hypothesized that salmonids would be found in more abundance in the inner bay, however there was no significant difference between the inner and outer bay. CPUE for pink was 16 (effort being defined as one beach seine haul) in the outer bay and 11 in the inner bay. CPUE for chum, sockeye, and Chinook was less than 4 in both areas. In contrast to salmonids, sand lance and juvenile herring were five times more abundant in waters that were well stratified with warmer less saline waters (inner bay). Demersal fish (flatfish, gadids and sculpins) vary little among habitats because bottom waters are similar.

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 Traitor's Cove Alaska, with speculations on the carrying capacity of the area. National Marine Fisheries Service, Fishery Bulletin 73(4): 846-861.**

Abstract: *Juvenile pink salmon, Oncorhynchus gorbuscha, and chum salmon, O. keta, 28 to 56 mm long (fork length) from Traitors River in southeastern Alaska, fed little in freshwater but fed heavily in the estuary, mainly on pelagic zooplankters. Fry did not feed on cloudy moonless nights. The rate of evacuation of pink salmon stomachs ranged from 6 h at 12.8°C to 16 h at 8.5°C. The abundance of zooplankton ranged from 9 to 154 organisms per liter and quantitatively did not change noticeably while fry were in the estuary. In 1964, 1965, and 1966, the estimated numbers of fry in Traitors Cove was 7, 1, and 4 million, respectively. An attempt was made to estimate the carrying capacity of Traitors Cove, using food consumption and evacuation rates in conjunction with estimates of standing crop of zooplankton. It was concluded that 50 to 100 million additional fry from hatcheries would probably exceed the carrying capacity of the estuary.*

This study examined feeding habits of pink and chum fry in Traitor's Cove, Alaska during outmigration and estuary residence. Chum and pink salmon collected during migration had little or no food in stomachs; however chum fed more than pink in freshwater. For those that had consumed food, immature stages of chironomids were the most frequent found stomach content. All fish collected in the estuary had food in their stomachs and those captured at night for both chum and pink had a higher percentage of unidentifiable food items in their stomachs. Fish did not feed during darkness on cloudy or moonless nights but pinks were seen feeding when a bright moon was out. Copepods occurred in 94% of pink fry stomachs consisting of 77% of their total volume, followed by barnacle nauplii and cladocerans in 56% (6% total volume). Copepods were found in 73% of chum fry stomachs consisting of 30% of their total food, followed by larvaceans which occurred in 54% (34% total volume). Compared to pinks, chum fed on larger and harder shelled items. Low amounts of epibenthic prey were found in stomach contents; however the study area consisted of rocky shorelines with little opportunity for bottom-feeding. The time it takes for stomach evacuation varied inversely with temperature, therefore fry consumed a volume of food required to fill their stomachs once a day at colder temperatures (8.5°C) and four times a day at warmer temperatures (12.8°C).

Bakus, G.Js, Orys, M. and J.D. Hendrick. The marine biology and oceanography of the Anchorage region, upper Cook Inlet, Alaska. Astarte, 12: 13-20.

Abstract: *Currents measured by drogues ranged from 0.9 to 4.5 kt in Knik Arm. Temperature (14.5-15.8^o), salinity (3.7-8.8 ppt), and dissolved oxygen (9.8-10.8 ml/l) were relatively uniform throughout the 21-30 m water column. Mudflat sediments were largely fine silts and clays. Pt. Woronzof intertidal sediments contained sand and pebbles, and offshore sediments sand, pebbles, and cobble. The organic content of mud was 2.3-5.5%; for sand and gravel 0.8-2.3%. The only macroscopic benthic alga found was Vaucheria longicaulis. The only marine infaunal organism found was the clam Macoma balthica. The only subtidal organisms collected were hydroids on the one boulder. Few gammarid amphipods were observed in mudflat tidepools at night. A marsh was the most diverse intertidal area studied. A summary of marine organism known from Anchorage region is presented.*

Aquatic Restoration & Research Institute

Blackbourn, D.J. 1976. Correlation analysis of factors related to the marine growth and survival of Fraser River pink salmon. Pages 198-200 in Proceedings of the 1976 northeast Pacific pink and chum salmon workshop. Alaska Department of Fish and Game, Juneau, Alaska.

This study attempted to use previously collected data within the Georgia Strait to make correlations between many factors (fry length, adult returner length, date of river migration, river discharge, water temperature etc.) and pink salmon survival. No factors individually correlated very highly with survival, so three groups of factors were chosen for a multiple regression analysis. The groups contained at least one factor from each life stage. When grouped the factors contributing most significantly to survival were Fraser River discharge (negative correlation), average number of coho/days of fishing (negative correlation), average pink fry fork length (positive correlation), the average solar radiation from March to May (positive correlation), the number of days between April 1st and peak date of migration (positive correlation) and the total number of pink fry passing Mission (negative correlation).

Blackburn, J., 1978. Pelagic and Demersal Fish Assessment in the lower Cook Inlet Estuary System. Alaska Department of Fish and Game, Final Report. Kodiak, AK. *In* Environmental Assessment of the Alaskan Continental Shelf; final reports of principal investigators volume 12, biological studies. pp 259-602.

This report details a multipart study of nearshore communities of fish and commercial invertebrates in the lower Cook Inlet (from the Forelands south). Relative abundances, seasonal movements and food habits of all species of Pacific Salmon as well as halibut, herring and crab are detailed. In addition environmental parameters that affect the length of oil retention within marine systems were measured so this report contains information about currents, tides, temperature, substrate and sediments. Fish were captured with beach seine, gill net and trammel net. In general catches of all species were highest during high tide. Juvenile pink and chum salmon were the dominate taxa in nearshore areas in the spring (April through May). Chums were present in abundance through the summer into September. Pelagic habitat was dominated by Pacific sand lance and herring, however juvenile pink, sockeye, chum, and Chinook salmon were also captured. Sockeye were common in June and early July. Pink, chum and Chinook were common in July and August. Stomach content analysis revealed that decapod larvae, fish eggs and larvae, and insect larvae will all important constituents of all juvenile salmon's diet. Gammarids were also an important part the chum diet.

Chamberlin, J.W., A.N. Kagley, K.L. Fresh, and T.P. Quinn. 2011. Movements of Yearling Chinook Salmon during the First Summer in marine Waters of Hood Canal, Washington. Transaction of the American Fisheries Society 140(2): 429-439.

Abstract: *Migration is a fundamental component of the life history and ecology of many species, but the extent and duration of specific migrations can vary depending on species and environment. Chinook salmon Oncorhynchus tshawytscha are characterized by a spectrum of life history types with different migration patterns and spatial distributions. The objective of this study was to quantify the movements of yearling Chinook salmon smolts during their initial summer in Hood Canal, along, narrow fjord in western Puget Sound, Washington. Fifty-eight yearling hatchery-reared smolts were tagged with acoustic transmitters and tracked during May–August 2008 with a network of 50 receivers placed throughout Hood Canal. A total of 41 fish were detected during the study period; of these, 18 fish were still being detected in Hood Canal after 100 d. Fish initially congregated near the release site and gradually dispersed during summer; individual movement rates ranged between 0.44 and 1.52 body lengths /s. Fish movement occurred both with and against tidal currents, and nearly all fish showed some period of inactivity, especially as recorded on receivers near estuaries and tidal deltas. Eight fish*

(20%) were detected as leaving Hood Canal during the study, but seven of them later returned to Hood Canal. The extended use of Hood Canal as rearing habitat indicated the importance of such environments beyond their role as migratory corridors to the Pacific Ocean.

This study utilized acoustic telemetry to track movements of yearling Chinook salmon in Hood Canal in order to describe marine movements and determine if juveniles followed a resident or ocean-type life history. After release 18 of 41 fish were still within Hood Canal after 100 days. Age-0 chinook residence times ranged from 5-130 days with most remaining for only 10-35. Overall movement patterns did not suggest migration toward the Pacific Ocean. Instead fish demonstrated patterns of inactivity with all fish remaining at one or more receiver for at least an hour and 70% of fish spending more than 2 hours at one or more receiver locations. Receivers located in the midchannel areas recorded the lowest levels of holding behavior, while receivers located in areas with freshwater input, a relatively protected shoreline, and with shallow riverine delta habitats (flat, mud, and or sand substrate) showed the greatest amount of holding behavior. The number and direction of movements occurred both with and against tides and during day and night. The authors conclude that the fish in this study displayed a mostly resident type behavior.

Congleton, J.L. 1979. Feeding patterns of juvenile chum in the Skagit River Salt Marsh. Fish Food Habitat Studies: Proceedings of the Second Pacific Northwest Technical Workshop. Pp 141-150. A Washington Sea Grant Publication. University of Washington, Seattle.

This study was undertaken in order to determine the diet, feeding areas and feeding chronology of chum salmon within the Skagit salt marsh. Juvenile chum salmon were collected by beach seine from March through May and stomach contents identified to the lowest taxonomic level possible. Stomach content results were reported both as percentage weight and as frequency of occurrence. Results showed that Diptera adults and pupae (mainly Chironomids) and oligochaeta made large contributions to the percent diet by weight. Harpacticoid copepods had a high frequency of occurrence but made up very little of the percent by weight. Results also showed that chum fry fed most intensely during high water when they are able to move into the marsh flats. Due to the fact that chironomids were in high abundance within stomach contents but low in drift samples, they concluded that chironomids were being consumed on substrate or on plant material rather than in the water column.

Copeland, T. and D. A. Venditti. 2009. Contribution of three life history types to smolt production in a Chinook salmon (Oncorhynchus tshawytscha) population. Can. J. Fish. Aquat. Sci. 66: 1658-1665.

Abstract: *The most productive juvenile life history in the Pahsimeroi River Chinook salmon (Oncorhynchus tshawytscha; Idaho, USA) population (in terms of smolt production) is being eliminated. Length at emigration and survival from spawning areas to Lower Granite Dam within each of three juvenile phenotypes (age-0 smolts, fall parr, age-1 smolts) were influenced by initial cohort abundance. The proportion of age-1 emigrants reaching Lower Granite Dam was dome-shaped with respect to initial cohort abundance. As initial abundance increased, higher proportions of juveniles adopted the age-1 smolt phenotype or emigrated as fall parr. The age-0 smolt phenotype had the highest relative survival, and the fall parr phenotype, the lowest. The contributions of each emigrant type to cohort smolt production varied with circumstances; hence, the full expression of phenotypic diversity is important to the study population. However, there were no records of tagged age-0 smolts surviving to return from the Pacific Ocean. Given the potential productivity of this life history, management and recovery efforts should be directed at the age-0 smolt phenotype.*

Copeland and Venditti conducted this study looking at survival regimes of three different phenotypes of stream-type juvenile Chinook salmon (age-0 smolt, fall parr, and age-1 smolt) to see if migration types result from facultative response or adaptive life history differences. They collected juvenile salmon with a rotary screw trap located 1.5 km upstream from river mouth. For all three life history types, survival varied with circumstances emphasizing the importance of having a diversity of phenotypes. Life history type was influenced by density and growth conditions and as abundance increased more fish followed the age-1 smolt or fall parr life history. Age-0 Chinook had the highest relative survival, but there were no records of this phenotype returning from the Pacific Ocean. This poses the question as to why the age-0 life history persists if it was never viable or is no longer viable.

Cornwell, T. J., D. L. Bottom, and K. K. Jones. 2001. Rearing of juvenile salmon in recovering wetlands of the Salmon River Estuary. Oregon Department of Fish and Wildlife, Information Reports 2001-05, Portland.

This report details the results of a fish distribution and abundance study within several restored wetlands under different ages of recovery as well as natural reference areas within the Salmon River estuary. This was part of a larger wetland study, the results of which can be found in Gray et al. 2002. Chinook, coho and chum juveniles were all caught during sampling with beach seines, pole seines and fyke nets. Most juvenile salmon caught were from naturally spawned parents. It was found that hatchery raised juveniles has shorter residence times perhaps due to their already larger size. Fewer coho than Chinook were found to utilize the wetland habitats and had an earlier timing of ocean migration. Scale samples also indicated that a large portion of the coho catches was sub yearling juveniles. Chum were caught March through May within the estuary while both Chinook and coho were caught starting February into July and August.

Crone, R. A., and C. E. Bond. 1976. Life history of coho salmon, Oncorhynchus kisutch, in Sashin Creek, southeastern Alaska. U.S. Fisheries Bulletin 74(4): 897-923.

Abstract: *The freshwater life of coho salmon, Oncorhynchus kisutch, in Sashin Creek, southeastern Alaska, was studied from the fall of 1963 through the summer of 1968. Additional information on age*

composition and fecundity of adults returning to Sashin Creek and a nearby stream was collected through the fall of 1972. Some pre-1963 data on coho salmon entering and leaving Sashin Creek were used. Weir counts and estimates of numbers of adult salmon determined from spawning ground counts and mean redd life were poor measures of the total escapement of coho salmon in Sashin Creek; an estimate made from tagging a portion of the escapement and subsequently determining tagged-to-untagged ratios of spawners on the riffles proved to be a more reliable measure. The number of spawning coho salmon varied for the years 1963 through 1967 from 162 to 916; the dominant age group was 43, The salinity of the surface water of the estuary of Sashin Creek usually is less than 10-15°/00; bioassays of salinity tolerance indicated that coho salmon fry can survive in these salinities. In 1964,44,000 coho salmon fry migrated to the estuary soon after emergence, although none of the scales collected from returning spawners in subsequent years showed less than 1 yr of freshwater residence. Survival curves constructed from periodic estimates of the stream populations of juvenile coho salmon for the years 1964-67 showed that mortality was highest in midsummer of the first year of life, when 62% to 78% of the juveniles were lost in a 1-mo period. Most coho salmon smolts migrated from Sashin Creek in late May or early June. In the spring of 1968, 1,440 smolts left Sashin Creek-37% were yearlings, 59% were 2-yr-olds, and 4% were 3-yr-olds. The average fork lengths were 83 mm for yearlings, 105 mm for 2-yr-olds, and 104 mm for 3-yr-olds.

This paper contains results from a variety of different studies conducted at different juvenile coho salmon life stages. It was found that a portion of coho emigrate early into estuaries as subyearling fry, so tests were performed in order to determine their capability to survive salinity. They contained fry in live boxes with varying salinities. Most of the fry stayed at the top of the box where salinity was lowest although some would spend some time down low in higher salinity. They also conducted an abrupt transfer study taking fry from three different natural salinities and transferred them into salinities ranging from 17.6 to 31 ppt. All fry survived 48 hours in salinities up to 29 ppt. Bioassays showed that these survivors should be able to acclimate fully to marine waters if they are given this refuge in partly saline waters.

