Neritic diet of juvenile Chinook in the San Juan Islands, WA, dominated by sandlance and herring

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Considerable attention has recently been devoted to determining the factors limiting growth and survival of wild Chinook salmon (*Oncorhynchus tshawytscha*) at different life history stages in the complex geography of the Northeast Pacific's Salish Sea, a shallow drowned intermontane valley watered by numerous rivers that includes Puget Sound and a central archipelago, the San Juan Islands. Previous studies found the nearshore diet of juvenile Chinook in Puget Sound dominated by invertebrates (crustaceans and terrestrials) with some nearshore and offshore use of fish (mainly sandlance and herring). The present study, based upon gut contents of 1,722 juvenile Chinook collected at two research stations in the San Juan Islands from 2009 to 2012, finds greater reliance on juvenile sandlance and herring as well as seasonal use of crustaceans and terrestrials. Total biomass consumed is related to the abundance and size of herring, which is more variable between locations and years than the availability of sandlance. Significant individual variation in prey use is observed, even when forage fish are available.

Keywords: Pacific salmon, prey use, life history diversity, forage fish.

Outmigrant juvenile Chinook (*Oncorhynchus tshawytscha*) from throughout the Salish Sea are found in nearshore habitats of the San Juan Islands from May through September.[1] The duration of individuals' residence in the islands, and the contribution of this neritic (shallow marine) life history stage to the growth and survival of Chinook have not been determined.

Chinook salmon rearing in rivers of the Salish Sea basin of Washington State and British Columbia must pass through several intermediate brackish habitats before they enter the Pacific Ocean.[2] Chinook from the Nisqually River emerge into Puget Sound, for example, with more than 120 kilometers of shallow marine waters before they enter the deeper, more dynamic and saline waters of the Strait of Juan de Fuca, still some distance from the ocean. Chinook from the Stillaguamish, Snohomish, and Skagit Rivers appear to disperse from estuarine deltas to nearby pocket estuaries and bays, where they continue to forage and grow for weeks before venturing into the Strait.[3] Chinook from the vast Fraser River watershed in British Columbia emerge last, after freshwater journeys of 200 km or longer, with the Strait still separating them from the ocean. Juvenile Chinook presumably pass through several stages of adaptation to increasing salinity, greater depths, a changing array of predators and new prey choices as they move seaward and grow from roughly 60 mm fork length to 150-200 mm. Different prey resources may be important for survival at each stage of these different journeys.

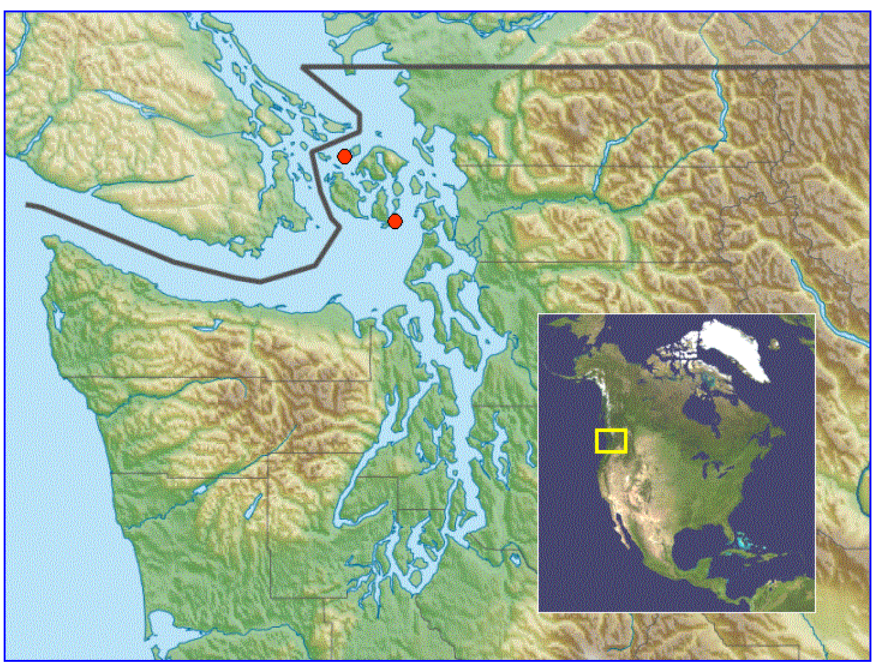
Studies of prey use by juvenile Chinook in two Puget Sound embayments, Sinclair Inlet in the central Sound[4] and Dabob Bay in the north Sound close to the Strait,[5] were limited by relatively small sample sizes and time spans. More extensive study of Chinook from nearshore 22 seine sites and offshore trawls throughout Puget Sound over a six year period identified insects and crustaceans as dominant prey; when fish were eaten, they were mainly Pacific Sandlance (*Ammodytes hexapterus*) and Pacific Herring (*Clupea pallasii*).[6]

It was only recently established that juvenile Chinook from throughout the Salish Sea, including Puget Sound, aggregate in the nearshore waters of the San Juan Islands—hundreds of kilometers of high energy shorelines—before they proceed westward through the Strait to the ocean.[7] Here we present data on prey use determined from gut lavage of juvenile Chinook (N=1,722) collected at two survey stations in the San Juan Islands from 2009 to 2012 as part of a long term study of nearshore trophic webs shared by endangered salmon and marine birds. Data collected thus far indicate that while juvenile Chinook use the same range of prey resources in the islands as they do in the central and north Sound, they eat a much higher proportion of fish in the islands, including herring but dominated by sandlance.

Materials & Methods

To investigate juvenile Chinook use of nearshore habitats in the San Juan Islands, we established two long-term fish monitoring stations in the archipelago in 2008. Each station is staffed by local volunteers, trained and supervised by our scientists. Locations were selected on the basis of results of exploratory beach seining we conducted at 15 sites from 2006 to 2008. Juvenile Chinook were most abundant and frequently found at Watmough Bight (Lopez Island) and Cowlitz Bay (Waldron Island), marked in red on Figure 1. These two sites represent extremes of salinity for the islands' nearshore waters. We also suspected that the Chinook aggregations at these sites would represent mainly South Sound and Fraser River populations, respectively.

Figure 1: Location of seining sites in the San Juan Islands, WA



Cowlitz Bay is at the northwestern extreme of the San Juan Islands, influenced by the Fraser River with nearshore salinities routinely falling to 26 parts per thousand (ppt). Bluff-backed gravel beaches are exposed to southwesterly prevailing winds. Sub-tidal substrate is compact sand with abundant native eelgrass (*Zostera marina*). Cowlitz was a historical herring spawning ground and fishery until the 1970s.[8] Watmough Bight is a narrow fjord-like embayment at the southeastern extreme of the islands mainly influenced by the Strait of Juan de Fuca with salinity generally in the 29-31 ppt range. The wetland-backed beach is composed of gravelly coarse sand, sheltered from southwesterly winds but occasionally inundated by northwesterly blows. Sub-tidal substrate is compact sand with a dense band of short styped macroalgae at a depth of about 5 meters. Watmough was the base camp for a wealthy Coast Salish (Native American) reef-net salmon fishery until the 1920s, and is roughly 8 km by sea from an important historical herring spawning ground at Mud Bay.[9]

A 36-meter floating Puget Sound beach seine (9.5 mm stretch mesh, 3 meters deep at the cod end, tapered) was set by boat in 4-6 meters of water parallel to the shore and hauled in by long lines at both ends. Collections were made every two weeks from mid-May to mid-September, the months when our exploratory surveys indicated that juvenile Chinook would be present. Based on visual observations of juvenile Chinook, seining was conducted on afternoon flood tides between 1600 and 1800 hours to maximize catch per set. This method has enabled us routinely to collect samples of 40-50 Chinook from the same feeding aggregation with a single seine set in roughly 15 minutes. Previous nearshore collections in the islands used 24-meter beach seines set by hand from shore, with fewer than 10 juvenile Chinook per set at the same sites.

