Grays Harbor Juvenile Fish Use Assessment: 2012 Annual Report

Prepared for the Chehalis Basin Habitat Work Group

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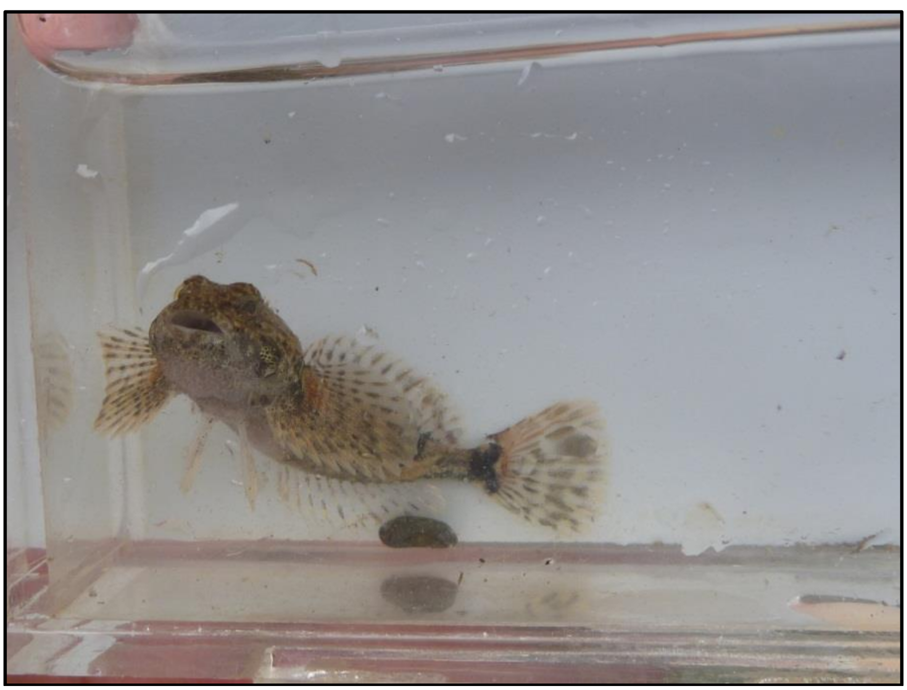
Wild Fish Conservancy
NORTHWEST
SCIENCE EDUCATION ADVOCACY

Setting the net in Half Moon Bay, Grays Harbor Estuary, 2012



Sculpin displaying in a Wild Fish Conservancy "photarium", April 2012

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Executive Summary

Grays Harbor (the Chehalis River estuary) is the second largest estuary in the state of Washington, covering 23,504 hectares 2,350 km^2 (23,504 hectares) at mean high high-water from the mouth at Westport to Montesano, and encompassing the tidally-influenced lower reaches of the Chehalis, Humptulips, Hoquiam, Wishkah, Johns and Elk Rivers as well as several smaller tributaries and sloughs. The total drainage area, including all of the above tributaries, is 6,605 km^2 (660,450 hectares), with 79% of the fresh water input from the Chehalis River.

Within the Chehalis basin there are numerous distinct stocks of native salmonids that are important to the overall biological diversity in Washington State. These include one stock of spring Chinook salmon (*Oncorhynchus tshawytscha*), one stock of summer Chinook, seven stocks of fall Chinook, seven stocks of coho salmon (*O. kisutch,)* two stocks of fall chum salmon (*O. keta*), two stocks of summer steelhead trout (*O. mykiss*), and eight stocks of winter steelhead (WDFW and WWTIT 1994). In addition, cutthroat trout (*O. clarki*) have been observed throughout the drainage, and bull trout (*Salvelinus confluentus*) have been documented as present, but specific distribution data do not exist. All of these stocks have been in decline, as have most salmonid stocks in the Pacific Northwest.

The objectives of this project are to develop a scientific basis for the evaluation of potential sites for future habitat restoration and protection projects (as well as identifying construction windows for those projects), to determine the seasonal trends in estuary residence, and to identify any potential fish health issues resulting from external macro-parasitic infections. The specific goals are to document the species composition, distribution, relative abundance, habitat use, and timing of juvenile salmonids and other fishes in the Grays Harbor estuary, from riverine tidal waters through marine habitats. Though this project focused on juvenile salmonids, abundance data on all other fish species caught were also recorded. The majority of the sampling was conducted using fine meshed beach seines which were deployed at 26 sites using a motorized skiff or set by hand. In 2012, we used three different beach seines to sample the various habitats in Grays Harbor, each suited to particular habitats and sampling sites. Sampling began in February and continued into mid-September during low tide cycles in the estuary. In 2012 we made 570 beach seine net sets; fyke netting, except at specific locations (e.g. recent breach in a dike in the Johns River), was discontinued both to maximize our ability to cover all the beach seine sites effectively and because we were unable to estimate capture efficiency at the fyke sites sampled in 2011.

In 2012, 24,038 salmonids were captured, nearly twice as many as in 2011 (13,228); the change was due primarily to increases in the number of chum salmon (15,755 vs. 6,810 in 2011) and Chinook salmon (7,337 vs. 4,719 in 2011). Catches of coho salmon declined in 2012 (792 vs. 1,499 in 2011). For chum salmon the difference was due in part to the earlier start of sampling (February in 2012, late March in 2011). However, even if the February (N=1,914) and early March catches of chum salmon catch are excluded, the 2012 chum catch was roughly 2,800 more than that of 2011.

Chum salmon were again the most abundant juvenile salmonid captured in 2012, followed by unmarked Chinook (6,876), unmarked coho (694), hatchery Chinook (461), and hatchery coho salmon (98). Chinook and coho salmon young-of-the-year (YOY) again dominated the catch of these species. In addition, 85 steelhead, 65 cutthroat and 4 bull trout (subadults or adults) were captured. Unmarked YOY Chinook salmon were captured throughout the sampling period from February to September (peaking in May), while the main "pulse" of hatchery fish occurred from May to August. Very few yearling Chinook salmon were captured in either year, although these fish are not efficiently captured by beach seining because they prefer deeper water. Unmarked YOY coho salmon were captured mainly from March through August (though present in very low numbers in February and September), with a pulse of emigrating yearling hatchery coho caught in April and May. Most juvenile chum salmon (all YOY) were caught from February through May (4 were caught in June). Other summary points on zone and habitat usage, predation risk, coded wire tag recoveries and probable effects of climate change on the Grays Harbor estuary and Chehalis River system are highlighted below.

- **Chinook salmon**: Unmarked YOY Chinook salmon where widely dispersed throughout the estuary during late spring and early summer and showed a clear seaward migration pattern as the sampling season progressed. However, the regression modeling shows that although abundance decreased later in the year, occurrence did not: YOY Chinook salmon continued to utilize estuarine habitats into the fall. They were more abundant in North Bay and less abundant in South Bay and the central estuary in comparison with the other zones, were notably less common at gravel/cobble/sand beach habitats, and both their presence and abundance were negatively correlated with temperature. Hatchery YOY Chinook salmon abundance was also negatively correlated with temperature, and they were also rarely caught (and in very low abundance) at beach sites. The occurrence of hatchery YOY Chinook was lower in forested, scrub/shrub, and high emergent marsh than in other habitats, and they were captured most frequently in North Bay, the central estuary, and South Bay, although their abundance was lower in these zones than in the surge plain or inner estuary (a very different pattern than for unmarked YOY Chinook). The presence of juvenile Chinook in all months sampled suggests a diversity of life histories are present in the basin.
- **Coho salmon**: Unmarked YOY coho were caught mainly in the central estuary in all months (though very low numbers were captured in February and September), particularly in the Hoquiam River system. Yearling coho, though present at lower densities, were more dispersed through the central estuary, South Bay, and North Bay, with a pattern of input from the Humptulips River from March-June. As with Chinook, coho salmon occurrence and abundance was negatively correlated with salinity; when salinity exceeded 5ppt their occurrence declined quickly, and above 20ppt they were essentially absent. Unmarked YOY coho salmon heavily favored forested habitats in 2012, followed by scrub/shrub cover habitats. Coho salmon were absent at sand flats and beach sites, and were also uncommon at mud flat sites, which was their preferred habitat in 2011. It is unclear if this is a result of higher densities of Chinook and chum salmon at mud flat habitats in 2012 or the higher production of coho in the Hoquiam River system, which contains large

areas of forested and scrub/shrub habitat. The presence of juvenile coho in all months sampled also suggests a diversity of life histories are present in the estuary; some YOY coho salmon were captured in tidal portions of the tributaries even in the fall.

- **Chum salmon**: Chum salmon were present at high densities from February to May (in June only 4 chum were captured), after which all chum salmon had migrated to sea, in keeping with their life history. Chum were widespread throughout the estuary (including North Bay) from February until April, and by May they were at much lower densities in the surge plain as the fish pushed through to the estuary. Chum were captured in highest densities at cobble/gravel/sand beaches in 2012, and were also common at sand flat and aquatic vegetation bed habitats. They were captured at lowest densities at forested sites, particularly in South Bay. The occurrence and abundance models for chum salmon indicate that tide stage (flood, ebb, slack) was an important factor in their occurrence, as was water temperature, although this is likely the result of their greater abundance earlier in the season.
- **Trout:** More <u>steelhead trout</u> were captured in 2012 than 2011, but the majority of these were juveniles captured in one set (N=68 hatchery, 13 unmarked) near the mouth of the Humptulips River in April. This precludes any comparison of their habitat preferences. Slightly fewer <u>cutthroat trout</u> were caught in 2012 (N=65) than in 2011 (N=92). Though cutthroat trout were encountered infrequently, enough were captured over time to observe some patterns of estuary use. Cutthroat densities were highest at scrub/shrub cover and emergent marsh sites, as in 2011, though some were also caught in every habitat except cobble/gravel/sand beaches and sand flats. Their densities closely aligned in space and time with those of YOY Chinook salmon, suggesting possible predation. Our catches of cutthroat trout demonstrate that this species is present in Grays Harbor through much of the year (March to September), though they were most commonly encountered from April to June. A total of four <u>bull trout</u> were captured in Grays Harbor during the sampling period in 2012.

Coded Wire Tags (CWT) and Genetic Analysis: Only 5 yearling coho salmon were recovered with CWT in 2012. At the time this report was generated, none of the CWT codes we recovered was present in the regional tagging database; it appears that these codes have not yet been updated and we will provide this information when it becomes available. WFC took fin clips (rayed fin) from 164 of the largest Chinook salmon smolts captured near the mouth and in the central and inner estuaries for genetic analysis in 2012; the tissue samples have been submitted to the WDFW genetics lab and results are expected in June, 2013.

Escapement: An additional goal of this project is to sample in years with "low", "average" and "high" escapement for the three main salmonid species (Chinook, coho and chum salmon) in order to analyze how the spatial and temporal distribution of juvenile salmon changes as the density of these species in the estuary fluxes. Based upon this definition, unmarked smolt productivity of Chinook salmon was categorized as average for 2011 and high for 2012; productivity of YOY coho salmon was considered high for 2010 and 2011, and about the upper limit of an average year for 2012; and smolt productivity for chum salmon was high for both 2011 and 2012. Thus, if productivity for all three species is low in 2013, one additional year of sampling may be adequate. The large increase in our Chinook and chum salmon captures in 2012 contributes additional uncertainty; at present the escapement levels for the past few years do not explain this variability. Note that the term "average" here refers to comparison with the escapement from 1969/1970 to 2011; historically, all of these species were present at much higher numbers in the Chehalis Basin.

Effects of climate change on salmon in the Chehalis Basin: Evidence that climate change and associated impacts are occurring is overwhelming. The documented impacts for Washington state and the Chehalis River/Grays Harbor estuary in particular are numerous but include elevated air, fresh water and surface ocean water temperatures, alterations in precipitation patterns and stream flows, ocean acidification, an increase in the frequency and severity of storms (with associated high water events), and sea level rise (SLR). Because salmon are affected by one or more of these changes during each stage of their life cycle, they will be cumulatively impacted. In western Washington, stocks of salmonids with extended freshwater rearing periods (including steelhead and coho and fall Chinook salmon) will be more sensitive to the predicted climate changes in freshwater. Changes in the availability of quality rearing habitat due to warmer temperatures is predicted to affect mainly summer and winter run steelhead and coho salmon.

Using a Sea Level Affecting Marshes Model (SLAMM) model, WFC modeled the effects of sea level rise on habitat availability for the Grays Harbor estuary using three scenarios: increases of ~59cm, 75cm, and 100cm. The most dramatic changes were in the central estuary and North Bay, where extensive loss of low elevation tidal mud and sand flats (roughly 83% lost) is predicted [Note: these losses would be accelerated if the dam being discussed for the mainstem Chehalis River is constructed, due to the accompanying decrease in downstream sediment transport]. Both Goose and Sand Islands are submerged by increasing sea levels by 2100 (59cm and 75cm scenarios) or 2075 (1 meter scenario). In the inner estuary zone, the extensive mud flats around Moon and Rennie Islands are expected to be submerged by 2075 in all three scenarios. In the surge plain, the predicted SLR will result in a rapid transition from forested tidal swamp to irregularly flooded marsh by 2025 even in the most conservative scenario; the net loss of forested area is predicted to be severe (~97% for tidal portions of the estuary as a whole). Rising sea levels are predicted to dramatically increase the area of the various types of marsh land; for transitional marsh, over 200-fold; for regularly flooded salt marsh, 2.5 - 4 fold; for irregularly flooded marsh, roughly 6 fold under all scenarios.

To counter these anticipated changes and provide wild salmon populations with the best opportunities for continued survival, ensuring future habitat availability, maintaining salmon life history diversity (by minimizing direct and genetic impacts from hatchery fish), and adjusting harvest to maintain sustainability under unfavorable environmental conditions are critical. In the estuary, increases in sea level will lead to inundation of lower elevation areas; planning for land acquisition and protection of these sensitive areas, rather than disruptive alterations (e.g. shoreline armoring, dikes, levees) will be essential in helping offset habitat loss (for a full discussion and inundation maps, see the accompanying WFC report entitled "Climate Change in the Chehalis River and Grays Harbor Estuary").

Section 1: Introduction

1.1 Purpose and Objectives

The juveniles of Pacific salmon spawning in the extensive rivers and streams of Water Resource Inventory Areas (WRIAs) 22 and 23 all must pass through the nearshore habitats in the Grays Harbor Estuary as they emigrate to the ocean. Estuarine environments are extremely productive habitats, and many populations of juvenile salmon spend extended periods of time rearing in this environment. Understanding the extent, timing, and species composition of fish usage in these habitats is a critical component in the development of a salmon restoration strategy for the entire basin. The Grays Harbor Juvenile Fish Use Assessment project is designed to investigate current estuarine habitat use, particularly by juvenile salmonids, and to provide a scientific basis for the selection and prioritization of future salmonid habitat restoration and protection projects within the Grays Harbor estuary.

The project had four primary goals at the outset:

- Determine the abundance, distribution, emigration timing and habitat preferences of juvenile salmonids in the Grays Harbor estuary and tidally-influenced portions of its major tributaries
- Gather information on the distribution, abundance and community structure of non-salmonid fishes in these same areas
- Use the capture of coded wire tagged salmonids to identify the basin of origin, infer estuarine residence times, and estimate emigration speeds and growth following release from the hatcheries
- Examine the underlying physical characteristics of the habitat types found in Grays Harbor to understand, and potentially model, the distribution of juvenile fishes in the estuary

This project was proposed, developed, and conducted by the Wild Fish Conservancy under a grant from the Salmon Recovery Funding Board and the U.S. Fish and Wildlife Service. In 2012, sampling began in February and continued until mid-September, and included 570 beach seine sets; 559 were seine sets at the core sites and 11 were seine sets completed at secondary sites. Sampling in the first year of this study (2011) began in mid-March and continued through the beginning of October, and included 694 beach seine sets (some additional sets were made to test net capture efficiency, but these catches are not included in the report). Of these, 608 were seine sets at the core sites and 20 were fyke net sets in tidal sloughs.

1.2 Study Area

Grays Harbor (the Chehalis River estuary) is the second largest estuary in the state of Washington after the Columbia River estuary (Puget Sound is technically considered a "fjord"). The Grays Harbor estuary is a bar-built estuary that was formed by the combined processes of sedimentation and erosion caused by both the Chehalis River and the Pacific Ocean (Chehalis Basin Habitat Work Group, 2010). The estuary covers 23,504 hectares at mean high high-water (MHHW) from the mouth at Westport to Montesano, and encompasses the tidally influences lower reaches of the Chehalis, Humptulips, Hoquiam, Wishkah, Johns and Elk Rivers as well as several smaller tributaries (Figure 1). The total drainage area, including all of the above tributaries, is 660,450 hectares, with 79% of the fresh water input from the Chehalis River (Simenstad & Eggers 1981). The system flows are rainfall driven, with peak flows from December- January in an average year, and minimal input from snowmelt in the southern Olympic Mountains (surface drainage occurs primarily through the Satsop River basin). In the inner estuary ("Inner Harbor"), the main river channel splits into north and south channels; the north channel has been dredged for navigation. Vertical salinity stratification, with a salt water wedge typical of estuarine systems, occurs only in the south channel (Simenstad and Eggers, 1981).

Between 1900 and 1980, the Grays Harbor estuary had an overall net decrease in tidal wetlands due to extensive diking and filling activities, particularly in the Inner portions of the estuary (Boule et al. 1983). A more recent analysis of historical estuarine habitat change detailed a 22% decline in tidal flats (3,493 hectares) due to upland conversion at the mouth of Grays Harbor and along the north channel, an increase in potential eelgrass habitat (1,793 hectares), and an increase in areas below extreme low-water (ELW) (409 hectares), mainly due to a deepening of the channel near the mouth of the estuary (Borde et al. 2003). Upland logging may have led to an increase in sediment transport to the estuary, resulting in loss of tidal flats due to increased elevation. Dredging for navigation has dramatically deepened the area near the mouth of the estuary, as well as along the north channel, resulting in changes in circulation; wakes from large vessels may have increased channel border erosion and loss of tidal flats in the southern area of the estuary. Historically, the estuary received sediment input from the Columbia River, but the construction of jetties (first in 1900, then in the 1930s) has reduced this input, which may also explain the loss of tidal flats in the lower estuary (Borde et al. 2003). The northern part of the estuary ("North Bay") consists of extensive mud flats, most of which are submerged at mean high tide, and has experienced little change.

Although much of the basin has been degraded by a combination of logging, channelization, gravel mining, water diversion, road building, diking, dredging, aquaculture, small-scale coal mining, mill effluent, sewage release and pesticide use for aquaculture and cranberry farming (Hiss et al. 1982; Wood & Stark 2002; Smith & Wenger 2001) , the area of the lower mainstem Chehalis River, the tidal surge plain (river km 1-17, just east of Aberdeen to the confluence of the Wynoochee River), contains high-quality rearing habitat for juvenile salmon, particularly coho, and has been well studied (Moser et al. 1991; Simenstad et al. 1992; Team 1997; Henning et al. 2006; Henning et al. 2007). The area contains numerous sloughs and tidal channels, a relatively undeveloped floodplain with seasonal inundation, and a riparian forest dominated by older stands of conifers and hardwoods (Ralph et al. 1994).

Specific Hypotheses:

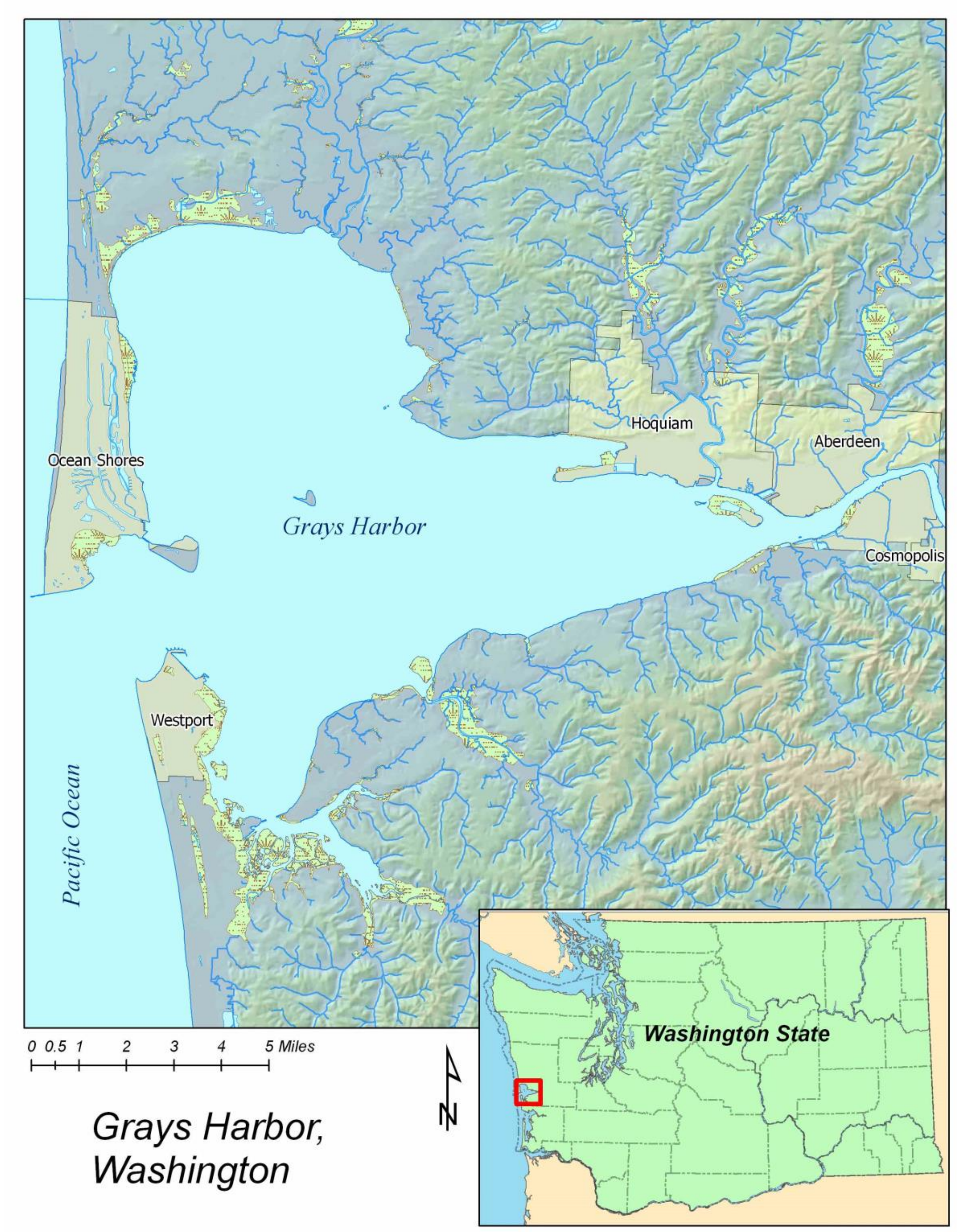
1) *There is differential use of estuarine habitat type by juvenile salmonids in the Grays Harbor estuary*
2) *Juvenile salmon utilize certain intertidal habitats in greater numbers than would be predicted by the abundance of those habitats alone within the habitat matrix of the Grays Harbor estuary ("habitat preference")*
3) *Juvenile salmon from upstream tributaries will utilize habitats in South Bay (Johns and Elk River estuaries), even though natural production in these systems is low, because of the presence of large areas with excellent rearing habitat*
4) *Few smolts emigrating from the Humptulips River will utilize "upstream" habitat (East of the Humptulips River delta), instead travelling to areas in South Bay or directly to sea* (based on the results of Schroder and Fresh 1992)

Additional Goals for 2012:

(a) *Determine if juvenile Chinook salmon originating outside the Chehalis basin are utilizing the Grays harbor estuary for rearing.* To determine if Grays Harbor estuary habitats are being used by juvenile Chinook salmon from other basins, particularly the Columbia River system, we sampled 164 juvenile Chinook salmon in 2012. The fish sampled were captured near the estuary mouth and central estuary and fin clips (from rayed fins) were taken and preserved. These samples have been submitted for genetic analysis to the WDFW genetics lab in Olympia; results are expected in June, 2013.

(b) *Research the effects of predicted sea level rise on habitat availability in the Grays Harbor estuary*. A literature search was conducted to better understand how climate change and the resulting sea level rise will affect the Pacific Northwest in general and salmon in the Chehalis Basin in particular (see separate report, "Climate Change in the Chehalis River basin and Grays Harbor estuary").

Figure 1: Location of Grays Harbor (the Chehalis River estuary) in Washington State, U.S.A.

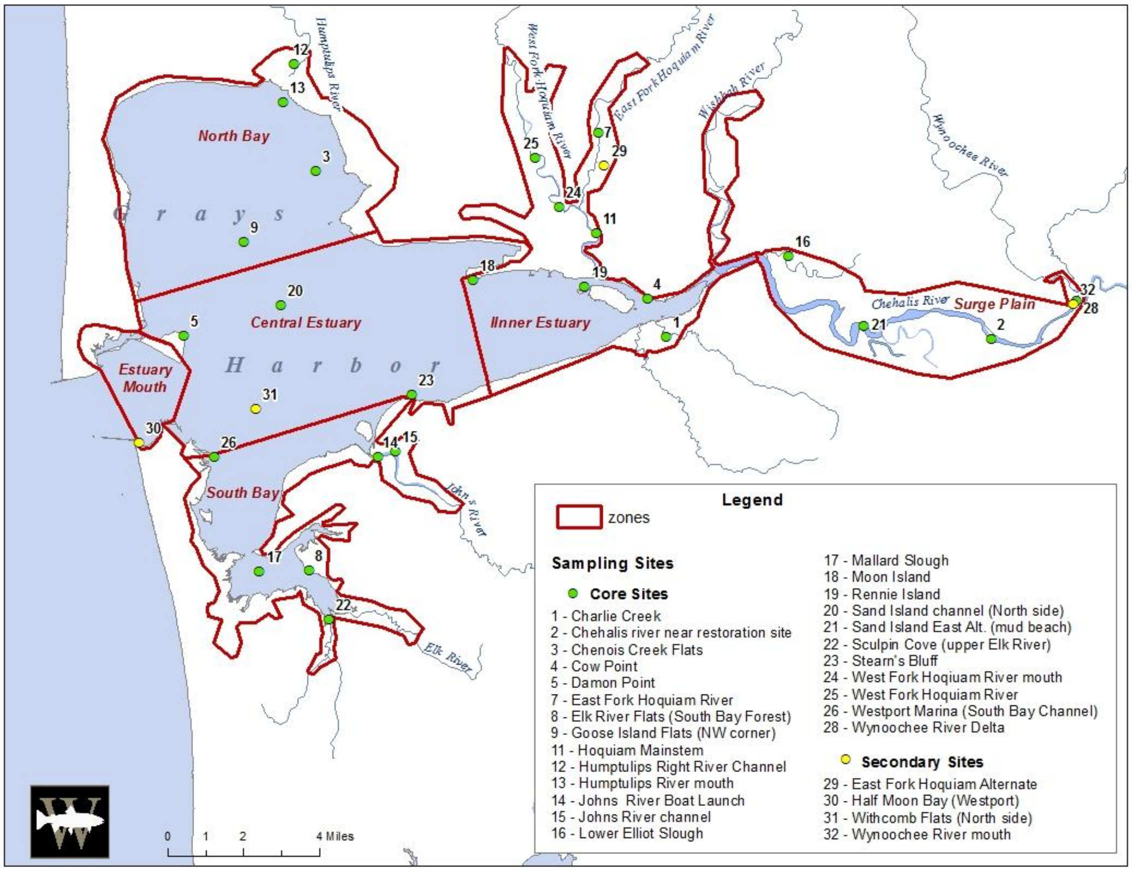


Section 2: Methods

2.1 Habitat Inventory/ Sample Site Selection

The intertidal areas of the Grays Harbor estuary were divided into six zones: mouth of the estuary, central estuary, north bay, south bay, inner estuary (referred to in the literature as the "inner harbor"), and Chehalis River surge plain (see Figure 2). The habitat classification was done using several geographic information systems (GIS) layers. The National Wetlands Inventory (NWI) GIS database was used as a basis for our classification (USFWS 2010). The NWI classes were used to group the polygons into subtidal, intertidal, emergent wetlands, shrub/scrub, and forested classes. Then soil data, Shore Zone Inventory data from the Washington Department of Natural Resources (WADNR 2001), and 2009 aerial imagery (USDA 2009) were used to manually subdivide the intertidal polygons into aquatic vegetation bed, mud flat, sand flat, and beach classes. During this step a comprehensive inspection of the classification result was conducted to verify the accuracy and make corrections as needed. Finally, the Shore Zone Inventory data ((WADNR 2001) was used to delineate some preliminary eelgrass habitats (a specific type of aquatic vegetation bed) (Figure 3). Additional locations of eelgrass habitat in the Grays Harbor estuary that were not in any current databases were noted during the 2011 summer sampling, when flows and turbidity decreased, allowing field identification and coordinate fixing via GPS. However, our increasing familiarity with the estuary in 2012 led us to the conclusion that most of the eelgrass habitats identified in the Shore Zone Inventory were poorly defined; unlike the "classic" eelgrass beds found in Puget Sound (a band of eelgrass along the shore at a particular tidal elevation), the majority of these actually contain multiple plant species, visible in mid-summer (but not before). As a result, in 2012 we re-classified eelgrass habitats as "aquatic vegetation beds" to better reflect the reality of multiple species occurrence; the data for 2011 were re-analyzed to incorporate this change. The habitat areas are included in the habitat maps (Figure 3) and tables used to calculate the percentage of each habitat type (and area) in the Grays Harbor estuary. As a result, some of the habitat area totals have changed since the 2011 annual report.

Figure 2: A map of the Chehalis River estuary (Grays Harbor), showing the size zones and locations of the core and secondary sites sampled in 2012.



The area (in hectares) of each habitat type, by zone, is shown in Table 1, below. These data were used to guide our choices of sampling sites; areas of open water were excluded (although in some cases we sampled the channel margins of some of these areas, which are typically aquatic vegetation beds or sand flats). Mud flats in north bay and the central estuary were sampled at very low or negative tides, when the exposed areas provide a barrier against which the net was drawn, allowing fish to become entrapped. These areas contain large quantities of woody debris, which limited our ability to sample with nets; our efforts to sample mud flats therefore focused on sampling adjacent aquatic vegetation beds.

Figure 3. A map of the Chehalis River estuary showing the six zones and the distribution of the eight habitat classification types.

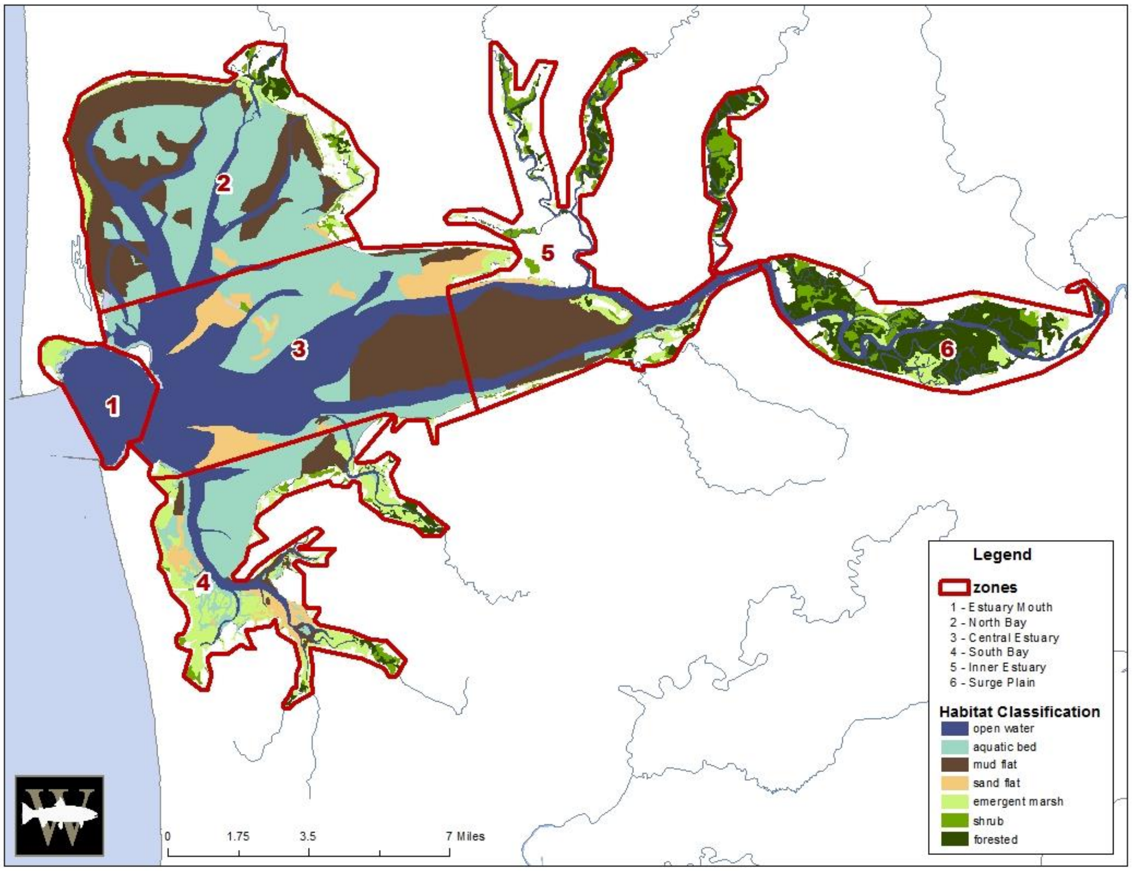


Table 1: Summary of Grays Harbor intertidal habitat types by zone (in hectares):

Habitat Type	South Bay	North Bay	Estuary Mouth	Central Estuary	Surge Plain	Inner Estuary	Total	% of Total
open water	585	1230	1143	4421	647	1158	9,183	30.8%
aquatic bed	1609	3531	21	2387	0	80	7,628	25.6%
mudflat	306	2426	0	1346	0	1700	5,778	19.4%
sand flat	273	53	0	1010	0	67	1,404	4.7%
emergent marsh	1126	353	90	132	336	274	2,312	7.8%
scrub/shrub	132	129	15	10	318	439	1,044	3.5%
forested	138	158	0	3	1598	561	2,458	8.2%
Total	4,169	7,881	1,270	9,310	2,900	4,278	**29,807**	100
% of Total	14.0%	26.4%	4.3%	31.2%	9.7%	14.4%		

To ensure coverage of the 6 zones and various habitat types in 2012, we utilized a two-tier sampling system consisting of primary ("core") sites (N=23; sampled bi-weekly) and secondary sites (N= 3; sampled whenever possible, with a goal of at least once per month). For specific site locations and GPS coordinates, see Appendix 1. Note that certain habitats (Cobble/Gravel/Sand beaches) occur infrequently in the estuary; our only sites with this habitat type are at Damon Point (Central Estuary) and Half Moon Bay (Estuary Mouth), both near the estuary's outlet. In addition, once it was determined (during the 2011 sampling season) that sampling at our initial "mud flat" sites resulted in sampling over aquatic vegetation beds, we sampled at a new site, Rennie Island (a mud flat without an adjacent aquatic vegetation bed) to incorporate a site with mud flat designation into the study (permission to sample at this site was not available in 2011). An additional site, Charlie Creek (south shore of the Central Estuary zone), was sampled in 2012; data for this site from 2011 was provided by Dr. Correigh Greene (NOAA); density calculations were adjusted based on the size of the net area they sampled with in 2011.