Dames and Moore. 1983. Knik Arm Crossing Project Technical Memorandum No. 15. Marine biological studies. Prepared for the U.S. Department of Transportation, Federal Highway Administration and the Alaska Department of Transportation and Public Facilities.

This study was a baseline data collection program that was designed to provide insight into the ecology of the Knik Arm with special emphasis on juvenile salmon outmigration. A total of 9 shoreline stations located on both the East and West shores of the Knik arm from Fish Creek to Anchorage were sampled with a 120ft beach seine. Sampling occurred from May 10th to June 9th. Chum salmon were the most abundant and were found in greater abundance on the eastern side at the last sampling date in June. Coho catches were higher on the western side of the arm with peak abundances from May 31 to June 2. Length/frequency analysis revealed four size groups at 35, 75, 122, 163mm. There was only a small catch of 51 sockeye and 35 Chinook juveniles and therefore length/frequency analysis could not determine ages. Sockeye were dispersed relatively evenly throughout the sampling area however Chinook occupied sites in great abundance at sites near the Anchorage area. Only 10 pink salmon were captured. Threespine sticklebacks were most abundant and other species include Dolly Varden, Saffron Cod, Rainbow Trout, Bering Cisco, Eulachon and Ringtail Snailfish. Stomach analysis of juveniles revealed that the majority of all species diets consisted of terrestrial insects (primarily winged adults) with only 25% of contents being from brackish water origin.

Dawley, E.M., R.D. Ledgerwood, T.H. Blahs, C.W. Sims, J.T. Durkin, R.A. Rica, A.E. Rankis, G.E. Mohan, and F. Ossiander. 1986. Migrational Characteristics, Biological Observations, and Relative Survival of Juvenile Salmonids Entering the Columbia River Estuary, 1966-1983. Coastal Zone and Estuarine Studies Division. National Marine Fisheries Service, Seattle WA, 270 pp.

This study examined the downstream migration of juvenile Chinook and coho salmon from 1966 to 1972 in the Columbia river. About 6.5 million juvenile, hatchery raised Chinook were cold branded and released during these years and recovered at Jones beach in order to document rates and timing of migration as well as survival. Juveniles were found to be concentrated in the shallow near shore areas along the beaches within the estuary. Diel migration studies found movement during daylight hours specifically with peaks between 0800-1100 and 1800-2000. Downstream migration peaks were in May and early June with a second stronger peak in late July-August. Juvenile Chinook salmon did not show significant size difference upon entering the estuary and departing. Evidence suggests that this is due to the short time that juvenile resided in the estuary. The timing of the coho downstream migration was consistent every year of study, occurring between May 5th and 16th. This is surprising seeing as coho were released from many different hatcheries every year. It was found that larger smolts arrive at the estuaries before smaller smolts.

This paper also reports the results of a food consumption study. Stomach contents were examined with species identified and fullness evaluated. Non-feeding fish compromised 20, 10 and 30% of the sample for Chinook, coho and steelhead respectively. These high non-feeding numbers could be attributed to short migrations or disease prior to release from the hatchery. There was probably also a decrease in food availability from the effects of the Mount St. Helens eruption which increased river turbidity. The most important taxa for food consumption for juvenile salmonids were Diptera, hymenoptera, coleoptera, ephemoptera, tricoptera and amphipoda.

Drucker, B. 1972. Some life history characteristics of coho salmon of the Karluk River system, Kodiak Island, Alaska. Fishery Bulletin 70:79-94.

Abstract: *This paper contains data on some life history characteristics of the coho salmon of the Karluk River system, Kodiak Island, Alaska: age, fecundity, length, and egg size of adults; and migration characteristics, age, and size of smolts. The greater age at maturity of Karluk coho salmon (4 and 5 years) because of the longer freshwater residence of the juveniles is unique among reported North American stocks and may result in greater freshwater mortality but less marine mortality because the smolts are larger when they enter the ocean. Fecundity of Karluk coho salmon also differs from that reported for other North American stocks in that they are extremely fecund-more similar to Asiatic stocks of the Kamchatka Peninsula.*

Juvenile coho salmon from Kodiak Island were studied and found to migrate mid-May to June. These fish migrate at a later age, spending at minimum one extra year in freshwater than those in areas further south in North America (Washington, Oregon, B.C.). Smolts tended to migrate during a period of relatively warmer water during the darkest periods of night.

Dunford, W.E. 1975. Space and food utilization by salmonids in marsh habitats of the Fraser River Estuary. M. Sc. Thesis, Dep. Zoology, Univ. British Columiba, Vancouver, B.C. 90 p.

Abstract: *The temporal utilization of space and food by juvenile Pacific salmon was studied in selected marsh habitats of the Fraser River Estuary. Two types of marginal habitat were examined- slough habitat (exposed to main current) and channel habitat (backwaters). Chum salmon fry (Oncorhynchus keta) and chinook salmon (O. tshawytsch) were the most abundant species present in both habitats, with peak densities ocurring in late April. Chum and Chinook exploited many similar food sources, and the size of prey selected was examined to show a size segregation of the diet. Chum tended to select a greater proportion of smaller, planktonic prey, while Chinook ingested a greater propportion of larger, benthic prey. The divergence in types of prey and prey size selected was greatest during maximum density in late April and early May. The density of chinook was greater than chum, except in early April. Few chum were taken after early June, while chinook were present until late July, showing a steady increase in length throughout the season. It is suggested that chinook may reside in the estuarine marsh habitats temporarily each spring and summer. The chum fry utilize the habitats for feeding, during migration, but disperse to marine habitats in a shorter time period than chinook.*

The timing of migration, time of residence within the estuary, prey size and prey composition of juvenile Chinook and chum salmon were studied in this thesis. The main findings are that juvenile Chinook and chum select different size prey when they are both at peak abundance in late April. Chum tended to eat a greater portion of smaller planktonic prey while Chinook ate larger benthic prey. It was also found that in general chum spent less time in the estuary. Fork lengths from the beginning to the end of the sampling season from March through August showed little growth. Chinook however spent more time in the estuary and fork lengths revealed a steady increase in size throughout the season. The predominant organisms eaten by chum in the estuary before the arrival of juvenile Chinook were chironomid pupae and amphipods. Upon the arrival of Chinook in high densities chum had a greater proportion of copepods and cladocera, while the Chinook were eating greater proportions of tabanid larvae and Neomysis. Later in the season Chinook began to eat more terrestrial insects mainly homoptera. Sockeye were also captured in this study but in small amounts.

Durkin, J.T. 1982. Migration Characteristics of Coho Salmon (Oncorhynchus Kisutch) Smolts in the Columbia River and its Estuary, p. 365-376. In V.S. Kennedy [ed.] Estuarine Comparisons. Academic Press, Inc., New York, NY.

Abstract: *Beach seine catches indicated a majority of migrating coho salmon (Oncorhynchus kisutch) smolts reached the upper Columbia River estuary between late April and early June, with peak numbers occurring between 6 and 17 May. Length measurements revealed that large individuals tended to migrate downstream before small individuals. Based on size, most Columbia River smolts were of hatchery origin rather than of natural spawning origin. Recovery of tagged fish showed rates of downstream movement increased from late March to mid-May. Beach seine and purse seine catches suggest greater migratory movement with day light. The principal prey organisms utilized by smolts were insects in the river and amphipods in the middle estuary and near the mouth. Predation on other fish was minor.*

This paper describes the general migration characteristics of coho salmon through the Colombia River estuary. Coho smolts arrived in early May, peaking from May 5-17. The average size of hatchery raised fish was 12.8cm to 13.8 and 8.8cm to 10.6 for wild salmon. The lengths were greatest in April and decreased with migration revealing that the larger fish migrated the earliest. The coho smolts were found mainly in the surface water and catches increased during mid-day and were lowest at night. Those fish captured above the estuary were primarily feeding on insects compared to those in the upper estuary which fed on tube dwelling amphipods. The upper river hatchery smolts tended to take a more direct route, whereas the lower river hatchery coho took a less direct migration to sea.

Gray, A., C.A. Simenstad, D.L. Bottom, and T.J. Cornwell. 2002. Contrasting Functional Performance of Juvenile Salmon Habitat in Recovering Wetlands of the Salmon River Estuary, Oregon, U.S.A. Restoration Ecology. 10(3): 514-526.

Abstract: *For an estuarine restoration project to be successful it must reverse anthropogenic effects and restore lost ecosystem functions. Restoration projects that aim to rehabilitate endangered species populations make project success even more important, because if misjudged damage to already weakened populations may result. Determining project success depends on our ability to assess the functional state or "performance" and the trajectory of ecosystem development. Mature system structure is often the desired "end point" of restoration and is assumed to provide maximum benefit for target species; however, few studies have measured linkages between structure and function and possible benefits available from early recovery stages. The Salmon River estuary, Oregon, U.S.A., offers a unique opportunity to simultaneously evaluate several estuarine restoration projects and the response of the marsh community while making comparisons with a concurring undiked portion of the estuary. Dikes installed in three locations in the estuary during the early 1960s were removed in 1978, 1987, and 1996, creating a "space for-time substitution" chronosequence. Analysis of the marsh community responses enables us to use the development state of the three recovering marshes to determine a trajectory of estuarine recovery over 23 years and to make comparisons with a reference marsh. We assessed the rate and pattern of juvenile salmon habitat development in terms of fish density, available prey resources, and diet composition of wild juvenile Oncorhynchus tshawytscha (chinook salmon). Results from the outmigration of 1998 and 1999 show differences in fish densities, prey resources, and diet composition among the four sites. Peaks in chinook salmon densities were greatest in the reference site in 1998 and in the youngest (1996) site in 1999. The 1996 marsh had higher densities of chironomids (insects; average 864/m2) and lower densities of amphipods (crustaceans; average 8/m3) when compared with the other sites. Fauna differences were reflected in the diets of juvenile chinook with those occupying the 1978 and 1996 marshes based on insects (especially chironomids), whereas those from the 1987 and reference marshes were based on crustaceans (especially amphipods). Tracking the development of recovering emergent marsh ecosystems in the Salmon River estuary reveals significant fish and invertebrate response in the first 2 to 3 years after marsh restoration. This pulse of productivity in newly restored systems is part of the trajectory of development and indicates some level of early functionality and the efficacy of restoring estuarine marshes for juvenile salmon habitat. However, to truly know the benefits consumers experience in recovering systems requires further analysis that we will present in forthcoming publications.*

This paper summarizes the results of fish utilization, prey resource and diet composition of juvenile Chinook in several areas under different stages of wetland restoration in the Salmon River estuary. The reference site that was fished for Chinook contained higher abundance than any of the other sites undergoing restoration. The reference site also had the highest abundance of benthic macroinvertebrates. They found trichopterans to be the most highly selected prey due to their low presence in drift and benthic samples yet high presence in Chinook stomachs.

Healey, M.C. 1979. Detritus and juvenile salmon production in the Nanaimo estuary: I. Production and feeding rates of juvenile chum salmon (*Oncorhynchus keta*). Journal of Fisheries Research Board of Canada. 36: 488-496.

Abstract: *Theories of food chain dynamics have important implications for the management of marine resources. As yet, however, there are few empirical studies of the food chain dynamics of resource species against which these theories can be judged. This paper compares the food requirements of juvenile chum salmon (Oncorhynchus keta) in the Nanaimo Estuary with the productivity of their principal food species. Chum were present in the estuary from March until June and the estuary population ranged up to 4.1 million in May 1975 and 2.4 million in April 1976. The average weight of chum was 0.66 g in 1975 and 0.65 g in 1976, and their rate of growth averaged ~6% body weight per day in both years. Food intake estimated by three independent methods ranged 4.4-18% body weight per day and was assumed to average 15% body weight per day. Annual fry production was 2,381 kg in 1975 and 1122 kg in 1976. Food intake was 6184 kg in 1975 and 2815 kg in 1976. The principle dietary item in both years was harpacticoid copepods. In 1975 Harpacticus uniremis made up 50% of the diet overall and >80% of the diet when fry were most abundant. The seasonal pattern of abundance of fry and H. uniremis on the estuary was the same, and the fry consumed most of the estimated production of H. uniremis. Juvenile chum production was potentially limited by food supply. Food chain dynamics were, therefore, important in the productivity of the chum population, but since both chum and its chief food were rare and ephemeral elements of the estuarine fauna, their interaction probably had little impact on the dynamics of the estuary as a whole.*

Juvenile chum were sampled from 1975-1976 in this study. Fry were present in the estuary from early march until early June. During low tides fry retreated in tidal creeks and stream channels on the east side of the estuary. The fry appeared to favor estuarine habitat containing quiet backwaters near deeper water, sand sediments, and the presence of eelgrass. In 1976 the fry from the early portion of the run spent considerably longer in the estuary than fry from the later part of the run. In 1975 residence times were 20 to 18 days. During both years harpacticoid copepods were the main prey of chum fry followed by shrimp larvae. In 1975, 50% of fry diet was made up of *Harpacticus uniremis* and this increased to >80% when fry were most abundant. The seasonal pattern of abundance of fry matched that of the *H. uniremis* in the estuary. Healey concludes that productivity of chum fry is limited by food supply.

Healey, M.C. 1980. Utilization of the Nanaimo River Estuary by juvenile chinook salmon, *Oncorhynchus tshawytscha*. Fish. Bull. 77: 653-668.

Abstract: *Chinook salmon are considered, normally, to spend from a few months to a year rearing in freshwater before migrating to sea. Although large downstream movement of fry, recently emerged from spawning gravels, has been observed in several river systems, it has been suggested that most of these migrant fry are lost to the population. This report describes the fate of downstream migrant chinook salmon fry in the Nanaimo River, British Columbia. In 1975 and 1976 most of the potential fry production from the river system was estimated to have passed by a trapping location near the river mouth. Many of these fry were subsequently found rearing in the intertidal area at the river mouth*

where salinity was commonly above 20%0. Very few chinook salmon fry were captured at other sampling sites within a 10 km radius of the river mouth. Juvenile chinook salmon were present in the intertidal area of the estuary from March to July each year, but peak numbers occurred in April and May. Peak estuary population was estimated to be 40,000-50,000 in 1975 and 20,000-25,000 in both 1976 and 1977. While in the estuary, chinook salmon grew about 1.32 mm per day or 5.8% of their body weight per day. Individual fish probably spent an average of about 25 days rearing in the estuary and left the estuary when about 70 mm fork length. While in the estuary, juvenile chinook salmon fed on harpacticoid copepods, amphipods, insect larvae, decapod larvae, and mysids. After leaving the estuary, they fed mainly on juvenile herring. The stomach content of chinook salmon captured in the estuary averaged 5% of body weight or less, and varied seasonally and between years. It appears that in the Nanaimo and probably in other systems with well-developed estuaries, that the estuary is an important nursery for chinook salmon fry.