Juvenile Chinook were segregated in a floating net pen, then transferred in small batches to an aerated, chilled and insulated bucket on the beach, before being individually sedated with MS-222, measured, caudal fin clipped (leaving a conspicuous mark lasting several weeks), gut lavaged, and placed in a separate aerated "recovery" bucket prior to release. Each fish was examined for injuries such as healed bites, and for ectoparasites, which were identified and removed. Gut contents were preserved in 75% ethanol for later identification. Fin clips are preserved in 75% ethanol for eventual genotyping.

A sub-sample of up to 20 forage fish collected in the same seine set as juvenile Chinook were measured, as were all of the forage fish recovered from Chinook gut contents. Forage fish collected from seines and gut contents were also preserved in 70% ethanol for genotyping.

Results

A total of 1,722 unmarked juvenile Chinook were collected and gut lavaged in 2009-2012. Most were between 100 and 130 mm fork length, with little variation in mean size from year to year, but somewhat larger fish at Watmough Bight (Figure 2; error bars show standard deviation from means).

Genotyping of the 2009 sample identified wild Chinook populations throughout the Salish Sea (Figure 3) with a greater proportion of South Puget Sound and Whidbey Island Chinook at Watmough, consistent with its location facing Admiralty Inlet. Cowlitz Bay, closer to the Fraser River Delta and Georgia Strait, hosted more British Columbia stocks. Marked fish were consistently encountered more frequently at Watmough Bight than Cowlitz Bay (Figure 4).

Figure 2: Annual mean size of unmarked juvenile Chinook

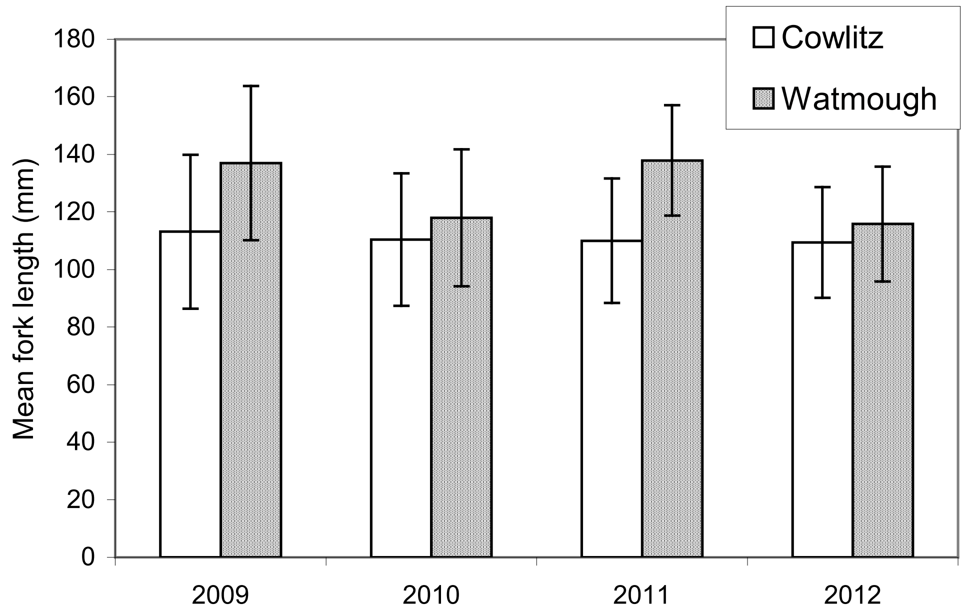


Figure 3: Proportional representation of Chinook stocks at study sites, 2009

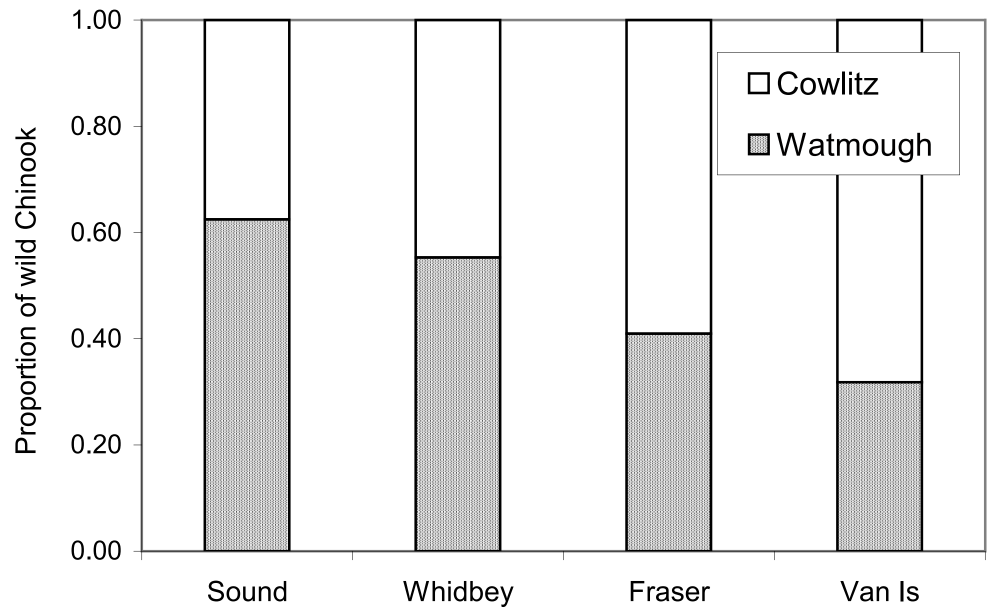
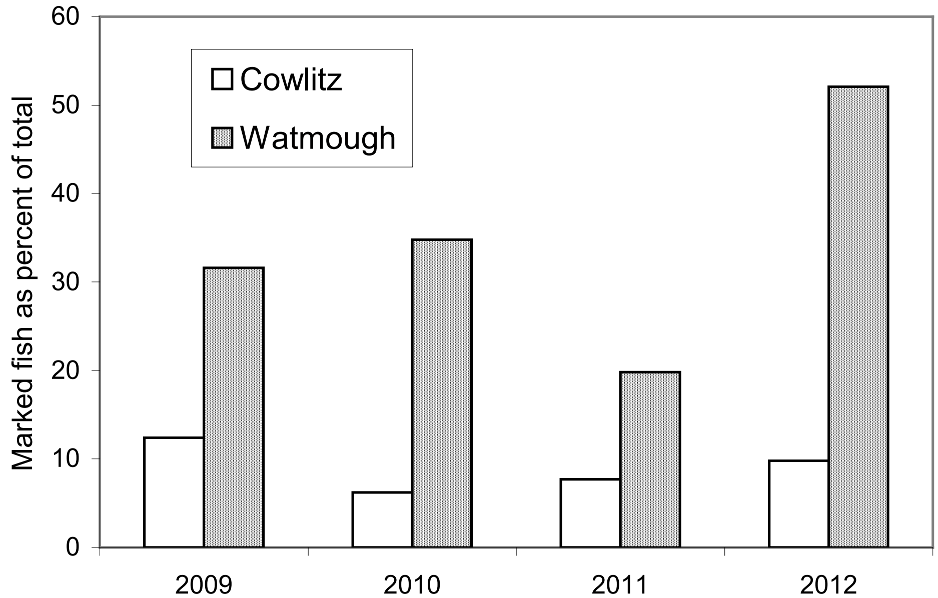
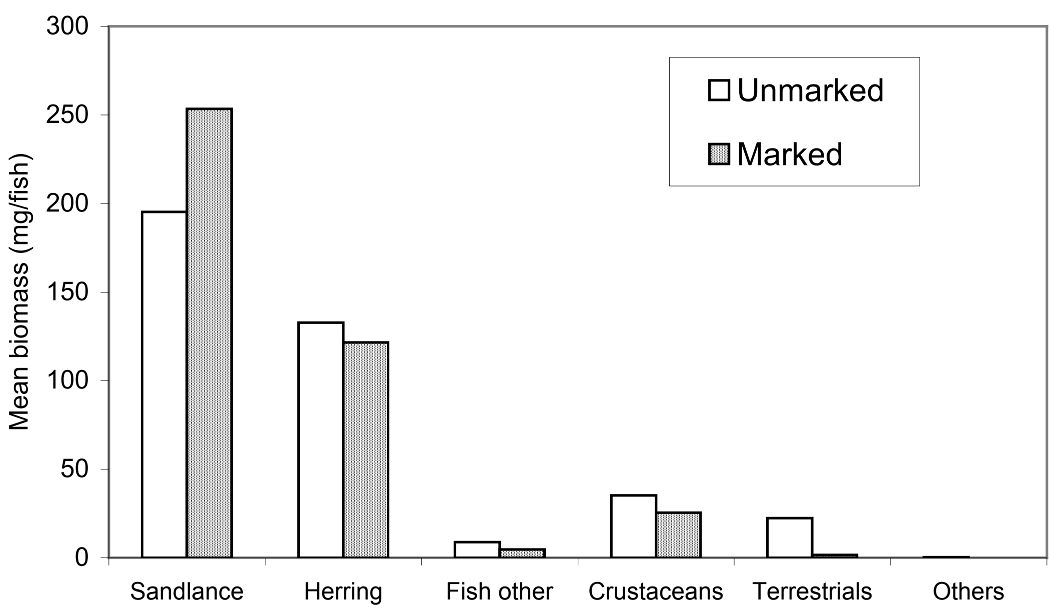