Some sites, particularly near the estuary mouth ("Half Moon Bay", the only site in this zone), were sampled less frequently due to the restrictions of tides, swell, and weather. A few sites that were sampled in 2011 were dropped in 2012 due to the presence of new log jams (Wishkah River), consistently poor salmon catches (Sand Island flats, on the southeast corner), a large numbers of snags, significant changes in channel morphology due to storm flows in the winter of 2011-12, or other logistical issues.

2.2 Field Sampling Methodology

Sampling was conducted using fine meshed beach seines which were deployed using a motorized skiff, or set by hand. One end of the net was fixed to shore; the net was then pulled offshore perpendicular to the beach and towed (or walked) back to shore in a 90° arc. At sites with tidal or river currents, we sampled at least twice in opposite directions to capture the variability introduced by the current, as daylight and tides allowed.

We used three different beach seines to sample the various habitats in Grays Harbor and the tidally influenced portions of its major tributaries, each suited to particular habitats (based on depth, current, and substrate). The large seine has 1/8" mesh, is 120' long and 12' deep in the middle of the net and had the heaviest lead lines, allowing use at the deepest sites and in strong currents (intertidal/subtidal fringe or channel margins). The wing of the net that was anchored to the beach tapered to 6', while the other wing had no taper; the large seine sampled an area of 1050.71 m^2 (0.1051 hectares) when deployed with this method. Tow lines (bridles) were attached to each end to facilitate deployment.

The medium net also has 1/8" mesh and is 100' long and 6' deep uniformly, sampling an area of 729. 7 m^2 (0.0723 hectares). We doubled the lead lines to allow this net to fish better in shallow areas of the main estuary, where stronger currents were common, but soft sediments made the use of the large seine undesirable (the large seine lead line sank into the mud, making retrieval difficult and damaging the fish by rolling them in large clumps of mud upon recovery). Early in the 2012 sampling season, this problem was particularly common at the Stearn's Bluff site, where excessive amounts of fine sediments threatened to result in high mortalities among newly emerged juvenile chum salmon; for this reason, sampling at this site was discontinued until early summer, when flows had removed the finest sediments. The small set net has 1/8"mesh, and is 80' long, with no taper, and sampled an area of 466.9816 m^2 (0.0467 hectares). This smaller net was rigged with 90' of net along 80' of lead and float line, creating a pocket in the net for holding fish. This net was primarily used in tributaries, the surge plain, or in North Bay (which is extremely shallow).

At each large seine sample site two consecutive seine hauls were conducted, with the net anchored to the same spot for each of the sample hauls but the net deployed in opposite directions, to provide a measure of catch variability. Shallow water habitats were sampled using the small seine protocol; at each site three consecutive hauls were conducted whenever possible, moving along the shore so that the same habitat was not sampled twice. Once the nets were closed they were brought into shore for catch processing. All fish captured were enumerated, identified to species, and visually scanned for marks and tags. Juvenile salmonids were also scanned for coded wire tags (CWT) and passive integrated transponder (PIT) tags; all CWT tagged salmon were kept (N=12) in order to determine basin of origin and release date. The first 20 individuals of each species/age class/mark status captured at a site were measured for fork length (mm).

Alternate (secondary) sites were sampled in June and July due to the presence of seals and their pups at our core sample sites on Goose and Sand Islands; due to the restrictions of the Marine Mammal Act, we could not resume sampling at the core sites until the seals and their pups had moved on.

Data Recording/Water Quality Measures

For each sampling set, data on date, time of day, net type, percent of net haul utilized in the set (with few exceptions, 100% of the net was utilized; in some cases, such as when currents collapsed the net prematurely, a smaller percentage was "fished"), current (ebb, flow, low slack, high slack), habitat, duration of the net set (used in reviewing the data to determine if the net was fished for an unusually long time due to snags, resulting in that particular set's catch being excluded from quantitative analysis) and weather were recorded. At each site temperature and salinity were measured using a water meter (Yellow Springs Instrument Co., Yellow Springs, Ohio); unfortunately our dissolved oxygen meter was again inoperable for most of the 2012 sampling season despite having been repaired by the manufacturer at considerable expense over the winter of 2011-12. Tidal heights were back-calculated from the Pro Tides website http://www.protides.com/map/state-map.php?Washington), using date and time of day to estimate the tide height from the curves (for a complete list of the tide stations used, see Appendix 4).

2.3 Age Class Assignments

To differentiate between subyearling and yearling Chinook and coho salmon, we examined the fork length (mm) distributions of catch by species and month, as well as comparing hatchery (marked) and unmarked (presumed wild) salmon. The delineations between the subyearling and yearling fish used in 2011 were slightly modified in 2012 so that the age class cutoffs were consistent in both years (Table 2). The length classes were quite clear, with few fish lengths falling in borderline length ranges. Based on our sampling protocol, and time limitations in the field to process large catches, only the first 20 of each species/marking (hatchery or wild, i.e. marked or unmarked) were measured for fork length. To estimate the age class designations of the remaining fish, we calculated the percentage of the catch that were subyearling salmon (based on fork length) and used that result to assign age classes to the remaining fish that were not measured in the field.

2.4 Catch Calculations/ Fish Densities

Catch Data

All data were originally recorded on a standardized data form in the field; subsequently data from the field forms were entered into Microsoft Access spreadsheets for analysis. Data were summarized into catch densities organized by sample site and date. To calculate the catch during each set, the total catch of each species was multiplied by the % of the net used in the set (usually 100%). For example, if only 90% of the net was utilized, the calculation was

(total catch for species Y) X (0.9) = adjusted total catch.

These adjusted total catch numbers are reported in sections 3.2 (salmonid seine total catch and 4.2 (non-salmonid total seine catch). Other graphs and figures pertain to fish densities, calculated in hectares (below).

Density Calculations

To calculate the density of each species for each set, we divided the adjusted catch by the area of the net used in that set to get the catch per meter squared. When two or three sets were made at the same site on a given date, the adjusted catches were summed and divided by the total area sampled (the number of sets made at that site with a net of particular area) to generate an average density by site on that date. To calculate the density of a given species (or age class of a species) in hectares (a hectare is 10,000 m^2), the formula was:

Density = (adjusted number of target species caught/total net area (m^2)) X(10,000)

To compare catch densities between sampling zones or habitat types, the above densities in hectares were summed by the appropriate factor (zone or habitat type, by month) to account for biases created by unequal sampling efforts across space or time and the use of different nets at different sites. This is equivalent to the concept of catch per unit effort (CPUE), with the number of sets made and the area of the net used taken into account, normalizing the catch. These data are presented in sections 3.3 (salmon distribution) and 4 (non-salmon distribution).

Section 3: Salmonid Results

3.1 Salmon Growth/Age Class

In general, smaller salmonids ("young-of-the-year" (YOY); elsewhere referred to as age 0+, or subyearlings) tend to spend more time in estuarine waters and are thus more dependent on estuarine habitats than larger juveniles ("yearlings"; age 1+), which typically reside in streams for their first year of life prior to smolting. These classifications apply mainly to Chinook and coho salmon, who have the most diverse patterns of estuarine usage (Hering et al. 2010; Bottom et al. 2005; Zaugg et al. 1985; Moser et al. 1991); chum salmon migrate directly to the sea shortly after hatching in early Spring and are thus all subyearlings (chum salmon in the Chehalis Basin are not marked, so all were considered "unmarked" although in recent years ~5% are of hatchery origin; data from WDFW). No pink or sockeye salmon were captured in 2012. Steelhead trout, which typically rear in freshwater for 1-3 years (Quinn 2005), were all considered yearlings or older (subadult or adult), as were cutthroat and bull trout.

Table 2: Chinook and coho salmon fork length (FL) age class cutoffs (mm)

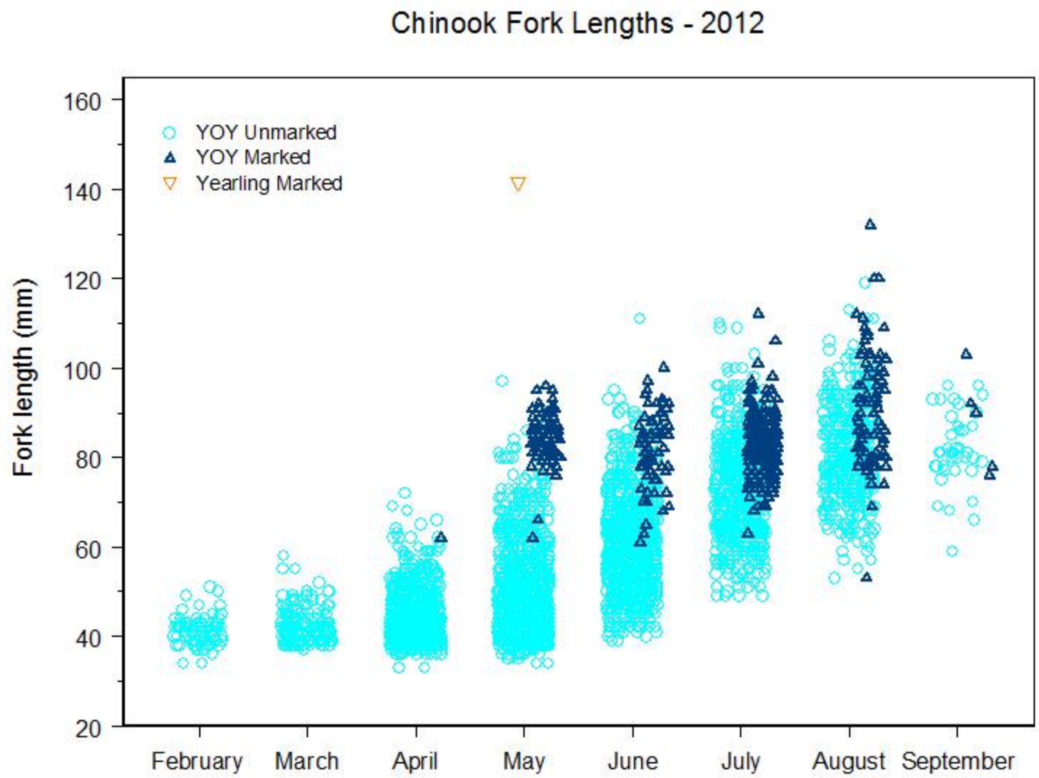
Month	Coho YOY ≤	Coho yearling ≥	Chinook YOY ≤	Chinook yearling ≥
February	70		100	
March	70		100	
April	80		100	
May	90		110	
June		130		130
July		130		140
August		130		150
September		130		165
October		130		175

Juvenile Salmon Size Trends

Chinook Salmon

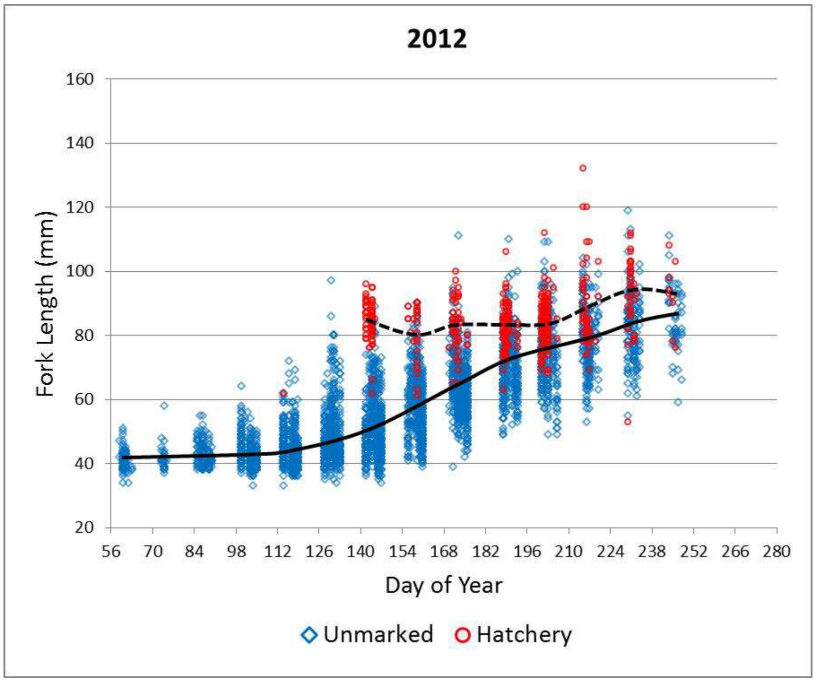
Unmarked juvenile Chinook salmon were caught throughout the sampling period from February to September. Very few yearling Chinook were captured (N=2; for this reason they are excluded from the figures that follow). The mean length of both hatchery origin and wild Chinook YOY salmon steadily increased during the study from approximately 41 mm FL in February to approximately 82 mm FL in September (Figure 4). The average length of hatchery YOY Chinook salmon was significantly greater than wild YOY Chinook in May, June, July, and August (Wilcoxon rank-sum *W* test: $p < 0.001$ for all pairwise comparisons). The average fork length of hatchery YOY Chinook salmon in May was 84.3 mm, vs. 49.7 mm for wild YOY Chinook; 81.9 mm vs. 61.5 mm (hatchery vs. unmarked) in June; 82.9 mm vs. 73.0 mm in July; and 90.7 mm vs. 81.3 mm in August. An estimated 98% of Chinook salmon released from hatcheries in the basin were adipose fin clipped (AdClip) in 2012 (data Pacific States Marine Fisheries Commission, Regional Mark Processing Center).

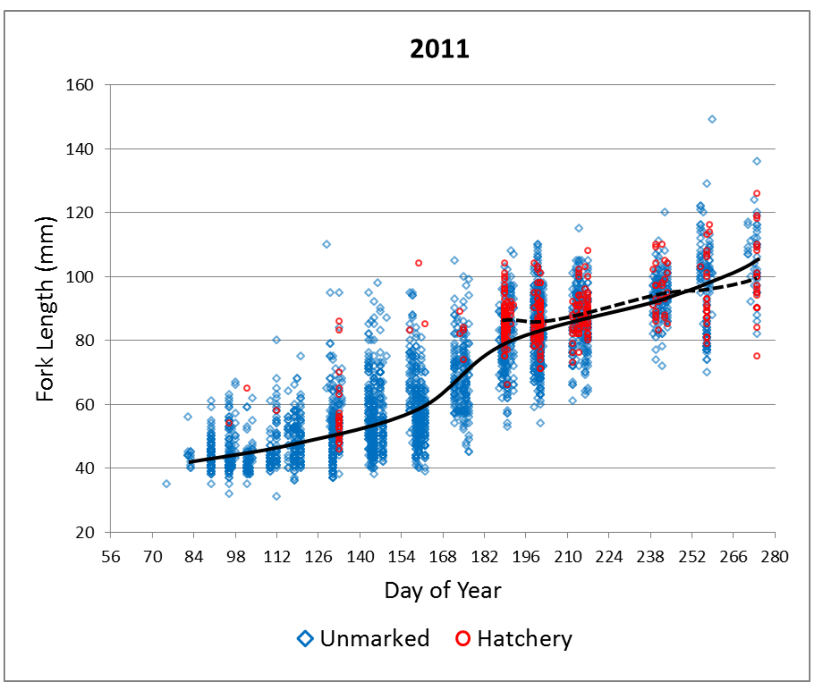
Figure 4: Chinook salmon fork lengths, by month, showing age class designations



A comparison of monthly growth for YOY Chinook salmon between 2011 and 2012 revealed an interesting pattern. In 2011, hatchery YOY salmon were significantly larger than their unmarked cohorts in June, but by July the unmarked fish had "caught up" following a particularly rapid period of growth between June and July (note the slope of the growth curve for unmarked fish in 2011; Figure 5). In 2012, the average FL of unmarked fish was lower than in 2011 after June; despite a rapid increase in mean FL from June to July, unmarked fish had a lower mean FL than hatchery fish throughout the sampling season. The growth of unmarked fish also plateaued in August and September of 2012, with little change in mean FL (this could be the result of new, smaller fish entering the estuary). In 2011, the pattern was similar but unmarked fish had a higher mean FL than hatchery fish in September (Figure 5). Although water temperature is often the major determinant of growth and metabolism if adequate food resources are available, a regression of temperature versus fork length was not significant. However, the effect could also be due to increased competition in 2012, when roughly twice as many juvenile Chinook salmon were captured. These hypotheses may be confounded by differences in the timing of hatchery Chinook releases between the years, a topic of ongoing investigation.

Figure 5: Comparison of growth (FL) by month for hatchery vs. unmarked YOY Chinook salmon in 2011 and 2012.



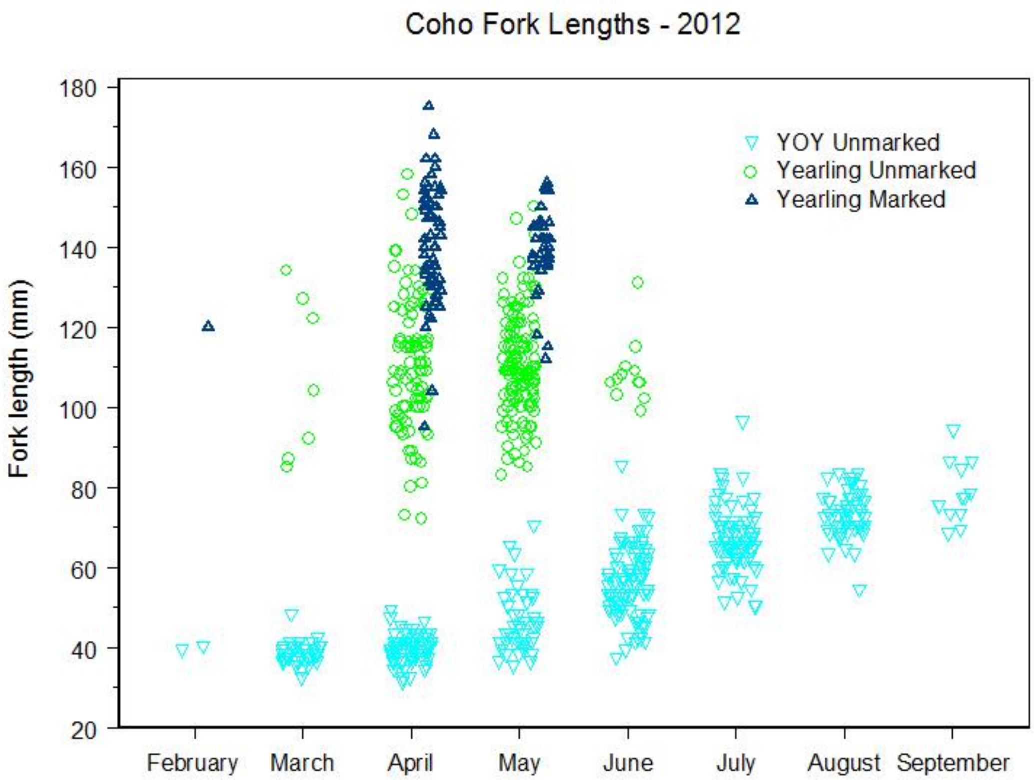


Coho Salmon

Subyearling coho salmon were also captured throughout the sampling period from February (very few) to September in 2012, and a “pulse” of outmigrating yearling coho salmon were caught primarily in April and May (Figure 6). In 2011, this pulse occurred over a longer period (April to June), which may be the result of differences in the timing of release for hatchery yearling coho salmon. An estimated 2-3% of hatchery YOY coho salmon are marked (total release of 721,966 in 2012), and over 99% of yearling coho were marked (total release of 2,238,561 in 2012; data from Pacific States Marine Fisheries Commission, Regional Mark Processing Center). Given the low marking rate for YOY coho salmon, all of these fish were considered unmarked.

The mean length of subyearling coho salmon steadily increased during the study from approximately 40 mm FL in February to approximately 78 mm FL in September (Figure 6). In contrast, the average fork length of yearling coho salmon was similar in both April and May among unmarked fish; there was a slight decline in average FL from April to May for hatchery yearling fish**.** This trend is driven in part by the timing of hatchery releases, i.e. it does not suggest that these fish failed to grow while in the estuary, but rather that yearling coho are rapidly transiting through the estuary, so different groups of fish were caught in April than in May. The pattern among yearling coho shows the inclination for smaller coho salmon to migrate through the estuary later than larger yearling coho salmon. This tendency presumably reflects the need for small individuals to increase their size and complete the smolt transformation before entering the ocean to improve their odds of survival at sea.

Figure 6: Coho salmon fork lengths, by month, showing age class designations



The mean fork length of hatchery yearlings was significantly greater than unmarked "wild" yearlings in both April and May (Wilcoxon rank-sum *W* test: Z = -4.95, p< 0.001; Z = -8.20, p< 0.001 respectively). The mean fork length of hatchery yearling coho salmon in April was 140.6 vs. 110.9 for unmarked yearling coho; and 139.6 versus 110.9 (hatchery vs. unmarked) in May.

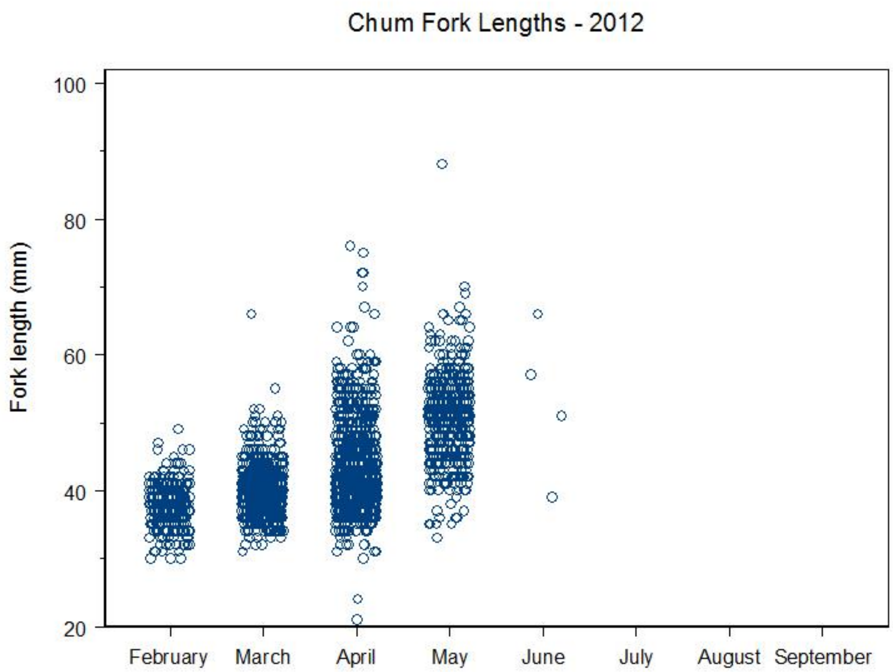
Chum Salmon

In 2012, we were able to commence sampling in February due to favorable low tide series during daylight hours (we were unable to start until March in 2011). Most juvenile chum salmon were caught between February and May, with very few individuals captured in June. By July all chum salmon had exited the estuary, consistent with their life history. Chum salmon dominated the salmon catch in February (84.4%, N=227) and were a large portion of the total catch (23.4% with post-larval flatfish excluded); many individuals that had not entirely reabsorbed their yolk sacs were captured, even near the estuary mouth (photo below). The mean fork length of juvenile chum salmon gradually increased from February (approximately 38mm) through May (approximately 51mm) (Figure 7). Some fish with a FL in excess of 70mm were captured in April and May; because hatchery chum salmon in the Chehalis basin are not marked, it is unclear if these fish were of hatchery origin (in the last three years (2010 - 2012), the percentage of hatchery chum salmon has been 3, 4, and 9%; WDFW).

This pattern of estuarine use may reflect the inherent changes in productivity and the relative growth opportunities of the estuary versus the nearshore ocean early in the year. Several studies have pointed out the especially large contribution of harpacticoid copepods in the diets of juvenile salmon (Naiman & Sibert 1979; Mayama & Ishida 2003) and the residence period of chum salmon may be driven by the relative abundance epibenthic prey (Wissmar & Simenstad 1988) during the late spring.

A chum salmon still reabsorbing its yolk sac.

Figure 7: Chum salmon fork lengths, by month (all chum salmon are YOY)


Chum Fork Lengths - 2012
Fork length (mm)
100
80
60
40
20
February
March
April
May
June
July
August
September

3.2 Salmonid Catch Totals (Raw data)

Data presented in this section refer to actual salmon catch numbers for 2012; note that in the following sections that deal with salmon densities by zone and habitat type, catch densities are presented by catch per hectare, and are thus increased by the multiplication factor required since our nets sample only a fraction of a hectare (ha). See section 2.3 for more information. In 2012, 24,038 salmonids were captured, nearly twice as many as in 2011 (13,228); the change was due primarily to increases in the number of chum salmon (15,755 vs. 6,810 in 2011) and Chinook salmon (7,337 vs. 4,719 in 2011) (Table 3). Catches of coho salmon declined in 2012 (792 vs. 1,499 in 2011). For chum salmon, the difference was due in part to the earlier start of sampling (February in 2012, late March in 2011).

Table 3: Salmonid catch totals for 2011 and 2012, by species and unmarked/hatchery designations

Species: hatchery/unmarked	2011 Season Total	2012 Season Total
Chinook Salmon - Unmarked	4322	6876
Chinook Salmon - Hatchery	397	461
Coho Salmon - Unmarked	1370	694
Coho Salmon - Hatchery	129	98
Chum Salmon	6810	15755
Sockeye	1	0
Steelhead - Unmarked	21	16
Steelhead - Hatchery	3	69
Rainbow trout	1	0
Cutthroat trout	92	65
Bull trout	2	4
Total:	**13148**	**24038**

In 2012, chum salmon again dominated the salmonid catch, and were already present in high numbers when sampling began in February, peaked in April, and had exited the estuary by the end of May (only 4 chum were caught in June) (Table 4; Figure 8c).

Chinook salmon were the second most common salmonid captured in 2012 (as in 2011) and were present during all months of the study, peaking in May but present in large numbers from April through August (Figure 8a). Coho salmon were most common from April through July, peaking in April (Figure 8b). As shown in the table below, unmarked fish dominated the catch for Chinook and coho salmon, but hatchery coho salmon were most commonly caught in April and May, while hatchery Chinook salmon were common from May through August (Table 4).

Figure 8a: Chinook salmon catch by month in Grays Harbor, 2012

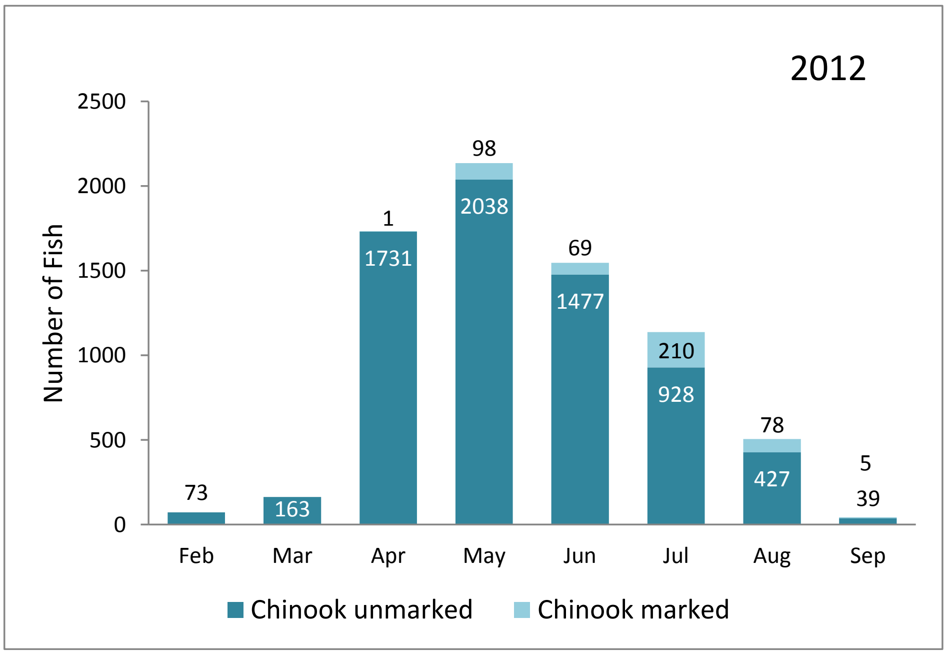


Figure 8b: Coho salmon catch by month in Grays Harbor, 2012 (note the different Y-axis scale)

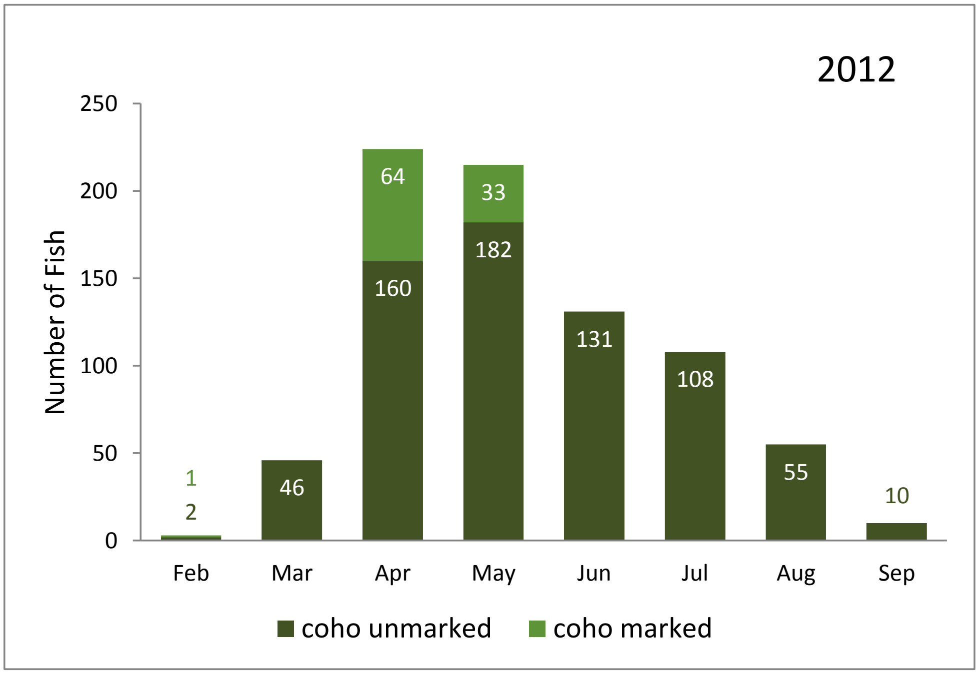


Figure 8c: Chum salmon catch by month in Grays Harbor, 2012 (note the different Y-axis scale; more chum salmon were caught than Chinook or coho salmon)

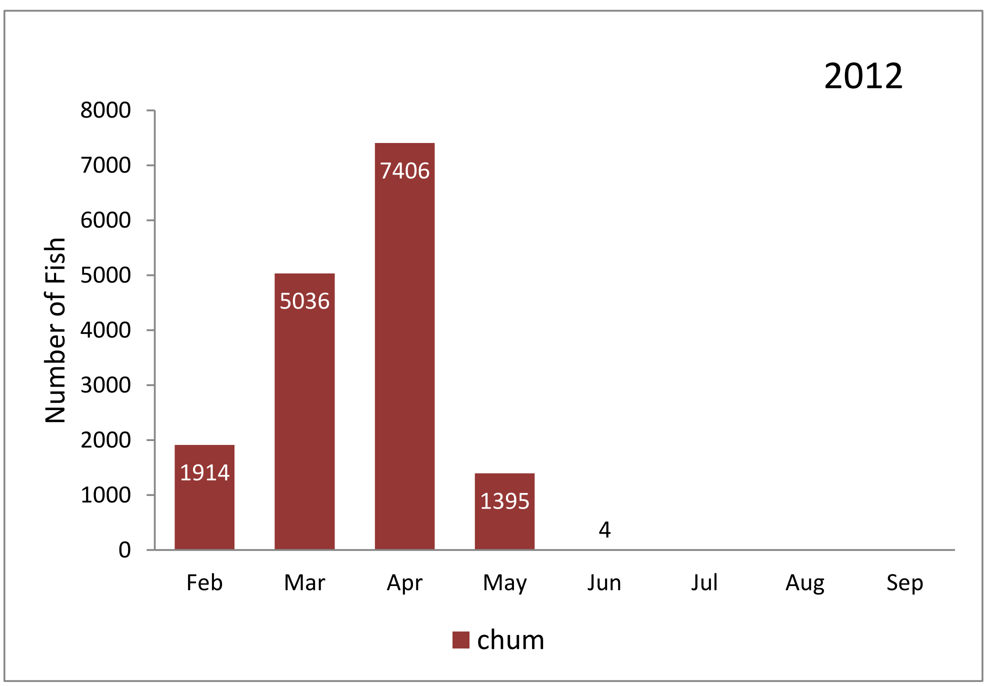


Table 4: Monthly totals for the three most common salmonid species captured in 2012

	Chinook		Coho		Chum
Month	unmarked	hatchery	unmarked	hatchery	
Feb	73		2	1	1914
Mar	163		46		5036
Apr	1731	1	160	64	7406
May	2038	98	182	33	1395
Jun	1477	69	131		4
Jul	928	210	108		
Aug	427	78	55		
Sep	39	5	10		

More steelhead were captured in 2012 than 2011, but the majority of these were juveniles (both hatchery and unmarked) captured in one set (N=68 hatchery, 13 unmarked) near the mouth of the Humptulips River in April. Slightly fewer cutthroat trout were caught in 2012 (N=65) than in 2011 (N=92).