Migration timing and arrival into the Nanaimo River estuary was studied for three consecutive years March through May. The majority of Chinook salmon juveniles in this system migrate as sub-yearlings and rear in semi-saline environments for several months. Incline plane migrant traps and mark recapture techniques were used to assess population size, while estuary beach seining captures were used to assess growth and stomach contents. It was found that juvenile Chinook are most abundant in the estuary in May then begin to decline in numbers. It was found that peak abundances of Chinook in the estuary varied among years occurring in early April, early May and mid-May. During the estuary life stage Chinook were feeding primarily on decapod larvae, amphipods and insect larvae. A shift in diet from invertebrates to fish (mostly herring) occurred as the salmon dispersed away from the intertidal area.

Healey, M.C. 1982. Juvenile Pacific Salmon in Estuaries: The Life Support System, p. 315-341. *In* V.S. Kennedy [ed.] Estuarine Comparisons. Academic Press, Inc., New York, NY.

Abstract: *This report summarizes information on the abundance, food requirements and production of five species of Pacific salmon (genus Oncorhynchus) in two estuaries in southern British Columbia and compares some of these features among seven other estuaries. Chum salmon are abundant in estuaries for 2 months in early spring, coho for 2 months in late spring, and chinook throughout the spring, summer and autumn. Pink and sockeye spend little time in estuaries. Habitats occupied by each species vary with fish size, tidal stage, and time of year. Tidal creeks through marshes, the junction of major and minor distributaries in the intertidal zone, and the delta front are favoured habitats. Many taxa contribute to the diet of juvenile salmon in different estuaries but relatively few taxa generally constitute the bulk of the diet. Food requirements of juvenile salmon are generally a small percentage of the total standing cop and annual production of prey, but a high proportion of the production of preferred prey is sometimes taken. Major prey tend to be detritus feeders, indicating that the food web supporting juvenile salmon is detritus based. The value of an estuary as rearing habitat for juvenile salmon appears to be influenced by delta configuration, and the efficiency with which allochthonous organic carbon is trapped.*

This literature review describes the length of time each salmon species spend in estuary as juveniles, as well as food chain relationships and food resource requirements in the Pacific Northwest area. Pink and chum migrate seaward as fry (30-44 mm), entering estuaries of their natal stream a day or two after emerging from redds. Pinks were found in tidal marshes of the Fraser Delta for no more than one or two days during high tide and continued migrating during the first ebb. Fry reared in Nanaimo estuary in May and June, leaving late June or July at 80 mm. Chum prefer low tide habitats at the junction of major and minor distributaries spending up to 3 weeks rearing in estuaries. Their migration is size related as larger fry move seaward first. Both sockeye and coho spend a year in freshwater and migrate to estuaries during April or May of their second year of life (60-100 mm). Chinook show the most varied pattern of estuary utilization entering the estuary either as fry (40 mm) within a few days of emergence in March-May, as fingerling smolts (60-80 mm) in May or June of their first year, or as yearling smolts (80-110 mm) in April and May of their second year. They colonize tidal creeks high in marsh areas and later the outer estuary, making a clear seaward progression of low tide distribution as time passes. In terms of reliance on estuary, Chinook are the most dependent as all life histories are present here, followed by chum and then coho who reside and feed in inner and outer estuaries. Pink and sockeye depend on estuaries very little and may only utilize estuarine environments to gradually acclimate to increased salinity. Results across studies which reviewed salmon diets varied greatly geographically, seasonally, and annually. Results of diets found are listed for each salmon type. Chinook which use estuaries most intensively have the least restrictive diet compared to chum and coho which are less dependent and have a more restricted diet. All juvenile salmon, especially chum and chinook, were dependent on benthic organisms. Healey concludes that high amount of detritus feeders in salmon diets suggest that salmon are supported on detritus based food webs and that salmon are opportunistic feeders.

Healey, M.C., R.J. LeBrasseur, J.R. Sibert, W.E. Barraclough, and J.C. Mason. 1976. Ecology of young salmon in Georgia Strait. Pages 201-207 in Gunstrom, G.K., editor. Proceedings of the 1976 Northeast Pacific pink and chum salmon workshop. Alaska Department of Fish and Game, Juneau, Alaska.

This study found that chum migration began in early March, peaking in early May, and ending in early June. During this period fry were most commonly found on the mudflat at the mouth of the river, with the exception of peak migration where fry also accumulated in Mark Bay. Average residence time in the sampling area was 18.5-32 days. In late May the fry left the mudflat and catches in nearshore marine environments peaked mid-June. Harpacticoid copepods, followed by larval shrimp and Diptera, formed majority of chum diet until late May when they shifted to Oikopleura and copepods.

Heifetz, J., S.W. Johnson, K.V. Koski, and M.L. Murphy. 1989. Migration timing, size, and salinity tolerance of sea-type sockeye salmon (*Oncorhynchus nerka*) in an Alaskan estuary. Canadian Journal of Fisheries and Aquatic Sciences 46:633-637.

Abstract: *Migration timing, size, and salinity tolerance were determined for sea-type sockeye salmon (Oncorhynchus nerka), which migrate to sea as underyearlings (age-0), in the Situk River estuary, Southeast Alaska. Ten sites in three habitat types were seined monthly from late April through August, 1987, and age-0 sockeye from the estuary were tested for salinity tolerance. Age-0 sockeye were most abundant (up to 13 m-2) from late April through June, and by late July, most sockeye had left the estuary. Mean fork length (FL) was 31 mm in April and increased 0.4 mm/d-1 to 70 mm in late July when most (72%) remaining sockeye had grown to about the same size as age-1 smolts (69-95 mm) emigrating in May and June. Mean FL of age-0 sockeye in the estuary in July was 23 mm greater than in freshwater areas of the river. Salinity tolerance was directly related to fish size, and a size of at least 58 mm was required for 100% survival in seawater. Because salinity in the estuary ranged 0-30‰, sockeye of all sizes could survive in the estuary. Thus, in 3-4 mo, sea-type sockeye attained a size large enough to adapt to seawater and migrate to sea.*

This study investigated migration timing in relation to salinity tolerances of age-0 sockeye in the estuary and freshwater. Age-0 sockeye migrated to and resided in the estuary for three months, April to late July, with abundances peaking in May-June, and most left by late July. Age-1 and -2 sockeye were only found in May and June. Age-0 sockeye grew rapidly in estuaries and in three months equaled a year of growing in freshwater. Size increases occurred rapidly in late April with a mean FL of 31 mm and increased to a mean FL of 70 mm by late June (increase of 0.4 mm/ day -1), however small fish <40 mm were always present and sizes varied widely 37-90 mm in July. Salinity tolerance of age-0 sockeye was directly related to the size of the fish and therefore survival was better in June than May. 50 mm appeared to be the minimum length required for survival, as those fish 50-59 mm long had a 100% survival. The distribution of age-0 fish less than 50 mm was directly influenced by salinity, which ranged widely between 0-3o ppt. Authors suggest sockeye exhibit a similar life-history pattern as chinook, differing in duration of residence in freshwater and the estuary.

Houghton, J., Starkes, J., Chambers, M., and D. Ormerod. 2005. A marine Fish and Benthos Studies in the Knik Arm Anchorage, Alaska. Prepared for Knik Arm bridge and toll authority and HDR Alaska Inc. Prepared by Pentec Environmental.

Background: *Knik Arm (the Arm) is a shallow glacial estuary with extreme physical habitats characterized by large tidal ranges, strong currents, massive inputs of glacial and coastal sediment, and severe seasonal ice scour. Despite these conditions, the 1983 Knik Arm Crossing studies (Dames & Moore 1983) demonstrated a surprising level of biological activity in the Arm. The present study provides recent data and analyses of ecological conditions in the Knik Arm estuary based on sampling of fish and benthic invertebrates conducted in 2004 and 2005. This study was initiated by the Knik Arm Bridge and Toll Authority (KABATA) as part of a baseline data collection program relating to ongoing environmental analyses of the proposed Knik Arm Crossing project.*

Off shore beach seining was conducted from July through November in 2004 and April through July 2005 for fish and macroinvertebrate collection in the Knik arm. Mid-channel tow nets were added to make sure that no species were missed in open water. There were no significant differences between beach seining and tow net. Multiple age classes of coho, sockeye and Chinook juveniles were captured late spring to early summer. Some coho and Chinook remained in the arm until late fall. Pink and chum fry were present with single peak abundances mostly in May and June. Other species caught were stickleback; longfin smelt, Eulachon, saffron cod etc. Results suggest that pink salmon move through the arm quickly.

Iwata, M. and S. Komatsu. 1984. Importance of Estuarine Residence for Adaptation of Chum Salmon (*Oncorhynchus keta*) Fry to Seawater. Can. J. Fish. Aquat. Sci. 41: 744-749.

Abstract: *Within 24 h after release from the Otsuchi Salmon Hatchery in Japan, most chum salmon (Oncorhynchus keta) fry migrated the 1.7km and were found in the surface layer (10-15‰ salinity) of the estuary. No fish were seen in the underlying seawater. Many fry remained in the brackish water for 2 d before migrating seaward. Plasma Na concentrations increased gradually from 134 to 156 mmol/L during seaward migration from the river to Otsuchi Bay. When fry were acclimated to one-third seawater for 3 and 6 h and then transferred to seawater, the Na concentration of the fry increased maximally to 161-172 mmol/L within 12 h. When they were acclimated to one-third seawater for 12 h, the Na concentrations reached the sweater-acclimated level without showing any peak; subsequent exposure to seawater did not cause any further change in plasma Na. Acclimation to isotonic estuary* *water for 12 h is thus sufficient for efficient adaptation of chum salmon fry to seawater.*

This study observed behavioral differences in migrating chum in the Otsuchi River. On day one of release, most fry were found in the estuary about 0.5 m deep in the upper low-salinity layer with none being observed in the lower sweater layer or in a midchannel away from the bank. About 90% of chum caught were in salinities isotonic to the fry, ranging from 10-15%. Within six hour, Plasma Na levels increased to match the increase in environmental salinity. No feeding occurred on the first day. One day 2 fish catches were highest at periods with no water flow on the surface. An additional lab experiment exposed a sample of chum to 1/3 seawater (12% salinity) before increasing to full-strength seawater (33.5%). Na concentration of fry acclimated to 1/3 seawater for 2 and 6 hours before transfer to seawater peaked within 12 hours. Those acclimated for 12 hours before transfer acclimated with no peak or change in plasma NA. Exposure to 1/3 seawater specifically improved regulatory performance for larger fry which in past studies have been less efficient osmoregulators than small fry.

Iwata, M., S. Hasegawa, and T. Hirano. 1982. Decreased seawater adaptability of chum salmon (*Oncorhynchus keta*) fry following prolonged rearing in freshwater. Can J. Fish. Aquat. Sci. 39: 509-514.

Abstract: *Chum salmon (Oncorhynchus keta) fry weighing about 1 g maintained plasma Na+ concentrations at 134- 140 mmol/L during seaward migration in the Otsuchi River. The plasma Na+ level increased slightly in the estuary, and reached 150- 160 mmol/L in the fry caught in the bay. On direct transfer from freshwater to seawater, the plasma Na+ concentrations of the fry weighing 0.4-2.3 g increased markedly after 1 h and reached a maximum after 3- 12 h. The fry of < 1.4 g attained seawater-acclimated plasma Na9 level of 156 mmol/L within 24 h after transfer, whereas fry of 1.8-2.3 g failed to adapt to seawater within 24 h. When seawater adaptability of fry of different lots was examined simultaneously in late April, 83- 109 d after hatch, the smaller fry adjusted their plasma Na+ levels more easily than the larger fry: the smallest fry attained seawater level after 12 h without showing any peak. Changes in seawater adaptability of the same lots of fry were also followed until 5 mo after hatching, and the osmoregulatory ability of the fry in seawater decreased gradually with an increase in body weight or in the time spent in freshwater.*

This study examined the relationship between chum fry size and time spent in freshwater, and how these factors related to seawater adaptability. Plasma Na+ concentrations increased from 140 mmol/L in freshwater to 163 mmol/L in seawater. Fry found in the estuary 24 hours after release had an average plasma Na+ concentration of 152 mmol/L, which was significantly higher than concentrations in the river. Concentrations were highest at 6 hours but decreased to seawater-acclimated levels after 12-24 hours. Chum were always found in the upper, low salinity area where salinity varied from 2-25‰. Plasma Na+ concentration levels increased with body weight and time spent in freshwater, therefore smaller fry that spent a shorter time rearing in freshwater adapted more efficiently to seawater than larger fish did. Chum, as well as pink, acquire salinity tolerance earlier than other salmonid species and were able to adapt to seawater relatively quickly after being transported directly to seawater.

Johnson, S.W., J.F. Thedinga, and K.V. Koski. 1992. Life History of Juvenile Ocean-type Chinook Salmon (Oncorhynchus tshawytscha) in the Situk River, Alaska. Can. J. Fish. Aquat. Sci. 49: 2621-2629.

Abstract: *This study examined the relationship between chum fry size and time spent in freshwater, and how these factors related to seawater adaptability. Plasma Na+ concentrations increased from 140 mmol/L in freshwater to 163 mmol/L in seawater. Fry found in the estuary 24 hours after release had an average plasma Na+ concentration of 152 mmol/L, which was significantly higher than concentrations in the river. Concentrations were highest at 6 hours but decreased to seawater-acclimated levels after 12-24 hours. Chum were always found in the upper, low salinity area where salinity varied from 2-25‰. Plasma Na+ concentration levels increased with body weight and time spent in freshwater, therefore smaller fry that spent a shorter time rearing in freshwater adapted more efficiently to seawater than larger fish did. Chum, as well as pink, acquire salinity tolerance earlier than other salmonid species and were able to adapt to seawater relatively quickly after being transported directly to seawater.*

This study found Chinook were present in the lower Situk river sampling sites from mid-April to early August. Migration from the upper river peaked in July when lower river density increased from 3 to 76 fish / 110 m2. Most Chinook captured in the lower river sites were smolts who resided there for about 48 days. In these lower sites fish were larger and tolerated seawater earlier than those from the upper river. Most fish reared in the upper river to 60 mm in length before migrating to the lower system where fish were > 60 mm. They reared until they were about 70-80 mm and then migrated to seawater. Fish emerged early enough and had an extended growing season that allowed them to reach the minimum size (60-70 mm) necessary to adapt to seawater as age-0 smolts. Migration in the Situk River was slightly later (July-August) than most southerly B.C. streams (June-July) thought the authors believe this could vary depending on the severity of the winter and spring. They classified these juveniles as having life history characteristics between typical stream- and ocean- type populations because they emigrate at age-0 and at a size and time similar to ocean-type fish in the Northern Pacific coast, however the adults enter freshwater June-July and spawning in mid-August to mid-September which is more characteristic of stream-type populations.