Figure 4: Marked fish as a percent of total juvenile Chinook collected, by year



Over four years of study, juvenile unmarked Chinook subsisted mainly on smaller fish (85.3 percent of prey biomass, Figure 5). Crustaceans and terrestrials were also taken, as well as a variety of worms, gastropods, cephalopods, chaetognaths and other taxa. There was little difference in the diet of marked Chinook collected at the same locations (N=439). Nine species of larval and juvenile fish were identified in Chinook gut contents including Pacific surf smelt (*Hypomesus pretiosus*), Tubesnouts (*Aulorhynchus flavidus*), Greenlings (*Hexagrammos spp*), and Snake Pricklebacks (*Lumpenus sagitta*). However, most of the fish consumed were Pacific sandlance (*Ammodytes hexapterus*, 50.8 percent of fish biomass consumed) or Pacific herring (*Clupea pallasii*, 46.5 percent).

Figure 5: Mean biomass eaten by juvenile Chinook, 2009-2012, by prey types



Sandlance and herring consumption varied considerably from year to year (Figure 6). Herring were less than 20 percent of the fish consumed by juvenile wild Chinook in 2009 and 2010, but between 40 and 60 percent of the fish biomass consumed in 2011 and 2012. Herring consumption was associated with greater total intake by juvenile Chinook (slope=1.12, r^2=0.9667, Figure 7). Herring did not substitute for sandlance; they added to sandlance and other prey consumed. Juvenile Chinook were no larger in 2011 or 2012 when they ate more herring, but herring from gut contents were smaller in those years (Figure 8). Smaller herring were associated with greater mean herring biomass consumption by juvenile Chinook (r^2=0.6723) and greater likelihood that individual Chinook ate herring (Figure 9). Mean size of herring from Chinook gut contents was smaller at both sampling locations in 2011 and 2012 (Figure 10; error bars show standard deviation from means).

Figure 6: Mean annual fish biomass consumed by juvenile unmarked Chinook

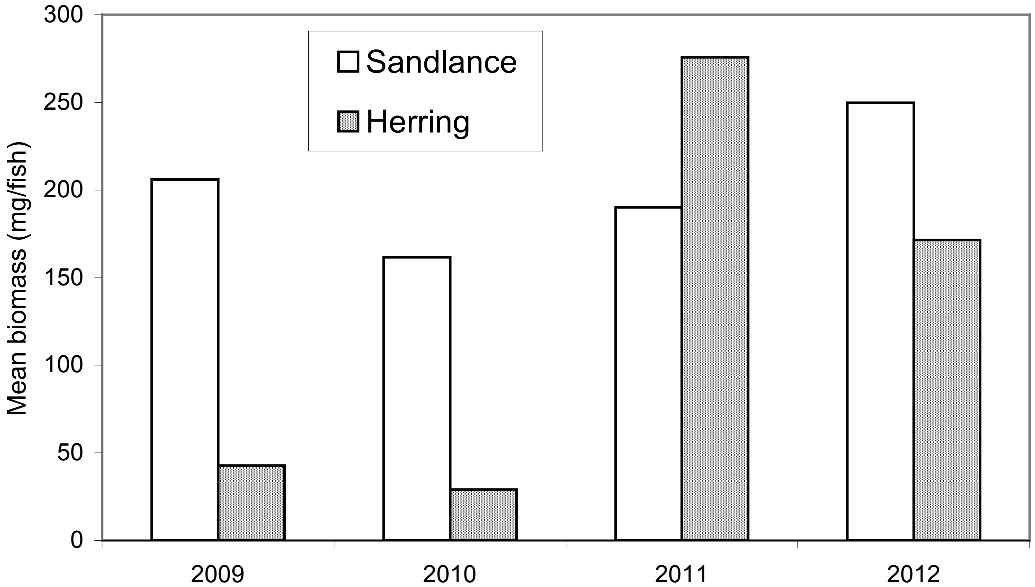


Figure 7: Herring biomass and total biomass consumed by juvenile unmarked Chinook, 2009-2012