3.3 Salmon Distribution and Timing (Densities)

Salmon Catch Densities by Zone and Site

To visualize the timing of our catches of salmonids in Grays Harbor in 2012, we generated new plots this year showing catch densities (not actual catch) within the zones for each species, age class, and mark status (Figure 9). They are presented in order by month to show the seaward emigration of the juvenile salmon; note that the number of plots differ by species/age class/mark status because low catches were not plotted (e.g. few chum in June). There are no plots for yearling Chinook salmon because very few were caught in either 2011 or 2012. These same plots for 2011 are located in Appendix 3.

Chinook salmon

In 2012, juvenile Chinook salmon were caught in every month from February through September, as in 2011. Almost all of the catch consisted of young-of-the-year (YOY) Chinook; note that yearlings prefer deeper water (channels) and are not captured effectively by beach seining. The 2012 estuary zone density plots reveal a gradual seaward emigration through the sampling season, with high densities of unmarked YOY

Chinook salmon in the surge plain early in the year. By April unmarked YOY Chinook salmon were at high densities (>200 fish/ha) in North Bay and the inner estuary; by June they were widespread, and by September most of the fish had exited, with some moderate densities (50-100 fish/ha) remaining in the central estuary (Figure 9a). Hatchery YOY Chinook salmon entered the estuary later in the year and were present in the surge plain and inner estuary at low-moderate densities by May (Figure 9b). By July they were largely absent from the surge plain and were found at moderate densities (50-100 fish/ha) in the central estuary and at higher densities (100-150 fish/ha) near the estuary mouth, and by September only a few fish remained in the inner and central estuary.

The pattern of outmigration in North Bay merits separate consideration because the Humptulips River, at the northern end of Grays Harbor, is a large contributor of Chinook salmon and production in the system is heavily influenced by contributions from the hatchery on the Humptulips River (572,214 and 545,867 Chinook smolts released in 2011 and 2012; data provided by staff at the WDFW Montesano office). Unmarked YOY Chinook salmon were present at high densities (>200 fish/ha) at the mouth of the Humptulips River from April to June, falling slightly in July (150-200 fish/ha); moderate densities were still present in August. As in the estuary at large, hatchery (hatchery) YOY Chinook salmon appeared later in the year, in June at the mouth of the Humptulips River. Surprisingly, they were present only at low densities (10-50 fish/ha) in June and July, and were rarely caught thereafter; typically hatchery releases result in large pulses of fish moving downstream together, but this was not reflected in our catch in 2012.

Coho salmon

Although overall coho salmon catch declined slightly in 2012, YOY coho were also captured in each month of sampling, although very few were captured in February (N=3) and September (N=10) (Figure 8b). Juvenile coho salmon densities were several times smaller than Chinook and chum salmon. The YOY coho, all of which are unmarked in the Chehalis Basin, were present at moderate densities (50-100 fish/ha) in the

Hoquiam River system (multiple forks) and at low densities in the surge plain, inner estuary and South Bay in March (Figure 9c). Densities in the Hoquiam system were higher than the main estuary through most of the sampling season, with the highest densities (>200 fish/ha) occurring in June-August; by September, densities were low (<50 fish/ha) everywhere. YOY coho densities were also higher in the lower Humptulips River than in the main estuary in April and June-September, although the densities were always lower (<50 fish/ha) than in the Hoquiam system. After June, there did not appear to be much of an influx of YOY coho from the mainstem Chehalis River (Figure 9c).

Yearling coho salmon smolts were mainly present from March-June in 2012, but hatchery yearlings were mainly present only in April and May (Figures 9d, e). The unmarked yearlings were captured in high densities (>200 fish/ha) only in April (inner estuary, Charlie Creek site) and June (Hoquiam River), and were at moderate densities in April (Humptulips mouth, surge plain) and May (Charlie Creek, South Bay near the Westport Marina). At the remaining sites, they were captured only at low (<50 fish/ha) densities, mostly in April and May; by June, the majority of yearlings appear to have exited the system.

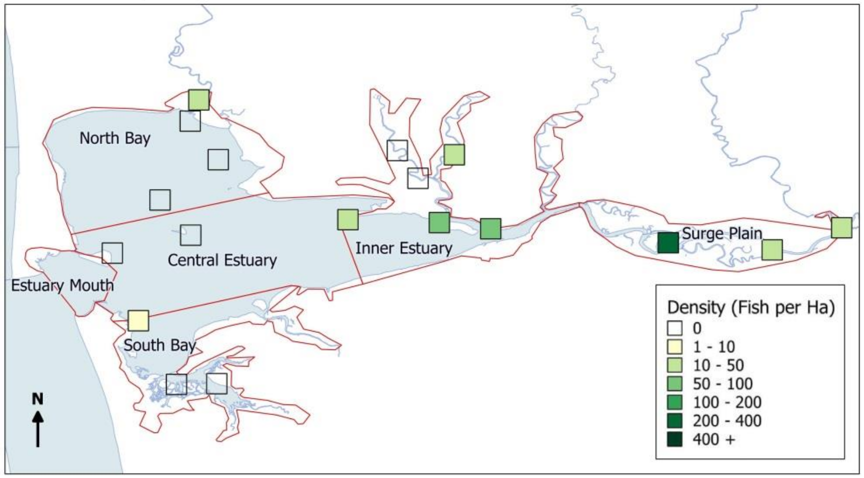
Chum salmon

Based on their life history, chum salmon fry typically enter an estuary from early February to late May, with the peak typically occurring in late March. Chum salmon (all YOY) were already present at high densities (>200 fish/ha) throughout much of the estuary when our sampling commenced in February (Figure 9f). Unlike in 2011, when chum salmon were largely absent from North Bay, they appeared to utilize North Bay habitats extensively from February-June in 2012. This may have been because we caught more than twice as many chum in 2012 than in 2011, though the result is more likely due to the fact that we did not begin sampling until late March in 2011. Chum were also present at high densities in the surge plain, inner estuary, central estuary and South Bay in March and April; by May, their densities had declined in the surge plain and South Bay. As with unmarked YOY Chinook and coho salmon, chum salmon appeared to emigrate from both the Humptulips and Hoquiam River systems. Abundance of chum peaked in April in 2012 (Figure 8c) and they had moved to sea by June (N=4).

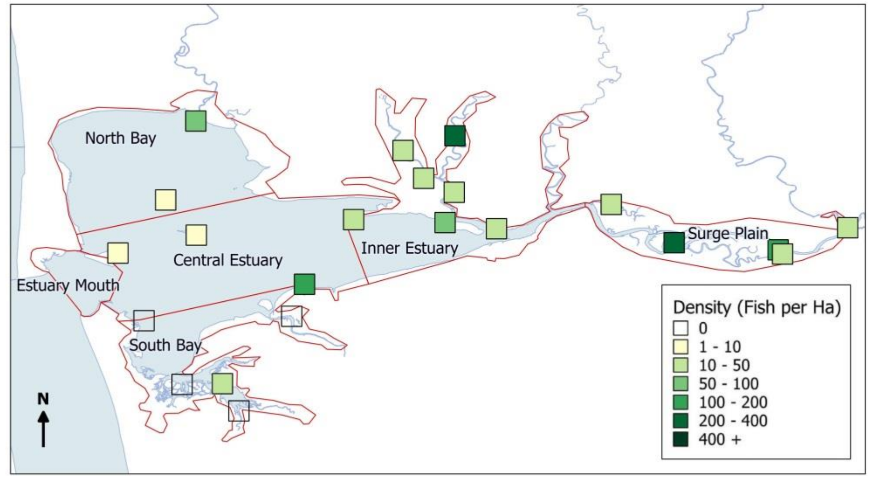
Fewer cutthroat trout were captured in 2012 (N=65) than 2011 (N=92), and the bulk of the steelhead were captured in one set at the Humptulips River mouth. As noted, only 4 bull trout were captured this year (two were captured in 2011). Because these species were not caught frequently and/or at high enough densities, few conclusions can be made about their distribution in 2012, since beach seining (shallow water) does not target these species effectively.

Figure 9a: Density and distribution of unmarked YOY Chinook salmon in 2012

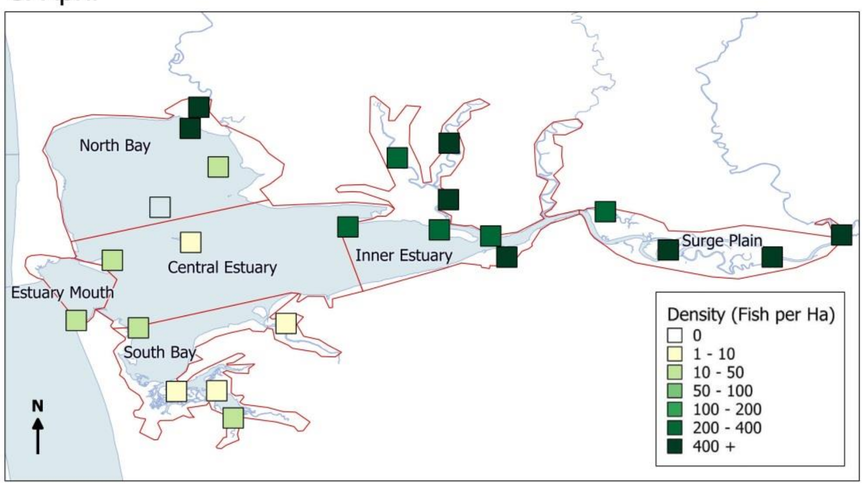
A. February



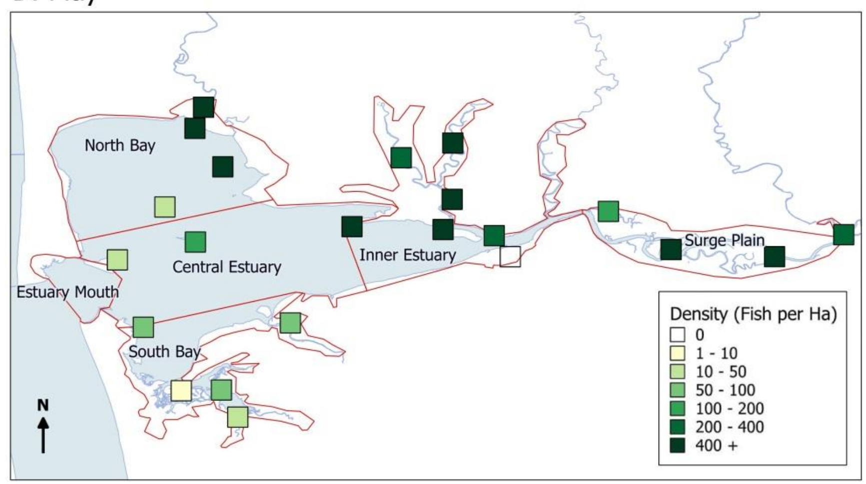
B. March



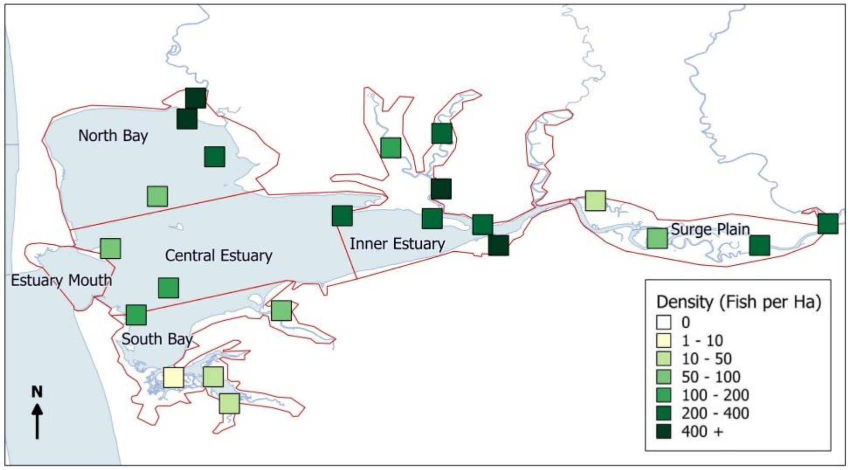
C. April



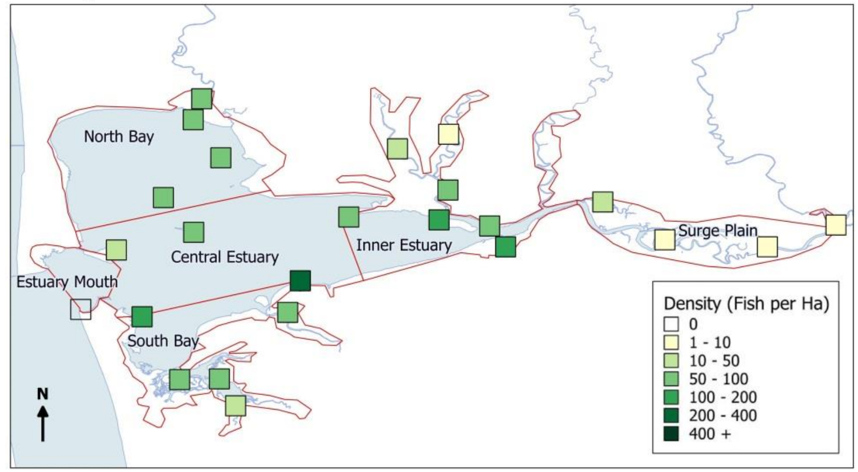
D. May



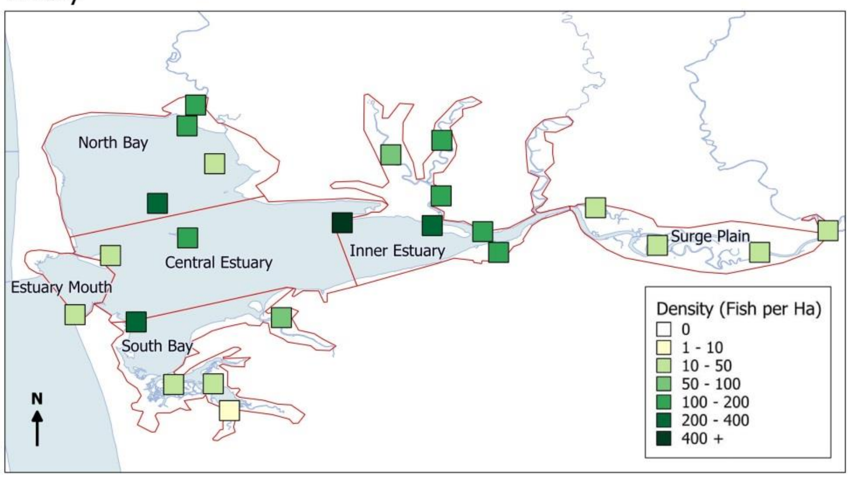
E. June



G. August



F. July



H. September

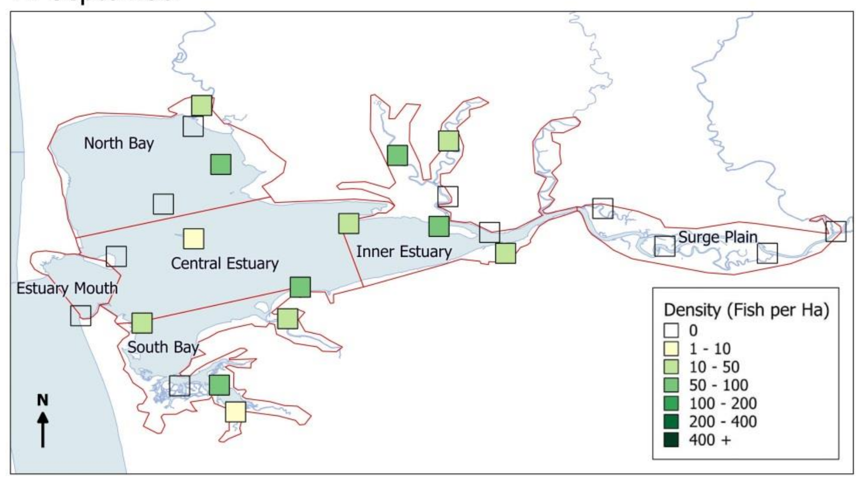
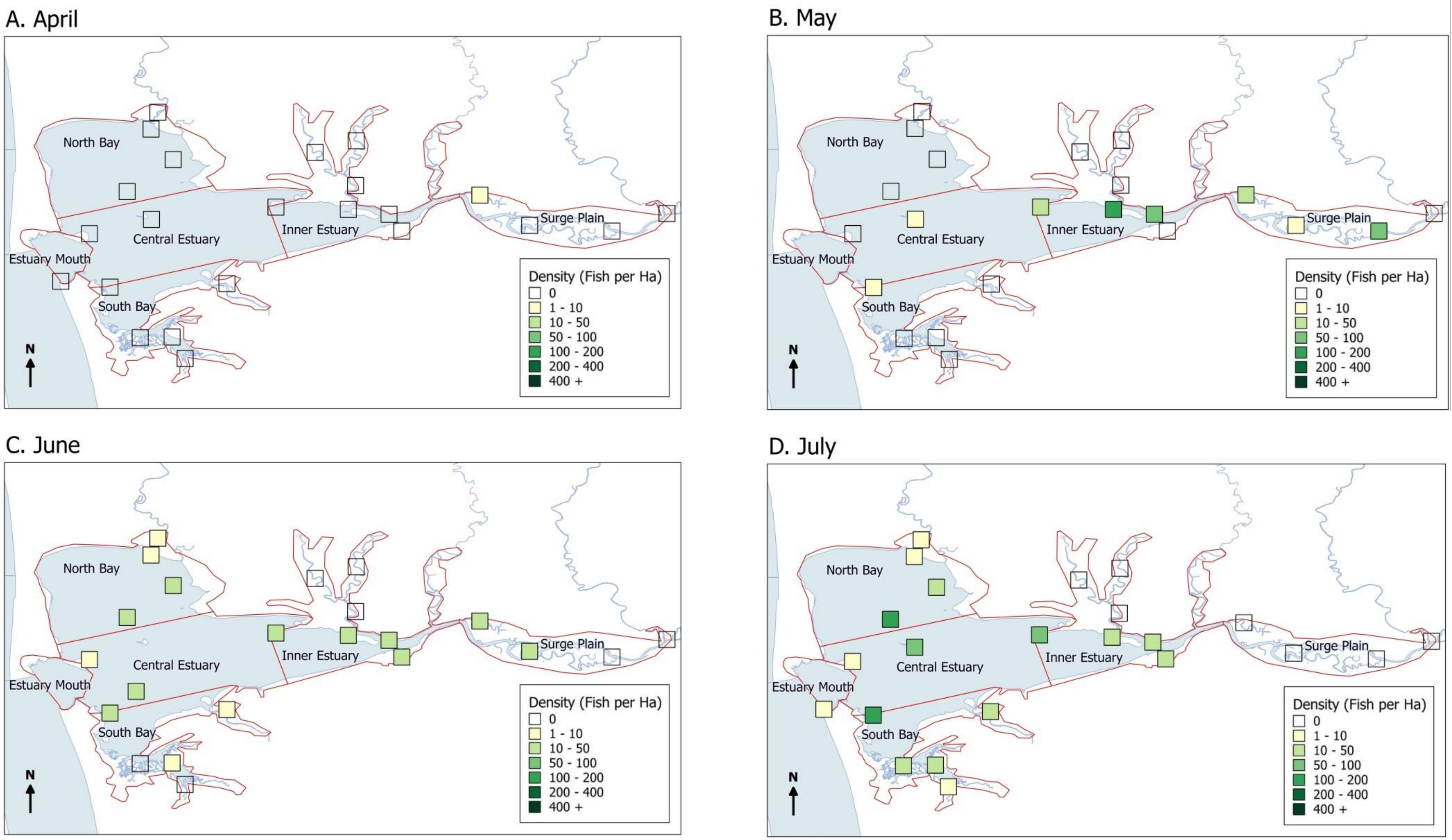
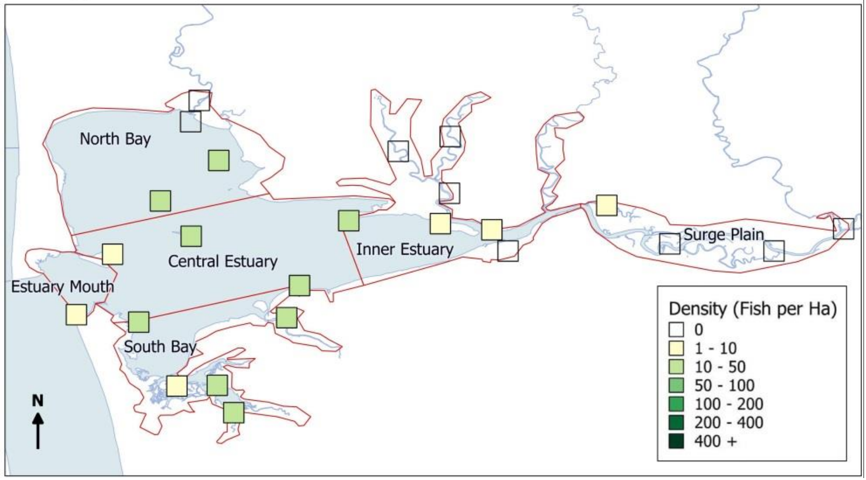


Figure 9b: Density and distribution of hatchery YOY Chinook salmon in 2012



E. August



F. September

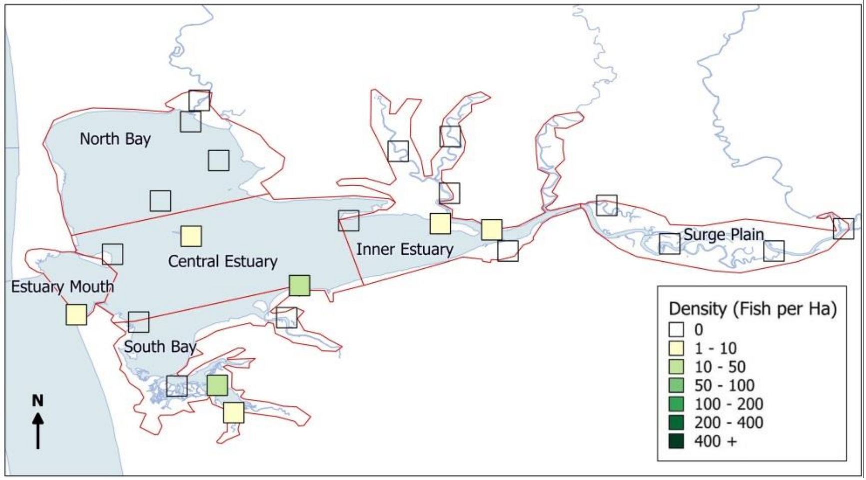
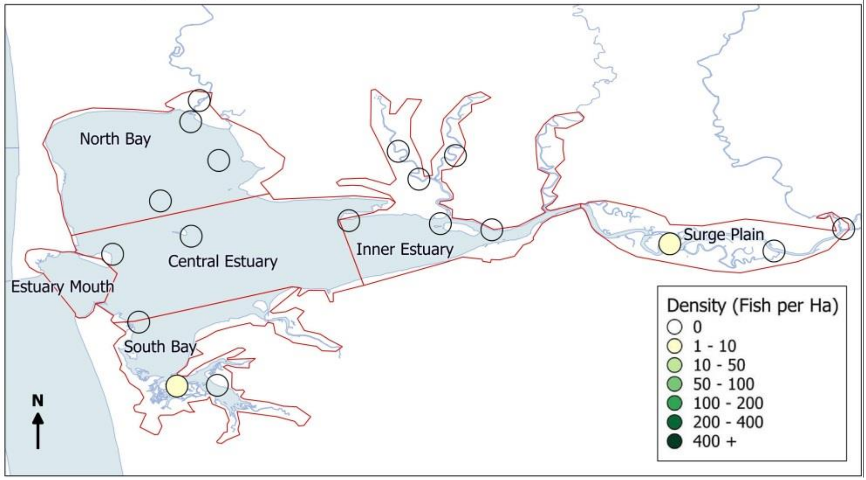
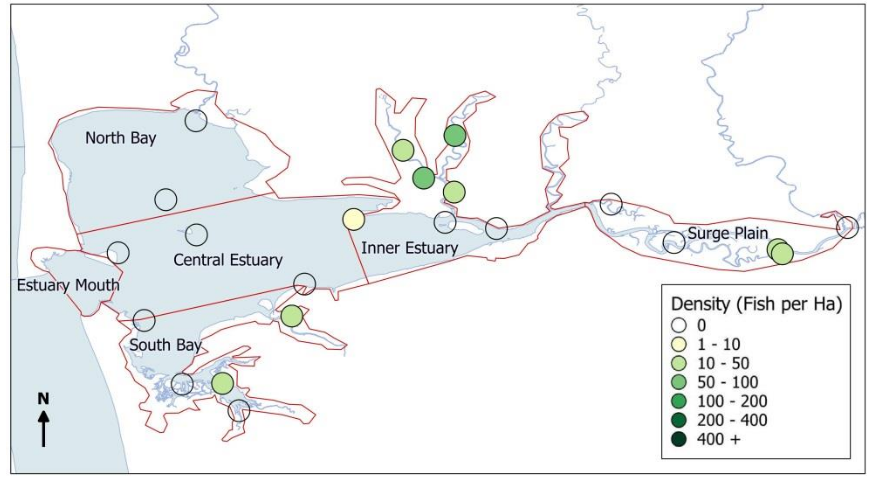