Kaczynski, V.W., R.J. Feller, and J. Clayton. 1973. Trophic Analysis of Juvenile Pink and Chum Salmon (*Oncorhynchs gorbushca* and *O. keta*) in Puget Sound. Journal of Fisheries Research Board of Canada. 30(7): 1003-1008.

Abstract: *Pink and chum salmon (Oncorhynchus gorbuscha and O. keta) fry and Clarke-Bumpus plankton tows were collected from three beach areas in Puget Sound in spring 1970. Chum fry and benthic pump samples were taken in 1971. The diets of the young of the two species were similar. Epibenthic harpacticoid copepods were the chief prey of the chum and pink salmon (57 and 36%, respectively, in 1970). Distinct differences were apparent, the more notable being the preference for invertebrate eggs exhibited by the pinks and the higher preferences for small gammarid amphipods and harpacticoids exhibited by the chums. The stomach contents showed no resemblance to the plankton hauls taken in the same area. The onshore stage of development appears to be a distinct ecological stage in the life cycles of these species.*

Pink and chum fry (3.2-6.0 cm) were collected in this study from three beach locations in the Puget Sound to determine factors influencing abundance and growth in estuaries. Stomach content analysis revealed that Harpacticoid copepods made up 57% of the fry's diet, followed by small gammarid amphipods (15%), and then barnacle nauplii (6%). The only significant feeding difference was that chum fry ate significantly more harpacticoid and adult Diptera, while pinks fed more extensively on invertebrate eggs. Similar to Parker (1971), they observed coho preying on pink fry.

Kask, B.A. and R.R. Parker. 1972. Observations on juvenile chinook salmon in the Somass River estuary Port Alberni. B.C. Fish. Res. Board. Can. Tech. Rep. 308. 15 pp.

Juvenile Chinook were sampled in the Somass River estuary with purse seines and dip nets. The stomach contents were analyzed for the age 0+ Chinook. It was found that 46% of food ingested was amphipods, 20% euphausiids, 22% fish larvae, with the remaining 12% scattered among other taxa. The amphipod *Anisogammarus confervicolus* was the most common. Juveniles caught closer to shore consumed more insects than those in open water, mainly chironomid larvae. They captured fish in all areas of the estuary and had results that suggested that juveniles were feeding at all parts of the halocline.

Kask, B.A., T.J. Brown, and C.D. McAllister. 1986. Nearshore epibenthos of the Campbell River estuary and Discoverey Passage, 1982, in relation to juvenile chinook diets. Can. Tech. Rep. Fish. Aquat. Sci. 1449: 53 p.

Abstract: *Following the experimental rehabilitation of the Campbell River estuary in 1981-82, a program was begun to monitor the use of the new as well as the established habitats by juvenile salmonids, particularly wild and hatchery reared chinook. The role of each of the nearshore habitats in providing food for the young fish was also monitored using an epibenthic sled. From March to December, 1982, one hundred forty-six nearshore samples were collected from three different habitat areas- estuarine, transition, and marine zones. Copepod nauplii, nematodes, and harpacticoids dominated the marine zone. Densities of nearshore epibenthos were highest in the marine zone and lowest in the estuarine zone. The juvenile chinook were found to consume prey items from freshwater and terrestrial, estuarine and nearshore epibenthic and marine pelagic (planktonic) environments, the nearshore epibenthos comprising the largest part of the diet in the transition zone.*

This study monitored the use of Campbell River estuary by juvenile hatchery and wild Chinook post rehabilitation. Specifically the study was looking at the role of different habitats and the amount of food (epibenthic prey) they provide. The sampling site was divided into Estuarine, Transition and Marine zones. Samples were collected with an epibenthic sled that was pulled along the shoreline in shallow water. Beach seining was used to collect Chinook juveniles and their stomach contents were analyzed and compared to epibenthic samples. In the estuary it was found that Chinook preyed primarily upon amphipods, harpactids and ispods supplemented by aquatic and terrestrial insects. Epibenthos only contributed 40% to the diet. The sled captured mostly harpacticoids and it was noted that ispods and other larger prey may avoid the sled. In the transition zone stomach contents consisted of 99% epibenthic animals with mostly harpacticoids and amphipods as well as pelagic calanoids. This was consistent with abundances found in the epibenthic sampling. The marine zone Chinook stomach contained high amounts of pelagic calanoids and decapod larvae supplemented by epibenthic amphipods. Although sampling with the sled caught large amounts of amphipods this abundance was not represented in the stomach contents.

Kjelson, M.A., P.F. Raquel, and F.W. Fisher. 1982. Life History of Fall-run Juvenile Chinook Salmon, *Onchorhynchustsawytscha*, in the Sacramento-San Joaquin Estuary, p. 393-411. *In* V.S. Kennedy [ed.] Estuarine Comparisons. Academic Press, Inc., New York, NY.

Abstract: *The Sacramento-San Joaquin Estuary is one of the largest on the Pacific Coast and supports a variety of anadromous species. Fall-run chinook salmon, the dominant race in the system, utilize the estuary for rearing and migration. Fry (<70 mm) rear in the estuary for about 2 months, primarily in the upper freshwater Delta. Brackish water bays are used primarily as a migration corridor by smolts (>70 mm). chinook in more northern estuaries appear to make greater use of brackish water for rearing. Peak fry rearing (February to March) and smolt migration (April to June) occurs two to three months earlier in the Sacramento-San Joaquin than in most northern estuaries. This reflects earlier spawning and high summer temperatures that force juveniles from the lower river and Delta. Fry abundance and distribution in the estuary are influenced by the magnitude and timing of river flows. Growth rates during estuarine rearing range from 0.4 to 1.2 mmday-1 and are similar to other Pacific coast estuaries. Chinook diet also is similar to other west coast estuaries and is dominated by dipterans, cladocerans, copepods, and amphipods. Survival during smolt outmigration is greater in the lower bays than in the Delta. Survival through the Delta in June is inversely related to water temperature and directly related to river flow as suggested for some northern systems. Alteration of the timing, magnitude, and distribution of flow in the Sacramento-San Joaquin Estuary has a major impact on juvenile chinook survival. Hatcheries produce about 26 million fall-run smolts annually with most released during May and June in upstream and estuarine waters.*

A bag seine and mid water trawl were used to capture Chinook fry and smolt in the Sacramento-San Joaquin river delta. Fry abundance within the estuary was greatest between February and March. They found that numbers peaked a few days after storm surges. Seining revealed that smaller fish distribute in shallower waters during daylight hours but move offshore at night. In general larger fry and smolts occupy deeper water further towards the middle of the estuary. Some fish were marked in hatcheries and based on recaptures it was found that Chinook fry reside in the estuaries for up to 62 days. Average growth rate was found to be 0.86 mm/day. This was higher than the growth rate for fish rearing in the river, 0.33 mm/day. Smolt migration occurred April to mid-June. Smolts were found to move through the estuary quickly.

Korman, J., B. Bravender, and C.D. Levings. 1997. Utilization of the Campbell River Estuary by Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) in 1994. Canadian Technical Report of Fisheries and Aquatic Sciences. 2169. pp. 20

Abstract: *Juvenile salmon population growth and abundance data collected in the Campbell River estuary in 1994 were analyzed to describe chinook habitat use, residency timing, growth, and potential competitive interactions between wild chinook fry, hatchery chinook, and other salmon species. Wild chinook fry densities were highest in estuarine zone sites while hatchery chinook densities were generally higher than wild densities in transition zone sites. Habitat type significantly affected density of wild chinook in the estuary where their densities were greatest at riparian and intertidal island sites. Hatchery and wild chinook juveniles showed different patterns in their seaward emigration timing. The timing of peak abundance of hatchery chinook in the estuary coincided with the peak abundance of wild fry; this was considered a likely period of strong competitive interaction between hatchery and wild chinook salmon. Wild and hatchery chinook juveniles were generally larger at transition zone sites*

compared to those from the estuarine zone. Growth rates of wild chinook tended to be slightly higher than growth rates of hatchery chinook. The inverse relationship between wild chinook fry size and total salmon biomass, assessed in mid-May, was similar to that established with earlier data, supporting the conclusion that growth of wild chinook in the Campbell River estuary may be density dependent. Close to half the estuarine habitat of the estuary has been degraded due to industrial development since the early 1900s. Recovery of degraded estuarine habitat would improve rearing conditions for wild chinook fry. These measures should be integrated with freshwater improvement.

This paper describes a survey conducted of hatchery and wild Chinook habitat use within the Campbell river estuary and transition zone. Fry were captured with beach seines in 21 lower river/estuary sites and 5 higher salinity transition zone sites. Results revealed that wild Chinook densities were higher in the estuary sites while hatchery raised Chinook densities were higher in the transition zone sites. Wild Chinook density was highest May 25th with a residency time average of three months. Hatchery raised Chinook spent much less time in the estuary with an average residence time of 1.5 months. The size of both hatchery and wild fry was larger at the transition zone sites over the estuary sites with growth rates of wild Chinook being slightly higher (0.49 and 0.55 mm/day).

Koski, K.V. 2009. The fate of coho salmon nomads: the story of an estuarine-rearing strategy promoting resilience. Ecology and Society. 14(1): 4. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art4/

This literature review describes the behavior of coho salmon nomads. Several studies described found a life-history strategy in which salmon migrate from natal streams as age-0 fry to estuaries in the spring and summer, and then returning to freshwater streams to overwinter before smolting. This estuarine migration is thought to be linked to increased feeding opportunities provided by estuaries. Coho were found to return to both natal and non-natal streams. Several studies observed that salinity tolerance is a function of size, not age. Estuarine coho fry grew 1.8-2.3 times faster than those remaining in freshwater and outgrew fry in both length and weight. This paper mentions that coho were observed rearing in the estuary in the Cook Inlet.

Levings, C.D., K. Conlin, and B. Raymond. 1991. Intertidal Habitats Used by Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) Rearing in the North Arm of the Fraser River Estuary. Marine Pollution Bulletin. 22(1): 20-26.

Abstract: *Results from surveys of juvenile chinook (Oncorhynchus tshawytscha) and their invertebrate food items in the North Arm of the Fraser River estuary are presented and related to habitat zones on narrow beaches. Fish catches were highest on unvegetated habitat in the low tide area. The weight of food items in stomachs was highest from fish in the mid intertidal area. The distribution and abundance of ten common prey used by chinook were also examined. Emergent vegetation (sedges (Carex lyngbyei), rushes (Scirpus spp., Typha spp.)) and riparian shrubs and trees in the middle and upper intertidal zones, respectively, were identified as vital components providing detritus and habitat for the chinook food organisms. Water volume over the unvegetated sand and mud flats in the low intertidal zone needs to be carefully managed in this part of the estuary where extensive dyking and filling has been conducted in the past. For the purposes of managing fish habitat to achieve a goal of no net loss of habitat in the Fraser, estuary, biologists are assigning highest values to the sedges and rushes. Our data support this is an interim measure, but further research is needed to investigate the importance of riparian vegetation as its significance may be underestimated.*

This study examined habitats used by juvenile Chinook in the Fraser River estuary. Juveniles were collected in three zones: Zone 1. Low-intertidal with unvegetated zone of mud/ sand, 2. Intermediate-intertidal with vegetation dominated by sedge/ rushes, 3. High-intertidal riparian with variety of vegetation. Chinook fry (44 mm) made up 84% of all catches with no significant differences in length between zones. Chinook smolts (91-86 mm) also showed no difference in lengths among zones. Fish catches were highest in Zone 1, contradicting previous studies that found high fish concentrations on shorelines. Feeding occurred most heavily in the mid-intertidal zone.

Levy, D.A., and T.G. Northcote. 1982. Juvenile Salmon Residency in a Marsh Area of the Fraser River Estuary. Can. J. Fish. Aquat. Sci. 39: 270-276.

Abstract: *Large numbers of juvenile chinook salmon (Oncorhynchus tshawytscha), chum salmon (O. keta), and pink salmon (O. gorbuscha) were present within tidal channels of a marsh area in the Fraser Estuary between March and June 1978. The tidal channels investigated dewatered at a low tide, necessitating daily emigrations by juvenile salmon out of the channels. While pink fry emigrated from tidal channels at the early and middle stages of ebbing tides, most chum and chinook fry emigrated near the later stages of ebbing tides. Mark-recapture studies demonstrated that chinook and chum fry resided temporarily in the marsh prior to migrating into the Pacific Ocean and returned to the same channel on several tidal cycles. Pink fry were abundant in the channels, but appeared to be transient. Chinook and chum showed an increase in average length which was attributable to estuarine growth.*

This study used a mark and recapture method to determine the length of time juvenile salmon spend in sedge-dominated marsh habitat. March through May juvenile chinook, chum, and pink dominated the fish community. Juvenile chinook fry had the highest recapture rates, then chum, followed by relatively low recapture of pink with the longest residence times being 30, 11, and 2 days respectively. In March- May chum and chinook measured 37.5-40.9 mm (38.2- 39.4 avg. fork length) compared to 46.2 mm in early June (chum) and 70.5 mm in early July (chinook) showing estuarine growth had occurred. Pink emigrated from the tidal channel during early and middle stages of dewatering, whereas chum and chinook were most often captured near the end of the dewatering phase.

McInerney, J. E. 1964 Salinity preference: An orientation mechanism in salmon migration. Journal of Fisheries Research Board of Canada 21, 995–1018.