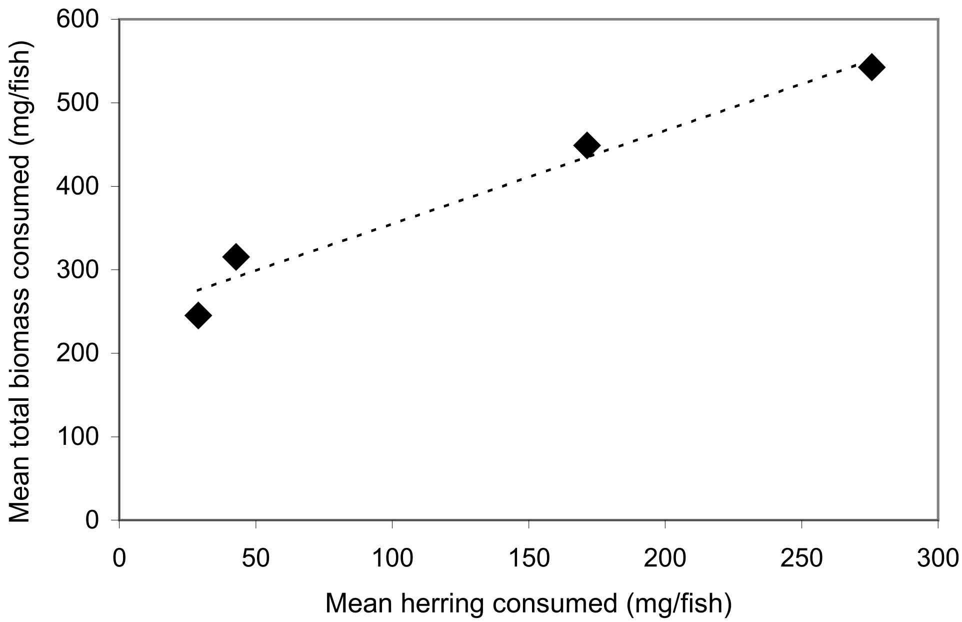


Figure 8: Mean annual herring consumption and mean size of herring consumed by juvenile unmarked Chinook, 2009-2012

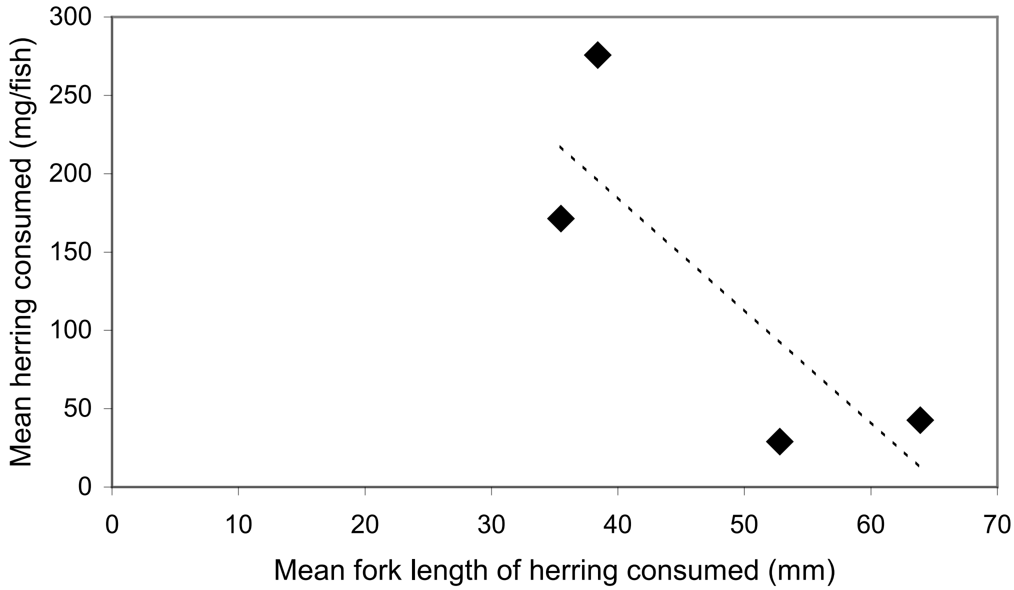
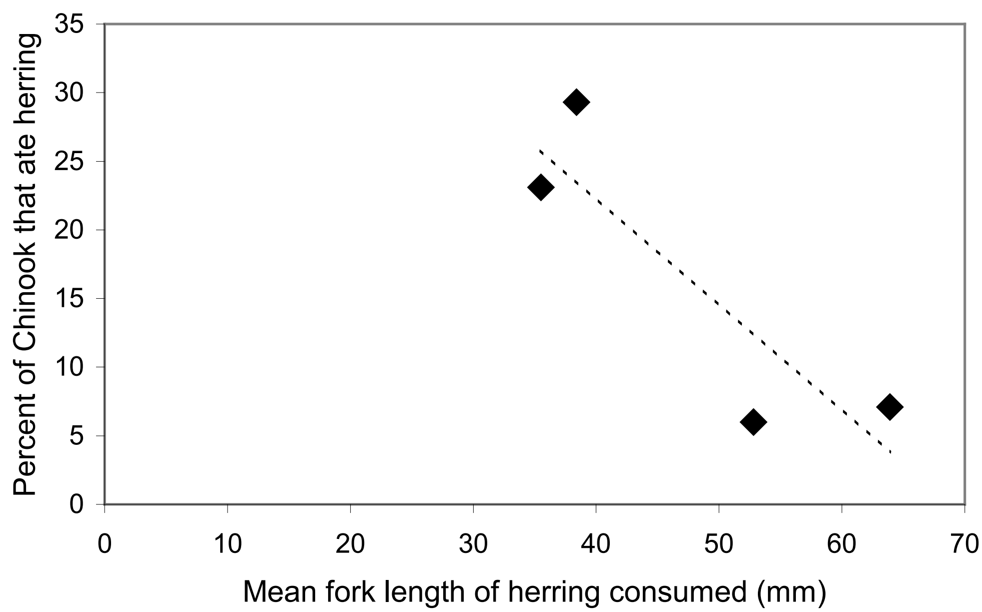


Figure 9: Percent of juvenile unmarked Chinook that ate herring and mean size of herring consumed, 2009-2012



Herring collected in the same seines with Chinook were nearly always all larger than herring recovered from Chinook gut contents (Figure 11; error bars show standard deviation from means of gut contents, and size range of seined fish). This may have been partly due to the mesh size of the seine we used, which cannot retain a herring smaller than 45 mm. But on most dates when herring were collected from both our seine and gut contents, the smallest seined herring were over 75 mm long.