Figure 9c: Density and distribution of unmarked YOY coho salmon in 2012

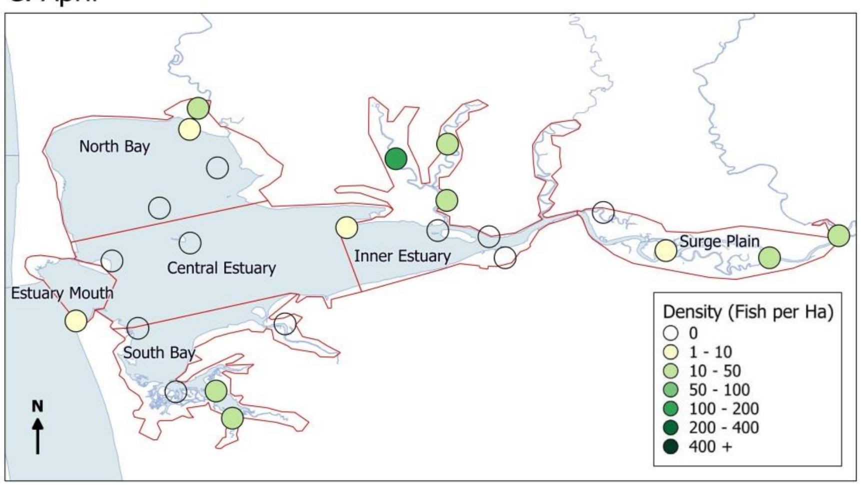
A. February



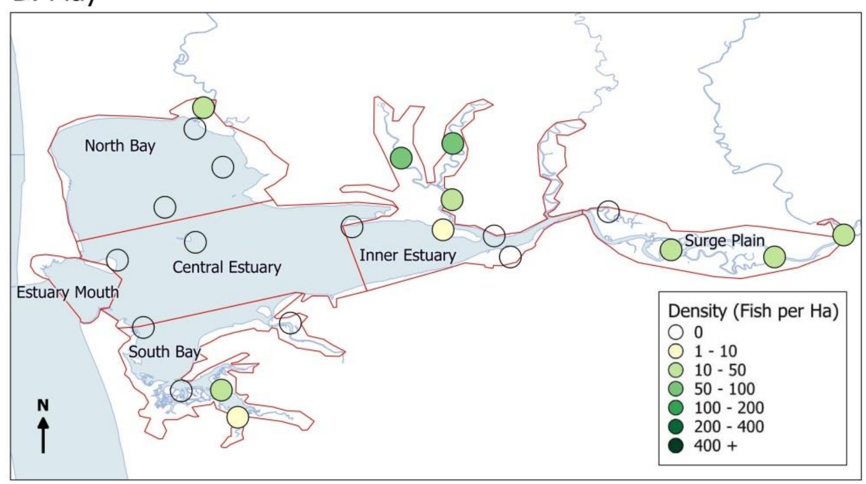
B. March



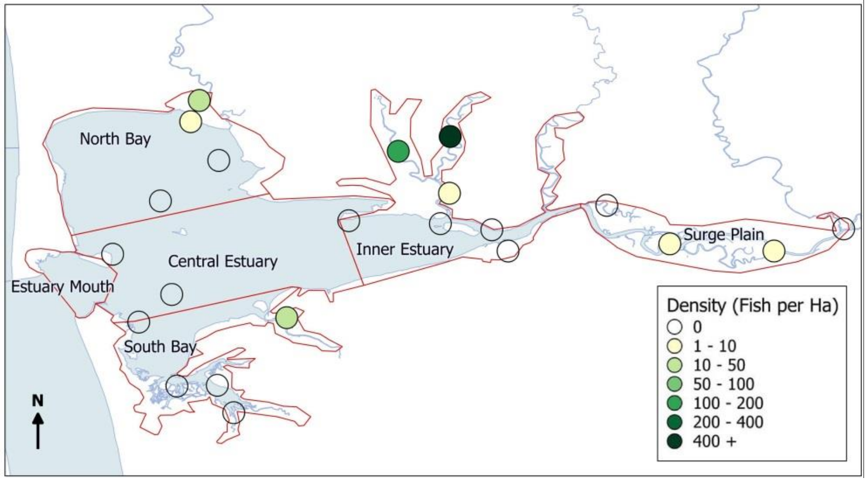
C. April



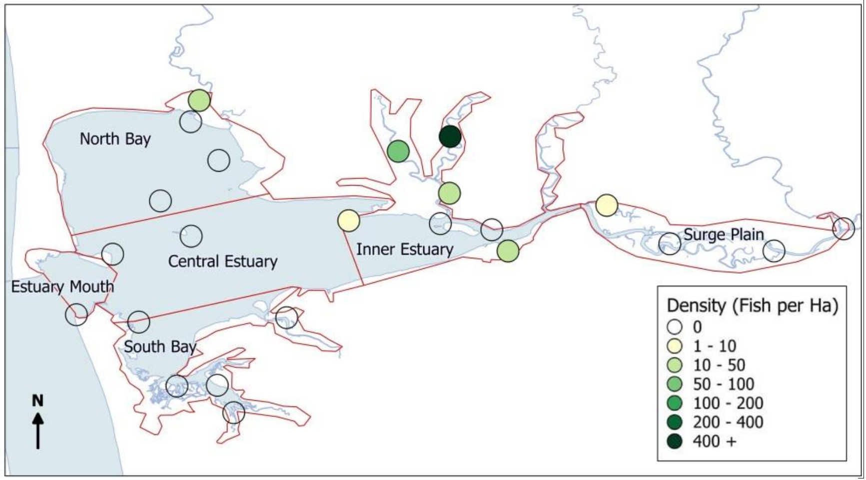
D. May



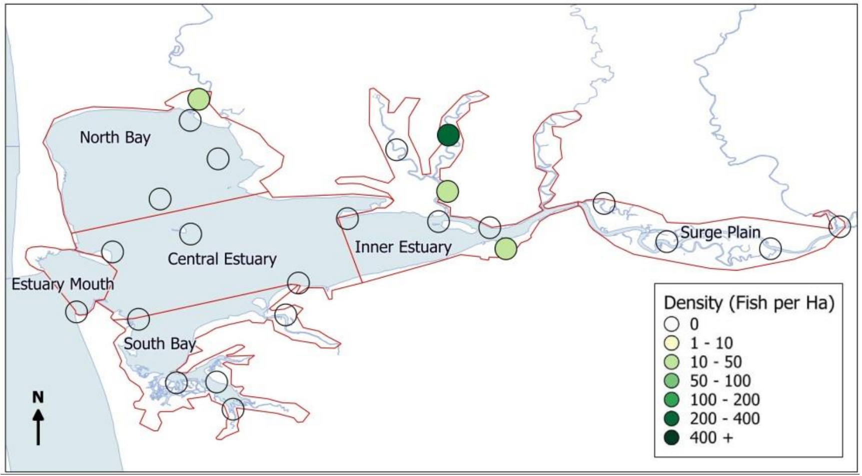
E. June



F. July



G. August



H. September

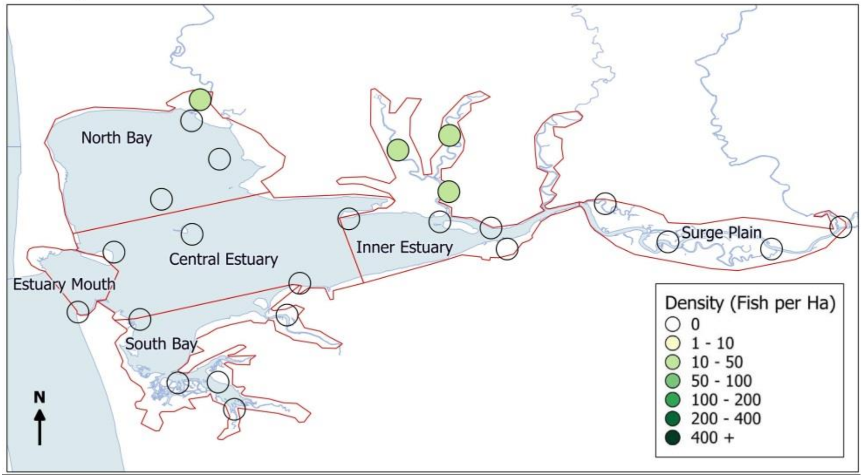


Figure 9d: Density and distribution of unmarked yearling coho salmon in 2012

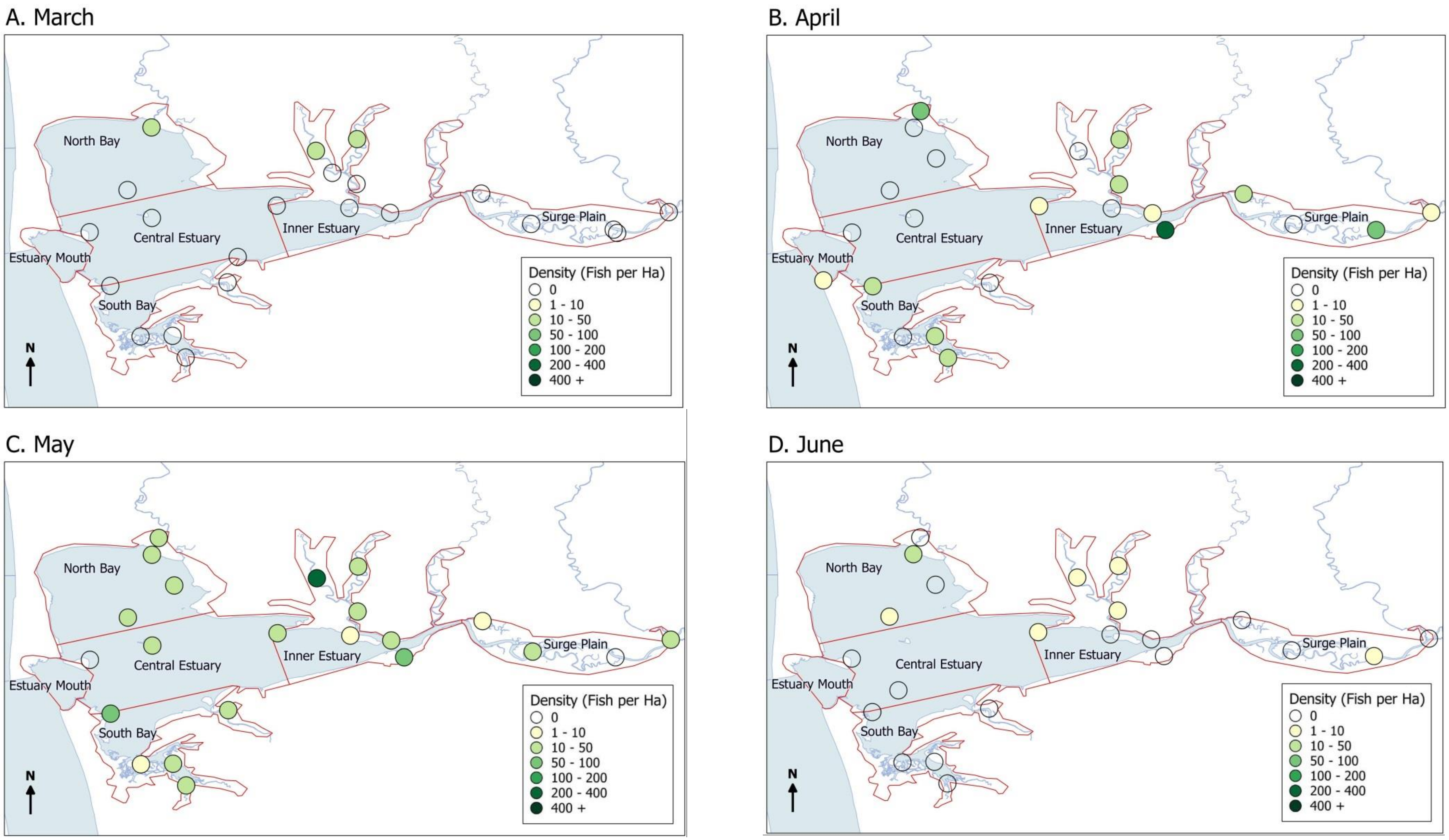
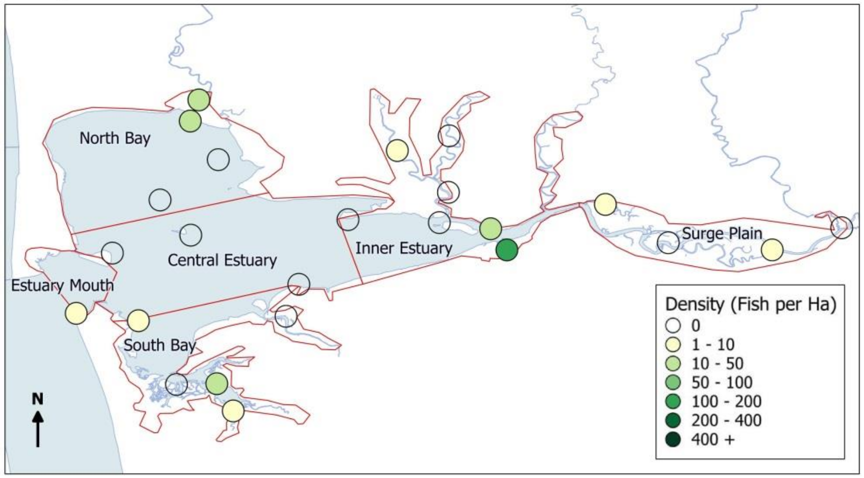


Figure 9e: Density and distribution of hatchery yearling coho salmon in 2012

A. April



B. May

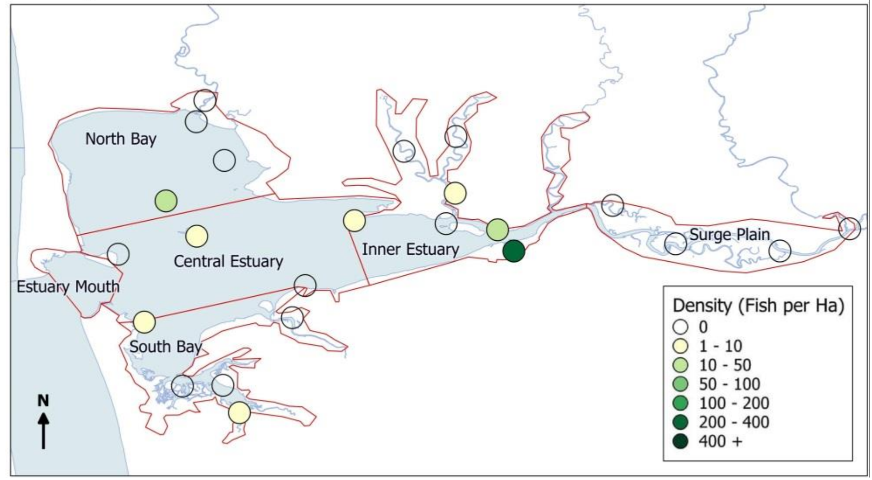
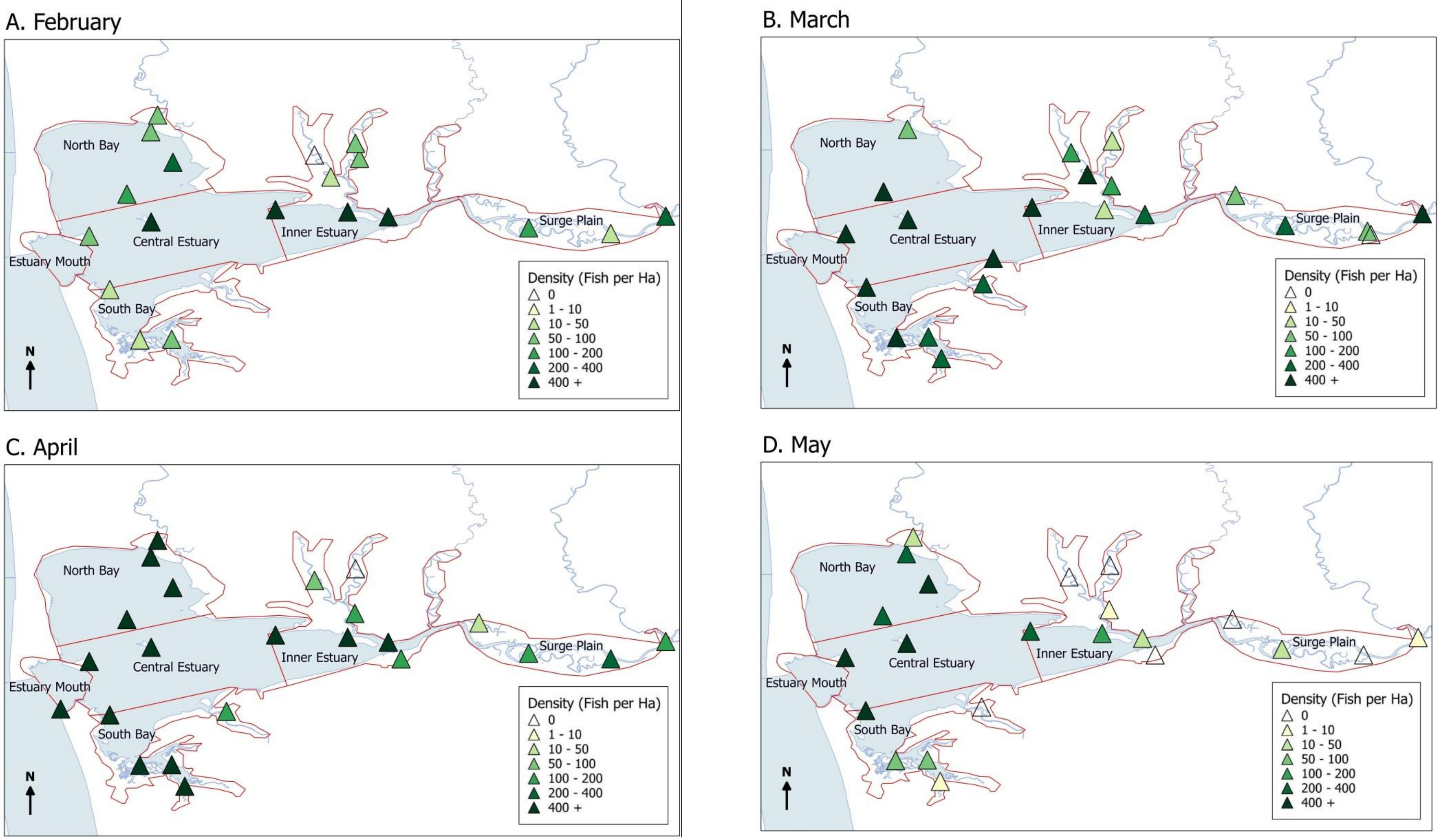
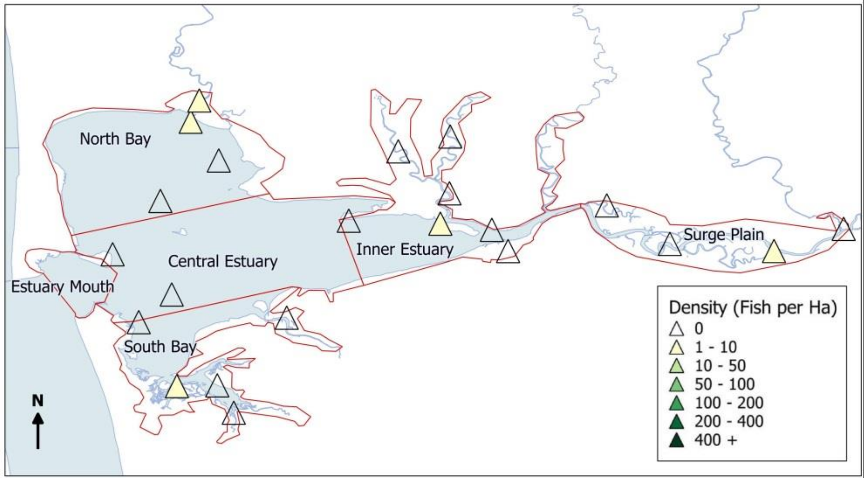


Figure 9f: Density and distribution of unmarked YOY chum salmon in 2012



E. June


North Bay
Central Estuary
Estuary Mouth
Inner Estuary
Surge Plain
South Bay
N
Density (Fish per Ha)
0
1 - 10
10 - 50
50 - 100
100 - 200
200 - 400
400 +

3.4 Salmon Occurrence and Abundance Modeling

In order to determine what factors influenced the occurrence and abundance of salmon across space and time in Grays Harbor, we constructed separate series of statistical models relating salmon abundance and occurrence to a series of temporal, spatial, and environmental variables. Models of abundance and occurrence were separated because of the inability to differentiate very low (undetected) abundance from cases where salmon were not present; the inclusion of catches with zero fish (of a particular age class/species) in models of abundance could preclude obtaining informative results. Occurrence models were therefore used to understand what factors influenced whether salmon were present at a site on a given occasion, and abundance models were used to understand what factors influenced abundance only when salmon were in fact present (Mullahy 1986). For occurrence models we used GLMs employing a logit-link function which assumes a binomial error distribution and relates a binary response (presence/absence in this case) to linear combinations of predictor variables on a logit scale (Nelder & Wedderbu 1972). For abundance analyses we used GLMs employing a log-link function and assuming a negative binomial distribution, which is appropriate for over-dispersed count data (e.g. most catches had a few salmon, but some had hundreds), and functions similarly to a Poisson distribution. This analysis related catches of salmon, censored to remove occasions where no salmon were captured, to linear combinations of predictor variables on a log-scale. Separate occurrence and abundance models were constructed for each species, age class, and origin (hatchery or unmarked). For each species, age, and origin, all subsets of up to five predictor variables (Table 5), as well as the full model (all variables included) were tested in a series of additive main effects models.

We used a multi-model inference approach to evaluate how well models fit the data. Akaike's Information Criterion for small sample sizes (AICc) was calculated to compare and rank the various models (Burnham & Anderson 2002)). The difference between the AICc of a candidate model and the model with the lowest score (ΔAICc) was calculated and used to rank models. Models with ΔAICc less than or equal to 3 were considered to have substantial support, while those with values from 4 to 7 had some support and those greater than 7 had little support (Burnham & Anderson 2002). We also calculated Akaike weights (w_i), indicating the strength of evidence supporting *i* as the best model, and relative likelihoods. Together these metrics were used to identify the best model or model group. All statistical analyses were performed in R (R Team 2012) unless otherwise noted.

Table 5: Variables used in GLM models used to predict salmon occurrence across space and time in the Grays Harbor estuary in 2011 and 2012.

Variable	Definition	Type	Mean	Range
Month	Month	Factor	--	2 – 9
Year	Year	Factor	--	2011 – 2012
Zone	Area of Grays Harbor	Factor	--	North, South, Central, Inner, Surge Plain
Habitat	Habitat Type	Factor	--	Forested, Scrub/Shrub Cover, High Emergent Marsh, Aquatic Vegetation Bed, Mud Flat, Sand Flat, Cobble/Gravel/Sand Beach
Salinity	Surface Water Salinity (ppt)	Continuous	15.4	0 – 31.4
Temp	Surface Water Temperature	Continuous	15.1	7.1 – 21.4
TideH	Tide Height (ft)	Continuous	3.0	-2.8 – 11.7
TideS	Tide Stage	Factor	--	Ebb, Flood, High Water, Low Water

The best model of unmarked YOY Chinook occurrence included month, water temperature, salinity, habitat, and year, while the best model of abundance substituted year for zone (not surprising given our increased catch of YOY Chinook salmon in 2012) (Table 6). Unmarked YOY Chinook occurrence and abundance were negatively correlated with temperature, rose from March through May, before steadily dropping through September, and were notably less common in beach habitats than any other habitat types. Unmarked YOY Chinook abundance was greater in North Bay than in other zones and lower in South Bay and the central estuary. Abundance also declined from June through September, <u>but occurrence did not</u>. Model selection results for occurrence were not well differentiated, with the three best models having $\Delta AICc < 3$. Abundance models were slightly better differentiated than models of occurrence, with just the two best models having $\Delta AICc < 3$, and all other model's $\Delta AICc > 7$. The similar inputs in best models of both types lend confidence to the importance of the variable selected.

The best model of YOY hatchery Chinook occurrence included month, water temperature, zone, habitat type, and year, while the best model of abundance substituted salinity for temperature and excluded year (Table 6). Models of hatchery YOY Chinook occurrence and abundance were not well differentiated, however, with several models having $\Delta AIC_c < 3$. YOY hatchery Chinook were generally not present until May in 2012 (June in 2011) and occurrence and abundance were greater thereafter, accounting for the importance of month. YOY hatchery Chinook occurrence was negatively correlated with water temperature, was greater in 2012 than 2011, and was low in forested sites, scrub/shrub cover, emergent marsh, and cobble beach habitat types, while abundance was notably low at beach sites. Hatchery Chinook occurred mainly in North Bay, central estuary, and South Bay, while abundance was lower in these three zones than the surge plain and inner estuary. This pattern indicates a direct downstream migration of hatchery YOY Chinook salmon into the main estuary where the smolts dispersed across a large area. Hatchery Chinook were present in the estuary for a shorter period of time than unmarked Chinook and in were at higher densities in the upper versus the lower estuary, where they occurred more often, but were also more dispersed.

Table 6: Model selection results for GLM models relating Chinook salmon abundance and occurrence to time of year, and environmental variables. The five best models including the full model, are listed from most plausible (ΔAIC_c=0) to least plausible. Models are separated by age class and by hatchery/unmarked origin.

Model[1]	AICc	ΔAICc	Relative likelihood	Akaike weight (w_i)	R^2	Cumulative Weight
YOY Unmarked Occurrence						
Month + Temp + Salinity + Habitat + Year	387.94	0.00	1.00	0.36	0.26	0.36
Month + Temp + Habitat + Year	388.01	0.07	0.97	0.35	0.25	0.71
Month + Temp + Habitat + TideH + Year	390.05	2.11	0.35	0.13	0.25	0.83
Month + Temp + Year	392.17	4.23	0.12	0.04	0.22	0.87
Month + Temp + TideH + Year	393.65	5.71	0.06	0.02	0.22	0.89
YOY Unmarked Abundance						
Month + Temp + Salinity + Zone + Habitat	3195.88	0.00	1.00	0.59	0.44	0.59
Month + Temp + Salinity + Zone + Habitat + TideS + Year	3196.78	0.90	0.64	0.38	0.45	0.97
Month + Temp + Zone + Habitat + TideS	3203.02	7.14	0.03	0.02	0.45	0.99
Month + Temp + Zone + Habitat	3204.60	8.72	0.01	0.01	0.44	1.00
Month + Temp + Zone + Habitat + Year	3206.78	10.90	0.00	0.00	0.44	1.00
YOY Hatchery Occurrence						
Month + Temp + Zone + Habitat + Year	395.53	0.00	1.00	0.33	0.39	0.33
Month + Salinity + Temp + Habitat + Year	395.64	0.12	0.94	0.31	0.37	0.65
Month + Temp + Habitat + TideH + Year	398.23	2.70	0.26	0.09	0.37	0.74
Month + Temp + Habitat + Year	398.52	2.99	0.22	0.07	0.37	0.81
Month + Temp + Habitat + TideS + Year	399.16	3.64	0.16	0.05	0.38	0.86
YOY Hatchery Abundance						
Month + Salinity + Zone + Habitat	671.41	0.00	1.00	0.42	0.52	0.42
Month + Salinity + Zone + Habitat + Year	672.78	1.37	0.50	0.21	0.52	0.63
Month + Temp + Zone + Habitat	673.57	2.17	0.34	0.14	0.51	0.78
Month + Temp + Salinity + Zone + Habitat	674.13	2.72	0.26	0.11	0.52	0.88
Month + Temp + Zone + Habitat + Year	675.23	3.82	0.15	0.06	0.51	0.95

[1]Yearling Chinook occurrence and abundance were not modeled since few were encountered.

The best model of unmarked YOY coho salmon occurrence included month, salinity, zone, habitat type, and year, while the best model of abundance included salinity, habitat type, tide stage and year (Table 7). Unmarked YOY coho occurrence and abundance were negatively correlated with salinity, with occurrence declining quickly at salinities above 5 ppt, and coho essentially absent above 20 ppt. Occurrence of unmarked YOY coho was greater in the inner estuary than other zones, and greater in forested and shrub/scrub cover sites than other habitat types, likely a reflection of their high abundance in the Hoquiam River system (central estuary zone), where these habitats predominate. Both the abundance and occurrence of coho salmon were lower in 2012 than 2011. Model selection results were modestly well differentiated (two models with ΔAIC*c* < 3). All of the best models included salinity, suggesting that osmoregulation was a dominate factor influencing unmarked YOY coho occurrence.

The best model of yearling unmarked coho occurrence included month and water temperature, while the best abundance model also included salinity and year (Table 14). Unmarked yearling coho were only present from March through June, peaking in April and May, corresponding to a rapid period of smolt emigration. Both occurrence and abundance were negatively correlated with temperature. The best model of hatchery coho abundance included month, as was expected given that they were essentially present only in April and May. Both hatchery and unmarked yearling coho occurrence peaked in May. Models of unmarked yearling coho occurrence and abundance were not well differentiated, complicating interpretation and inference, while modeling of hatchery yearling coho abundance was not performed due to the small number of occasions in which they were encountered.

Table 7**:** Model selection results for GLM models relating coho salmon occurrence and abundance to time of year, and environmental variables. The five best models including the full model, are listed from most plausible (ΔAIC*c*=0) to least plausible. Models are separated by age class and by hatchery/unmarked origin.

Model[1]	AIC*c*	ΔAIC*c*	Relative likelihood	Akaike weight (w_i)	R^2	Cumulative Weight
YOY Unmarked Occurrence						
Month + Salinity + Zone + Habitat + Year	436.82	0.00	1.00	0.57	0.35	0.57
Salinity + Zone + Habitat + TideH + Year	439.37	2.55	0.28	0.16	0.33	0.72
Salinity + Temp + Zone + Habitat + Year	440.03	3.21	0.20	0.11	0.33	0.84
Salinity + Zone + Habitat + Year	440.11	3.29	0.19	0.11	0.32	0.95
Month + Salinity + Temp + Zone + Habitat + TideS + TideH + Year	442.53	5.70	0.06	0.03	0.36	0.98
YOY Unmarked Abundance						
Salinity + Habitat + TideS + Year	896.03	0.00	1.00	0.59	0.37	0.59
Temp + Salinity + Habitat + TideS + Year	898.36	2.33	0.31	0.18	0.37	0.77
Salinity + Zone + Habitat + TideS + Year	899.22	3.19	0.20	0.12	0.40	0.89
Salinity + Habitat + TideS	900.86	4.83	0.09	0.05	0.34	0.94
Temp + Salinity + Habitat + TideS	903.06	7.03	0.03	0.02	0.34	0.96

Yearling Unmarked Occurrence						
Month + Temp	264.22	0.00	1.00	0.21	0.44	0.21
Month + Temp + year	265.17	0.96	0.62	0.13	0.44	0.35
Month + Salinity + Temp	265.34	1.13	0.57	0.12	0.43	0.47
Month + Temp + TidH	266.19	1.97	0.37	0.08	0.44	0.55
Month + Salinity + Temp + Year	266.31	2.10	0.35	0.08	0.44	0.62
Yearling Unmarked Abundance						
Month + Temp + Salinity + Year	446.80	0.00	1.00	0.22	0.26	0.22
Temp + Salinity + Year	447.39	0.59	0.74	0.16	0.18	0.38
Month + Salinity + Year	447.77	0.97	0.62	0.14	0.23	0.52
Salinity + Year	449.17	2.37	0.31	0.07	0.14	0.59
Month + Temp + Salinity + TideS + Year	449.61	2.81	0.25	0.05	0.31	0.64

[1]Yearling hatchery coho occurrence and abundance were not modeled since few were encountered.

The best model of chum salmon occurrence included month, water temperature, estuary zone, habitat type, and tide stage, while the best model of chum abundance included month, water temperature and habitat. Chum salmon occurrence was high February through May, decreased in June, and was absent thereafter; abundance was highest in April and decreased substantially in May and June. Occurrence and abundance were lower in forest, scrub/shrub and emergent marsh habitats. Models of chum occurrence and abundance were poorly differentiated, with multiple models having ΔAIC*c* < 3 (Table 8). However, all of the best models included month, suggesting that timing was the dominate factor influencing chum occurrence, as expected from their life history pattern. The inclusion of temperature in some models may have resulted from the colder conditions which were generally prevalent during the early season, when chum salmon were present.

Table 8: Model selection results for GLM models relating chum salmon occurrence and abundance to time of year, and environmental variables. The five best models including the full model, are listed from most plausible (ΔAIC*c*=0) to least plausible.

Model1[1]	AICc	ΔAICc	Relative likelihood	Akaike weight (w_i)	R^2	Cumulative Weight
YOY Unmarked Occurrence						
Month + Temp + Zone + Habitat + TideS	198.98	0.00	1.00	0.15	0.76	0.15
Month + Salinity + Zone + Habitat + TideS	199.48	0.50	0.78	0.11	0.76	0.26
Month + Salinity + Zone + TideS + TideH	199.96	0.97	0.61	0.09	0.74	0.35
Month + Salinity + TideS + TideH + Year	200.35	1.36	0.51	0.07	0.73	0.43
Month + Salinity + TideS + TideH	200.90	1.92	0.38	0.06	0.76	0.48
YOY Unmarked Abundance						
Month + Temp + Habitat	1689.06	0.00	1.00	0.27	0.35	0.27
Month + Temp + Zone + Habitat	1690.44	1.38	0.50	0.14	0.38	0.41
Month + Temp + Habitat + Year	1690.75	1.70	0.43	0.12	0.35	0.53
Month + Temp + Habitat + Tide	1690.85	1.79	0.41	0.11	0.37	0.64
Month + Salinity + Habitat	1691.25	2.19	0.33	0.09	0.34	0.73

[1]All chum were assumed to be wild due to the inability to differentiate hatchery chum; few are marked externally.

3.5 Salmonid Habitat Usage by Habitat Type

Estuarine Habitat Use by Salmon Species

The following bar graphs show data regarding habitat usage by species (Figure 10). While the figures are useful for comparing relative habitat usage between species, they do not take into account the effects of other variables (water temperature, salinity, density dependence, etc.) that may affect habitat utilization by juvenile salmonids; for this reason, the final summary (see Section 6), incorporating the regression modeling of physical variables, provides a better overall picture of the variables determining habitat usage. Note that the Y-axis scales vary between species due to large differences in the densities encountered; the horizontal gridlines in the graphs differ to draw the reader's attention to this point.

Overall habitat use by species

Overall, unmarked YOY Chinook salmon were widely distributed in all habitat types, highest in scrub/shrub and lowest in beach and sand flats. Hatchery YOY Chinook salmon were captured at highest densities in sand flat, mud flat and aquatic vegetation bed habitats but were at low densities everywhere in comparison with unmarked YOY Chinook salmon (Figure 10a). Not enough yearling wild Chinook salmon were captured to allow generalizations**.**

Unmarked YOY coho salmon were less widespread than Chinook salmon in 2012; densities were highest in forest and scrub/shrub habitats and few were captured elsewhere; none were captured at sand flat sites. Unmarked yearling coho, though present at much lower densities than YOY coho salmon, were captured in highest densities at forested sites, and at roughly equal densities in scrub/shrub, high emergent marsh and sand flat sites. Few hatchery yearling coho salmon were captured, making it difficult to draw conclusions, though hatchery yearlings were at highest densities in high emergent marsh habitat (Figure 10b).

In 2012, chum salmon (all unmarked YOY) were found at highest densities at aquatic vegetation bed habitats, though they were also at high densities off gravel/cobble/sand beach sites (particularly Damon Point, just North of the estuary mouth) and sand and mud flats, in that order. Chum salmon were very rare in forested or scrub/shrub cover habitats (Figure 10c).

Cutthroat trout were rarely caught, but densities were highest at scrub/shrub, high emergent marsh, and forested sites (Figure 10d).

Note: In Figure 10 (below), X-axis labels are: B= cobble/gravel/sand beach; SF= sand flat; MF= mud flat; AVB= aquatic vegetation beds; HEM= high emergent marsh; SC= scrub/shrub; and F= forested.

Figure 10a. Chinook salmon density, by habitat type, 2012

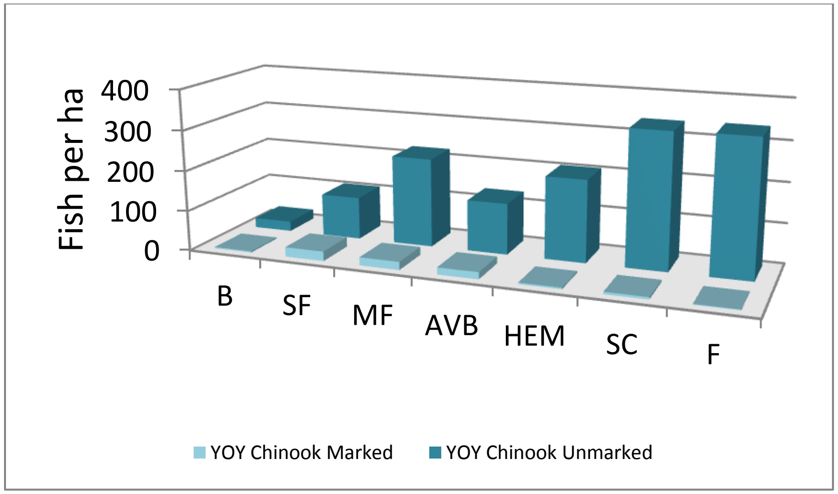


Figure 10b. Coho salmon density, by habitat type, 2012

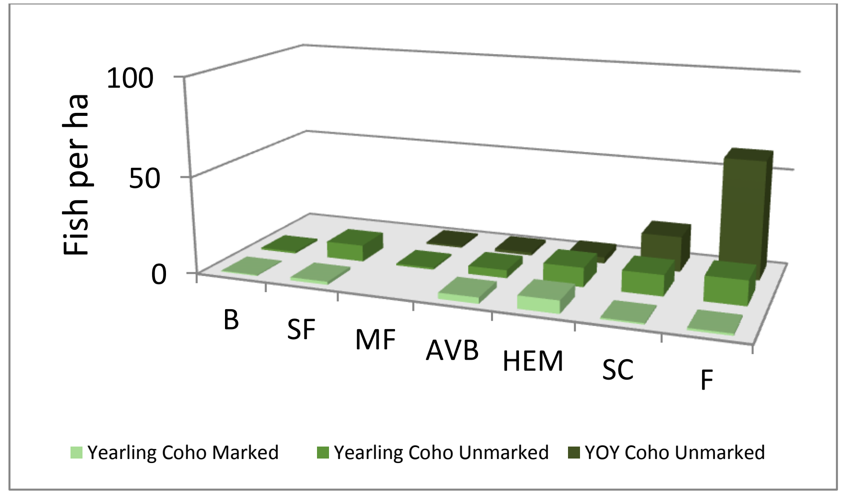


Figure 10c. Chum salmon density, by habitat type, 2012

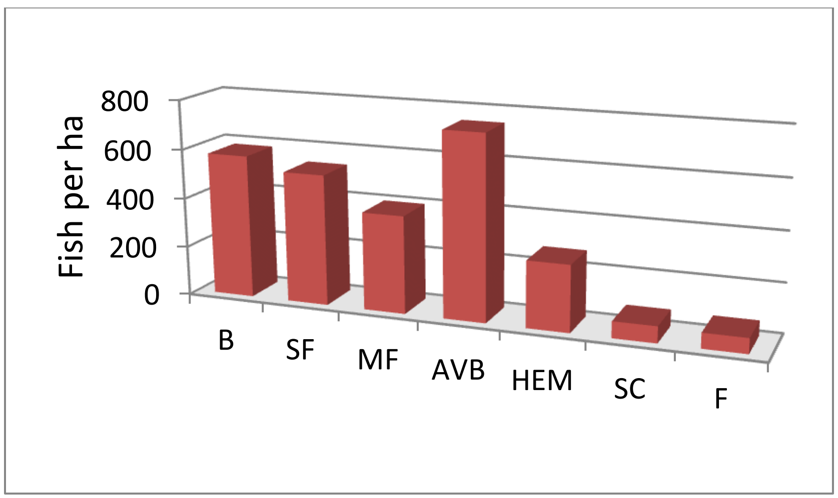


Figure 10d. Cutthroat trout density, by habitat type, 2012

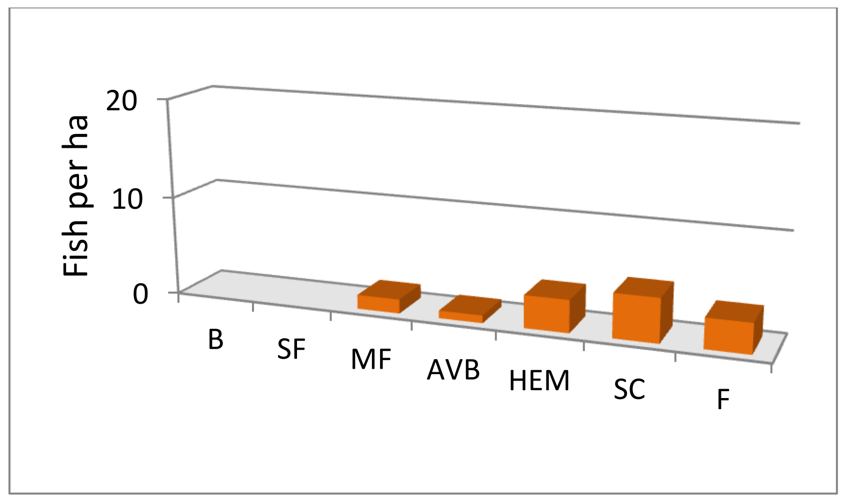


Table 9: Median densities for unmarked YOY Chinook, unmarked YOY coho, and YOY chum, among habitat types.