Abstract: *An examination of the modal salinity preferences of five Pacific salmon species showed the following pattern of temporal changes. The sequence began with a preference for fresh water, then changed gradually, in the direction of increasing seawater concentration. The terminal pattern indicated a preference for water of open ocean concentration. This temporal progression of salinity preference changes was shown to parallel closely the salinity gradients typical of river outflows through which young salmon pass on their way to the ocean. On the basis of this evidence the following orientation mechanism was proposed: that juvenile Pacific salmon are able to use estuarial salinity gradients as one of the directive cues in their seaward migration.*

A salinity preference test was performed for all five species of Pacific Salmon juveniles in the lab. Fish were placed in tanks that contained a portion of lower salinity water and a portion of higher salinity water (20 different concentration combinations). Tests were performed at various stages of development throughout the year. The results show that the salinity preference orientation for all species except coho is gradual from the beginning with fish selecting more saline waters with time. Coho, who typically spend a year in freshwater avoid saline waters for the first year in the lab. Similarly a portion of sockeye do as well, however some sockeye migrate as fry and show an orientation to more saline waters in the lab as well. All species exposed to sea water during the initial part of the experiment undergo a complete preference for seawater. Fish that are not initially exposed to salt water undergo a gradual preference to more saline waters but then a percentage of them revert back to freshwater preference in the late fall.

MacDonald, J.S., C.D. Levings, C.D. McAllister, U.H.M. Fagerlund, and J.R. McBride. 1988. A Field Experiment to Test the Importance of Estuaries for Chinook Salmon (*Oncohynchus tshawytscha*) Survival: Short-term Results. Can. J. Fish. Aquat. Sci. 45: 1366-1377.

Abstract: *In late April of 1983, 1984, 1985, 140,000 marked chinook salmon (Oncorhynchus tshawytscha) smolts (2-4 g) were transported by helicopter from Quinsam Hatchery to four release sites near Campbell River, B.C. (river, estuarine, transition, and marine), in an experiment to test the importance of estuarine residency to chinook survival. At the marine site, fish were released directly into seawater. These fish had high cortisol levels and larger interrenal nuclear diameters than those at the estuarine site, indicating a transitory stress response to seawater exposure. Nevertheless, there was little direct mortality due to stress or osmoregulatory shock at any of the release sites. Marine-released fish were exposed to more bird and fish predators. Mortality of caged chinook was higher at the marine location than at all other sites despite seawater challenge tests indicating that the chinook were smolted and "ready for sea". Beach seine data obtained biweekly for 4 mo after the releases showed that fish released directly into marine waters rarely dispersed to the Campbell River estuary. Fish released immediately adjacent to the mouth of the estuary (transition zone) had the widest immediate dispersal pattern, with many of them returning to the estuary. Estuarine zone fish displayed the most restricted distribution. Fish released to the river and estuary remained in the sampling area for a longer period (34-47 d) than those released in the marine or transition zone (20-23 d).*

This study, conducted in the spring of 1983- 1985, released juvenile chinook smolts in four different degrees of marine influence (river, estuarine, transition, and marine) to test the importance of estuarine residency to chinook survival. No differences were found in the amount of food eaten or in growth rates for each zone. The chinook released in the river and estuary zones had higher survival rates than those in marine or transitional. Chinook released in estuary and river zones showed delayed seaward migration, dispersed at lower rates, travelled shorter distances after release, and were recaptured in the greatest numbers. The fish occupied the estuary for 21-47 day periods. Marine fish were only captured within 8 weeks of release compared to 18-20 weeks for all other zones. Marine fish also had the highest cortisol levels and high mortality rates of caged fish compared to the estuarine site. Transitional released fish showed a tendency to migrate to the estuary for some time before moving out to sea. Estuary contained river food sources as well as marine food entering the estuary through tides. Referenced past study that found estuarine fish have more food in stomachs than riverine. Non-salmonid fish predators were smaller in the estuary than in the intertidal regions and avian predators occurred less frequently at river and estuarine sites than in marine influenced sites.

MacDonald, J.S., I.K. Birtwell, and G.M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can. J. Fish. Aquat. Sci. 44(6): 1233-1346.

Abstract: *Salmonid behaviour and abundance in several microhabitats within the Campbell River estuary was observed monthly, from May to July, by divers using snorkels and face masks. Concurrent*

vertical profiles of physical and biological parameters at each microhabitat were taken to characterize habitats frequented by the fish. Data were collected at high and low tide to record behavioural reactions to changes in water velocity, salinity, and temperature associated with tidal height and salt wedge intrusion. Samples of plankton collected at each microhabitat were compared with stomach contents sf salmonids caught nearby to determine if interspecific differences in diet could be correlated with differences in the habitats they occupied. Fish occurred in loose assemblages, aligned with the current, feeding near estuarine banks. As water velocities increased with the ebbing tide, the fish concentrated in a shear region near the mouth of a slough and behind large rocks and submerged vegetation. At both high and low tide, larger coho (Onssahynchus kisuesh) and chinook salmon (Oncorhynchus tshawytscha) (usually hatchery reared) were in deeper, frequently more saline water and further from shore than the smaller conspecifics. Hatchery chinook, however, were also seen in sloughs where water velocity was low. Marine influence as reflected in plankton composition and salmonid diet was greater in the outer estuary and in the deep salt water that intrudes the inner regions of the estuary. Differences in the habitats occupied by the fish were reflected in differences in their diets.

Hatchery and wild juvenile salmon's behavior was observed and numbers counted by snorkeling in Campbell Creek May-July. Stations were set up at two different zones, one mostly freshwater at the mouth of the river and the other in the transition zone (more saline). Habitat parameters were also measured or observed by snorkeling. Some fish were captured with a beach seine for stomach content analysis and plankton samples were collected at each site. It was found that velocity; temperature and salinity were most influential in explaining differences in catch numbers among microhabitats. Coho were found in areas of higher salinity and velocity than Chinook. Hatchery Chinook occupied the slowest waters. Few salmon ever showed any aggressive or territorial behavior. This study emphasizes the importance of high currents because although fish are seen less frequently there, the higher velocities act to dislodge invertebrates and offer feeding opportunities.

Magnusson, A. and R. Hilborn. 2003. Estuarine Influence on Survival Rates of Coho (*Oncorhynchus kisutch*) and Chinook Salmon (*Oncorhynchus tshawytscha*) Released from Hatcheries on the U.S. Pacific Coast. Estuaries 26 (4b): 1094-1103.

Abstract: *While it has long been known that Pacific salmon use estuarine habitat it has proven much harder to establish that the loss of estuarine habitat results in reduced survival. We used coded-wire tagging of hatchery fish to estimate the survival from release until maturity and related this survival to several indicators of estuarine condition. We found a significant relationship between the survival of chinook salmon (Oncorhynchus tshawytscha) and the percentage of the estuary that is in pristine condition, but no significant relationship for coho salmon (Oncorhynchus kisutch). This supports field observations that chinook salmon use estuarine habitat much more than coho salmon and confirms that the loss of estuarine habitat results in lower survival of chinook salmon.*

This study analyzed and compared survival rates of Coho and fall Chinook smolts in Pacific estuaries with respect to the size of the estuary, the percentage of the estuary in natural condition, and the presence of oyster aquaculture. Subyearling Chinook were more dependent on estuarine habitat for growth and the transition from fresh to salt water. Their survival rates were more than three times as high in pristine estuaries compared to those with zero pristine habitats. Coho smolts did not follow this trend and used the estuaries less intensively. Pristine estuarine habitats offer better protection from predators and are less likely to reflect anthropogenic factors such as pollutants or exotic species.

Manzer, J.I. 1969. Stomach contents of juvenile Pacific salmon in Chatham Sound and adjacent waters. Journal of Fishereies research Board of Canada. 26: 2219-2223.

Abstract: *Stomach contents of young Pacific salmon in Chatham sound and adjacent waters of northern British Columbia from June through August indicated interspecific differences in the kinds of organisms consumed. Pinks (Oncorhynchus gorbuscha) and chums (O. keta) were mainly planktophagous, copepods and Larvacea (Oikopleura spp.) being most important; cohos (O. kisutch) were piscivorous, herring larvae (Clupea spp.) and sand lance (Ammodytidae spp.) being important. With pinks and chums, while they were still relatively abundant along the beaches, the dominant food item progressively changed from copepods in the southern areas to Larvacea in the northern areas.*

Manzer nvestigated stomach contents to describe the diets of pink, chum, coho, and sockeye juvenile salmon. Pink and chum were mainly planktophagous and fed on copepods and Larvacea most abundantly. The abundance of copepods compared to larvae differed spatially most likely due to availability. Coho were generally piscivorous, feeding on herring larvae and sandlance. Sockeye showed characteristics of both food preferences choosing mainly plankton but also consuming fish as well.

Mason, J.C. 1974. Behavioral ecology of chum salmon fry (*Oncorhynchus keta*) in a small estuary. Journal of Fisheries Research Board of Canada. 31: 83-92.

Abstract: *Chum salmon fry (Oncorhynchus keta) in the estuary of a small coastal stream exploited fresh water, estuarine, and marine food chains and, by so doing, were exposed to marked, daily fluctuations in salinity that demanded active selection of fresh water on ebbing tides day and night. The resulting delay in seaward migration and associated behavioral observations are inadequately reflected in published accounts of the life history and behavior of chum fry in natural systems and laboratory situations, and the downstream displacement theory. The biological basis for delayed seaward migration of chum fry merits the attention of fishery researchers and resource manages alike.*

This paper presents evidence that juvenile chum actively select freshwater with diel changes in tide within a small estuary and delay seaward migration. Beach seine hauls were conducted during May along the entire reach from fresh to marine (deep bay) waters and chum were marked by adipose clipping. A subsample of stomach contents was analyzed. In addition stream drift and benthos samples were collected as well as zooplankton samples. Recaptures of chum fry at varying stations from where they were marked indicate that they are actively moving up and down the stream channel in and out of the estuary. Three days after marking they had a recovery rate of 17% at a freshwater station. There was also direct visible observation of schooling chum moving into the estuary at high tide and back into freshwater as the tide was receding. In contrast coho were not found to move into the estuary during high tide, they remained in freshwater. Chum diel movement in and out of saline waters was also indicated in their stomach contents. This study presents contrary results to the belief that chum are easily displaced by current during darkness (Hoar 1958)

McCabe, G.T. Jr., W.D. Muir, R.L. Emmett, and J.T. Durkin. 1983. Interrelations between juvenile salmonids and nonsalmonid fish in the Columbia river estuary. Fish. Bull. 81: 815-826.

Abstract: *Interrelationships between juvenile salmonids-coho salmon, Oncorhynchus kisutch; chinook salmon, O. tshawytscha; and steelhead, Salmo gairdneri- and nonsalmonid fish were studied in the Columbia River estuary during 1980. Nonsalmonid species were numerically dominant in pelagic and intertidal areas of the lower estuary. In pelagic and intertidal areas of the upper estuary, juvenile salmonids, particularly subyearling chinook salmon were proportionally important. Nonsalmonid species commonly associated with juvenile subyearling chinook salmon included American shad, Alosa sapidissima; Pacific herring, Clupea harengus pallasi; northern anchovy, Engraulis mordax; surf smelt, Hypomesus pretiosus; longfin smelt, Spirinchus thaleichthys; peamouth, Mylocheilus caurinus; threespine stickleback, Gasterosteus aculeatus; shiner perch, Cymatogaster aggregata; Pacific staghorn sculpin, Leptocottus armatus; and starry flounder, Platichthys stellatus. Commonly associated species were generally defined only in reference to subyearling chinook salmon because, of all the juvenile salmonids, subyearling chinook salmon were clearly the most abundant and available in sizable numbers for the longest time. Predation on juvenile salmonids by non· salmonids and other juvenile salmonids was insignificant Significant diet overlap occurred among subyearling and yearling chinook salmon, coho salmon, and steelhead during the spring. American shad, threespine stickleback, and starry flounder had significant diet overlaps with juvenile salmonids.*

The objective of this study was to measure the general abundances, length, and species of salmonids and non-salmonids present in the Colombia River estuary and determine whether predation or competition for food and habitat was occurring. Overall juvenile chinook, coho, and steelhead were the most common salmonids, with chinook having the greatest overall abundance and residing in the estuary the longest (March- September). Non-salmonid fish were dominant in the lower area of the estuary. Juvenile chinook and steelhead were almost exclusively found in pelagic areas, compared to the coho salmon which were occasionally found in intertidal areas. Stomach content analysis revealed there was little to no predation on salmonids occurring in the estuary. While fish were consumed, the principal prey items for salmonids and commonly associated non-salmonids were invertebrates. During the spring all salmonids, except steelhead, had significant diet overlap in the pelagic areas, as well as with the American shad in the lower estuary and three-spine stickleback in the upper. In the spring the only major diet overlap was between subyearling chinook salmon and starry flounder, and they found no diet overlap for the summer months.

McConnaughey, T. and C.P. McRoy. 1979. ^{13}C label identifies eelgrass (*Zostera marina*) carbon in an Alaskan estuarine food web. Mar. Biol. 53: 263-269.

Abstract: *The food web of Izembek Lagoon, Alaska draws most of its carbon from eelgrass (Zostera marina) and phytoplankton. The ^{13}C:^{12}C ratios of these primary producers are sufficiently different to enable their contributions to consumers to be estimated from consumer 13C:12C ratios. Although the technique is conceptually simple, carbon inputs from other sources and isotope fractionations occurring in the food web limit its precision. Isotopic data nevertheless helps to establish the major carbon fluxes through the community and to assess the importance of eelgrass carbon to individual animals. It is*

particularly useful when dealing with detritus food chains, where direct observations of animal feeding habits are difficult to make. The Izembek community draws much of its carbon from eelgrass. Detritus food chains provide the major pathway for assimilation of eelgrass carbon by the community, but grazers are also important. Eelgrass carbon is more important to benthic animals than to the eelgrass epibiota and the fishes, which depend mainly on phytoplankton carbon.

In this study, ^{13}C:^{12}C ratios were used to determine relationships between eelgrass and animal carbon. Eelgrass isotopes were found to be very similar to herbivores but dissimilar to suspension feeders. Detritus feeders varied in their similarity. Despite eelgrass dominance as far as biomass in the ecosystem it does not contribute a proportional amount of carbon to the food web. It was found that microalgae contributed at least as much carbon as eelgrass.

McMahon, T. E., and L. B. Holtby. 1992. Behaviour, habitat use, and movements of coho salmon (Oncorhynchus kisutch) smolts during seaward migration. Canadian Journal of Fisheries and Aquatic Sciences 49:1478-1485.