Figure 10: Mean annual size of herring from Chinook gut contents by location

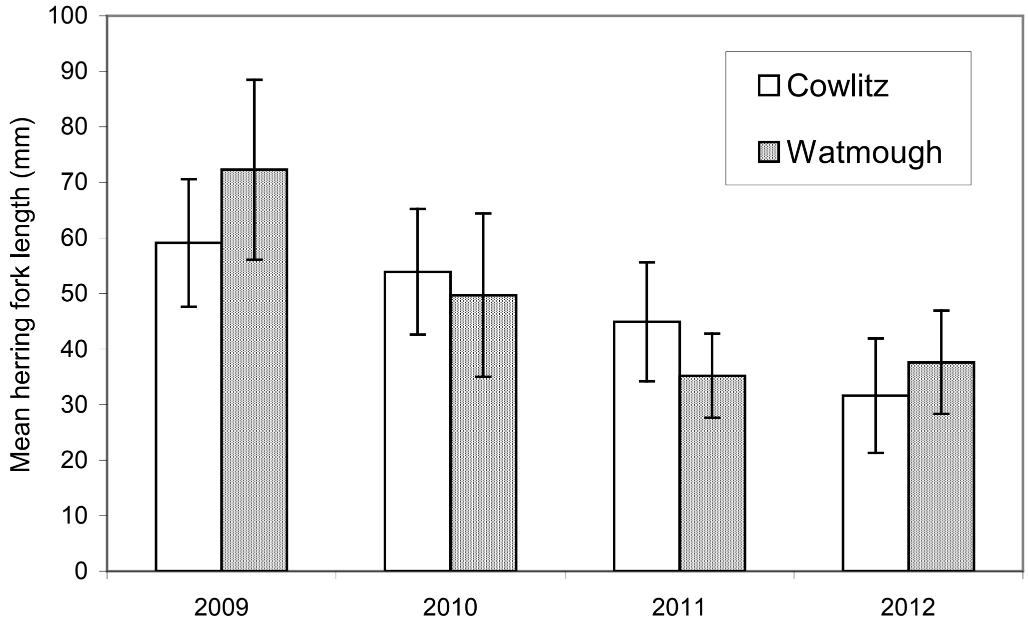
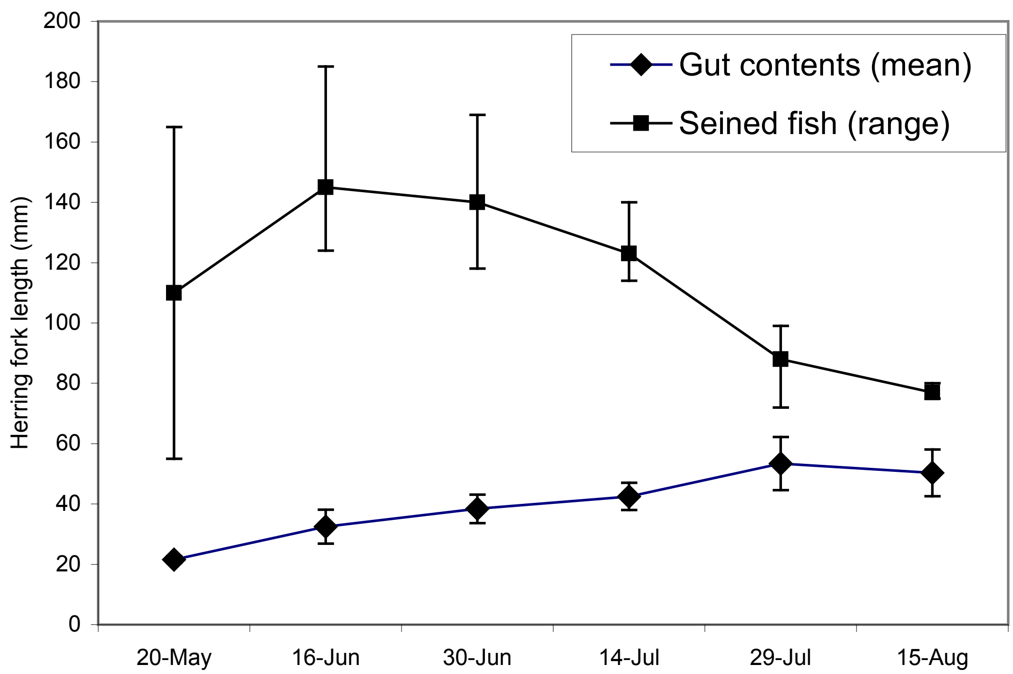


Figure 11: Mean size of herring eaten by juvenile Chinook and range of herring from seines, summer 2011



Over the course of the four months that juvenile Chinook forage in neritic waters of the San Juan Islands, times of arrival of sandlance and herring in the nearshore, mean size at arrival, and residence times vary annually at our sampling locations. Juvenile Chinook tend to eat more sandlance and herring earlier in the summer (Figure 12). The summer abundance of unmarked juvenile Chinook, as estimated by catch per unit effort (CPUE), was also greatest earlier in summer, and was generally greater at Cowlitz than

Watmough (Figure 13). Chinook abundance was greatest at both study sites in 2011 and 2012 when herring formed a larger proportion of their diet (Figure 14).

On average, each juvenile Chinook ate more herring biomass at Watmough where there was less competition from other Chinook (Figure 15). Chinook abundance did not increase at Watmough during the months when herring were being eaten, as might be expected if Chinook relocate from higher competition to lower competition bays.

Figure 12: Mean number of forage fish eaten by juvenile unmarked Chinook, by month and year

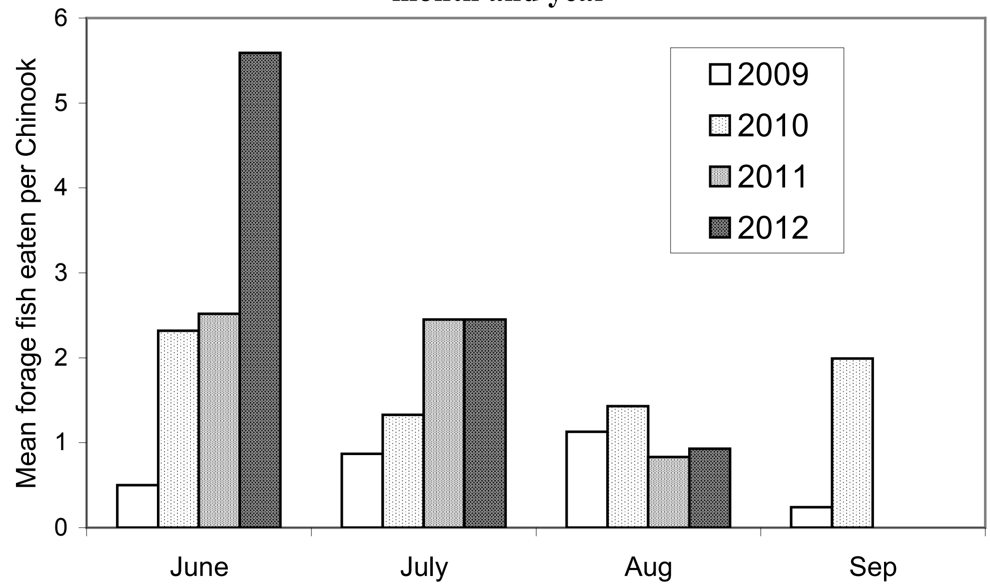


Figure 13: Mean seasonal abundance of unmarked juvenile Chinook estimated by CPUE, 2009-2012

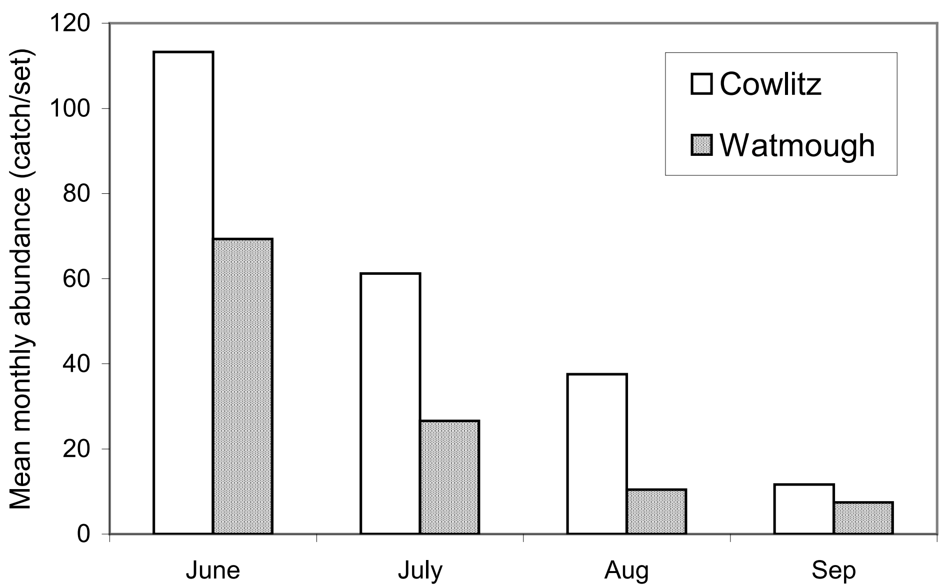


Figure 14: Annual abundance of unmarked juvenile Chinook estimated from CPUE, by location