	Chinook YOY unmarked	Coho YOY unmarked	Chum YOY unmarked
Cobble Beach Habitat	19.0		975.5
Sand Flats	92.79		752.3
Mud Flats	176.1	9.5	171.3
Aquatic Vegetation Beds	74.9	8.2	480.6
High Emergent Marsh	54.82	10.7	121.4
Scrub/Shrub Cover	167.7	21.4	149.9
Forested	139.2	48.2	45.2

Data on habitat usage was also plotted using box plots (below; Figure 11) to provide another visual depiction of overall habitat usage; these data are further summarized in the synthesis, which includes the regression modeling (Section 6).

Figure 11a: Box plots showing habitat usage by young-of-the-year (YOY) Chinook salmon in the Grays Harbor estuary in 2012. Outliers are shown beyond the upper quartile bar (connected to the boxes by dashed lines); note that the width of the boxes is proportional to how commonly salmon were captured in that habitat. X-axis labels are: B= cobble/gravel/sand beach; SF= sand flat; MF= mud flat; AVB= aquatic vegetation beds; HEM= high emergent marsh; SC= scrub/shrub; and F= forested.

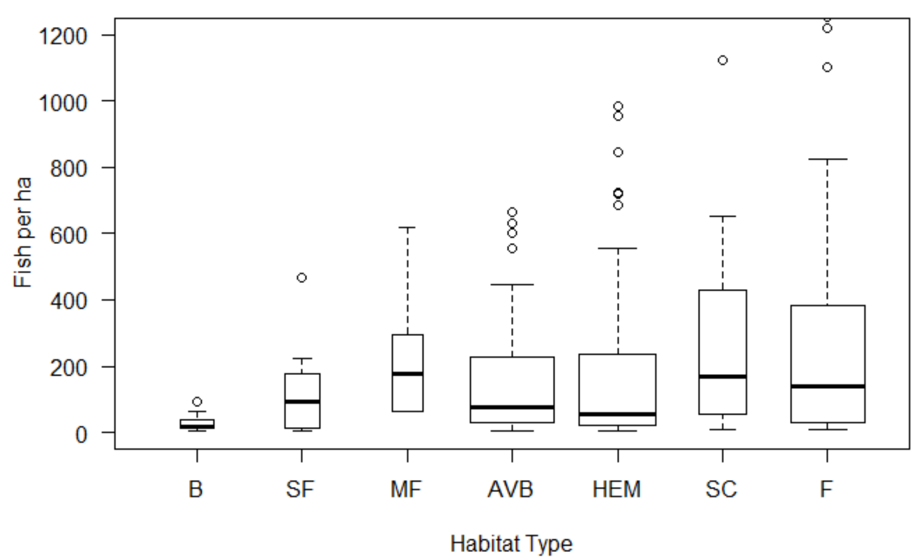


Figure 11b: Box plots showing habitat usage by young-of-the-year (YOY) coho salmon in the Grays Harbor estuary in 2012. Outliers are shown beyond the upper quartile bar (connected to the boxes by dashed lines); note that the width of the boxes is proportional to how commonly salmon were captured in that habitat.

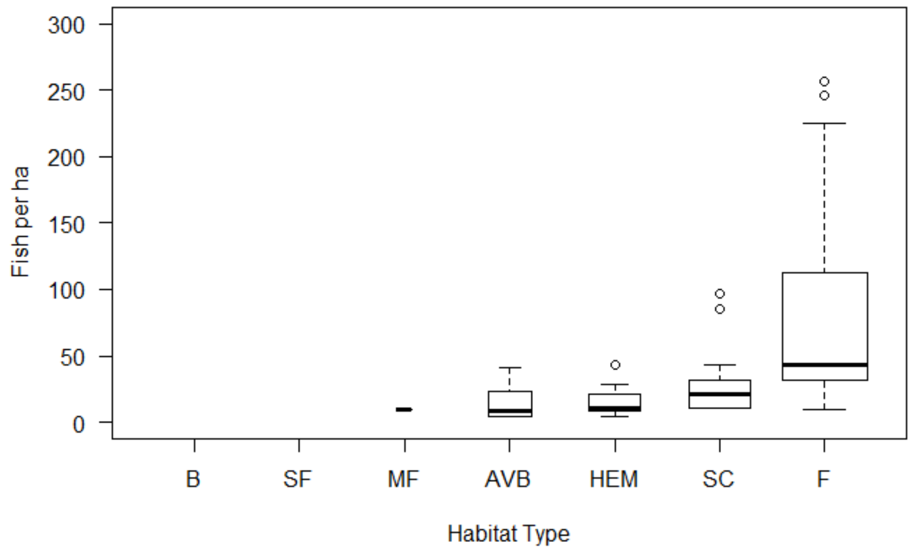
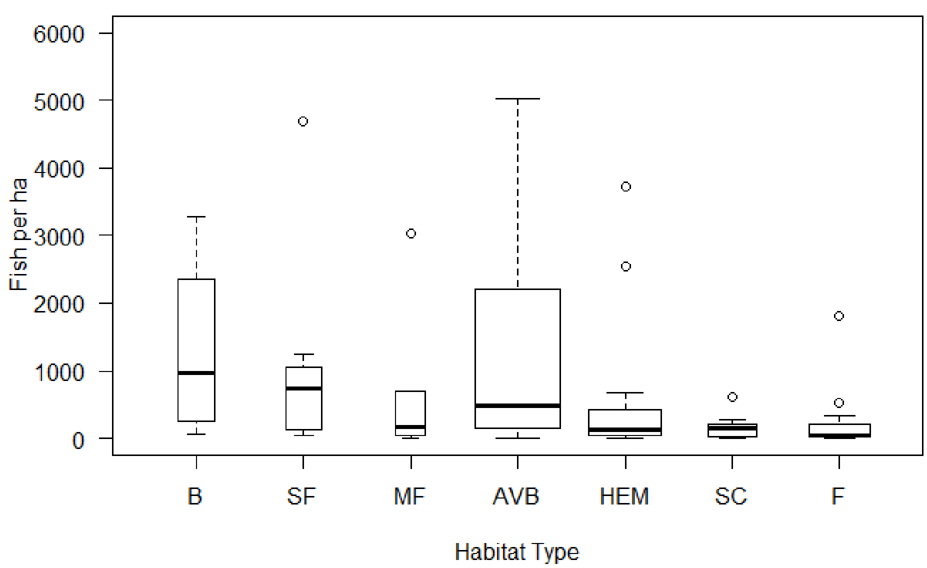


Figure 11c: Box plots showing habitat usage by chum salmon (all are YOY) in the Grays Harbor estuary in 2012. Outliers are shown beyond the upper quartile bar (connected to the boxes by dashed lines); note that the width of the boxes is proportional to how commonly salmon were captured in that habitat.



3.6 Coded Wire Tag (CWT) Recoveries/Analysis

Only 5 yearling coho salmon were recovered with CWT in 2012. CWTs were extracted from fish in the lab and codes were read under magnification (40X). In 2011, codes were matched to the Pacific States Marine Fisheries Commission Regional Mark Information System (RMIS) database, and to the WDFW Wild Salmon Production/Evaluation Unit database. The codes were further verified by contact with individual hatcheries, fish biologists within WDFW, and biologists at the Quinault Tribe Department of Natural Resources (QDNR). At the time this report was generated, none of the CWT codes we recovered in 2012 were present in the regional tagging database; it appears that these codes have not yet been updated and we will provide this information when it becomes available.

In 2011, the recovery of juvenile coho salmon that originated from the Queets River indicated that the Grays Harbor estuary was utilized by non-basin hatchery fish for feeding, physiological maturation, or predator avoidance. A 2006 report (Kurt L Fresh et al. 2006) observed a similar type of pattern for Chinook salmon (use of an area by non-local hatchery salmon) in Puget Sound. It is also reasonable to hypothesize that naturally produced Chinook salmon from out of basin are also utilizing the estuary, given that these hatchery fish are entering estuarine waters at the same time as some of the wild smolts; this was addressed by taking fin clip samples from Chinook smolts for genetic analysis in 2012.

Section 4: Non-Salmonid Species

4.1 Non-Salmon Species Catch

During 2012, we caught a total of 121,648 non-salmonids, consisting of 44 different species, from mid-February to early September (four others were unidentified due to their small size and/or larval state (e.g. "unidentified flat fish")). Four species of baitfish were captured (surf smelt, anchovy, herring, sand lance) (Table 10). The most abundant species were three-spine stickleback (*Gasterosteus aculeatus*) and surf smelt (*Hypomesus pretiosus pretiosus*), accounting for 37.7% and 13.5% of the non-salmon catch, respectively (Figure 12). The next most abundant species were shiner perch (*Cymatogaster aggregate*; 12.8%) and northern anchovy (*Engraulis* *mordax*; 12.6%). Together, these four species made up roughly 76% of the non-salmon catch for 2012, very similar to what we observed in 2011 (Figure 12). Common species typically occurred in more than one third of the collections and had average density values greater than 100 fish per hectare.

Figure 12: Common non-salmon species shown as percentage of non-salmon catch

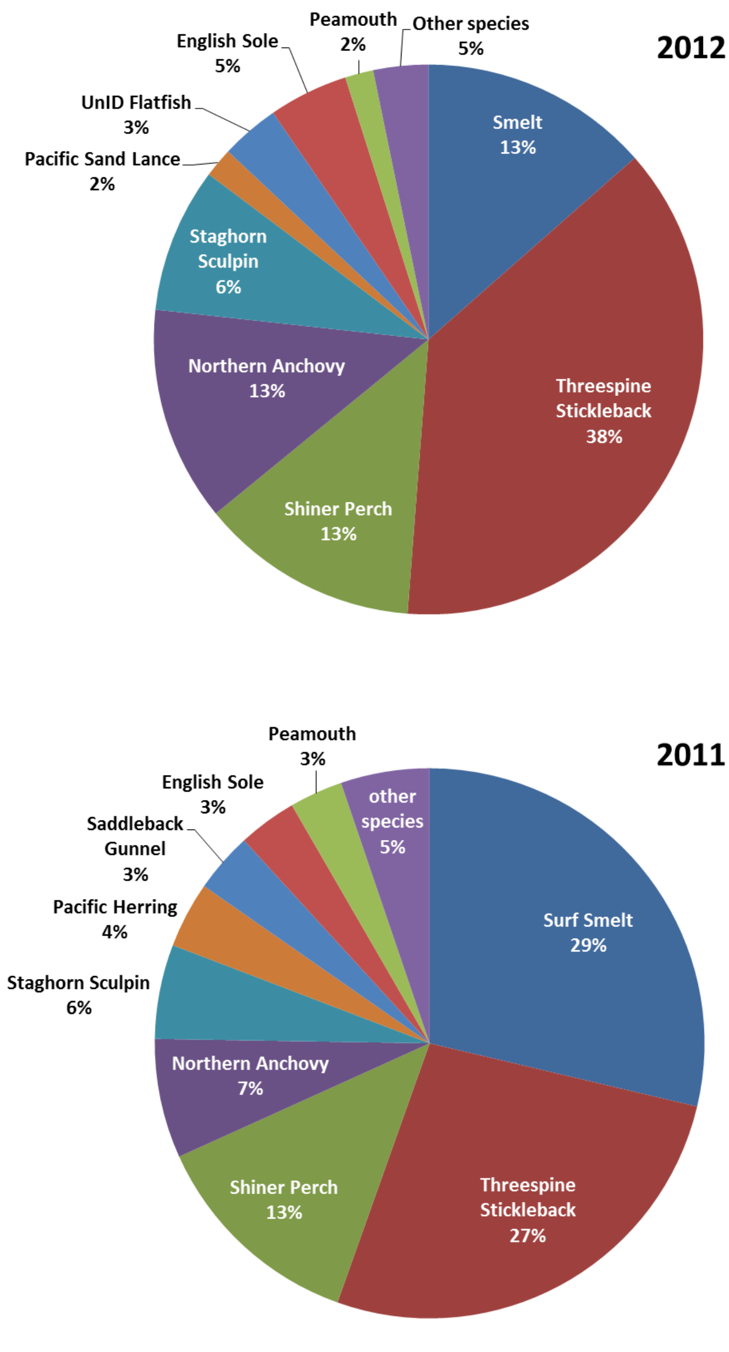


Table 10: Total non-salmonid catch by species for 2011 and 2012

common name	scientific name	Total 2011	common name	Total 2012
Surf Smelt	*Hypomesus pretiosus pretiosus*	33692	Threespine Stickleback	45868
Threespine Stickleback	*Gasterosteus aculeatus*	31404	Surf Smelt	16442
Shiner Perch	*Cymatogaster aggregata*	15029	Shiner Perch	15656
Northern Anchovy	*Engraulis mordax*	8239	Northern Anchovy	15379
Pacific Staghorn Sculpin	*Leptocottus armatus*	6514	Staghorn Sculpin	10367
Pacific Herring	*Clupea harengus pallasi*	4556	English Sole	5688
Saddleback Gunnel	*Pholis ornata*	4135	UnID Flatfish	4186
English Sole	*Parophrys vetulus*	4042	Pacific Sand Lance	2104
Peamouth	*Mylocheilus caurinus*	3672	Peamouth	2024
Unidentified Minnow		1975	Saddleback Gunnel	1342
Pacific Sand Lance	*Ammodytes hexapterus*	746	Starry Flounder	491
Starry Flounder	*Platichthys stellatus*	729	Bay Pipefish	474
Bay Pipefish	*Syngnathus griseolineatus*	685	Prickly Sculpin	466
Sand Sole	*Psettichthys melanostictus*	418	Pacific Snake Prickleba	425
Unidentified Flatfish		414	UnID Sculpin	270
Prickly Sculpin	*Cottus asper*	229	Pacific Herring	74
Pacific Snake Prickleback	*Lumpenus sagitta*	199	Silver Surfperch	46
Northern Pikeminnow	*Ptychocheilus oregonensis*	114	Northern Pikeminnow	41
Largescale Sucker	*Catostomus macrocheilus*	109	Arrow Goby	39
Red-sided Shiner	*Richardsonius balteatus*	97	UnID Minnow	37
Silver Surfperch	*Hyperprosopum ellipticum*	97	UI Larval Fish	34
Bay Goby	*Lepidogobius lepidus*	52	Sand Sole	24
Unidentified Larval Fish		35	Torrent Sculpin	21
Pile Perch	*Rhacochilus vacca*	33	Buffalo Sculpin	19
American Shad	*Alosa sapidissima*	31	Bay Goby	18
Plainfin Midshipman	*Porichthys notatus*	31	White Seaperch	17
Buffalo Sculpin	*Enophrys bison*	29	Shad	15
Black Rockfish	*Sebastes melanops*	25	Pile Perch	14
Whitefish	*Prosopium williamsoni*	10	Reticulate Sculpin	9
Tube-snout	*Aulorhyncus flavidus*	9	Coastrange Sculpin	7
Speckled Dace	*Rhinichthys osculus*	8	Largescale Sucker	7
Pacific Ocean Perch	*Sebastes alutus*	7	Riffle Sculpin	7
Unidentified Sculpin		7	Whitefish	7
Arrow Goby	*Clevelandia ios*	6	Lingcod	5
Rock Greenling	*Hexagrammos lagocephalus*	6	Red-sided Shiner	5
Striped Seaperch	*Embiotoca lateralis*	5	Speckled Dace	4
Cabezon	*Scorpaenichthyes marmoratus*	4	Sanddab	3
Crescent Gunnel	*Pholis laeta*	4	Sharpnose Sculpin	3
Reticulate Sculpin	*Cottus perplexus*	4	Top Smelt	2
Torrent sculpin	*Cottus rhotheus*	3	Crescent Gunnel	1
Kelp Greenling	*Hexagrammos decagrammus*	2	Kelp Greenling	1
Pacific Tomcod	*Microgadus proximus*	2	Pacific Lamprey	1
White Sturgeon	*Acipenser transmontanus*	2	Plainfin Midshipman	1
Coastrange Sculpin	*Cottus aleuticus*	1	River Lamprey	1
High Cockscomb	*Anoplarchus purpurescens*	1	True Cod	1
Largemouth Bass	*Micropterus salmoides*	1	Tubesnout	1
Lingcod	*Ophiodon elongatus*	1	White Sturgeon	1
Pacific Sardine	*Sardinops sagax*	1		
Pumpkinseed	*Lepomis gibbosus*	1		
Sharpnose Sculpin	*Clinocottus acuticeps*	1		
Total		**117,417**		**121,648**

4.2 Non-Salmon Species Abundance and Unusual Catches

Baitfish

Of the six species of baitfish, only surf smelt, northern anchovy (*Engraulis mordax*), and Pacific herring (*Clupea harengus pallasi*) were commonly captured in 2012. Surf smelt and northern anchovy were the most commonly captured bait fish, occurring in every zone and almost every habitat type. Surf smelt and anchovy were represented in adult, juvenile and post-larval stages, while Pacific herring and sand lance (*Ammodytes hexapterus*) were present only as juvenile and post-larval fish. No sardine were captured in 2012. Of the six zones, the central estuary, estuary mouth, South Bay and to a lesser extent North Bay, produced high densities of the five major baitfish species, while the peak abundance of surf smelt occurred near the estuary mouth (10,471 post-larval smelt were caught in one set at the Westport marina site; 475 juvenile smelt were caught in one set at Damon Point). All the baitfish shared common patterns of association with beach, sand flat and aquatic vegetation bed habitat types, which partially reflects the availability of these habitats in the lower estuary.

Only two species of baitfish (adult and juvenile surf smelt and juvenile and post-larval anchovy) were abundant over enough of the sampling period to indicate residence and actual utilization of the estuary. Pacific sand lance were caught infrequently (although occasionally in great abundance) in the central estuary, particularly at sand and cobble beach sites near the mouth. A few American shad (*Alosa sapidissima*) were captured in 2012 (N=15). Surf smelt were at their peak abundance during April and May, primarily as post-larval and juvenile fish. By June, smelt densities fell considerably, but the juvenile fish continued to be present in the catch in substantial (although diminishing) numbers until August. There was no obvious relationship between the occurrence of post-larval/juvenile herring and the adults to suggest that these influxes were associated with spawning in the estuary; abundance of herring was lower in 2012 than in 2011. Patterns of abundance for northern anchovy were erratic; large numbers of fish were caught in June and September, but few in July.

Other Common Non-salmonids

Of the remaining species of non-salmonids, six were considered common: three-spine stickleback, shiner perch, Pacific staghorn sculpin (*Leptocottus armatus*), English sole (*Parophrys vetulus*), peamouth (*Mylocheilus caurinus*) and saddleback gunnel (*Pholis ornate*). Three-spine stickleback and shiner perch were particularly abundant and they occurred in almost every month, every zone and every habitat type. Both species reproduced in the estuary and both species were present in various life history stages, which we recorded as adult and juvenile stages only in shiner perch.

Three-spine stickleback were ubiquitous throughout the sampling period, but recruitment peaked in August and September when many tiny juveniles became ever-present in our catch. Although stickleback were present in all the sampling zones, the greatest densities occurred in the central estuary, North Bay and South Bay. Adult shiner perch began to appear in our samples in May (slightly later than in 2011) and densities steadily increased until July, the peak month of reproduction for this viviparous species. The new cohort of juveniles took over as the dominant life stage and the average density of juvenile shiner perch increased after July. Shiner perch were present throughout the estuary, particularly in South Bay.

Staghorn sculpin were another common catch at nearly every site except for those that were fully freshwater. Both staghorn sculpin and saddleback gunnel shared common patterns of abundance, by zone and by habitat type, although the distribution of staghorn sculpin extended a little higher in the estuary because they can tolerate lower salinities than saddleback gunnels. Very large staghorn sculpin were present in late summer at our "Sculpin Cove" sampling site in the Elk River estuary, often exceeding 200mm.

English sole and starry flounder (*Platichthys stellatus*) were the two most common flatfish collected in 2012, as in 2011. Grays Harbor is an important rearing area for juvenile English sole, which utilize the extensive shallow sublittoral and lower littoral habitats (Simenstad & Eggers 1981). English sole were most abundant in South Bay, and their relative abundance diminished from the lower estuary to the surge plain**.** Like several other species, North Bay had a relatively low abundance of English sole compared with South Bay and the central estuary. In contrast, starry flounder were the most abundant flat fish in the surge plain.

Also captured near the estuary mouth in March and April of 2012 were two top smelt (*Atherinops affinis*), the first such capture in our study. This species is not commonly found as far North as Grays Harbor, preferring the warmer waters of the southern Oregon and northern California coasts. A few top smelt were captured in the Columbia River estuary in 2012, also near the mouth (Curtis Roegner, NOAA, personal communication). WDFW were notified of these catches and expressed interest in any future collections.

Section 5: Fish Community Modeling

5.1: Site Modeling – Physical Variables

Due to the size of the Grays Harbor estuary and the number of tributaries entering near the estuary mouth, modeling the system presents interesting challenges in comparison with more traditional, "straight line" systems where one major river meets up with a small estuary before entering the ocean. As opposed to the straight line model, the tributaries of Grays Harbor are radially aligned, with the estuary mouth at the West and (in compass order) the Humptulips (North), Hoquiam (Northeast), Wishkah (NE), Chehalis (East), John's and Elk Rivers (South) (Figures 1, 2). In the absence of a good model of tidal flow for the estuary, the challenge is to relate the sampling areas along each of these axis that, despite being relatively far apart in straight line distance in some cases ("as the crow flies"; e.g. Humptulips River sites and Elk River sites are ~12 miles apart), are roughly equidistant from the estuary mouth due to the radial arrangement (Figure 2).

A Principal Components Analysis (PCA) of the core and secondary sampling sites' physical variables was conducted to determine which characteristics were most influential in relating the sites (McCune & Grace 2002). In 2012, separate analyses were conducted for the 2012 sampling year and for both years combined. Analyzing the years separately allows us to examine changes between the years that may indicate that different factors (e.g. salinity or temperature) varied significantly between the years, and may explain differences in fish distributions. Analyzing all the years together (as will also be done after the conclusion of sampling in 2013) allows us to examine broader patterns and include the annual variability expected in this type of study; the assumption is that including more years of data will improve our ability to discern the major components driving fish location and abundance.

The initial analysis was conducted using current direction/tide stage (or slack water), tidal height, salinity, and water temperature as the main components, and revealed that the greatest variance in the data was explained by current direction (coded simply as flood, ebb, slack because actual velocity data were not available) while the second major axis was set by tidal height (Figure 13, Table 11; "TideStag"=current direction, "TideHt"=tide height, and WaterTem=temperature °C).

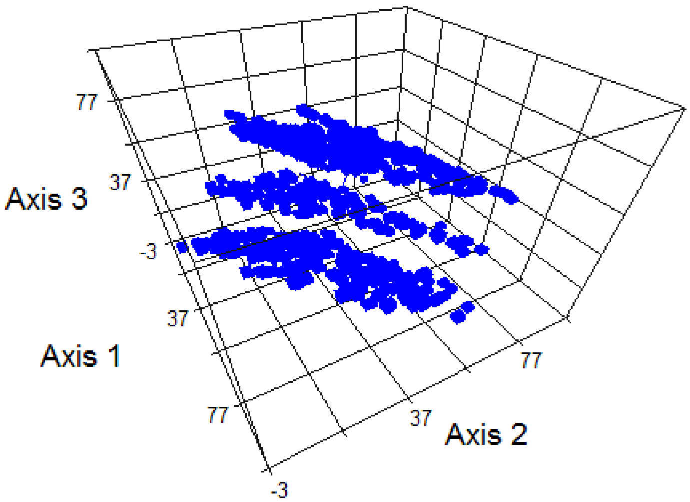
Table 11: Results of the Principal Components Analysis (PCA) with 4 variables for 2012

```
********* PRINCIPAL COMPONENTS ANALYSIS **********
Randomization test requested.        999 runs.
      3616 = Seed for random number generator.

VARIANCE EXTRACTED, FIRST  4 AXES
----------------------------------------------------------------
                                                    Broken-stick
AXIS    Eigenvalue   % of Variance  Cum.% of Var.  Eigenvalue
----------------------------------------------------------------
  1        1.509        37.720        37.720         2.083
  2        1.111        27.776        65.496         1.083
  3        0.769        19.230        84.726         0.583
  4        0.611        15.274       100.000         0.250
----------------------------------------------------------------

FIRST 4 EIGENVECTORS, scaled to unit length.
These can be used as coordinates in a distance-based biplot,
where the distances among objects approximate their Euclidean
distances.
---------------------------------------------------------------------------
                              Eigenvector
attrib            1           2           3           4
TideStag     -0.5410     -0.3651      0.6137     -0.4443
TideHt       -0.3974     -0.6679     -0.3905      0.4934
Salinity     -0.5491      0.3455     -0.6089     -0.4565
WaterTem     -0.4979      0.5488      0.3164      0.5923
---------------------------------------------------------------------------
```

Figure 13: Plot of the Principal Components Analysis (PCA) with 4 variables for 2012



In figure 13, we see three "sheets" of data spread across the three dimensional space; these are the result of categorizing tide stage (current) into three bins (flood, ebb, slack). This forces the data into three separate planes, and as a result most of the variability is explained by current (37.7%). The remaining components explain the remainder of the variance (tide height = 27.8%; salinity = 19.2%, and temperature = 15.3%; Table 11). These values are very similar to the results we obtained in the PCA for the 2011 data. We then modeled the data using both 2011 and 2012 combined (Figure 14, Table 12).

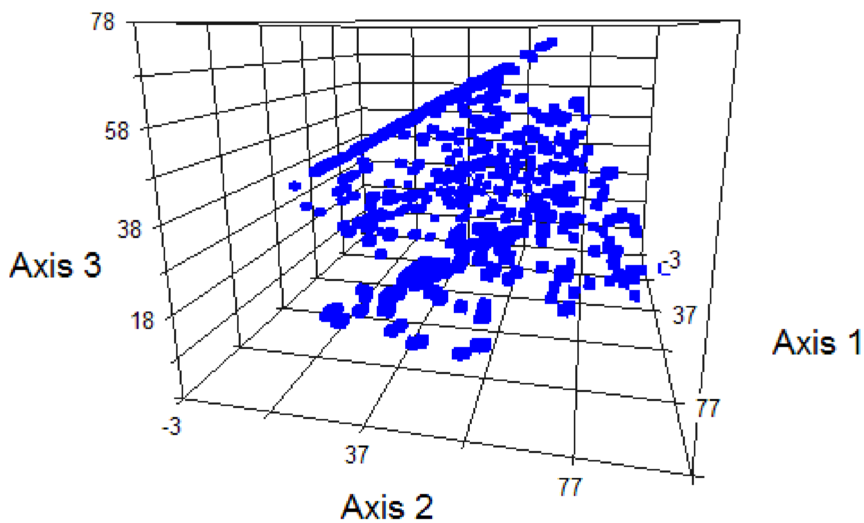
Table 12: Results of the Principal Components Analysis (PCA) with 4 variables for 2011 and 2012 combined

```
********* PRINCIPAL COMPONENTS ANALYSIS **********
Randomization test. 999 runs.3547 = Seed for random number generator.
VARIANCE EXTRACTED, FIRST  4 AXES
```

AXIS	Eigenvalue	% of Variance	Cum.% of Var.	Broken-stick Eigenvalue
1	1.473	**36.818**	36.818	2.083
2	0.999	**24.983**	61.801	1.083
3	0.846	**21.155**	82.956	0.583
4	0.682	**17.044**	100.000	0.250

```
FIRST 4 EIGENVECTORS, scaled to unit length.
These can be used as coordinates in a distance-based biplot,
where the distances among objects approximate their Euclidean
distances.
--------------------------------------------------------------------------
                              Eigenvector
attrib             1            2            3            4
TideStag     -0.4241       0.5623       0.6780      -0.2106
TideHt       -0.4327       0.5611      -0.6531       0.2671
Salinity     -0.5720      -0.3970      -0.2388      -0.6769
WaterTem     -0.5529      -0.4598       0.2383       0.6528
--------------------------------------------------------------------------
```

Figure 14: Plot of the Principal Components Analysis (PCA) with 4 variables for 2011 and 2012 combined



The amount of the variance explained using the four components and both years of data was very similar to the runs for each year independently. The "plane" (straight line) along the upper left of this 3D plot is mainly due to the number of sites where the salinity was zero (at tributary sites above the influx of salt water). From this angle, the three planes of data are still apparent. To examine the respective input of the three quantitative components, tide stage was removed and the model rerun (Figure 15, Table 13):

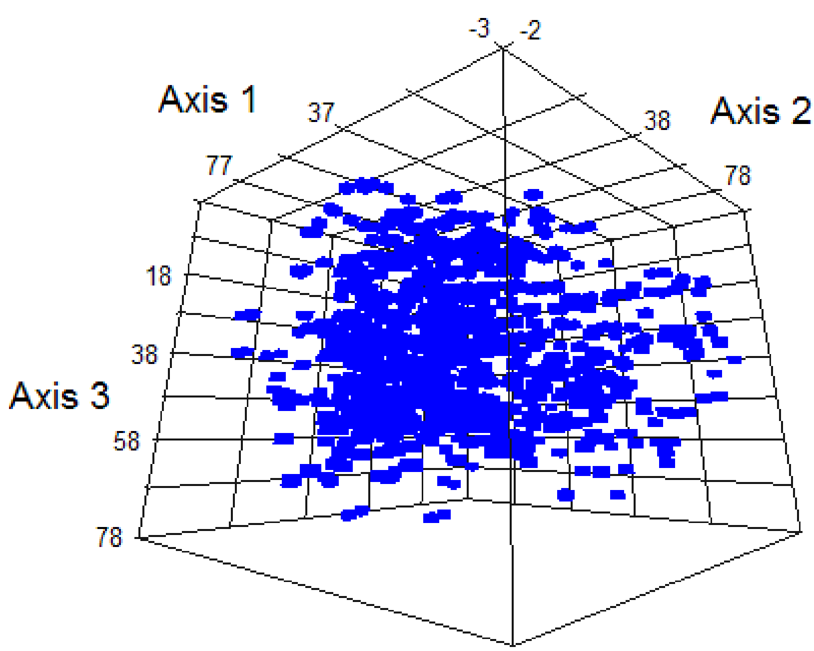
Table 13: Results of the Principal Components Analysis (PCA) with 3 variables (current removed) for 2011 and 2012 combined

```
********* PRINCIPAL COMPONENTS ANALYSIS **********
Randomization test. 999 runs.5363 = Seed for random number generator.

VARIANCE EXTRACTED, FIRST  3 AXES
---------------------------------------------------------------
                                                  Broken-stick
AXIS    Eigenvalue   % of Variance  Cum.% of Var.  Eigenvalue
---------------------------------------------------------------
  1         1.372        45.736         45.736         1.833
  2         0.936        31.191         76.927         0.833
  3         0.692        23.073        100.000         0.333
---------------------------------------------------------------

FIRST 3 EIGENVECTORS, scaled to unit length.
These can be used as coordinates in a distance-based biplot,
where the distances among objects approximate their Euclidean
distances.
-----------------------------------------------------------------------
                             Eigenvector
attrib              1            2            3
TideHt         -0.4071       0.8951      -0.1820
Salinity       -0.6664      -0.1549       0.7293
WaterTem       -0.6246      -0.4182      -0.6596
-----------------------------------------------------------------------
```

Figure 15: Plot of the Principal Components Analysis (PCA) with 3 variables for 2011 and 2012 combined



Removal of the current (tide stage) component yields a 3D scatterplot with little discernible pattern and no clear axis. The removal of this component increases the variance explained by the remaining components (Table 13), as expected (tide height = 45.7%; salinity = 31.2.%). If the plot is rotated, the effect of salinity is still present, but less clear. These investigations into the physical site data provide a preliminary investigation and data matrix that will be used to model the fish community (both salmonids and non-salmonids) during the summer of 2013.

5.2 Long Term Data Collection Goals: Escapement

The long term data collection goal for this project is to sample the Grays Harbor estuary in years that represent different levels of wild smolt productivity, including a "low", "average" and "high" year. Estimates of wild smolt productivity for the whole of Grays Harbor are unavailable. However, natural spawner escapement estimates from WDFW (based upon index streams) are available, and these provide a coarse proxy to wild smolt production. It should be noted that using escapement as in index of smolt productivity relies on simplifying assumptions that disregard density-dependent effects and the considerable annual and stream-specific variation in productivity and survival.

Escapement estimates were available from 1969 for chum salmon and 1970 for Chinook and coho salmon. Spring Chinook salmon constitute a very small portion of the Grays Harbor population and were therefore omitted from the index. Annual escapement varied widely over the historical period of record, especially for coho salmon and chum salmon. The distribution of the escapement data is right skewed for all three species (Chinook, g_1 = 0.965; chum, g_1 = 1.674; coho, g_1 = 0.979), so quartiles were used to define productivity categories since it reflects the spread of data. The interquartile range (the middle 50% of observations) was used to define the lower and upper limits of an "average" year for each species of salmon (Figure 16). Escapement numbers below the 1st quartile represent a "low" productivity year; and escapement numbers above the 3rd quartile represent a "high" productivity year. Based upon this definition, wild smolt productivity of Chinook salmon was categorized as average for 2011 and high for 2012; productivity of YOY coho salmon was considered high for 2010 and 2011, and about the upper limit of an average year for 2012; and smolt productivity for chum salmon was high for both 2011 and 2012 (Table 14).