Abstract: *Coho salmon (Oncorhynchus kisutch) smolts formed aggregations in pools with large woody debris during their migration downstream and into the Carnation Creek estuary, British Columbia. Smolts utilized the estuary throughout the smolt run, with periods of high outmigration coinciding with spring tides which brought warmer, more saline water into the estuary. Smolt abundance in the stream and estuary was positively related to debris volume, and 82% of the 1260 smolts observed during underwater counts occurred within 1 m of debris. Debris volume and smolt density were significantly lower in clearcut than in buffered stream sections. Our observations support the need to retain and manage large woody debris for smolt habitat in streams and estuaries.*

This study examined the migration patterns and habitat used by coho smolts in Carnation Creek, British Columbia. Most smolts migrated to the estuary by mid-April, approximately 10 days after release, and left the estuary by early June. Overall densities were highest in the estuary. Few smolts were observed in the sections were clear-cutting had occurred and densities were 5 times higher in the buffered section. Densities were positively correlated with the total volume of large woody debris in a 50 meter reach. Over 80% of smolts were found within 1 meter of woody debris and 95% were found within 2 meters. Coho densities were not significantly correlated with debris area, bank cover, percent canopy, percent pools, or mean/maximum depth. About 95% of smolts were found in groups of greater than 5 fish. These aggregation sizes increased as the run progressed and were significantly greater in the estuary.

Meador, J.P., F.C. Sommer, G.M. Ylitalo, and C.A. Sloan. 2006. Altered growth and related physiological responses in juvenile Chinook salmon (*Oncorhynchus tshawytscha*) from dietary exposure to polycyclic aromatic hydrocarbons (PAHs). Canadian Journal of Fish and Aquatic Science. 63: 2364-2376.

Abstract: *A dietary feeding study with polycyclic aromatic hydrocarbons (PAHs) was conducted with juvenile Chinook salmon (Oncorhynchus tshawytscha) to mimic exposure from urban estuaries during their transition from freshwater to seawater. A significant reduction in mean fish dry weight was observed only for the highest doses; however, analysis of variance (ANOVA) using standard deviations and examination of the cumulative frequency plots revealed high variability among all treatments. The skewed fish weight distribution revealed a large number of small fish in several treatments compared with control fish. Analyses of whole-body lipids and several parameters in blood plasma related to*

growth and metabolism indicated alterations for most treatments. These results and trends in growth, plasma chemistry, and lipids as a consequence of PAH exposure were similar to those in fish exhibiting starvation, which we have termed "toxicant-induced starvation". Based on these results, we conclude that PAHs are toxic to salmonids at this life stage and the reduction in biomass and lipid stores observed here would have the potential to cause increased mortality for individuals during their first winter.

The goal of this study was to assess the effects of a diet containing PAHs on Chinook smolts acclimated to seawater. Body weight and lipid content were analyzed to determine toxicity but revealed that fish given food containing PAHs were in better health, being larger and having higher lipid content. However further analysis of lipid classification and plasma chemistry indicated that these PAH fed fish were undergoing stress. The lipid and blood parameters that were depressed were similar to those found in fish that are undergoing starvation even though the fish are getting adequate food. The cause of these physiological changes is unknown. The concentrations of PAH used in this study were similar to usual concentrations in urban estuaries. However, salmon in urban estuaries are likely exposed to higher levels of PAHs than those in this study because they are exposed to it through food and through the water.

Meehan, W.R., and D.B. Siniff. 1962. A study of the downstream migrations of anadromous fishes in the Taku River, Alaska. Transactions of the American Fisheries Society 91(4): 399-407.

Abstract: *A modified scoop trap was designed and constructed to sample downstream-migrant juvenile salmon in the Taku River, a turbid river in southeastern Alaska. A sampling program was designed to determine the behavior of these migrants with respect to their seasonal and daily timing, the size and age composition of the various species, and the correlation between certain of these biological measurements and the physical characteristics of the environment. The length-weight relationships and condition factors of chinook, coho, and sockeye smolts were determined; differences in these relationships by week and by time of day are discussed.*

This study of juvenile migrating salmon in the Taku River found chum, coho, chinook, and sockeye present in samples taken upstream from estuary. Peak chum migrated earliest beginning April, followed by chinook (early May), coho (mid-May), and sockeye (early June). All fish tended to follow a nocturnal migration. Chinook and sockeye activity peaked in the early morning hours.

Mortensen, D., Wertheimer, A., Taylor, S. and J. Landingham. 2000. The relation between early marine growth of pink salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fisheries Bulletin 98: 2, 319-335.

Abstract: *Juvenile pink salmon, Oncorhynchus gorbuscha, from four consecutive brood years were tagged as they emigrated to the estuarine waters of Auke Bay, and information was obtained on the relationships between early marine growth, environmental conditions, and survival to adulthood. Juveniles that emigrated from Auke Creek later in the spring spent significantly less time in the estuary. Individual growth rates of tagged fish recovered in Auke Bay ranged from 3.1% to 7.1% per day. In all study years, juvenile pink salmon grew more slowly in early April than in late April and early May. Water temperature and growth were significantly correlated in all years, but growth did not consistently correlate with the biomass of epibenthic prey or zooplankton available to the fish. Comparisons of expected and observed growth rates suggested that low prey availability, as well as low temperatures may have limited growth for early spring emigrants. Although early emigrants encountered poorer growth conditions, survivors were larger at a given date than later emigrants, their*

larger size possibly protecting them from size-selective predation. Early marine growth was significantly related to intra-annual cohort survival to adults (r2=0.65, P<0.05). Larger fish consistently survived better than their smaller cohorts for all years. Although early marine growth was an important determinate of survival within a cohort of pink salmon, other factors, such as predator abundance, contributed to the large interannual variability observed.

Pink salmon fry were marked with coded wire tags during their spring downstream migration out of Auke Lake in this study. Off shore areas were tow netted and near shore areas were beach seined and subsample of catch retained for stomach analysis. Growth of recaptured fish was correlated with water temperature and prey biomass over the period of their mark and recovery. They found that pink salmon that had migrated downstream early in the season had longer residencies in the estuary (mean of 30 days). While pink salmon migrating downstream later had shorter residence times (mean of just 7 days). It was shown in the stomach content analysis that pink switch from a mostly epibenthic prey diet between April and May to a predominately pelagic diet later in the season. Even pink fry caught offshore had epibenthic contents suggesting movement from offshore to nearshore habitats. Growth rates for fish tagged in April varied between 2.93% bwd to 4.88%. Growth rates for the May tagged fish were 4.82% bwd to 6.66% suggesting much faster growth. This increased growth rate correlates with warmer estuary temperatures. It was also found that pink growth rates during estuary residence is positively correlated to marine survival for three of the four study years (r^2 =0.93)

Moulton, L.L. 1997. Early marine residence, growth and feeding by juvenile salmon in Northern Cook Inlet, Alaska. Alaska Fishery Research Bulletin 4: 2, 154-177.

Abstract: *Juvenile salmon were captured in June and July 1993 with a surface townet in the northern portion of Cook Inlet, a glacially turbid estuary. Hydroacoustic sampling indicated that most fish targets were in the top 2 m of the water column. Many salmon juveniles, particularly chinook Oncorhynchus tshawytscha, sockeye O. nerka, and coho O. kisutch, moved rapidly out of the sampling area, although residence in northern Cook Inlet extended into mid-July. Chum salmon O. keta were more abundant than any other salmon species in northern Cook Inlet, and by July were widely distributed throughout the study area. Diets of juvenile salmon in June were similar to those reported in other studies, calanoid copepods, fish larvae, and other zooplankton being abundant in stomachs. Chum salmon, followed by pink salmon O. gorbuscha, fed most intensively. Drift insects were an important part of chum salmon diets in June and predominated the diet of all species in July. Heavy feeding on drift insects demonstrated by all juvenile salmon was probably a response to high turbidities reducing feeding efficiency and effecting a nearsurface orientation. Apparent growth in chum salmon juveniles was within the reported range for other regions. During July, both chum and pink salmon juveniles rearing in northern Cook Inlet achieved growth rates and conditions comparable to those of nearby Prince William Sound, which is not glacially occluded.*

This study examined the entry timing of juvenile salmon into the Northern Cook Inlet, the duration of residence, their size and growth, distribution and feeding intensity as well as the availability of prey. Sampling was conducted by surface trawl tows from the Susitna River delta south to the forelands. The greatest concentrations of salmon were found on the northwest shoreline and Susitna River delta. For the most part they found that all species were surface oriented. Pink compromised the catch in June composing 25% of the total catch. Pink numbers rapidly declined in July when chum numbers increased. Chinook abundance peaked in mid-June then again in mid-July and their catch rates had a significant negative correlation with salinity. Coho were the least abundant and the only salmon caught in September. Chinook were found to be of three age classes with age 1+ peaking in June and age 0+ peaking in July. Very few age 2+ were collected. Sockeye sizes varied significantly with no dominant modes. The most dramatic size modes occurred in coho. In June the average coho size was 65-85mm. The June migrants consisted of large age 1+ and age 2+ while July migrants were almost entirely age 1+. Pink salmon juveniles were consistent in size at about 40mm in June and July. Chum were the only species to show significant growth throughout the season with an average of 1.15 mm/day in July. It was observed that all species besides chum moved out of the sampling area relatively quickly.

Murphy, M.L., J.F. Thedinga, and K.V., Koski. 1988. Size and Diet of Juvenile Pacific Salmon During Seaward Migration Through a Small Estuary in Southeastern Alaska. Fishery Bulletin. 86(2): 213-222.

Abstract: *To assess competition and predation among juvenile Pacific salmon (Oncorhynchus spp.) migrating through the estuary of Porcupine Creek, a small stream in southeastern Alaska, their size and diet were determined in 1979 and 1981. Mean fork length (FL) during May and June increased from 32 to 73 mm (1.5 mm/day) for pink salmon, O. gorbuscha; from 39 to 51 mm (0.4 mm/day) for chum salmon, O. keta; and during June and July, from 99 to 165 mm (1.6 mm/day) for coho salmon, O. kisutch. Prey, in order of importance, included larval fish (mostly Gadidae), larval molluscs (Mesogastropoda), and calanoid copepods for pink salmon; larval molluscs, larvaceans, and hyperiid amphipods for chum salmon; and fish (Clupea harengus pallasi, Ammodytes hexapterus, and Gadidae), insects, and larval decapods (Brachyrhyncha) for coho salmon. No pink or chum salmon were found in the coho salmon stomachs. Prey size for pink and chum salmon was similar (median, 0.4 mm long for both species), and much smaller than that of coho salmon (median, 2.3 mm). Diet overlap was greater between pink and chum salmon than between either species and coho salmon. Pink salmon, however, ate almost exclusively (95%) pelagic prey, whereas chum salmon ate both pelagic (74%) and epibenthic (26%) prey. Rapid early growth and differences in diet probably help minimize predation and competition among salmon during seaward migration.*

The goal of this study was to compare the size and diet of pink, chum and coho salmon in order to determine potential predation and competition between species during their migration through a small estuary. Fish were captured by beach seines at 6 sites total divided between the inner, middle and outer basin. It was found that pink and chum had similar diets and were more likely to compete for food while coho were eating larger prey because they migrate into the estuary at a larger size. Estimations of growth for pink salmon were 1.5 mm/day which is higher than most reported rates. Chum growth estimates were lower than reported values at 0.4 mm/day. The growth estimate for coho at 1.6 mm/day was very close to previously study's values. It was determined that the period of predation on pink and chum by coho is probably relatively short.

Aquatic Restoration & Research Institute

Murphy, M.L., J. Heifetz, J.F. Thedinga, S.W. Johnson, and K V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (Oncorhynchus) in the glacial Taku River, Southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 46:1677-1685.

Abstract: *Habitat utilization was determined in summer 1986 by sampling 54 sites of nine habitat types: main channels, backwaters, braids, channel edges, and sloughs in the river; and beaver ponds, terrace tributaries, tributary mouths, and upland sloughs on the valley floor. Physical characteristics were measured at all sites, and all habitats except main channels (current too swift for rearing salmon) were seined to determine fish density. Sockeye (Oncorhynchus nerka) averaged 23 fish/188 rn2, nearly twice the density of coho (0. kisutch) and four times that of chinook (0. tshawytscha), 14 and 6 fish/16B8 m2, respectively. Sockeye were age 0, 27-84 mm fork length (FL), and most abundant in upland sloughs, beaver ponds, and tributary mouths. Coho were ages 0 and 1, 33-1 32 mm FL, and most abundant in beaver ponds and upland sloughs. Chinook were age 0,4&93 mm FL, and more abundant than the other species in habitats with faster currents (1-20 cm/s), particularly channel edges. Each species was absent from about one-quarter of the seining sites of each habitat type. Thus, the lower Taku River provides important summer habitat for juvenile salmon, but many suitable areas were unoccupied, possibly because of their distance from spawning areas and poor access for colonizing fish*

The researchers sampled main channels, backwaters, braids, channel edges, river sloughs, beaver ponds, terrace tributaries, tributary mouths, and upland sloughs on valley floor in order to determine patterns of habitat used by juvenile salmon in the summer. Sockeye, coho, and chinook were the most abundant salmonids. Sockeye were overall more abundant and their densities doubled that of the coho and were four times that of chinook. About 99% of sockeye and chinook were age-0 (27-84 mm), while coho were a mix of age-0 and age-1 (22-132 mm). Salmon distribution was most closely related to water velocity. Turbidity was only a secondary factor which surprised the authors as the Taku River is a fairly turbid stream. Chinook were found in slow to moderate currents compared to sockeye and coho who occupied slow or still water. Virtually no fish were found in areas with currents greater than 30 cm/s. Each species was present in only about ¾ of the sites. Sockeye abundances were highest in sloughs in the river and tributary mouths, beaver ponds, and upland sloughs off channels (velocities less than 10 cm/s). Coho were scarce in river habitats and preferred off-channel habitats with slow water with the highest densities found in beaver ponds and upland sloughs. Chinook were found in riverine habitats including, sloughs, channel edges, off channel terrace tributaries and tributary mouths. Chinook showed opposite patterns to that of coho and were absent from beaver ponds and upland sloughs. Overlap was most common for coho and sockeye (80%), compared to sockeye and chinook (38%) and coho and chinook (18%).

Murphy, M. L., K V. Koski, J. M. Lorenz, and J. F. Thedinga. 1997. Downstream migrations of juvenile Pacific salmon (Oncorhynchus spp.) in a glacial transboundary river. Canadian Journal of Fisheries and Aquatic Sciences 54(12): 2837-2846.