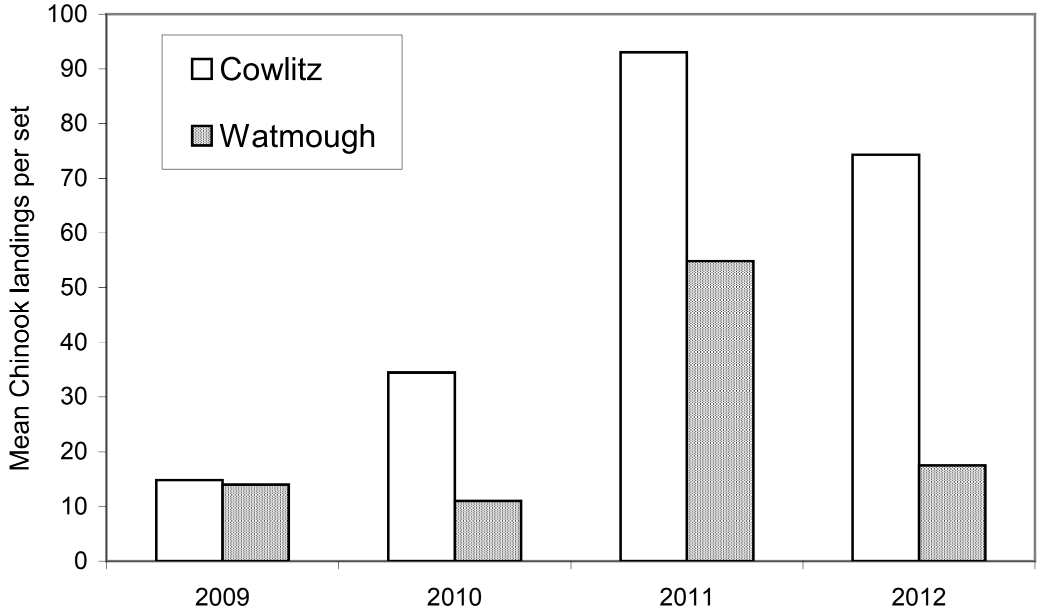
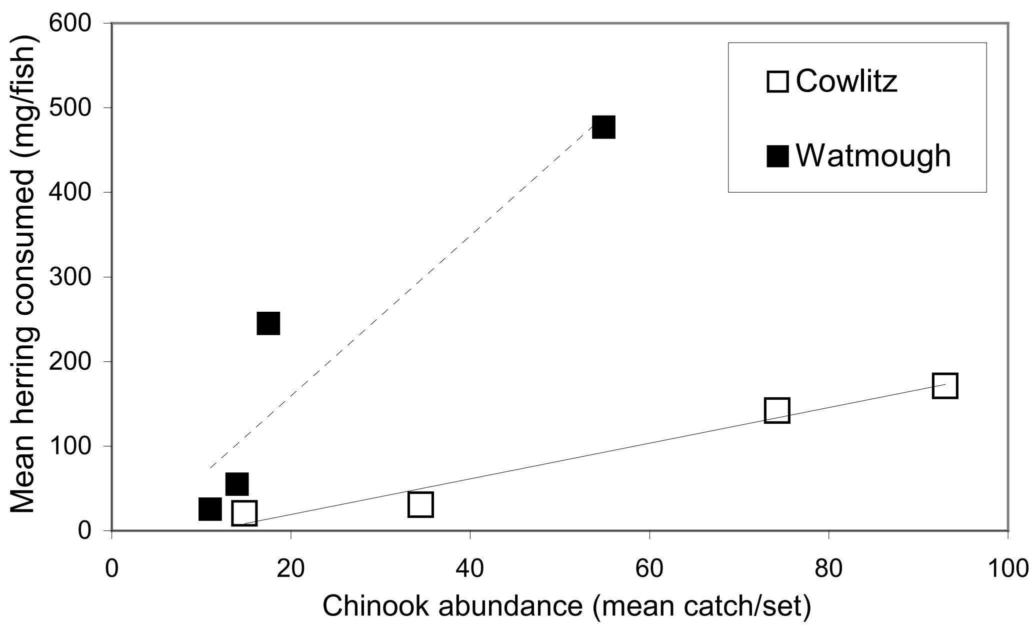


Figure 15: Mean herring biomass consumed by unmarked juvenile Chinook and juvenile Chinook abundance, 2009-2012



It is unclear whether juvenile Chinook investigate bays until they encounter large aggregations of sandlance, herring, or other Chinook; or whether they take up residence in suitable bays until forage fish arrive, consuming whatever else may be available in the meantime. Alternative prey resources, chiefly arthropods, often comprise as much as 100 percent of the diet of juvenile Chinook at the beginning or end of the summer.

Crustaceans such as larval crabs, euphausiids, hyperiid amphipods and calanoid copepods were mainly consumed in late summer in 2009-2010 and early summer in 2011-2012 (Figure 16). Insects such as larval and adult midges (Chironomidae), small wasps and winged swarming ants (Hymenoptera) and bark lice (Psocoptera) tended to be eaten in late summer (Figure 17). Use of insects was an order of magnitude greater at Cowlitz Bay than Watmough, and included more diverse insect taxa, albeit still a small fraction (less than 15 percent) of total annual biomass consumed. Chinook tend to be more abundant at Cowlitz over a longer season, possibly facilitated by availability of insects (Figure 14). Early-arriving Chinook were less likely to consume insects than late-arriving Chinook. For example, late arriving Fraser River and Georgia Strait stocks were more insectivorous in 2009 (Figure 18, N=213) than early arriving South Sound stocks, which were more piscivorous.