Figure 16**:** Box and whisker plot summarizing annual escapement data for fall Chinook salmon, chum salmon and coho salmon from 1969 to 2011. The interquartile range (grey box) represents the range of escapement values that constitute a “normal” productivity year. Annual escapement values that fall above or below the interquartile range are considered “high” or “low” productivity years.

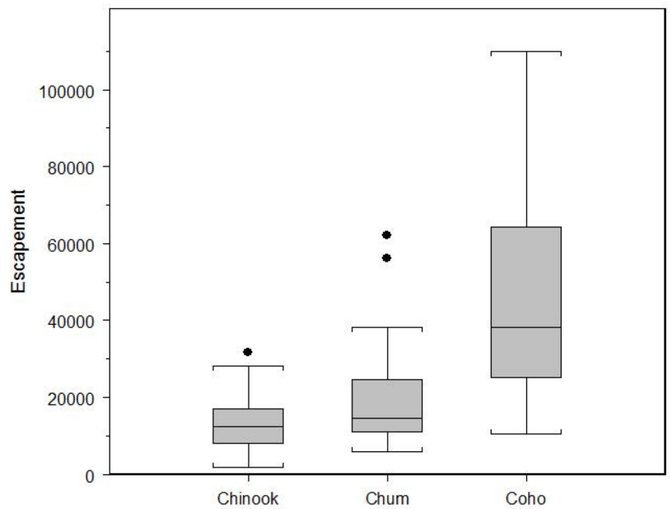


Table 14: Escapement values defining the interquartile range, or “normal” productivity year, for fall Chinook, coho and chum salmon. Values that fall above or below the interquartile range are considered “high” or “low” productivity years. Escapement estimates for the brood years that produced most of the juvenile salmon captured in 2011 and 2012 are shown in red.

	Fall Chinook	*Coho*	*Chum*
1st Quartile	8,106	25,349	11,012
3rd Quartile	17,083	64,240	24,673
2011 escapement	20,317	64,403	29,043
2010 escapement	16,951	102,237	33,537
2009 escapement		69,403	

Section 6: Synthesis and Recovery Priorities

Estuaries have been shown to enhance the survival of juvenile salmon by providing:

(1) habitat for overwintering juvenile salmonids forced downstream during high river flows (Sommer et al. 2001; Simenstad et al. 1992; Henning et al. 2007);

(2) complex low-velocity refugia such as off-channel sloughs and large woody debris (LWD) (Gonor et al. 1988; Swales & Levings 1989; Wick 2002; Henning et al. 2006; Simenstad & Eggers 1981; Henning et al. 2007);

(3) time for migrating juveniles to adapt physiologically to sea water (Folmar & Dickhoff 1980; Healey 1980; Levy & Northcote 1982; Iwata & Komatsu 1984; Zaugg et al. 1985);

(4) opportune feeding conditions as drift insects and other prey items are trapped and concentrated due to flow reversals (Tschaplinski 1987; Eggleston et al. 1998; Simenstad & Eggers 1981);

(5) settling of suspended sediments and detritus, which can fuel soft-sediment habitat formation and detritus-based food webs exploited by salmon (Simenstad et al. 1982; Maier & Simenstad 2009; Thorpe 1994; Bottom et al. 2005).

(6) a refuge from piscivorous and avian predators, due in part to the often turbid water resulting from river flows and tidal action (Gregory & Levings 1998; De Robertis et al. 2003; Simenstad et al. 1982; Thorpe 1994).

The results from our 2011 and 2012 sampling indicate a wide range of habitat utilization by the various species and age classes of salmonids found in Grays Harbor. In 2012, clear growth trends were again observed for YOY Chinook, coho and chum salmon, indicating that the estuary is functioning as a refuge for these fish as they physiologically mature and prepare to enter the ocean. Individual points are discussed below.

6.1 Salmonid Spatial and Temporal Habitat Usage

Life history variation has been recognized as a critical factor in resilience - the ability of native stocks to persevere and recover from perturbations in abundance, habitat and climate variability- among Pacific Northwest salmonid stocks (Greene et al. 2010; Bottom et al. 2005;

Simenstad et al. 1982). In many systems with enhanced hatchery production, the range of life histories has been reduced via the selection of a limited diversity of broodstock, particularly with regard to run timing. In many systems, this has resulted in "pulses" of emigrants reaching the estuarine rearing habitats at the same time, which may create artificially heightened competition for estuarine habitat. While meeting our objective of documenting temporal and spatial habitat usage by salmonids in Grays Harbor, a secondary goal is to identify alternative estuarine life history strategies that are still extant in the Chehalis basin and may be important both for the restoration of salmon populations in the watershed and their ability to persevere under the predicted changes in climate.

Chinook Salmon

Roughly one-third more unmarked Chinook salmon were captured in 2012 than in 2011; the capture of hatchery Chinook was also slightly higher. Chinook salmon were the second most abundant salmonid captured (after chum salmon) and were present during all sampling months in 2012, as in 2011. The escapement of Chinook salmon in the Chehalis Basin (provided by WDFW) was also slightly higher in 2011, which may explain why more YOY fish were caught in 2012. Very few yearling Chinook salmon were caught in 2012 (or 2011), a result that closely resembles that of an earlier study in the Chehalis basin (Deschamps et al. 1970). Yearling Chinook salmon have previously been reported to reside in deeper dendritic tidal or river channels (Zaugg et al. 1985; Thorpe 1994; K. Fresh et al. 2005) that are not effectively sampled by beach seining, which may explain our low catches.

Unmarked Chinook abundance again peaked in May, but large numbers were present from April through July (Figure 8a). Hatchery YOY Chinook were present in the estuary mainly from May through August (though technically present in April and September, catches were ≤5 fish in those months), slightly earlier than in 2011, when they were present from July through September. Unmarked YOY Chinook salmon where widely dispersed throughout the estuary during late spring and early summer and showed a clear seaward migration pattern as the sampling season progressed (Figure 9a). However, the regression modeling shows that although abundance decreased later in the year, occurrence did not – YOY Chinook salmon continued to utilize estuarine habitats into the fall. The timing of catch in both years of this study closely follows that of Simenstad and Eggers (1981), who reported catches of YOY Chinook salmon nearly year-round in Grays Harbor, and of Deschamps et al. (1970), who had their peak Chinook catch in May. This suggests a variety of Chinook salmon life histories are present in the basin, and, particularly for unmarked Chinook, estuarine residence times are longer than for the other salmonid species.

Unmarked YOY Chinook salmon steadily increased in fork length from February through September (Figure 4). They were more abundant in North Bay and less abundant in South Bay and the central estuary zone in comparison with the rest, were notably less common at gravel/cobble/sand beach habitats (Figures 10a, 11a), and both their presence and abundance were negatively correlated with temperature. Hatchery yearlings were significantly larger (FL) than their unmarked peers in each month from May to August. Hatchery YOY Chinook salmon abundance was also negatively correlated with temperature, and they were also rarely caught (and in very low abundance) at beach sites (Figure 10a). The occurrence of hatchery YOY Chinook was lower in forested, scrub/shrub, and high emergent marsh than in other habitats, and they were captured most frequently in North Bay, the central estuary, and South Bay, although their abundance was lower in these zones than in the surge plain or inner estuary (a very different pattern than for unmarked YOY Chinook). This pattern reflects a more direct downstream migration into the main estuary; hatchery YOY Chinook salmon were present for a shorter period of time than unmarked YOY Chinook.

Coho Salmon

Overall, juvenile coho salmon catch was lower in 2012 (N=792) than in 2011 (N=1499), particularly for unmarked coho (2012, N= 694; 2011, N=1,370). Coho salmon escapement declined in 2011 (data from WDFW), which partly explains the decrease in YOY coho captured in 2012, but the 2010 escapement was high (Table 14), suggesting that our catches of yearling coho should have been higher in 2012. Unmarked YOY coho were present throughout the sampling season, though at very low abundance in February (N=2) and September (N=10); marked coho were only present in February (N=1) and April and May (Figure 8b). Previous studies in Grays Harbor reported YOY coho captures from March through October, peaking in mid-April through mid-June (Brix 1981; Tokar et al. 1970). The abundance of unmarked coho peaked in May of 2012, and the YOY were caught mainly in the central estuary in all months, particularly in the Hoquiam River system (Figure 9c). Yearling coho, though present at lower densities, were more dispersed through the central estuary, South Bay, and North Bay, with a pattern of input from the Humptulips River from March-June (Figures 9d, e).

Unmarked YOY coho salmon heavily favored forested habitats in 2012, followed by scrub/shrub cover habitats (Figure 11b). Coho were absent at sand flats and beach sites, and were also uncommon at mud flat sites. The mean fork length of YOY coho salmon steadily increased during the study from April to September (Figure 6); there was little increase in mean fork length from February to April. Hatchery yearlings were significantly longer (FL) than their wild counterparts in both April and May. However, the average fork length of hatchery yearling coho decreased slightly from April through May, corroborating the evidence that yearlings did not reside for long periods of time within the estuary (the fish captured in May did not decrease in size; rather, new pulses of smaller coho from upstream made up the catch). This finding was also consistent with studies elsewhere that have observed larger coho smolts, which may be more ocean ready, migrating before smaller smolts (Irvine and Ward 1989). As with Chinook, coho salmon occurrence and abundance was negatively correlated with salinity; when salinity exceeded 5ppt their occurrence declined quickly, and above 20ppt they were essentially absent. This suggests that YOY coho are rearing in the estuary for extended periods of time (unlike the yearlings, which quickly migrated to sea) and are not yet fully able to osmoregulate in salt water; it is likely that many of these fish will not smolt until 2013 (the "nomad" lifestyle alluded to in other studies (Koski 2009; Bell & W. Duffy 2007)). Studies conducted in the lower Chehalis River in the late 1960's reported capturing coho in their third year (by scale analysis), again suggesting that historically, multiple life histories existed within the basin (Deschamps et al. 1970), although no coho salmon large enough to be three year olds were captured in 2011 or 2012.

Chum Salmon

More than twice as many juvenile chum salmon (all YOY) were captured in 2012 (15,755; Table 3) as in 2011, partly because we commenced sampling earlier in the year (February as opposed to late March in 2011). However, even if the February (N=1,914) and early March catches are excluded, the 2012 catch was higher by 2,800 chum salmon. The escapement of chum salmon in 2011 was very close to that of 2010 (data from WDFW; Table 14), so the causes of our increased catch in 2012 are uncertain. Chum salmon were present from February to June (N=4), at which point all chum salmon had migrated to sea, as in 2011 and in keeping with their life history (Wright 1973; Tokar et al. 1970; Brix 1981; Simenstad & Eggers 1981). Previous research in the Chehalis River indicates that the chum emigration is underway as early as January in most years (Deschamps et al. 1970). Mean fork length increased throughout the months they were present in 2012.

Chum were widespread throughout the estuary from February until April, and by May they were at much lower densities in the surge plain as the fish pushed through to the estuary (Figure 9f). Peak abundance occurred in April in 2012 and then decreased quickly (Figure 8c). Unlike in 2011, chum were commonly captured at high densities in North Bay in 2012, and it appears that our results from the 2011 sampling season (when we posited that chum may be excluded from North Bay by low salinity) may have been biased by the later start. Chum were captured in highest densities at cobble/gravel/sand beaches in 2012, and were also common at sand flat and aquatic vegetation bed habitats (Table 9, Figure 11c). They were captured at lowest densities at forested sites, particularly in South Bay. The occurrence and abundance models for chum salmon indicate that timing was an important factor, as was water temperature, although this is likely the result of their greater abundance earlier in the season.

Steelhead trout

More steelhead were captured in 2012 than 2011, but the majority of these were juveniles (both hatchery and unmarked) captured in one set (N=68 hatchery, 13 unmarked) near the mouth of the Humptulips River in April (Table 3). This precludes any conclusions about their habitat preferences. The timing of the juvenile steelhead catch in 2011 and 2012 was generally in agreement with that reported in previous studies (Brix 1974; Tokar et al. 1970; Simenstad & Eggers 1981), though our sampling methodology does not effectively cover deeper channels where steelhead are likely to be in greater abundance (Quinn 2005). In July of 2012, one adult steelhead (FL=762mm) was captured at Cow Point, the first adult steelhead we have documented.

Cutthroat trout

Slightly fewer cutthroat trout were caught in 2012 (N=65) than in 2011 (N=92). Though cutthroat trout were encountered infrequently, enough were captured to observe some patterns of estuary use. Cutthroat densities were highest at scrub/shrub cover and emergent marsh sites, as in 2011 (Figure 10d), though some were also caught in every habitat except cobble/gravel/ sand beaches and sand flats (Figure 10d). Their densities closely aligned in space and time with those of YOY Chinook salmon, suggesting possible predation. Our catches of cutthroat trout demonstrate that this species is present in Grays Harbor through much of the year (March to September), though they were most commonly encountered from April to June. The widespread habitat use we have documented is in contrast with the results of previous studies (Deschamps et al. 1971; Deschamps et al. 1970; Simenstad & Eggers 1981).

Bull trout

A total of four bull trout (*Salvelinus confluentus*) were captured in Grays Harbor during a sampling period that ran from late February to mid-September. Two bull trout were captured in South Bay, one on March 13th, and the other on April 10th. Another fish was captured at Cow Point in the Inner Estuary on April 9th; and a fourth bull trout in the Hoquiam River on June 8th (see table and figure below). The fish ranged in fork length from 310 mm to 470 mm.

Table 15: Summary of bull trout captures in the Grays Harbor estuary, 2012

#	Date	Site	Coordinates	Length	Zone	Capture method
1	3/13/12	Sculpin Cove	N46.837564, W-124.023062	310 mm	South Bay	Seine
2	4/10/12	Mallard Slough	N46.855625, W-124.061887	470 mm	South Bay	Seine
3	4/9/12	Cow Point	N46.961900, W -123.847065	330 mm	Upper Estuary	Seine
4	6/8/12	Mainstem Hoquiam River	N46.961900, W -123.847065	345 mm	Upper Estuary	Seine

Figure 17: Map showing the locations of bull trout captures in Grays Harbor, 2012

Predation

Few large pikeminnow and only a few large staghorn sculpin (particularly in South Bay) were captured in 2012, suggesting that size classes of these predators big enough to consume smolts are not overly abundant in Grays Harbor, although our sampling methodology does not cover the deeper channels effectively. Steelhead densities where too low in 2012 to allow any conclusions to be made; most of the fish were captured in a single set in April. Cutthroat trout were also rare, but densities were highest at scrub/shrub cover and high emergent marsh sites, where unmarked YOY Chinook and chum were common at high densities (Figure 10). This suggests cutthroat trout may forage upon the YOY salmon year classes (as has been found in Puget Sound (E. J. Duffy & Beauchamp 2008)), though we have no direct evidence that this is occurring; juvenile salmon were almost always outnumbered by non-salmonid species in the catches after February. Only four bull trout were captured in 2012; the low abundance suggests that bull trout, while present in the estuary, are not likely present in large enough numbers to be considered a major predator of juvenile salmonids. The low number of bull trout captured to date in this study is similar to the results of previous studies (Jeanes & Morello 2006; Tokar et al. 1970; Wright 1973; Simenstad & Eggers 1981). We also directly observed a few cases of predation upon chum salmon and very small Chinook salmon early in the year by staghorn sculpin, although most of these specimens were not large enough to consume juvenile salmon after they reach ~50mm in fork length.

Modeling summary

A principal components analysis (PCA) of the physical site characteristics identified tide stage (ebb, slack, etc.) and tidal height as the components that explained the most variance. When tide stage was excluded, tidal height and salinity were the dominant components. The inclusion of an additional variable, the "distance from the estuary mouth," did not significantly improve the model and was not included in 2012. The scatter of sampling sites in the ordination showed a pattern without a clear principal axis, indicating that there was no easily defined relationship between the physical characteristics available for the sampling sites in either 2011 or 2012 (Figure 15).

Regression analysis of factors affecting salmon occurrence and abundance revealed differential use of the estuary between species and age classes of salmon. Sampling month was the most commonly selected variable across species and age classes, highlighting the importance of seasonality in the use of the estuary by salmon. For chum (all YOY) and yearling coho salmon (unmarked and hatchery), timing, as expected, explained much of the variability in abundance since these two species were only present in the spring and moved more rapidly through the estuary than Chinook salmon (Table 4, Figure 9). Additionally, the period of highest abundance for unmarked yearling coho (April and May) was also the period of highest abundance for hatchery yearling coho. Chum and yearling coho salmon models also included a correlation with temperature, which may be an artifact of when sampling was initiated; catches of both species were greatest early in the season when temperatures were low, potentially explaining the effect of temperature on their abundance. In contrast, a negative correlation between abundance and salinity explained much of the variability in YOY coho abundance, and coho were essentially absent above 20 ppt. Models of YOY coho suggested that their use of the estuary was primarily confined to the freshwater and slightly brackish areas, particularly sites with scrub-shrub or forest cover, which may provide cover from predators. Unmarked subyearling Chinook were the most widely distributed group across space and time. Although timing was also correlated with their abundance, unmarked YOY Chinook, unlike yearling coho and chum salmon, were present in all sampling months (Figure 4). Hatchery Chinook were generally not present until May in 2012 (June in 2011) and occurrence and abundance were greater thereafter, accounting for the importance of month. Both hatchery and unmarked YOY Chinook abundance were negatively correlated with water temperature. Hatchery Chinook occurred mainly in North Bay, the central estuary, and South Bay, but their overall abundance was lower in these three zones than elsewhere. These patterns, and a low presence in forested sites, scrub cover, and emergent marsh habitat, indicate a direct downstream migration of hatchery YOY Chinook salmon into the main estuary where the smolts disperse across a large area.

6.2 Grays Harbor Salmonid Habitat Recovery Priorities

In 2012 we identified two additional areas of concern for habitat restoration and recovery. We also revisited the Johns River dike breach reported in 2011 and report on the results of a fyke net sampling, below.

1) Shoreline tire armoring, Ocosta "Point". During 2012 field work we noticed that a section of the shoreline near Ocosta (slightly southwest from Bottle Beach State Park; west of state route 105) is heavily armored with discarded tires (images from Google Earth 2011 aerial photos, see below).

A close up of the area highlighted in blue is shown below:

This picture (below) was taken during the 2012 sampling season from the water and shows the same area:

Concerned about the potential for chemicals toxic to juvenile salmon and other fishes to escape from discarded tires, we briefly reviewed the literature on this topic. Modern tires are no longer composed mainly of natural rubber but instead have a number of synthetic ingredients, as outlined in a review by (Evans 1997):

> Common rubber additives include pigments (zinc oxide, titanium oxide, and zinc sulfate), binders (sulfur), reinforcing agents (carbon black, zinc oxide, silicon, clays, and carbonates), and softeners, plasticizers, and accelerators (white lead, lead monoxide, zinc oxide, lime magnesia, organic acids, oils, tars, and resin) for expedition of the manufacturing process and improvement of physical properties (Alger 1989; Brydson 1987; R. W. Beck and Associates 1990). In addition to these, Yamaguchi et al. (1991) have reported classes of other rubber additive compounds such as vulcanization accelerators (thiurams, dithiocarbamates, sulfenamides, guanidines, and thiazoles), activators (metallic oxides and fatty acids), and antioxidants (p-phenylenediamines, naphthylamines, diphenylamines, phenols, and quinolines).

Few studies have scrutinized the effects of tire leachate on fish, but those that did were informative. Typically, tires or pieces of tire (to increase surface area) were soaked in fresh water for days or weeks and the “extract” (leachate) was then used to expose fish while the remainder was tested for the presence quantity of chemicals and metals (mainly zinc). Alternatively, the tires were soaked for a period of days (5-40) to test whether the amount of chemicals leaching from the tires decreased over time. Most researchers found that the shorter leachates contained the highest concentration of chemicals, and that subsequent extracts (soaking the same tires again with newly replaced water) had gradually diminishing levels of contaminants (Evans 1997; Stephensen et al. 2003). The sensitivity of fish to tire leachate also varies by species; rainbow trout are among the most sensitive, and larval rainbow trout were killed after exposure to leachate derived from 5, 10, 20 and 40 day soaking times (100% mortality); used tire leachate had a similar effect [some tests were aimed at determining whether chemicals in the surface of the tires were toxic or whether the main body of the tire contained these chemicals, hence the use of used tires; some researchers found used tires were more toxic]. Rainbow trout fry were also susceptible; exposure to new or used tire leachate derived by as short as a 24 hour soak continued to kill all fry for up to 52 days; only tires that were at least 10 years old produced non-toxic leachate. Other species of fish, including fathead minnows, guppies, and goldfish were less sensitive (Evans 1997).

Even fewer studies have examined the effects of tire leachates derived by soaking tires in salt water. Leachate derived from 7, 14, and 21 days soaks in salinities of 5, 15, 25 and 35 ppt caused significant mortality among sheepshead minnows, but only those at 5 ppt and 15ppt (a common range in estuaries) were lethal; high salinity appeared to negate the toxic effects of the leachate (Evans 1997). In cases were the leachate was not lethal, growth of the minnows was reduced by exposure to leachate derived at 5 and 15 ppt, and histological assessment showed effects to the brain and eyes. The toxic component was not identified but was hypothesized to be a neurotoxin based on the histology results. Organic analysis of tire leachate in saline solutions by the Maryland Department of Agriculture found that the levels of two polycyclic aromatic hydrocarbons (PAH), naphthalene and 2-methylnapthalene, were detectible in leachate from 5ppt, but not at higher salinities. Naphthalene was present at levels below the standards for marine waters by the USEPA; there were no guidelines for 2-methylnapthalene (Evans 1997).

A study by Hartwell et al. (1998) set out specifically to test the toxicity of tire leachate in estuarine and marine conditions to determine whether tires were suitable for use as artificial reefs. They found that acute toxicity in sheepshead minnow and grass shrimp was highest with initial leachates (100% mortality at 5ppt), but that subsequent extractions from the same tires resulted in decreased toxicity (50% mortality in the second extraction, 22.5% in the third for the fish; grass shrimp were less affected)(Hartwell et al. 1998). At 15ppt, mortality was significantly higher among fish exposed to the first two extractions but not in the third, and no significant differences in mortality occurred at 25ppt (the salinity of full sea water is ~34ppt). The behavior of the exposed fish was also affected, with fish showing "lethargy, erratic movement, loss of equilibrium and paralysis"; typically this was followed by death the next day (Hartwell et al. 1998). However, the behavior of fish exposed to leachate derived from higher salinity water (first extraction at 25ppt) also showed these effects, although mortality was low. The differences between the leachates at different salinities was attributed to differences in the solubility of the chemicals and possible interactions with the salts present, as well as the effects of salinity on the tolerance of the fish, or a combination of these. The authors concluded that tire leachate causes both lethal and nonlethal toxic effects on aquatic animals, that these effects were more severe in lower salinity environments, and that older tires were less of a threat. They cautioned, however, that "because the identity of the toxic chemicals in the leachates is unknown, no assessment can be made regarding possible bioaccumulative effects" (Hartwell et al. 1998).

Based on these results, it is likely that the tires presently submerged near Ocosta point are no longer an acute threat to aquatic fish in the area (effects on other aquatic organisms, birds, etc. are beyond the scope of this report). However, there may be long-term effects among fish and other organisms due to bioaccumulation, so consultation with a toxicologist is recommended. In the future, tires use as shoreline armoring in the estuary should be discouraged; shoreline armoring in general should be avoided whenever possible as it is often counter-productive:

> *"Ironically, shoreline armoring by sea walls, riprap, or revetments typically decreases the volume of sediment available to sustain beaches. Because wave energy reflected off coastal armor carries sediment offshore, and the armoring itself reduces erosion of protected bluffs, protected shores gradually lose sediment and shallow water habitat (Johannessen and MacLennan, 2007). The resulting increased water depths and greater wave energy tends to weaken the protective structures."* (from Huppert et al. 2009)

As used tires continue to occupy landfill space, a variety of new uses have been investigated. We came across one such use in the review by (Evans 1997); clearly this should not be repeated:

> In Washington State, two roadbeds along the mouth of the Columbia River were constructed from a million recycled tires to provide structural fill in 1995. Less than a year later, the buried rubber started burning, causing the asphalt pavement laid over the fill to crack and releasing noxious smoke containing benzene and oily hydrocarbon mixtures that have begun to flow onto the mudflats below, threatening a nearby saltwater marsh and freshwater wetlands.

2) Auto wrecking yard on Charlie Creek.

Presently an auto wrecking yard, adjacent to state route 105, borders Charlie Creek along two sides on the southern shore of the inner estuary (see below. Image from Google Earth, 2011 photo). The location on the edge of the creek and adjacent to the estuary is a concern given that toxic chemicals (oil, antifreeze, etc.) from the automobiles may leak into the soil and enter both water bodies through groundwater. During sampling immediately upstream of the wrecking yard we documented the presence of juvenile Chinook, coho and chum salmon (Table 16), as well as a cutthroat trout, so salmonids are using this area for rearing. Some of the coho salmon were of hatchery origin (adipose fin clipped), so fish from the estuary are also entering the creek to utilize the habitat. Other fish species captured included juvenile smelt, English sole, starry flounder, saddleback gunnels, snake prickleback, staghorn sculpin, 3-spine stickleback, juvenile and adult shiner perch, peamouth, arrow goby and prickly sculpin. Predicted sea level rise due to climate change will likely inundate this property in the coming decades given its low elevation and proximity to the estuary.


Port Industrial Rd
101
Rennie Island
Auto Wrecking Yard
State Route 105
© 2013 Google
Google earth


Auto Wrecking Yard
Charlie Creek Site
State Route 105
© 2013 Google
Google earth

Table 16: Salmonid catches at the Charlie Creek site in 2012

Site Name	Date	Chinook Wild	Chinook Ad Clip	Coho Wild	Coho Ad Clip	Chum Salmon	Cutthroat Trout
Charlie Creek	4/14/2012	34		4		2	
Charlie Creek	4/14/2012	23		1		2	
Charlie Creek	4/27/2012	20		9		8	
Charlie Creek	4/27/2012	1		7	7		
Charlie Creek	5/11/2012			2	5		
Charlie Creek	5/12/2012	11				37	
Charlie Creek	6/8/2012	12					
Charlie Creek	6/8/2012	12					
Charlie Creek	6/24/2012	18	1				
Charlie Creek	7/10/2012	6	1				
Charlie Creek	7/10/2012	7					
Charlie Creek	7/22/2012	4		1			
Charlie Creek	7/22/2012						
Charlie Creek	8/5/2012	2					1
Charlie Creek	8/5/2012	5		1			
Charlie Creek	8/19/2012	3					
Charlie Creek	8/19/2012	3					
Charlie Creek	8/31/2012						
Charlie Creek	8/31/2012	1					

A second auto wrecking yard is located further West along the south shore of the estuary (just off O'Leary Creek road). The land elevation here is higher, making it less likely that increasing sea levels will inundate the property in the short term, but seepage of chemicals into the groundwater remains a concern (image from Google Earth, also from 2011 photo, below). Ideally both of these businesses would be relocated to higher ground, away from running water and with adequate containment for possible chemical spills, by 2025 when sea level rise begins to threaten this area with inundation. If a "land swap" was arranged for county property elsewhere, these areas could be become marshland as sea level rise increases, but we are unfamiliar with the legal challenges that might pose.

3) Johns River Dike Breach

In late 2011, we observed a natural break in one of the dikes on the East side of Johns River, due to tidal erosion (picture below).

By 2012, the breach had widened significantly and increased tidal flushing was inundating a large area behind the dike (picture below; note the exposed poles used to position a submerged culvert with a vertical "drain" [background, center, with hole in it]; it is unlikely that fish could easily pass through this system while it was intact. The black plastic sheets in the picture run the entire length of the dyke).

On 6/18/2012 we set a fyke net in the slough behind the breach to determine if juvenile salmon and other fish were utilizing this habitat. Our catch consisted of 13 unmarked Chinook salmon, 2 unmarked coho (YOY), 1 juvenile herring, 6 bay pipefish, 112 three-spine stickleback, 2 adult shiner perch, and 2 anchovy. Juvenile fish have quickly responded to this new habitat opportunity. As noted in 2011, this area of the Johns river is still heavily diked and contains abundant rearing habitat for juvenile salmon (estimated to be in excess of 150 hectares); restoration projects in this area should continue to be encouraged.

6.3: Response to Specific Review Panel Questions (2012 Update)

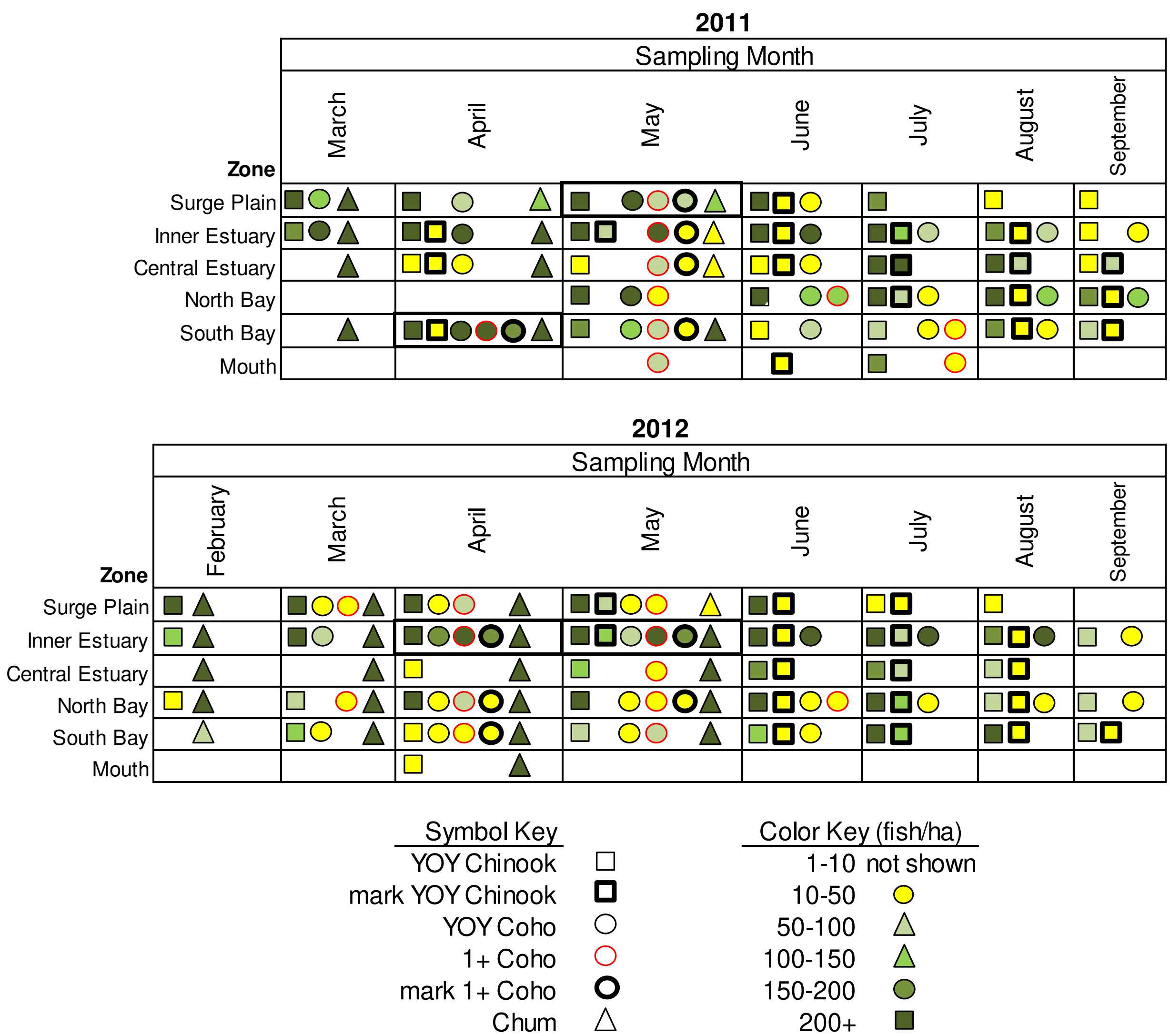
Hatchery vs. Wild Salmon Displacement

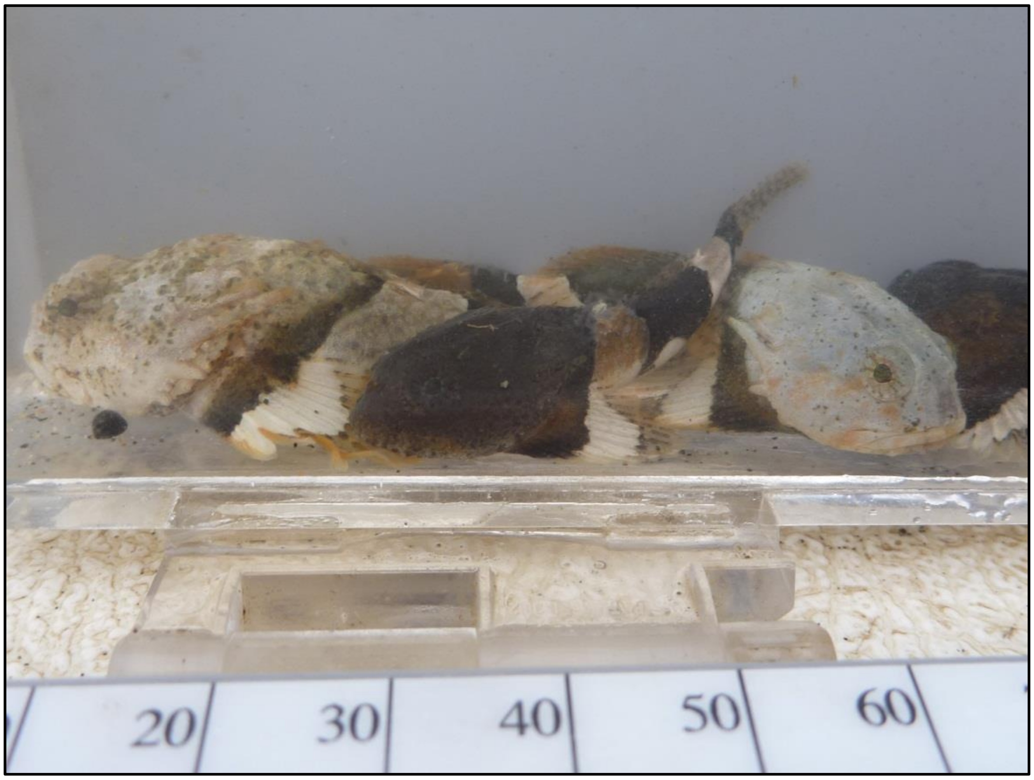
The degree to which wild and hatchery salmon use of Grays Harbor overlaps may be of importance since estuary rearing habitat is thought to be a constraining factor on production for salmon, particularly, Chinook. If hatchery fish cause density dependent displacement of wild conspecifics, this could negatively impact wild stocks. Although our study was not designed to explicitly test whether displacement occurred - a complex question that would likely entail telemetry, individual-based models, or other analytical approaches - we can report the degree to which occurrence and abundance of hatchery and unmarked conspecifics coincided.