Abstract: *Migrations of juvenile Pacific salmon (Oncorhynchus spp.) in the glacial Taku River (seventh order) were studied to assess movement from up river spawning areas (in British Columbia) into lower-river rearing areas (in Alaska). Differences between fyke-net catches in the river and seine catches in the river's estuary indicated that many downstream migrants remained in the lower river instead of migrating to sea. In particular, age-0 coho salmon (O. kisutch) and chinook salmon (O. tshawytscha) moved downriver from May to November but were not caught in the estuary.Age-0 sockeye salmon (O. nerka),coho presmolts, and other groups delayed entry into the estuary after moving downriver. We tagged groups of juvenile coho (ages 0–2) from the fyke net with coded-wire to determine when they left the river. One-third of all tags recovered from sport and commercial fisheries occurred 2–3 years later, showing that many coho remained in fresh water for 1–2 years after moving to the lower river. Lower-river areas of large glacial rivers like the Taku River can provide essential rearing habitat for juvenile salmon spawned upriver and are important to consider in integrated whole-river management of transboundary rivers.*

This study describes the timing, size and age of migrating juvenile salmonids within the Taku River. Catches differed between the river and the estuary as well as across seasons. The estuary was dominated by chum fry May-June, age-0 sockeye in July and August. Chum migrated to the estuary May and June. When entering the estuary these chum fry were smaller than those in the river but averaged 7 mm larger in June. Chinook smolts moved through the estuary in May and June (54-120 mm). About 98% of these smolts were age-1. Coho smolts were found in estuaries from early May to mid-August, peaking in June. Coho migration was linked to the first major increase in river discharge in the early spring or summer. Of tagged coho, about ¾ of fish released in 1989 were caught in 1990 and the remaining ¼ were caught in 1991 showing they remained in freshwater for a year after migrating to the lower river. Sockeye showed a bimodal migration with two major peaks with the largest fish migrating earlier. Age-1 (58-63 mm) and -2 (70-75 mm) fish moved into the estuary in May and June. In May these fish averaged 6 mm larger than those found in the river in May, but sizes were comparable in June after these larger fish had migrated. Murphy describes the river as a 'patch-dynamic system'.

Myers, K.W. and H.F. Horton. 1982. Temporal Use of An Oregon Estuary By Hatchery and Wild Juvenile Salmon, p. 377-392. *In* V.S. Kennedy [ed.] Estuarine Comparisons. Academic Press, Inc., New York, NY.

Abstract: *Temporal use of Yaquina Bay, Oregon, (July 1977- December1978) by accelerated-growth (age-0) hatchery coho (Oncorhynchus kisutch) and wild salmon (Oncorhynchus spp.) juveniles was determined by periodic sampling of nearshore and channel sites in the estuary. "Residency half-life" ranged from two to nine days for different release groups of hatchery coho juveniles, and was longer for fish released earlier in the year (June) than for groups released later (September-October). Wild populations of chum (O. keta) and coho were present at the sample sites for 2-3 mo (March-June), and wild chinook (O. tshawytscha) were present during 9 mo (January, April-November). Lack of overlap in peak abundances of wild chum (early April), coho (mid May), and chinook (mid July-early August), suggests interspecific temporal partitioning. Releasing age-0 hatchery coho after peak abundances of wild chinook should be considered as a means of decreasing overlap in temporal use of the estuary.*

Competition among species in an estuary was investigated to determine if abundant hatchery released coho had a negative effect on wild salmon. It was found that the majority of age 0+ hatchery released fished left the estuary after 1 month. A smaller portion remained in the estuary and exhibited growth during that time in 1977 but not in 1978. It is possible that growth was suppressed this year due to large numbers of juveniles in the estuary. Time of release from the hatchery was found to be important in determining the length of residence time. It was also found that chum use the estuary as a feeding ground but do not reside as long as coho. Wild Chinook were found within the estuary during the 9 sampling months and moved from the upper estuary into the lower. There was very little peak abundance overlap among all wild species of salmon. The study results led the authors to suggest that hatchery raised coho should not be released until after the peak abundance of Chinook.

Naimman, R.J. and J.R. Sibert. 1979. Detritus and juvenile salmon production in the Nanaimo Estuary: III. Importance of detrital carbon to the estuarine ecosystem. Journal of the Fisheries Research Board of Canada. 36: 504-520.

Abstract: *Sources of autotrophic and allochthonous organic carbon available to the Nanaimo Estuary delta, British Colombia, were studied from 1974 to 1978. Annually, benthic microalgae produce 4-55 g C·m-2, phytoplankton ~7.5 g C·m-2, and macroalgae 0.9-7.5 g C·m-2 . Zostera marina (26.8 g C·m-2 · yr-1) and Carex (~564 g C·m-2· yr-1) are productive but enter the food web as detritus. Allochthonous sources are most important with organic matter from the river, especially dissolved organic carbon (~2500 g C·m-2 · yr-1) and fine particulates (56 g C·m-2 · yr-1), contributing greatest amounts. The standing crop of organic detritus in the top 5 cm of sediments averages from 58 to 233 g C·m-2, depending upon the station. The timing of organic inputs are important, however. Seventy to 93% of total annual river inputs occur during autumn freshets, Zostera enters the food web during winter, Carex may contribute in early spring, and algae are productive over summer months. Activity and biomass of microbes are high most of the year in surface sediments but in the water column microbes are relatively active only during warmer months. Surface sediment ATP concentrations range seasonally from 3 to 36 µg·g sediment -1; and concentrations in the water column range from <0.2 to 1.5 µg·L-1. Microbial activity, measured with 14C-glucose, ranges seasonally from 4 to 20% uptake per hour for surface sediments and from <1 to nearly 40% ·h-1 in the water column. These results are compared with those from other studies and coupled to concurrent studies of meiofauna and salmon ecology to show a link between detritus, microbes, harpacticoid copepods, and the food, growth, and production of juvenile chum salmon (Oncorhynchus keta).*

This study attempted to describe the detritus-based food chain present in a mudflat estuary and its relation to juvenile salmon. The standing stock of detritus within the estuary varies between 50 and 300 $gC \cdot m^{-2}$ with it being the highest at the station closest to the river during high discharge. The Nanaimo estuary has tidal variations averaging 3m which provides a discharge into the estuary of several orders magnitude higher than the river yet not nearly as much organic carbon. The main sources of carbon in the estuary are, in this order; allochthonous inputs from the watershed, phytoplankton and epibenthic algae, eelgrass, and marshes. Their findings support the theory that oceans' food webs are predominately detrital. A direct link to chum salmon is presented. Detritus is broken down by microbes which are consumed by harpacticoid copepods, which are an important food source for chum salmon during the first few weeks of sea life critical to marine survival (Healey 1979).

Nemeth, M. J., C. C. Kaplan, A. P. Ramos, G. D. Wade, D. M. Savarese, and C. D. Lyons. 2007. Baseline studies of marine fish and mammals in Upper Cook Inlet, April through October 2006. Final report prepared by LGL Alaska Research Associates, Inc., Anchorage, Alaska for DRven Corporation,
Anchorage, Alaska.

This study was conducted over the span of three years in the Cook Inlet; the Ladd and Susitna Flats area. Nearshore and off shore surveys of marine fish were conducted using beach seines and hydroacoustics. Beluga whale sighting were recorded and were found to correlate with the timing and density of fish (eulachon, juvenile Chinook, juvenile coho). A comprehensive literature cited is attached to this report and offers a good summarization of the known life history traits of each species of salmon as well as other marine fishes within the Cook Inlet.

Parker, R.R. 1971. Size Selective Predation Among Juvenile Salmonid Fishes in a British Columbia Inlet. Journal of the Fisheries Research Board of Canada. 28(10): 1503-1510.

Abstract: *Field observations suggest early sea mortality of pink (Oncorhynchus gorbuscha) and chum (O. keta) salmon fry is largely due to predation by juvenile coho (O. Kisutch) salmon. A series of experiments demonstrates a strong bias toward the smaller individuals of the prey population. This results in an apparent growth rate 0.3-0.5% per day due to the biased mortality alone. With a high innate growth rate ($\bar{g}$~1.4%/day), the prey are shown to "outgrow" the predator ($\bar{g}$ ~0.7%/day), and hence become unavailable. Chums are shown to have an advantage over pinks through slightly earlier entry into the estuary and a larger initial size. The mechanism of selection used by the predator is not known from this study.*

Parker collected juvenile pink, chum, and coho salmon and observed them in aquariums in order to determine if coho predators were biased by size of prey (chum/ pink). The study showed the cohos had a stronger selectivity for smaller prey. Chums (38 mm) had a slight advantage over pinks (33-37 mm) as they are larger as unfed fry and they enter the estuary during the earlier portion of the pink migration. Pink have a high innate growth rate of 1.4% a day which allows them to eventually "outgrow" the coho as a food source.

Pinder, A.C., W.D. Riley, A.T. Ibbotson, and W.R.C. Beaumont. 2007. Evidence for an autumn downstream migration and the subsequent estuarine residence of 0+ year juvenile Atlantic Salmon *Salmo salar* L., in England. Journal of Fish Biology 71: 260-264.

Abstract: *The use of passive integrated transponder technology facilitated the first observations of the autumn migration of 0+ year Atlantic salmon Salmo salar parr into tidal rearing habitats in the U.K. The quality of these habitats in relation to smolt production and the ecological significance of this alternative life-history strategy are presently not understood.*

This study looked at migration movements of age 0+ year juvenile Atlantic salmon. Most previous literature had found that Atlantic salmon spend 1 year in fresh water before migrating as smolts in the spring, however this study's results coincided with trends seen in 2004 and 2005 of 0+ year parr moving from upstream summer habitat to the tidal zone during an autumn migration. Their study found that 25% of the spring smolt run followed this trend and concluded that estuaries provide an important overwintering habitat for these juvenile fish. The question that emerges from this study is why these fish undergo a partial migration prior to the normal spring smolt run.

Pomeroy, W.M. and J.G. Stockner. 1976. Effects of Environmental Disturbance on the Distribution and Primary Production of Benthic Algae on a British Columbia Estuary. Journal of Fisheries Research Board of Canada. 33:1175-1187.

Abstract: *Construction of a river training dyke at Squamish, B.C., has resulted in a strong salinity, water transparency, and sedimentation gradients across the estuary face which have significantly affected the distribution and primary production of benthic algae. The estuary west of the dyke is now a very unstable habitat for algal colonization and growth. During river freshet, heavy sedimentation and salinities less than 3‰ make algal survival difficult. At other times of the year, a salinity range of up to 25‰ is common over a tidal cycle. Algae in this area are generally strongly euryhaline, the dominant species being Enteromorpha minima, Rhizoclonium riparium, and Vaucheria dichotoma; mean production is 0.6 g C m-2 day -1. The eastern portion of the estuary has a more stable benthic environment; lower sedimentation and higher salinity result in greater species diversity, biomass, and primary production. Dominant species are E. minima, Ulva lactuca, Pylaiella littoralis, and a variety of diatom communities. These algae tend to be weakly euryhaline, with optimum salinities between 15 and 30. Mean production is 2.2 g C m-2 day -1. Recent intrusion of Fucus vesiculosus strongly indicates that the eastern estuary is developing into a more marine habitat.*

This paper examined the effects of anthropogenic environmental disturbances on benthic algae. The three deltas sampled differed as to the characteristic algal classes present, however Chlorophytes were the dominant algae recorded overall. The estuarine area west of the dyke is unstable algal habitat with high sedimentation and low salinity. Benthic algae on the western side experience up to 25% variation in salinity depending on river flow and tidal amplitude compared to only 6% variation for the east side of the dyke. Sedimentation levels on the west side were approximately twice as high as those on the eastern side and consisted of fine glacial sediments which formed a firm clay-like layer on substrate making it unstable for colonization. The eastern and central deltas provide better habitat for algal growth and colonization due to increased light as a result of low sedimentation, higher salinities, and therefore higher primary production. Salinity controlled the presence or absence of weakly euryhaline species and was responsible for 35-73% of variation in net production. Mainly weakly euryhaline algae were located east of the dyke.

Aquatic Restoration & Research Institute

Powers, S. P., Bishop, M. A., Moffitt, S., and G. H. Reeves. 2006. Variability in freshwater, estuarine, marine residence of Sockeye Salmon within the Copper and Bering River Deltas. American Fisheries Society Symposium 53.

Abstract: *Variability in the duration of freshwater and marine residence of sockeye salmon Oncorhynchus nerka has been recognized for some time and is the basis for separating the species into different life history strategies. We analyzed the results of annual age-composition surveys of spawning sockeye salmon conducted by Alaska Department of Fish and Game in the Copper River Delta and Bering River regions of southcentral Alaska from 1990 to 2004 to quantify the variability in freshwater and marine residence time. Significant variation among years and among locations was detected by multivariate analysis of similarity. The two most common life history forms were sockeye salmon that spent one winter in freshwater after emergence followed by either 2 or 3 years in marine waters before returning to spawn (1.2 or 1.3 European age notation). Sockeye salmon exhibiting these two strategies accounted for 36% and 46%,respectively, of all sockeye salmon aged over the 14 year surveys (n = 93,936). Sockeye salmon spending less than 1 year in freshwater following emergence (0.1,0.2,0.3 and 0.4) accounted for 14% of all adult sockeye salmon surveyed compared to 82% that spent 1 year in freshwater (1.1,1.2,1.3,1.4) and 4% that spent 2 years (2.1,2.2,2.3). Only one fish was aged that spent 3 years in freshwater. Large interannual and among site variability in the proportion of fishes that spend 0 years in freshwater was apparent. The magnitude of 0-type sockeye salmon was best correlated with site locations (sloughs had a higher proportion than lake sites). Despite the low average contribution of 0-type sockeye salmon to the adult spawning population, large numbers of sockeye salmon leave freshwater as age-0 fry and parr. These sockeye salmon can be found in the estuarine waters near the outflow of major sloughs and rivers for a 45-d period coinciding with peak out-migration from freshwater areas. All juvenile stages of sockeye salmon seem to have similar residence time in the estuary, suggesting that for sockeye salmon out-migration at an early age does not lead to longer nearshore residence time for sockeye salmon.*

This study found that within the Copper and Bering River deltas sockeye age 0+ accounted for 14% of all returning adult sockeye salmon surveyed. The majority of these age 0+ juveniles were correlated with slough like site locations. They found that age class does not correlate with time spent in nearshore habitat and all out-migrating fish spend equal time in estuaries despite difference in age class.