Figure 16: Seasonal use of crustaceans by unmarked juvenile Chinook, 2009-2012

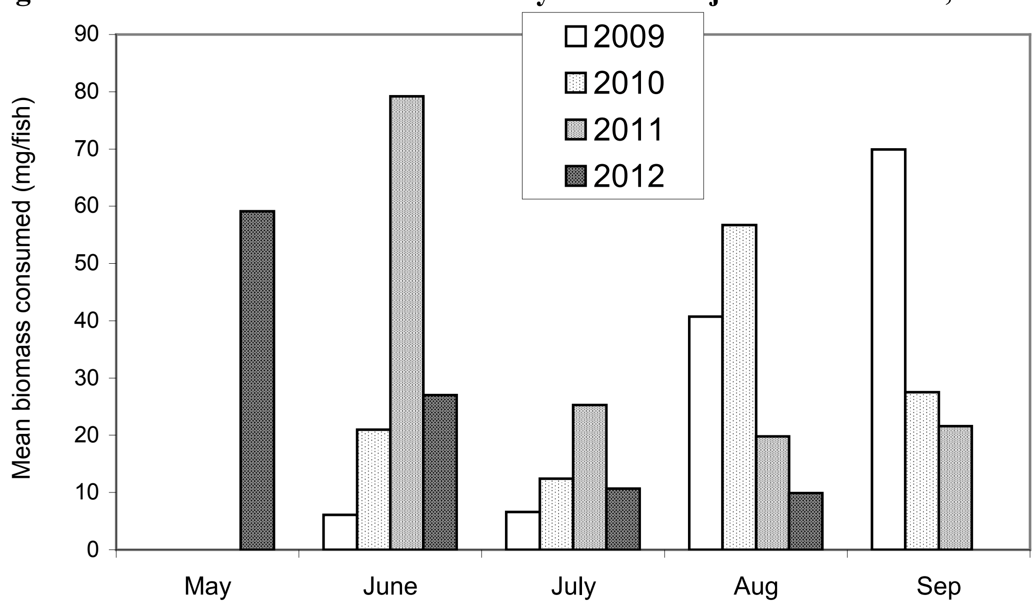


Figure 17: Seasonal use of insects by unmarked juvenile Chinook, 2009-2012

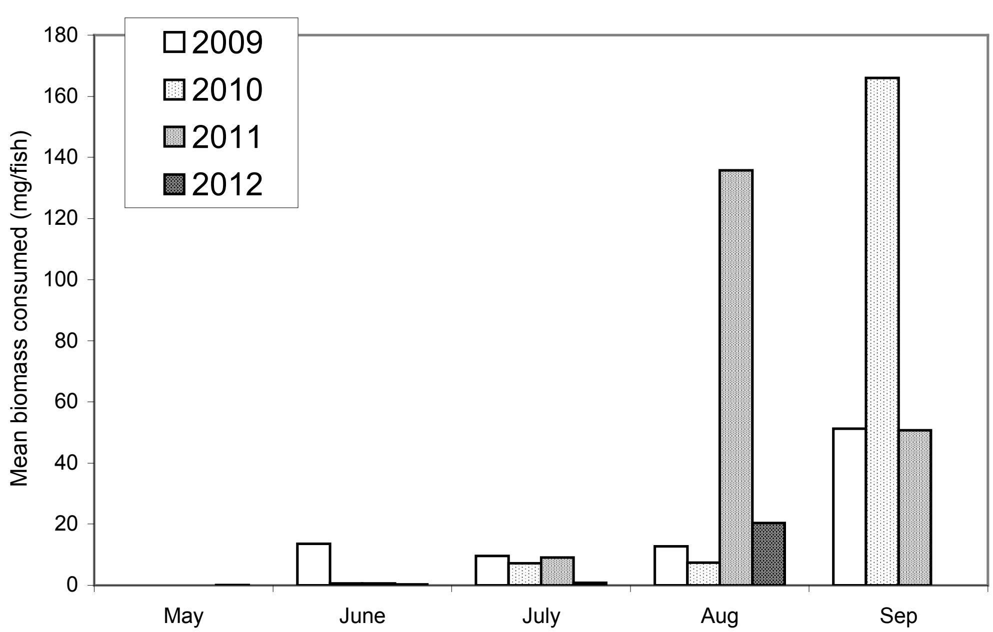
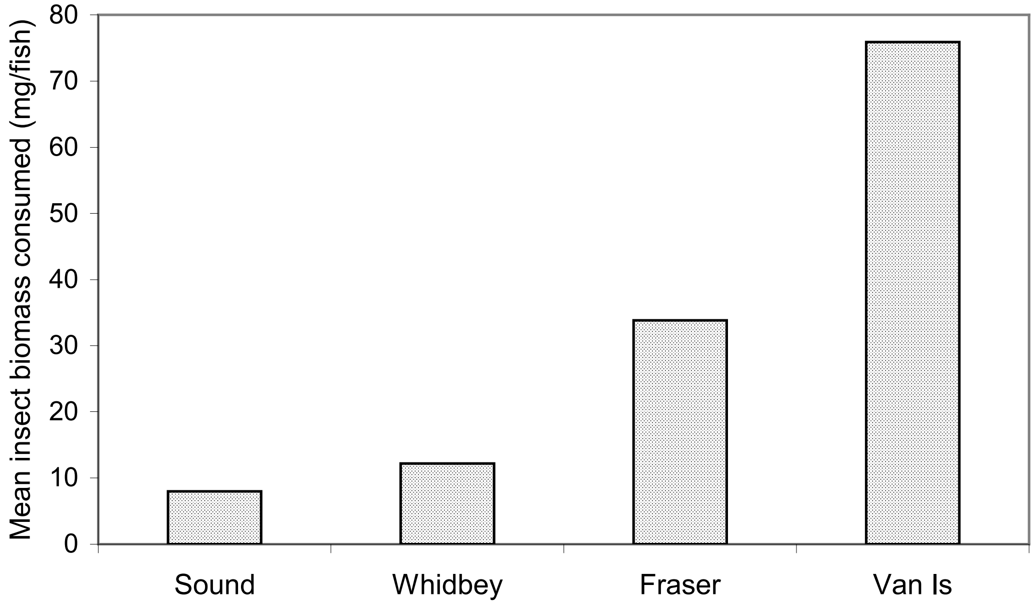
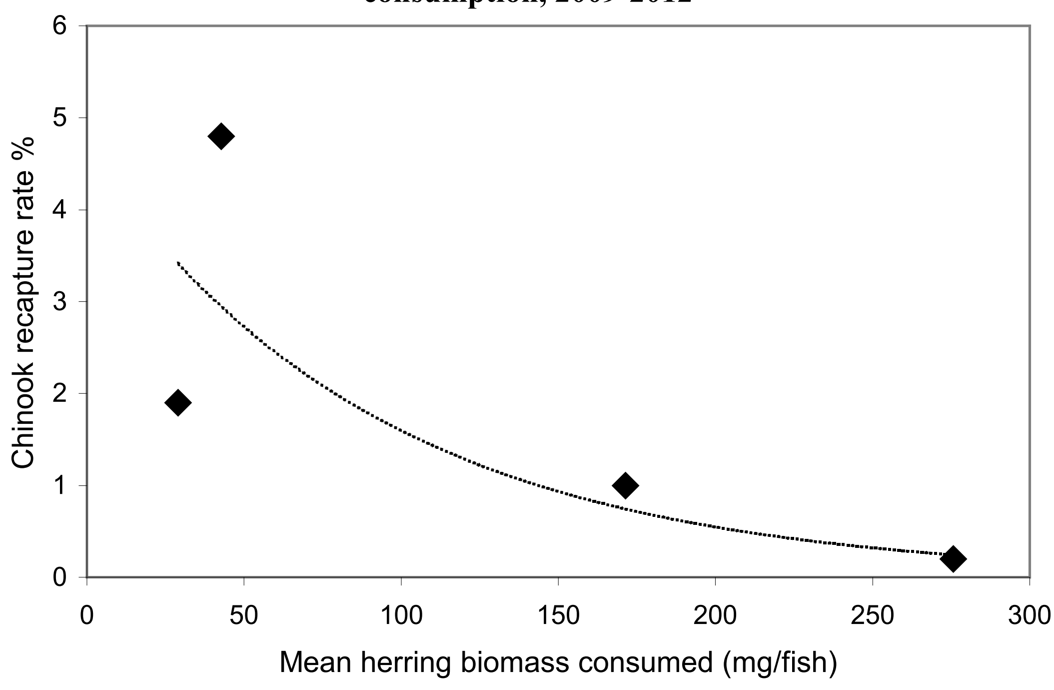