Only the overlap of hatchery and unmarked YOY Chinook salmon can be examined, since large numbers of hatchery YOYs are released and are mass-marked, enabling identification in the field. Although hatchery chum and yearling coho are also released, few chum are marked, precluding comparison, and small catches of yearling coho in 2012 make comparison difficult. Unmarked YOY Chinook were the most widely distributed species/age class across space and time, although there was a progressive shift in densities over the season from peak concentrations in the surge plain early in the season, to the inner estuary and North Bay in April, May and June, and finally to littoral habitats in the lower estuary in July and August (Figure 9a). Peak density diminished through this progression as the juvenile Chinook salmon dispersed, from >200 fish/ha in the surge plain in April to <50 fish/ha at the estuary mouth in July. In contrast, hatchery YOY Chinook were present at low-moderate densities in May in the surge plain and inner estuary, were present through the central and inner estuary and North Bay in June, and were captured at moderate-high densities in the central estuary in July (Figure 9b). As in 2011, this suggests that the early season may provide a temporal refuge for unmarked Chinook from potential competition by hatchery salmon. Hatchery Chinook salmon also appeared to move more quickly through the estuary, which may also minimize competition between the two. Finally, in stark contrast to other areas in Washington, such as Puget Sound, densities of hatchery Chinook were generally much lower than for unmarked fish, also potentially limiting the scope for competition (e.g., Duffy et al. 2011).

To examine the information from the density plots in a more condensed approach, that information was combined to make Figure 18, which shows the densities of the various salmon species and origins (hatchery or unmarked) by month and zone. The data from 2011 were also examined, and show that only in the South Bay zone in April were densities of unmarked and hatchery Chinook, coho and chum salmon simultaneously high enough to indicate potential competition between them. In 2012, the only zone to have a similar occurrence was the inner estuary in April and May (Figure 18). This provides an indication of potential competition only; a more thorough understanding of spatial distribution and prey availability would be needed to determine if competition is actually occurring.

Figure 18: Tabular summary of density plots by zone and month, 2012





Buffalo sculpin captured off Damon Point, Grays Harbor, 2012

Additional Goals for 2012-13

- Historical analysis: at the conclusion of this project, our catch data will be compared to that of Simenstad and Eggers (1981) to provide a snapshot of salmon population levels roughly 30 years later.
- A fish community analysis via PCA and/or non-metric multi-dimensional scaling (NMDS) will be conducted on salmonid and non-salmonid fish communities to further investigate the relationships potentially governing fish distributions in the estuary. This will also allow us to better examine the potential for competition between species in the various habitats. (Summer 2013)
- Regression/GLM analysis: in 2013, we will include chlorophyll/turbidity data recently available from Department of Ecology water quality stations in Grays Harbor as explanatory variables to determine if primary (and associated secondary) production affects juvenile fish distribution in the estuary.
- Though we expect each year to be unique, 2012 stood out as one of the top five wettest years on record, despite a long dry spell in the fall. 2011 was also unusual in that it had the wettest, coldest spring in 60 years and a relatively wet summer and dry autumn. A goal of this project is to sample in years with "normal", "low" and "high" escapement for the three main salmonid species (Chinook, coho and chum salmon) in order to analyze how the spatial and temporal distribution of juvenile salmon changes as the density of these species in the estuary fluxes. Wild smolt productivity of Chinook salmon was categorized as normal for 2011 and high for 2012; productivity of YOY coho salmon was considered high for 2010 and 2011, and about the upper limit of a normal year for 2012; and smolt productivity for chum salmon was high for both 2011 and 2012 (Table 14).

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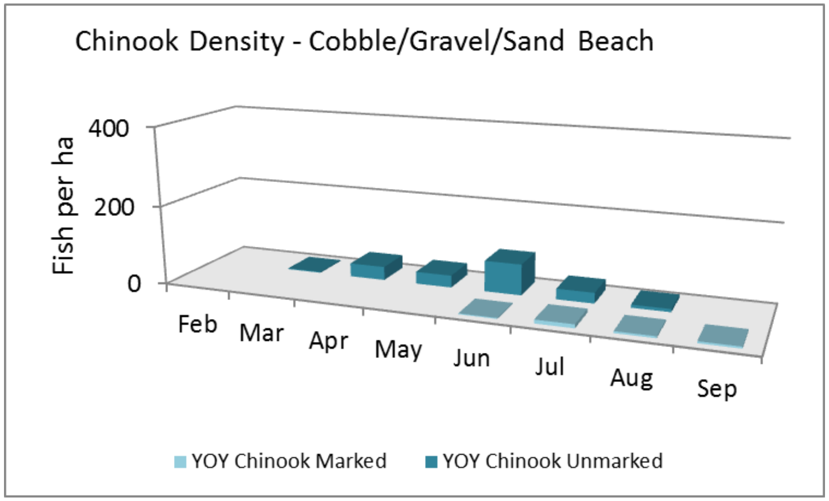
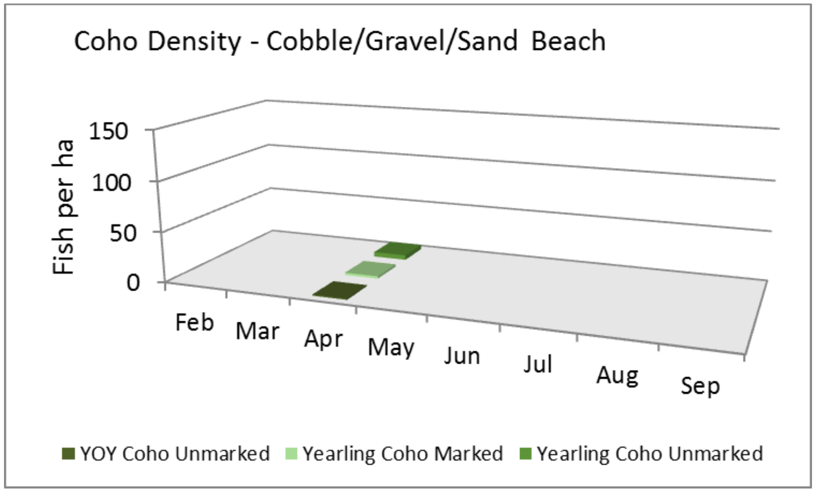
Appendices

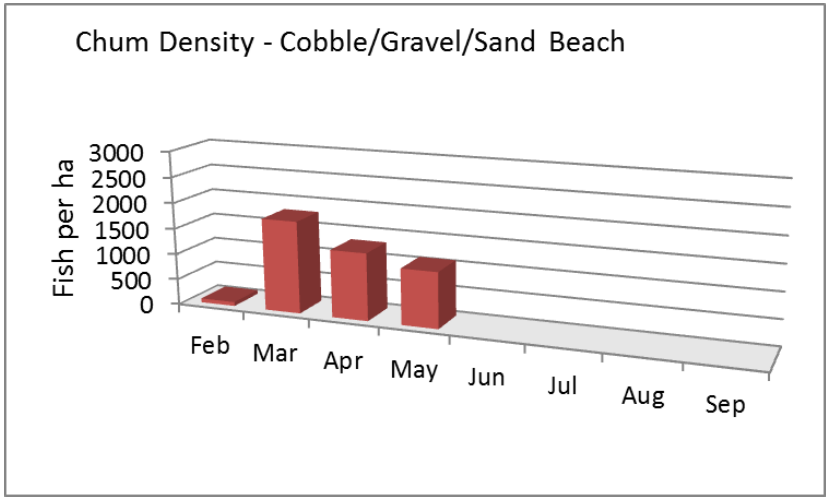
Appendix 1: Core (bold text) and secondary sites sampled in 2012

Full Site Name	Degrees N	Degrees W	Habitat Type	Zone	Site type
Half Moon Bay (Westport)	46.904246	-124.130385	Cobble/Gravel/Sand Beach	Mouth	secondary site
Charlie Creek	46.947480	-123.836100	High Emergent Marsh	Central estuary	core site
Damon Point	46.945315	-124.105779	Cobble/Gravel/Sand Beach	Central estuary	core site
Sand Island channel (North side)	46.957501	-124.052176	Aquatic Vegetation Bed	Central estuary	core site
Stearn's Bluff	46.924029	-123.978258	Aquatic Vegetation Bed	Central estuary	core site
Withcomb Flats (North side)	46.917876	-124.065349	Sand Flat	Central estuary	secondary site
Chenois Creek Flats	47.009079	-124.033366	Aquatic Vegetation Bed	North Bay	core site
Goose Island Flats (NW corner)	46.981537	-124.073087	Aquatic Vegetation Bed	North Bay	core site
Humptulips Right River Channel	47.049975	-124.046594	Forested	North Bay	core site
Humptulips River mouth	47.035434	-124.052548	High Emergent Marsh	North Bay	core site
Elk River Flats	46.856100	-124.034283	Aquatic Vegetation Bed	South Bay	core site
Johns River channel	46.902084	-123.987036	High Emergent Marsh	South Bay	core site
Mallard Slough	46.855625	-124.061887	High Emergent Marsh	South Bay	core site
Sculpin Cove (upper Elk River)	46.837564	-124.023062	High Emergent Marsh	South Bay	core site
Westport Marina	46.899119	-124.087932	Sand Flat	South Bay	core site
Chehalis river near restoration site	46.947571	-123.654645	Scrub/Shrub Cover	Surge Plain	core site
Lower Elliot Slough	46.978491	-123.768695	Forested	Surge Plain	core site
Sand Island East Alternate	46.952415	-123.725693	High Emergent Marsh	Surge Plain	core site
Wynoochee River Delta	46.962568	-123.607227	Forested	Surge Plain	core site
Cow Point	46.961900	-123.847065	Aquatic Vegetation Bed	Upper estuary	core site
East Fork Hoquiam Alternate	47.012436	-123.871884	Forested	Upper estuary	secondary site
East Fork Hoquiam River	47.025343	-123.875533	Forested	Upper estuary	core site
Hoquiam Mainstem	46.986803	-123.875924	Scrub/Shrub Cover	Upper estuary	core site
Rennie Island	46.966157	-123.882173	Mud Flat	Upper estuary	core site
West Fork Hoqiuam River mouth	46.996364	-123.896837	Scrub/Shrub Cover	Upper estuary	core site
West Fork Hoquiam River	47.015359	-123.910941	Forested	Upper estuary	core site

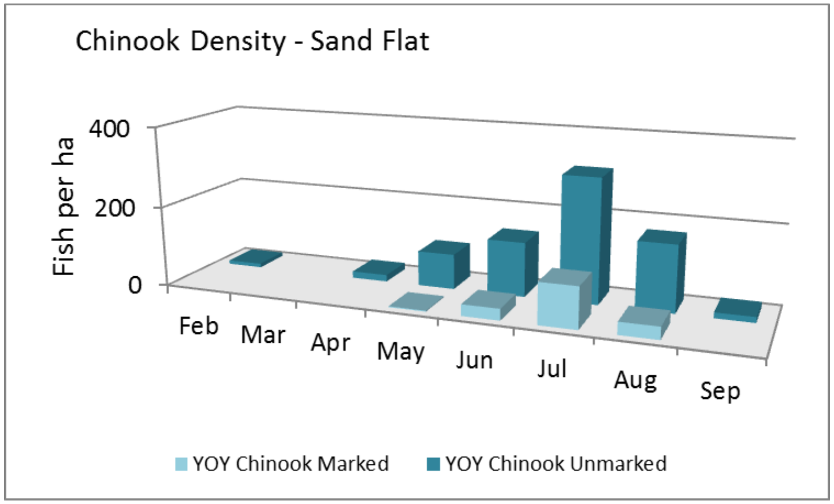
Appendix 2:Salmon habitat usage by month,2012

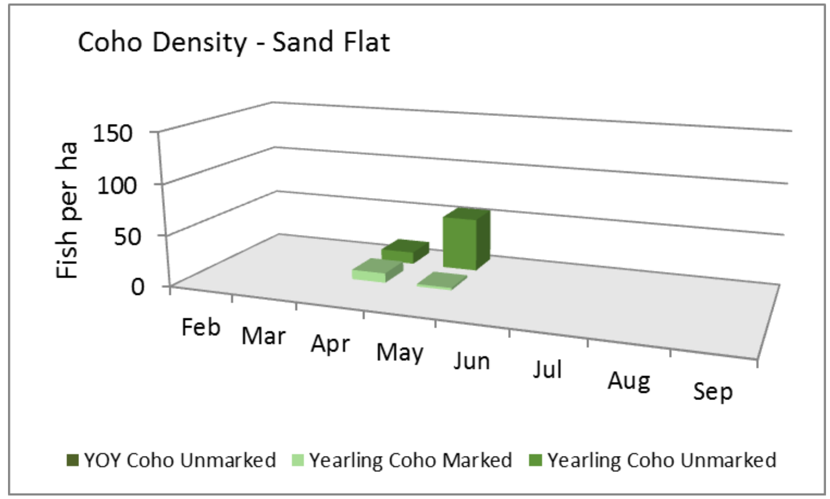


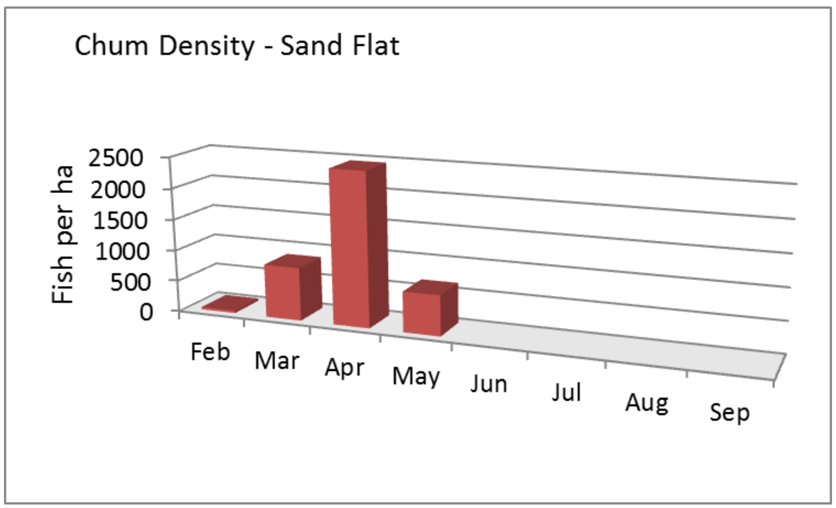




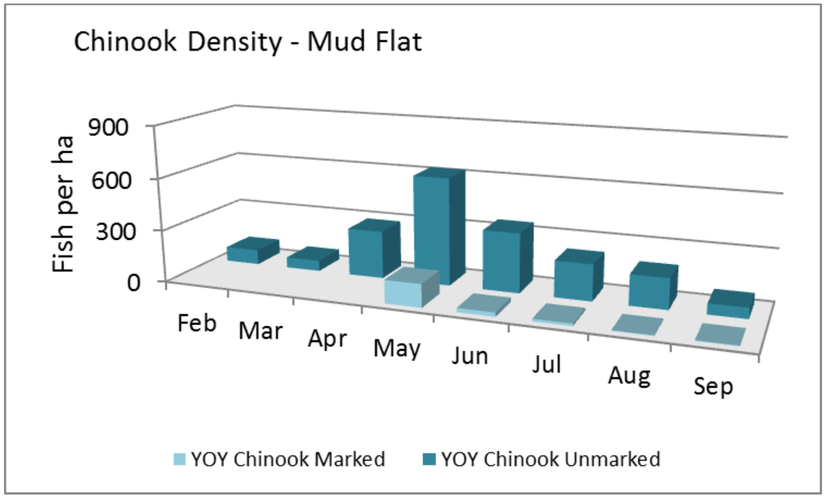
Salmonid density by month, sand flat, 2012

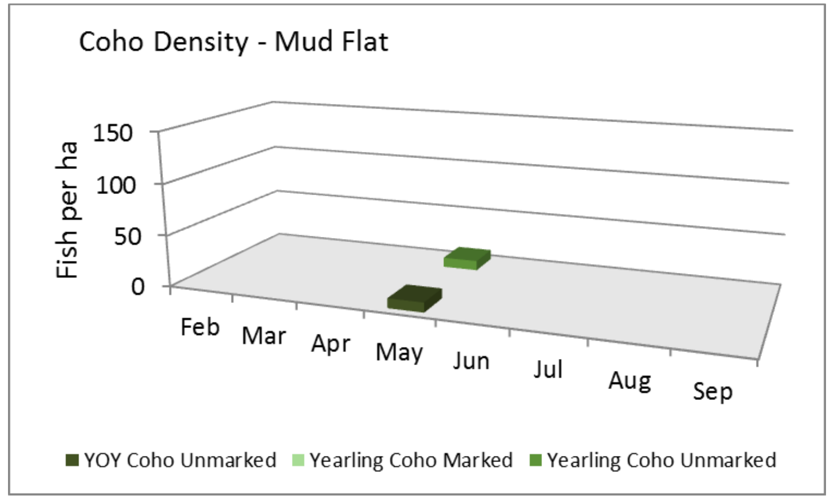


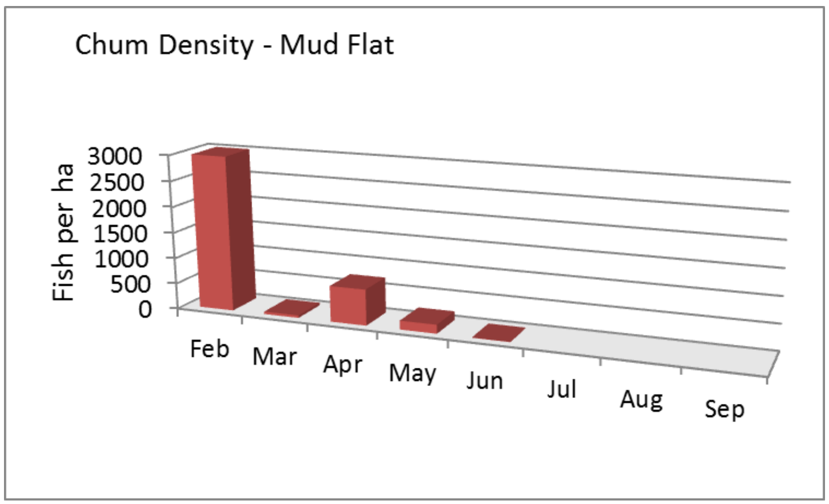




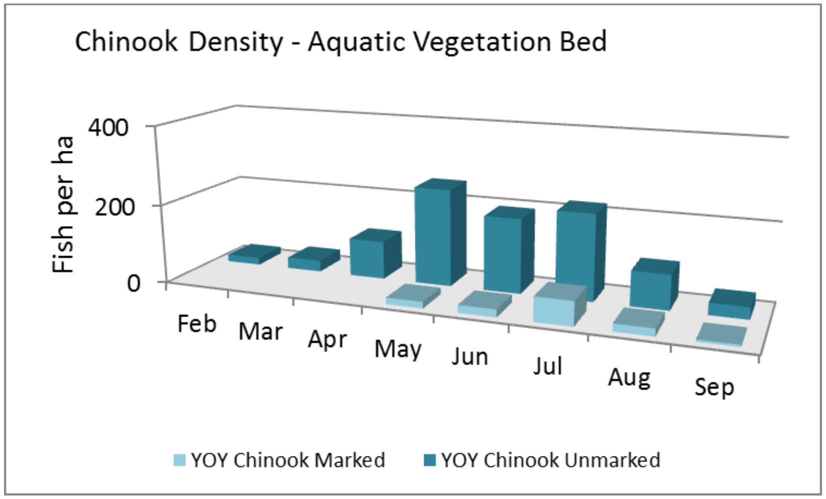
Salmonid density by month, mud flat, 2012