Prevel-Ramos, A., Brady, J., and J. Houghton. 2012. Knik Arm Anadromous Fish Study Designs. U.S. Fish & Wildlife Service, Anchorage, AK.

This literature review investigates and describes study designs for measuring presence, distribution by habitat type, and timing of anadromous fish in Knik Arm, Alaska. This review describes different sampling methods previously used in the Knik Arm and emphasizes that there is no one method effective for all habitat types. Sampling methods described include beach seines for intertidal habitats, surface trawl net tows or surface-oriented gill nets for offshore habitats, fyke nets for measuring near riprap shoreline structures, bottom trawls for deeper habitats, and vessel-based acoustic sampling. A clear chart describes the seines and nets sizes, as well as sampling methods, used by each study group separated by habitat. Hydroacoustic sampling was found to be ineffective for sampling juvenile salmonids and bottom trawling nets often fouled on the rocky bottom damaging gear and causing safety concerns. Collectively these studies found estuarine habitats provide juvenile anadromous fish with a neutral migration corridor, an area of osmoregulation before heading to sea, a place to feed, and refuge from predators. They also describe salmon abundances and residency times for each salmon type caught.

Quinn, T. P. 2006 The Behavior and Ecology of Pacific Salmon and Trout. University of Washington Press, Seattle WA.

Chapter 12: Downstream Migration and Chapter 13: Estuarine Residence and Migration

Quiñones, R.M. and T.J. Mulligan. 2005. Habitat Use by Juvenile Salmonoids in the Smith River Estuary, California. Transactions of the American Fisheries Society. 134(5): 1147-1158.

Abstract: *Estuaries are highly productive areas that serve as important nursery habitat for many species of fish. Estuaries provide juvenile salmonids Oncorhynchus spp. with foraging habitats, refuge from predators, and areas in which smoltification and orientation for return migrations can occur. Our primary goal was to describe how juvenile salmonids use the Smith River estuary in northern California, a system that is largely devoid of instream cover and the slough habitat it once contained. The presence of juvenile salmonids was quantified through direct observation (snorkel surveys) and calculations of relative densities in the mid channel and stream margin habitats of the estuary. We completed a total of 755 dives between May 1999 and November 2000. We found that significant differences existed between the relative densities of juvenile Chinook salmon O. tshawytscha and trout (coastal cutthroat trout O.clarkii clarkii and steelhead O. mykiss) observed in habitats with and without cover along stream margins. Stepwise logistic analysis was used to correlate the presence or absence of Chinook* *salmon and trout to stream reach, habitat type, flow (m3/s), salinity (‰), temperature (□C), and depth (m). In general, juvenile salmonids appeared to preferentially use habitats with overhanging riparian vegetation. However, Chinook salmon presence was most correlated with areas of low salinity (□5‰), while trout presence was most influenced by habitat type. Trout were present most often in stream margin habitats, regardless of other physical factors. Our study demonstrates that riparian vegetation may be an essential component of juvenile salmonid rearing habitat in estuaries with little instream cover.*

This study divided the Smith River into three reaches: upper (low bottom salinity, gravel substrate, and older riparian vegetation), middle (intermediate bottom salinity, cobble, and young riparian), and lower (high bottom salinity, sand substrate, and marsh vegetation). Chinook salmon were most highly correlated with low-salinity areas. In all reach types Chinook salmon and trout densities were highest in habitats with cover and these densities decreased progressively as cover decreased and in mid channel habitats. However, cover was more important for rearing juvenile chinook which preferred only cover habitats, compared to trout which used all three to some degree. The authors attribute this difference to Chinook's greater preference of cover or trout's greater preference for stream margins despite the vegetation present. They also conclude that the chinook and trout are in competition for the cover habitat. Depth was not found to significantly influence habitat selection, although more of the generally larger Chinook were found in deeper habitats than the smaller steelhead juveniles.

St. John, M. A., Macdonald, J. S., Harrison, P. J., Beamish, R. J. & Choromanski, E. 1992 The Fraser River plume: some preliminary observations on the distribution of juvenile salmon, herring, and their prey. Fisheries Oceanography 1, 153–162.

Abstract: *Zooplankton and fish densities in the southern Strait of Georgia were observed to coincide with variations in surface salinities resulting from the outflow of the Fraser River. Vertical net hauls in the euphotic zone revealed that copepods, amphipods, and euphausiids were significantly more abundant per m3 in the brackish estuarine plume (surface salinities - 10-15 ppt) when compared to the area covered by the freshwater of the Fraser River plume (0-10 ppt) and the region of the Strait of Georgia (25-30 ppt) unaffected by the oufflow of the Fraser River. The estuarine and riverine plumes had significantly higher fish densities (adult and juvenile herring, and juvenile salmonids [excluding chinook]) than the Strait of Georgia region, with no significant differences in densities of juvenile Chinook salmon observed between regions. The highest catches of juvenile salmonids were at the boundary between the estuarine plume and the Strait of Georgia. Zooplankton found in the stomach contents of both adult and juvenile herring suggested that the herring were filter-feeding on the zooplankton in the estuarine plume. Juvenile salmonids fed primarily on small unidentifiable juvenile fish. The existence of increased densities of prey items in the estuarine plume is proposed to be the primary mechanism resulting in increased residence time in this region by outmigrating juvenile salmonids. Utilization of aggregated zooplankton could lead to increased salmonid growth rates and therefore to enhanced survival of individuals utilizing the Fraser River plume environment.*

This study examined the differences in prey abundance (zooplankton) and juvenile salmon abundance in three habitats; the freshwater river plume, the estuary and the marine Strait of Georgia. They found that zooplankton were more abundant in estuarine, brackish water than in the freshwater of the Fraser River plume. The highest catches of juvenile salmon occurred at the boundary between the estuary plume and the Strait of Georgia.

Simenstad, C.A., K.L. Fresh, and E.O. Salo. 1982. The Role of Puget Sound and Washington Coastal Estuaries in the Life History of Pacific Salmon: An Unappreciated Function, p. 343-364. *In* V.S. Kennedy [ed.] Estuarine Comparisons. Academic Press, Inc., New York, NY.

Abstract: *Washington State has approximately 100 diverse estuaries, ranging from the more classic coastal estuaries to Puget Sound, a continuum of estuaries with transitional habitats. Of the five Pacific salmon species, chum and chinook utilize these estuaries most extensively. Estimated residence times of individual juvenile salmon range from 4 days (chum salmon) to 6 months (chinook) while individual residence times of adults range from 1-6 weeks. Some salmon populations may, however, remain within Puget Sound until maturity. Juveniles of all species utilize neritic habitats, but chum and chinook also use shallow, sublittoral habitats. Abundant, uniquely estuarine prey organisms are eaten by juveniles of all species, although less so by pink, sockeye, and coho, and contribute to high growth rates in estuaries. Significant predation on juveniles in estuaries has yet to be documented. We hypothesize that pacific salmon use Washington's estuaries for : 1) productive foraging, 2) physiological transition, and 3) refugia from predators. These functions have probably changed due to salmon culture practices and alterations of estuarine habitat, and it is possible these changes could adversely impact salmon growth and survival. The importance of estuaries to salmon production should be more carefully considered in estuary and salmon management.*

This paper provides a synthesis of previously gained knowledge on juvenile Pacific salmon use of the Puget Sound. It details the human impacts and changes to the estuaries of the Puget Sound, the status of the different salmon species past and present, the migration timing of each species, and the residence time and feeding habits of each species. It also briefly discusses predation and growth as well as adult salmon use of the estuaries.

Thorsteinson, F.V. 1962. Herring Predation on Pink Salmon Fry in a Southeastern Alaska Estuary. Transactions of the American Fisheries Society. 91(3): 321-323.

This study in Little Port Walter, Alaska examined herring predation on pink salmon fry. Pink salmon fry emerge from spawning bed at 30 mm and move immediately to estuary in late March and remain until they reach 40 mm. Collected herring at the mouth of the river and observed Pacific herring actively feeding on young salmon. Pink salmon fry occurred in 64% of stomachs of herring that had consumed fish (250 total) with 1-69 per stomach for a total of 4,505 fry and an average of 18 per stomach. No one size group of herring preferred pink fry over another. Herring generally inhabit deep saline water whereas pink salmon inhabit the less saline surface water; however herring frequently foraged in the upper layer. Feeding occurred most actively during the day.

Waples, R.S., R.W. Zabel, M.D. Scheuerell, and B.L. Sanderson. 2007. Evolutionary responses by native species to major anthropogenic changes to their ecosystems: Pacific salmon in the Columbia River hydropower system. Molecular Ecology 17: 84-96.

Abstract: *The human footprint is now large in all the Earth's ecosystems, and construction of large dams in major river basins is among the anthropogenic changes that have had the most profound ecological consequences, particularly for migratory fishes. In the Columbia River basin of the western USA, considerable effort has been directed toward evaluating demographic effects of dams, yet little attention has been paid to evolutionary responses of migratory salmon to altered selective regimes. Here we make a first attempt to address this information gap. Transformation of the free-flowing*

Columbia River into a series of slackwater reservoirs has relaxed selection for adults capable of migrating long distances upstream against strong flows; conditions now favor fish capable of migrating through lakes and finding and navigating fish ladders. Juveniles must now be capable of surviving passage through multiple dams or collection and transportation around the dams. River flow patterns deliver some groups of juvenile salmon to the estuary later than is optimal for ocean survival, but countervailing selective pressures might constrain an evolutionary response toward earlier migration timing. Dams have increased the cost of migration, which reduces energy available for sexual selection and favours a non-migratory life history. Reservoirs are a benign environment for many non-native species that are competitors with or predators on salmon, and evolutionary responses are likely (but undocumented). More research is needed to tease apart the relative importance of evolutionary vs. plastic responses of salmon to these environmental changes; this research is logistically challenging for species with life histories like Pacific salmon, but results should substantially improve our understanding of key processes. If the Columbia River is ever returned to a quasinatural, free-flowing state, remaining populations might face a Darwinian debt (and temporarily reduced fitness) as they struggle to re-evolve historical adaptations.

This literature review focuses on ecosystem changes in and along the Columbia River due to the hydropower systems and how these modifications are affecting evolutionary changes in salmon. The paper identifies ecological and environmental changes associated with hydropower dams including changes in physical conditions, changes in water quality, dam passage, downstream effects, and effects of invasive species. Next they list the direct and long-term alterations these changes may have on salmon and consider the evolutionary responses that might be expected. Past studies found maturation, growth, tolerance to high temperature, egg numbers, and secondary sexual characteristics are all life history traits that are highly heritable and could allow for evolutionary adaptations. Overall the results show that selective regimes of the Columbia River have been altered by the hydropower system and that there is a strong heritable component to many traits that would be under strong selection.

Webster, S.J., L.M. Dill, and J.S. Korstrom. 2007. The effects of depth and salinity on juvenile Chinook salmon *Oncorhynchus tshawytscha* (Walbaum) habitat choice in an artificial estuary. Journal of Fish Biology. 71: 842-851.

Abstract: *The energetic cost for juvenile Chinook salmon Oncorhynchus tshawytscha to forage in habitats of different salinity and depth was quantified using a behavioural titration based on ideal free distribution theory. When given a choice between freshwater habitats of different depths (>0·33 or <0·33 m), a greater proportion of fish used the deeper habitat. When the deeper habitat was saltwater, the proportion of fish using it increased. When food was added to both the shallow freshwater and deep saline habitats, however, fish distribution returned to that observed when both habitats were fresh water. This indicates that the preference for deep saline habitats during the stratified phase was driven by some benefit associated with residency in deeper water, rather than salinity. The low perceived cost of low salinity might be in part due to the fish's ability to minimize this cost by only making brief forays into the alternate freshwater habitat. When the food ration delivered to the more costly, shallow habitat was 50% greater than that delivered to the less costly, deep habitat, fish distributed themselves equally between the two habitats, presumably because of equal net benefits. This study demonstrates that juvenile Chinook salmon prefer deep saline habitat to shallow freshwater habitats but will make brief forays into the freshwater habitat if food availability is sufficiently high.*

This study utilized behavioral titration to quantify the relative costs of deep saltwater habitats versus

Aquatic Restoration & Research Institute

shallow freshwater habitats for juvenile chinook in a laboratory setting. Chinook preferred the deeper habitat versus shallow, and the abundance of fish in this deep habitat increased further after salt water was added. When food was added to the tanks during the stratified phase, the fish returned to the original freshwater distribution. They calculated that there must be 50% more food present in the shallow habitat in order to offset the cost of foraging in that habitat. The overall conclusion was that water depth has a larger influence on chinook habitat preference than salinity.

Wolf, E.G., B. Morson, and K.W. Fucik. 1983. Preliminary Studies of Food Habitats of Juvenile Fish, China Poot Marsh and Potter Marsh, Alaska, 1978. Estuaries. 6(2): 103-114.

Abstract: *During the year 1978, juvenile salmonids were collected from coastal streams running through (China Poot Marsh and the stomach contents analyzed. Stomach contents of threespine stickleback (Gasterosteus aculeatus) and staghorn sculpin (Leptocottus armatus) from China Poot and of threespine stickleback from Potter Marsh were also analyzed; these two species were generally caught in tidal pools on the marshes. The juvenile coho salmon (Oncorhynchus kisutch) had the most varied diet; 37 different prey items were identified in the stomachs. By comparison, 25, 26, and 33 prey taxa were identified in the stomach contents of Dolly Varden char (Salvelinus malma), threespine stickleback, and staghorn sculpin, respectively. Amphipods were the dominant prey of all fish collected from China Poot Marsh; chironomidae larvae were the most common item in the stomach contents of threespine stickleback from Potter Marsh. The diets of all species changed over the course of the study periled; the change was most dramatic for juvenile salmonids and sculpins.*

Sampled stomach contents of juvenile salmonids in Alaskan coastal streams using 15x1.5 m beach seine (6 mm mesh) in tidal creeks and wetland pools. Coho (64-105 mm) had the most varied diet of all fish collected with 37 different prey items compared to 25, 26, 33 in Dolly Varden char, threespine stickleback, and Pacific staghorn sculpin. Amphipods occurred most frequently in all fish stomachs and diets of juvenile salmonids changed from June through September. Little or no plant or detrital material in juvenile salmon stomachs, however organic detritus from coastal marshes may be important source of food for Harpacticoid copepods.