Figure 18: Use of insects by different Chinook stocks, 2009



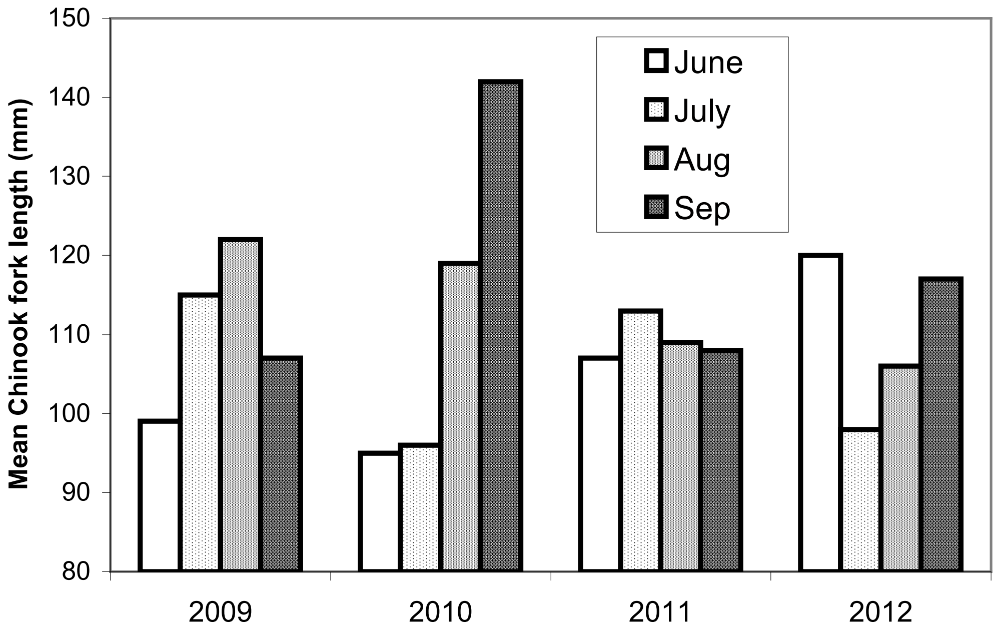
Recapture rates are a clue to residence times, which may vary in response to prey availability. We classified juvenile Chinook as recaptures if they had partly healed lower caudal fins from our tissue clips. A seine set sampled approximately 15 percent of the contiguous nearshore habitat within each of our study sites. If juvenile Chinook remained as residents, seining again in two weeks would result in 15 percent recaptures on average. Recapture rates were less than 5 percent over the course of the study, suggesting that a majority of juvenile Chinook left the study sites less than two weeks after we first clipped them. Recapture rates were highest in 2009-2010 when few herring were eaten, and fell in 2011-2012 when more herring were eaten and Chinook consumed more total biomass (Figure 19). Juvenile Chinook were a little more likely to linger when their calorie intake was lower.

Figure 19: Unmarked juvenile Chinook annual recapture rates and mean herring consumption, 2009-2012



Month-to-month size data are also inconsistent with long residence times at our study sites (Figure 20). In only one year of the study (2010) did the mean size of Chinook trend upward over the course of a summer, as would be expected if a substantial portion of the fish remained resident and continued to grow. Recaptures were not very frequent that year (1.9 percent) suggesting that the size trend was not a result of long residence. In other years, mean size fluctuated from June through September without a sustained trend. As noted above, Puget Sound stocks seem to arrive in the islands earlier than Fraser River and Georgia Strait stocks, so month-to-month changes in size may largely reflect changes in stock mixtures at our sites.

Figure 20. Mean monthly size of unmarked juvenile Chinook, Cowlitz Bay



There was considerable variation in prey use within the feeding aggregations we sampled. In a collection of 31 juvenile Chinook from a single set on August 4, 2012, for example, 14 had eaten only herring or sandlance; 9 had eaten only crustaceans or insects; 5 had eaten a combination of fish and invertebrates; and 3 had no gut contents. It remains unclear whether individual Chinook develop enduring prey preferences from experience and learning[14] express srome underlying genetic variation in prey preferences as part of a "portfolio strategy" that minimizes the risk from annual variations in prey abundance,[15] or simply exploit whichever patches of prey they first encounter when they begin feeding.

Discussion

Unmarked juvenile Chinook visiting Cowlitz Bay and Watmough Bight in 2009-2012 used similar prey resources to outmigrant juvenile Chinook previously studied in Puget Sound.[5] Reliance on sandlance and herring was greater in the San Juan Islands, however, and use of crustaceans and terrestrials was more seasonal and site-linked: intermediate between the behavior of juvenile Chinook in Puget Sound, river deltas and pocket estuaries, and their behavior in open seas.

Sandlance were consumed in every year and almost every month of our study, and contributed more total biomass to the composite diet of unmarked juvenile Chinook than any other prey resource. When juvenile Chinook were able to prey on very small juvenile herring (20-60 mm, Figure 11) they also tended to consume more total prey (Figure 7). Herring consumption was also associated with greater abundance of Chinook (Figure 14) and somewhat shorter residence times (Figure 19) at our study sites. Herring may play a keystone[13] role in the neritic food web of juvenile Salish Sea Chinook.

Herring once spawned throughout of the San Juan Islands but have declined since the 1970s and show little sign of recovery.[10, 11] Relatively small spawning events occur sporadically in the islands, generally in April, and may account for some of the herring eaten by Chinook in our sample. Herring that hatch in April should attain 45 mm by mid-summer, when juvenile Chinook are abundant in the islands. Another plausible source of herring taken by juvenile Chinook in the San Juan Islands is the population that spawns in the nearby Gulf Islands of British Columbia with its peak in April.[12]

Juvenile Chinook migrating through the San Juan Islands in the summer months may eat lower quality diets and suffer greater mortality than their ancestors a century ago due to the decline of spring-spawning herring. It is also possible that a greater proportion of juvenile Chinook remain in the islands after September and become “Blackmouth” that remain in the islands until they are ready to return to their natal streams to spawn.

It may be relevant that the period of this study was a La Niña cycle (cooler). Research will continue under the El Niño conditions expected in 2013-2016. As a result of climate change, moreover, the Salish Sea is likely to experience stormier winters and an acceleration of shoreline erosion, beach recession, and the migration or extirpation of shallow marine vegetation, which may further reduce the availability of small herring for migrating juvenile Chinook. At the same time, we do not yet understand the reproductive ecology of sandlance sufficiently to determine whether forecast cyclical weather patterns or climate trends will affect this other important forage fish in the neritic Chinook diet.

Acknowledgments

We gratefully acknowledge the initial financial support of the National Fish and Wildlife Foundation and the Washington Salmon Recovery Funding Board in 2009-2010; the technical assistance of David Teel, David Kulikowsky, Paul Moran and Kurt Fresh at the NOAA Northwest Fisheries Science Center; volunteer training provided by Professor Anne Beaudreau (University of Alaska, Fairbanks) and Audrey Thompson (The Wild Fish Conservancy); and the energy and enthusiasm of our community volunteers on Lopez and Waldron Islands.

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