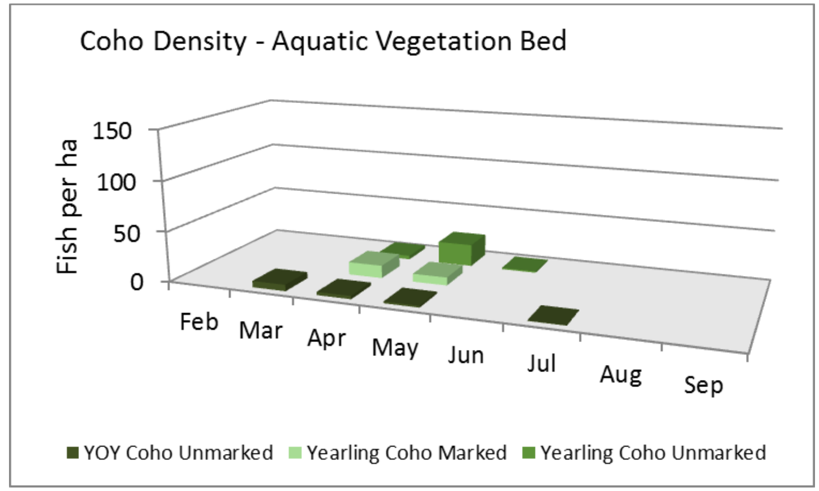


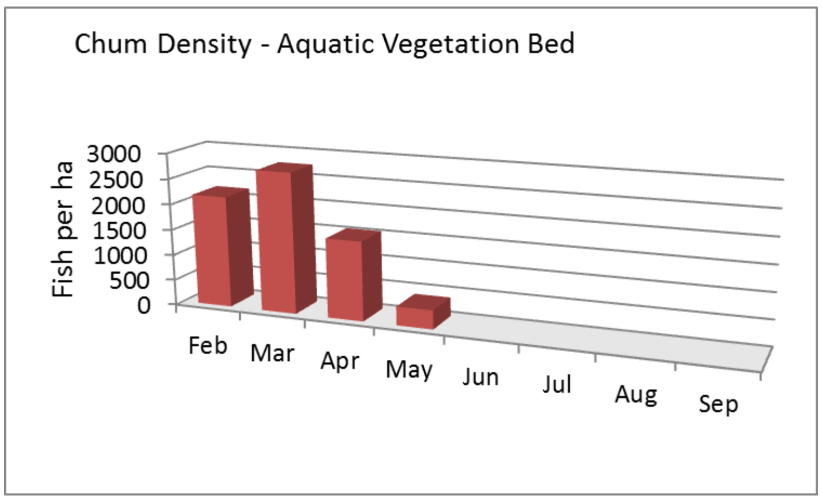


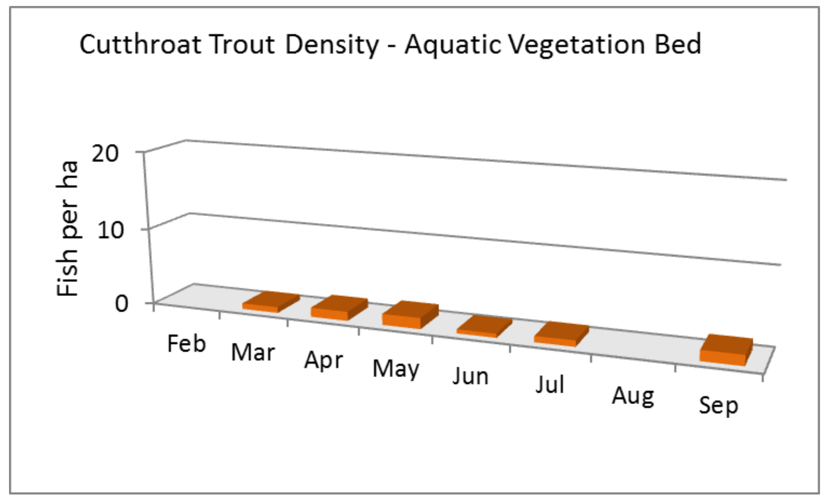


Salmonid density by month, aquatic vegetation bed, 2012

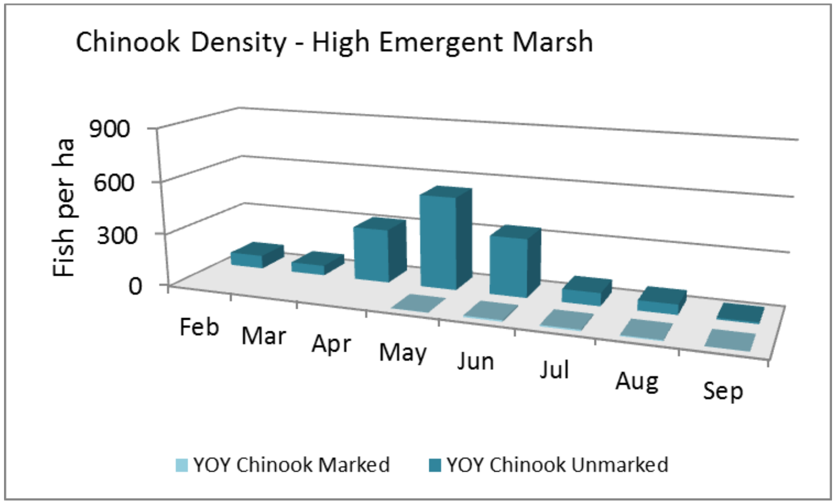


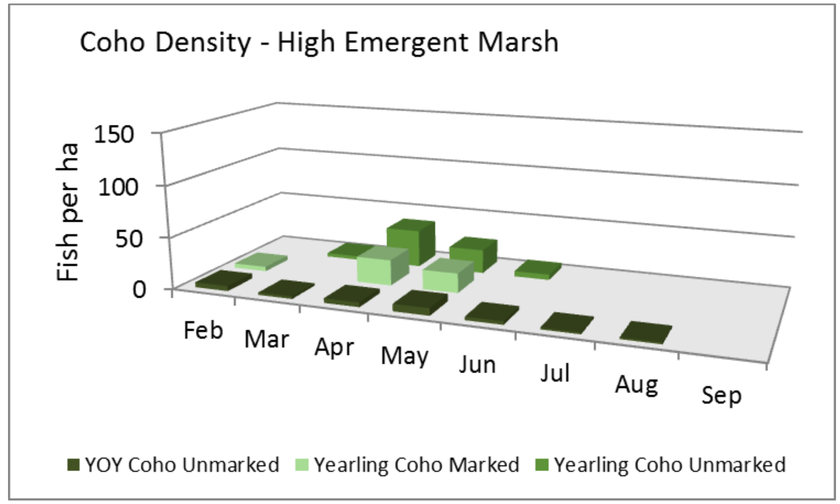


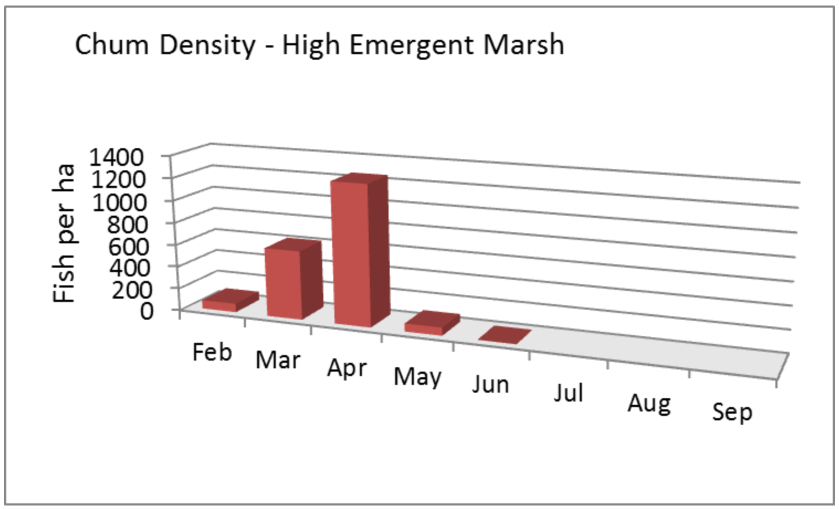


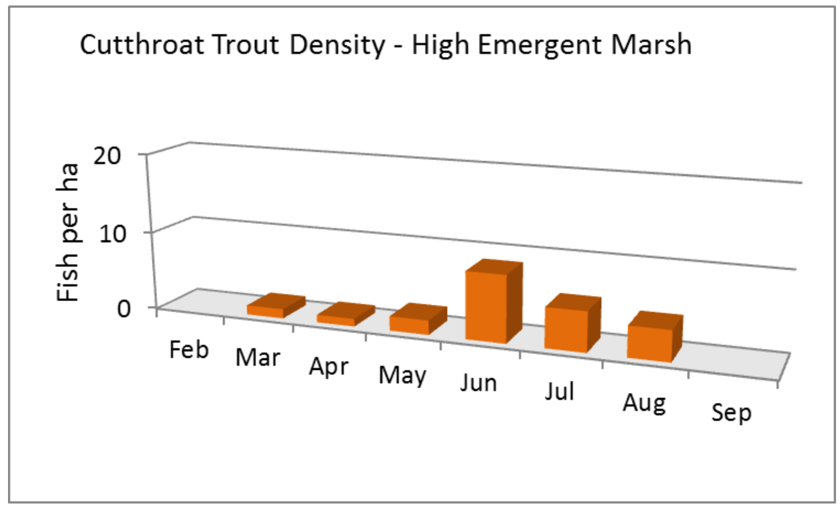


Salmonid density by month, high emergent marsh, 2012

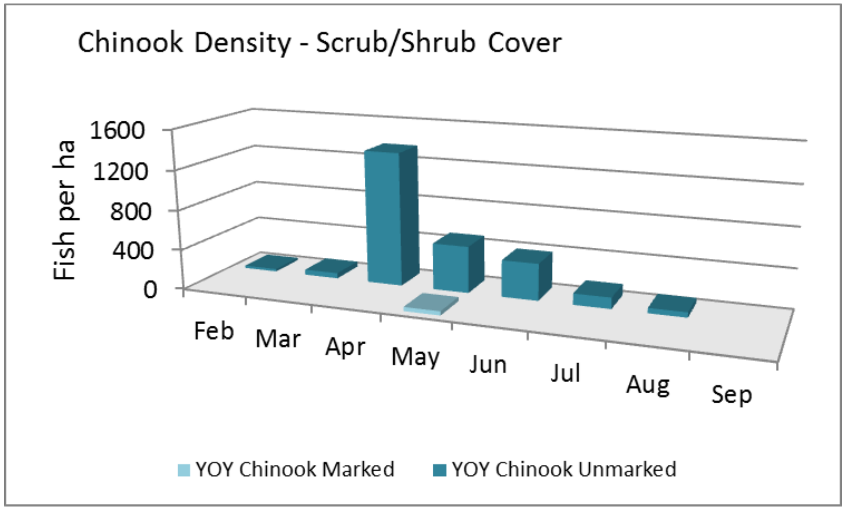


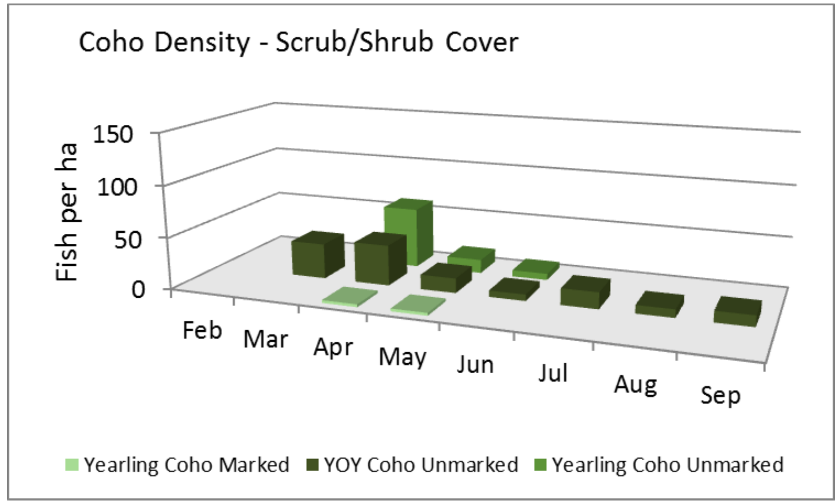


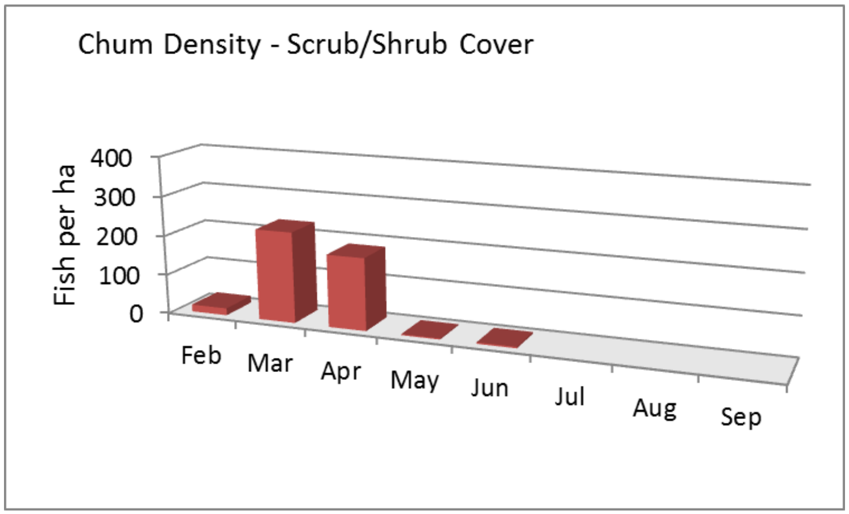


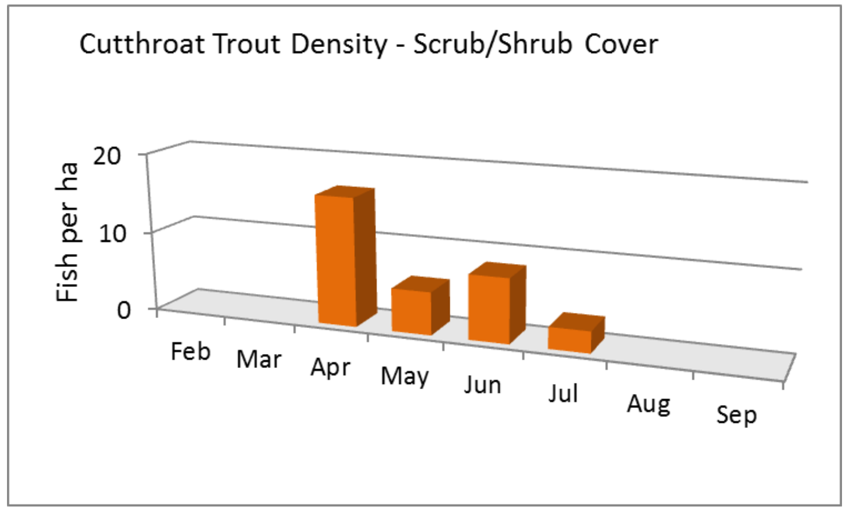


Salmonid density by month, scrub/shrub cover, 2012

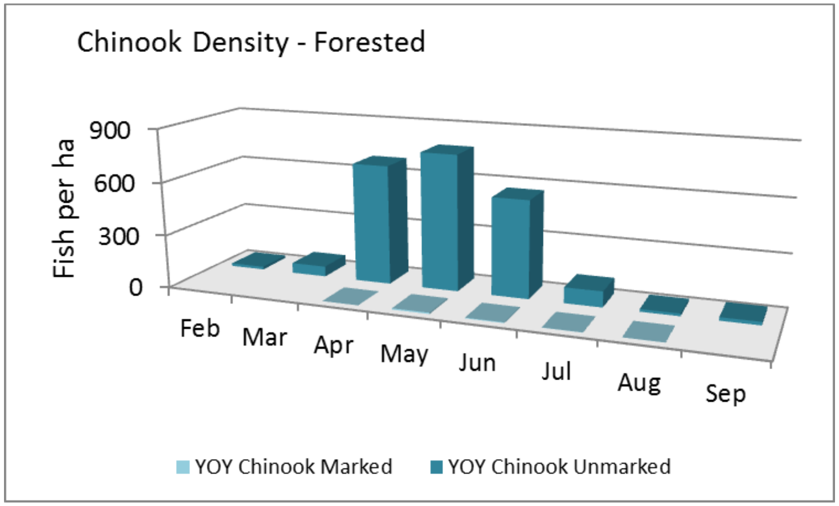


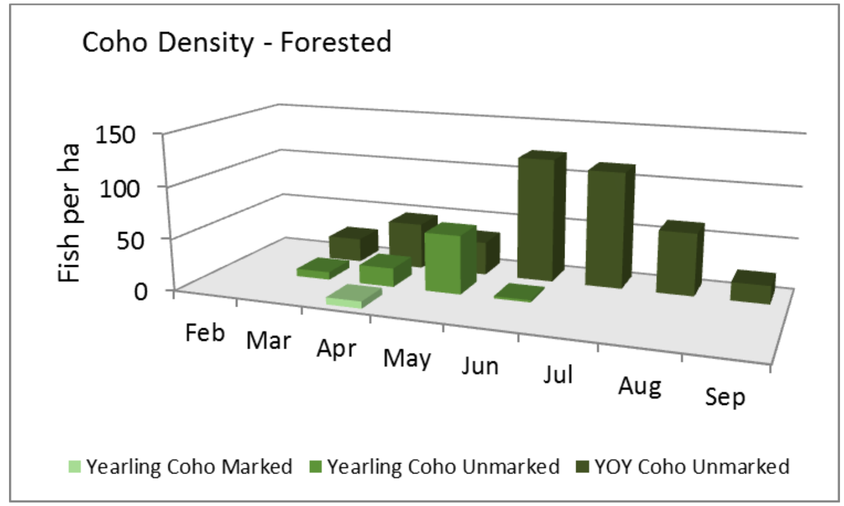


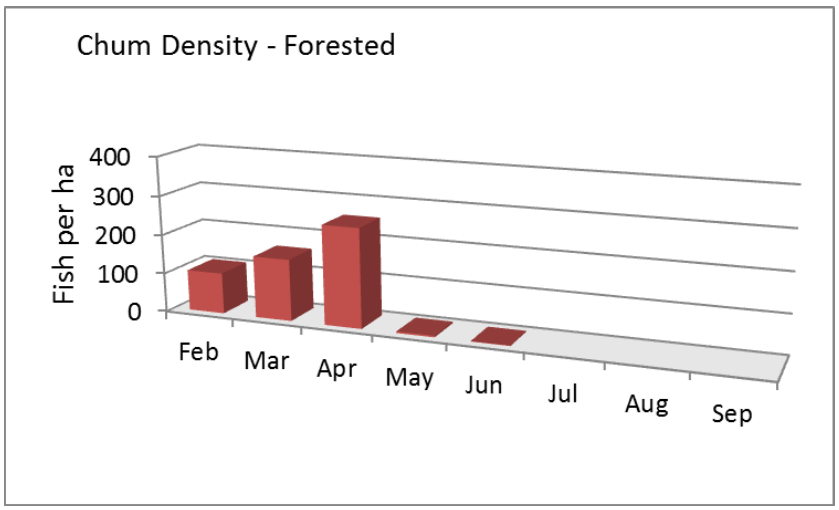


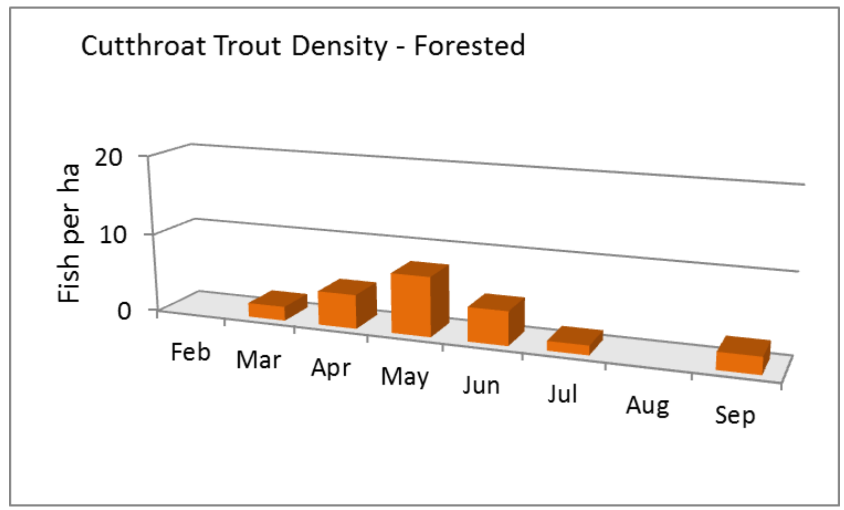


Salmonid density by month, forested, 2012

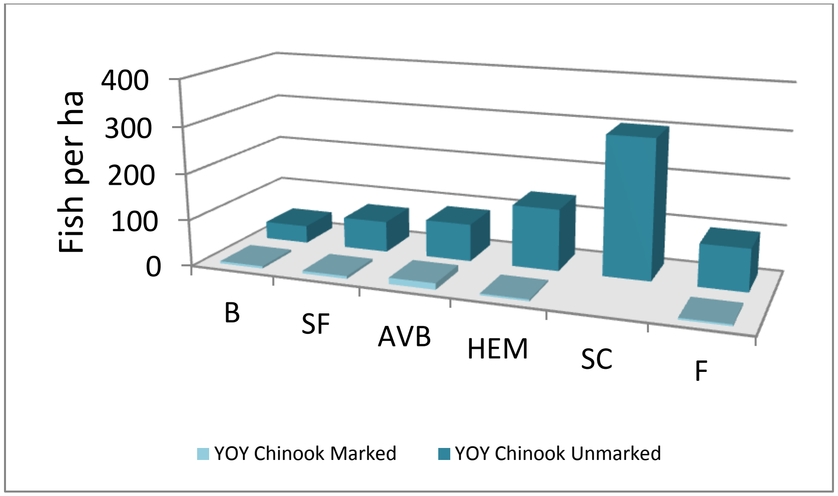




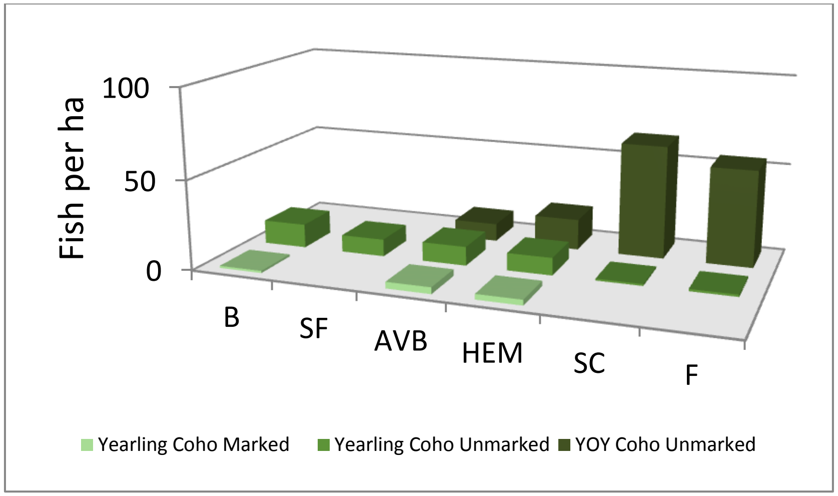




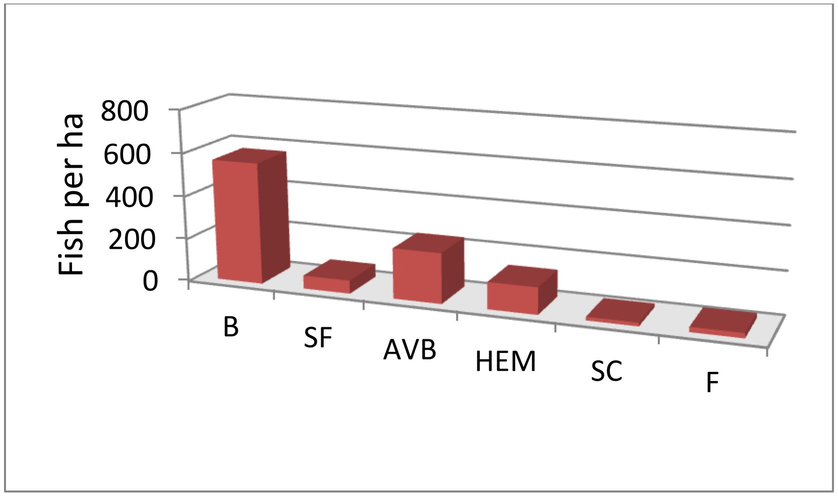
Chinook salmon density, by habitat type, 2011



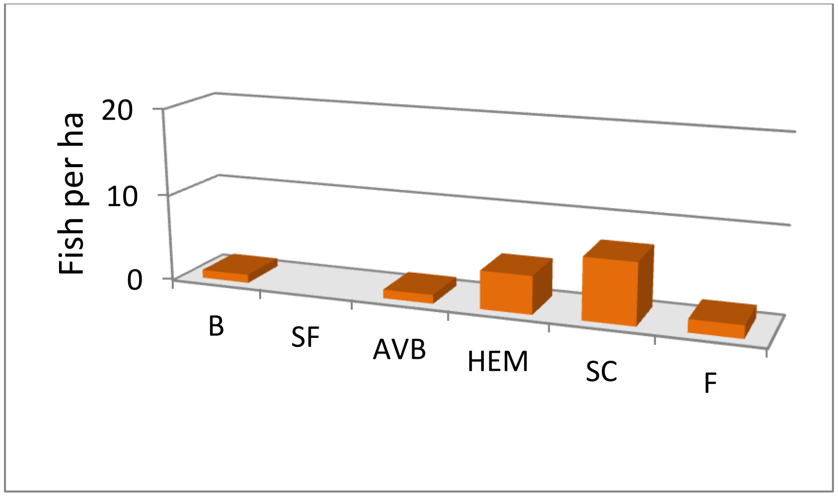
Coho salmon density, by habitat type, 2011



Chum salmon density, by habitat type, 2011



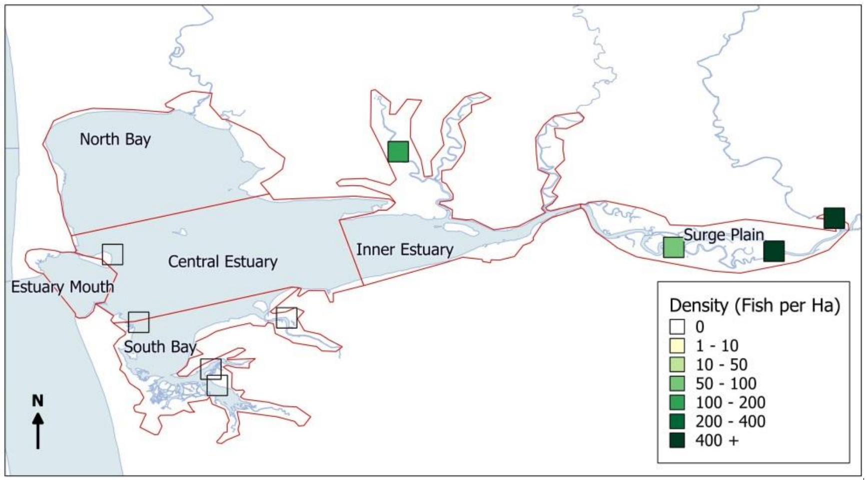
Cutthroat trout density, by habitat type, 2011



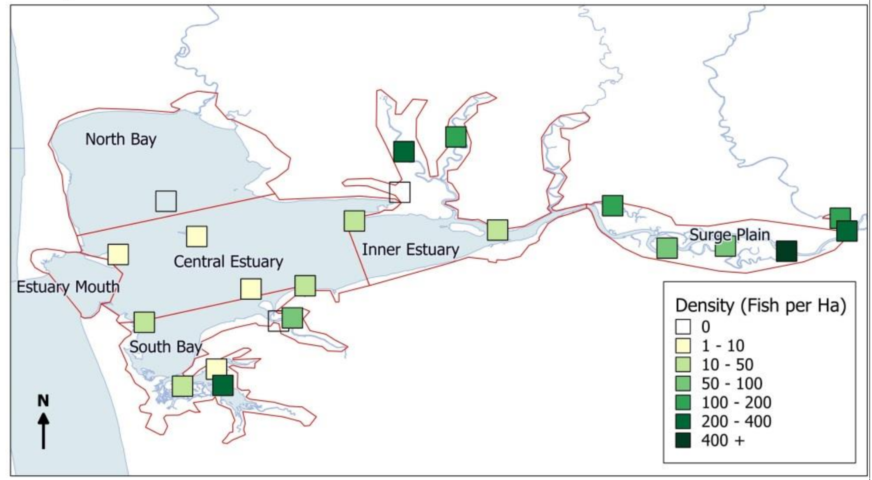
Appendix 3. 2011 Salmon density plots

Density and distribution of unmarked YOY Chinook salmon, 2011

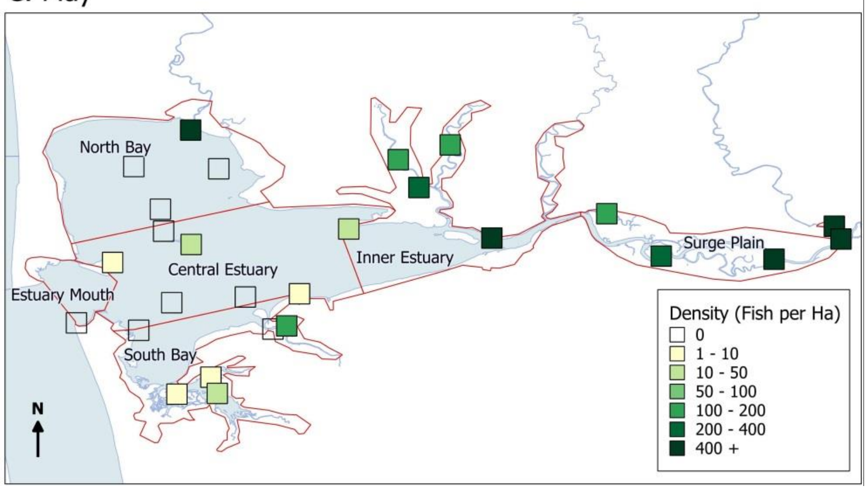
A. March



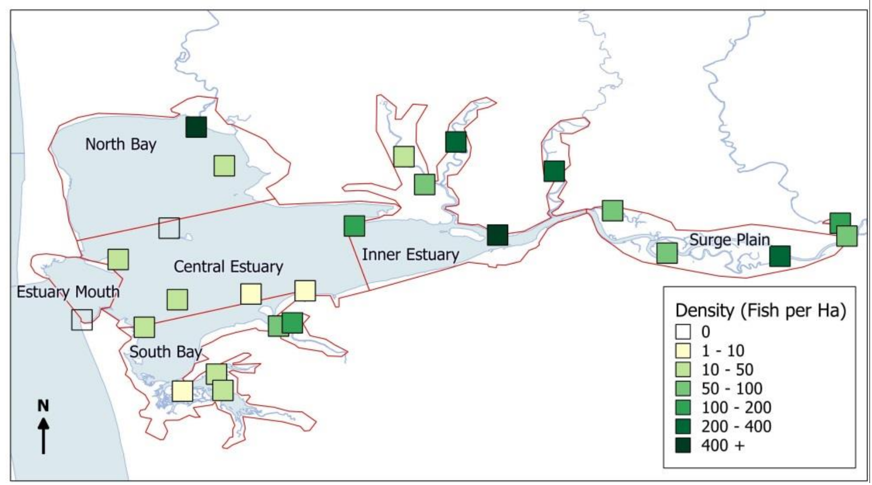
B. April



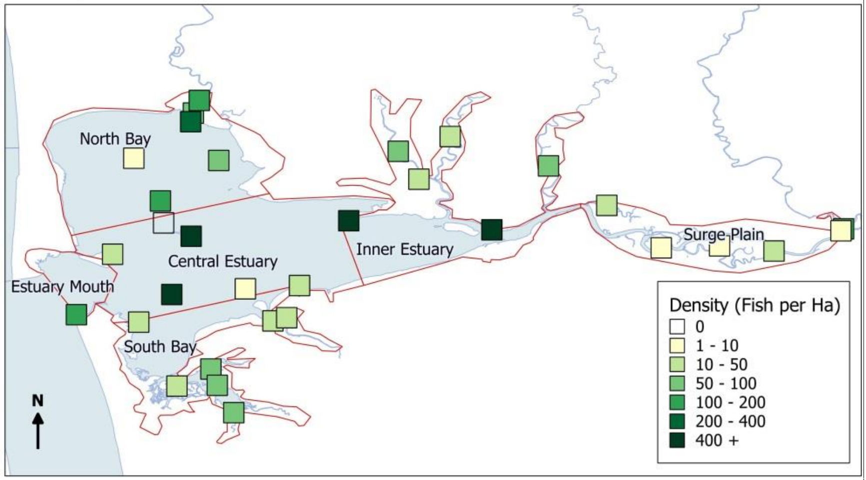
C. May



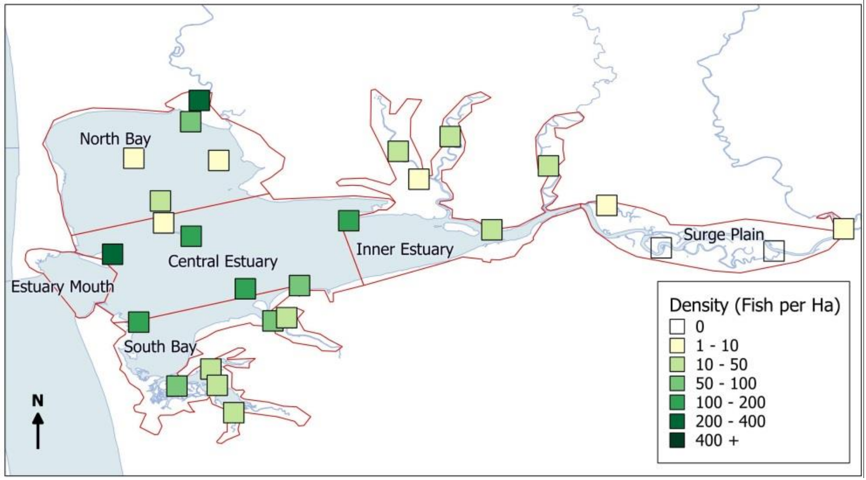
D. June



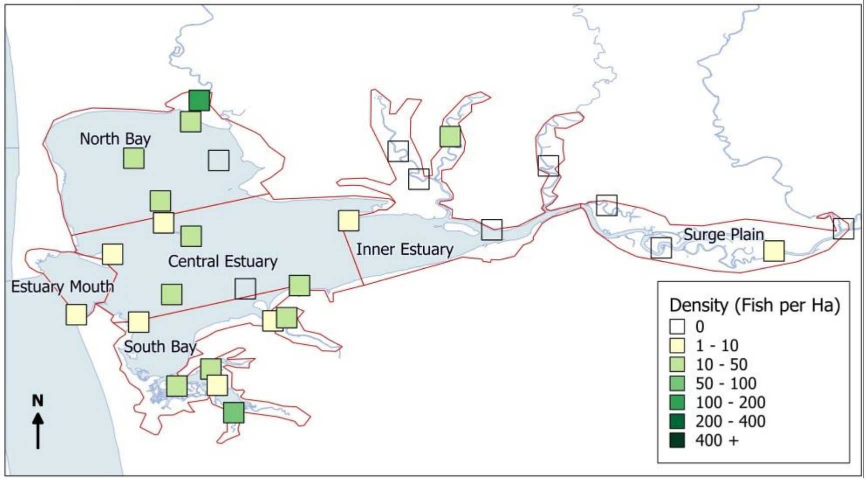
E. July



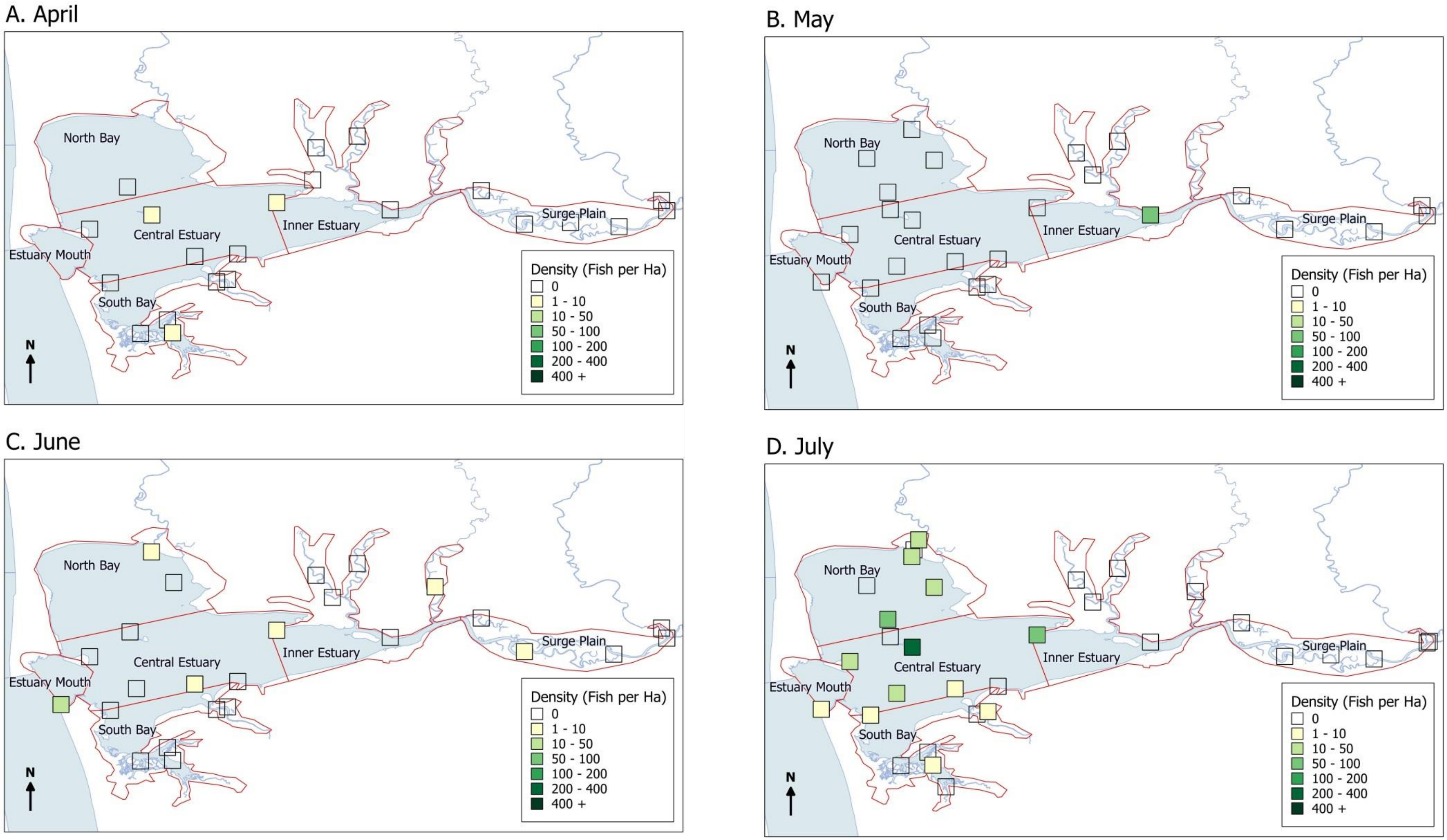
F. August



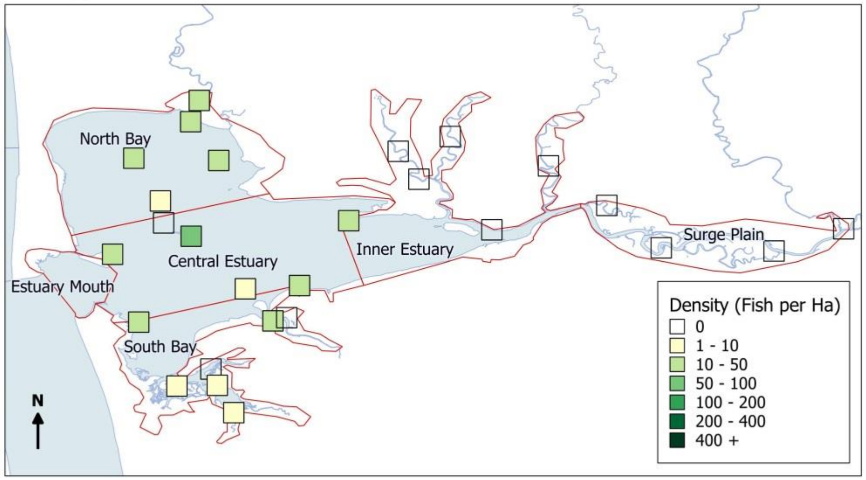
G. September



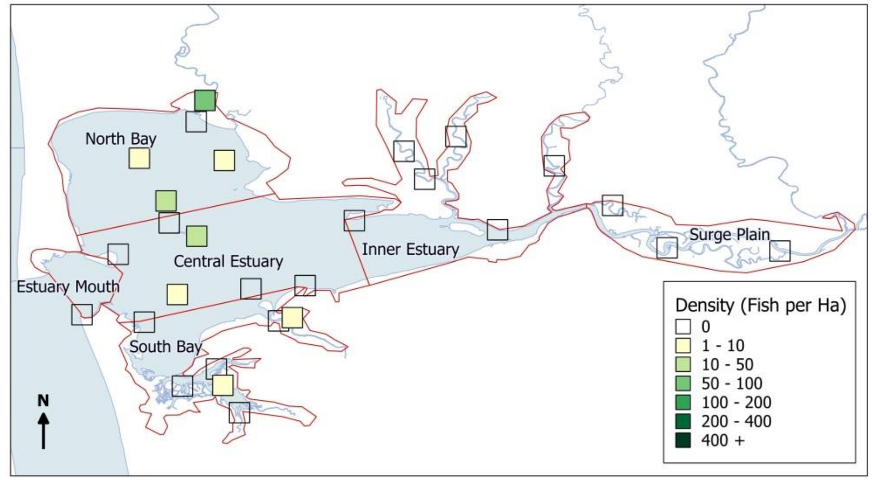
Density and distribution of hatchery YOY Chinook salmon, 2011



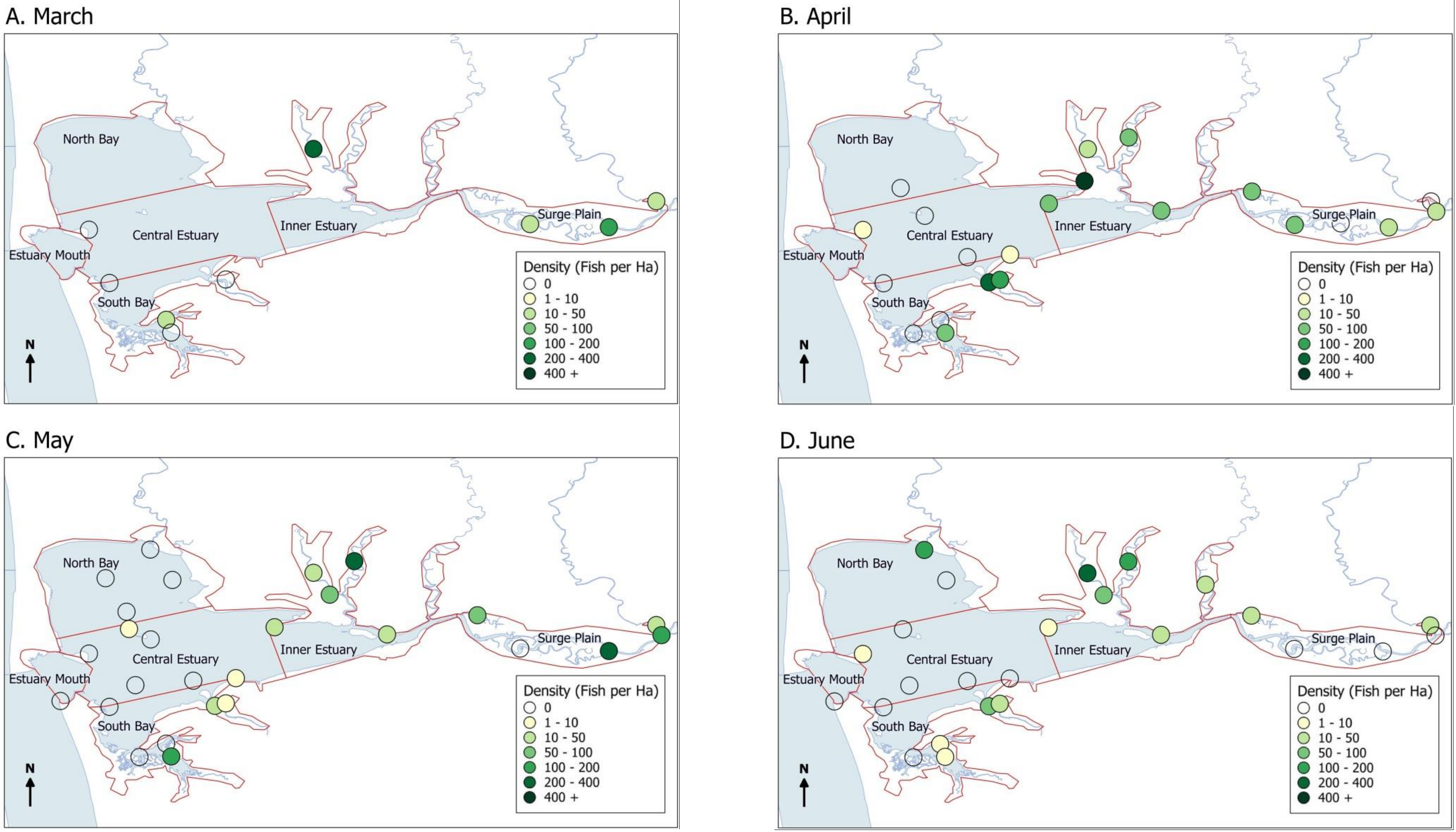
E. August



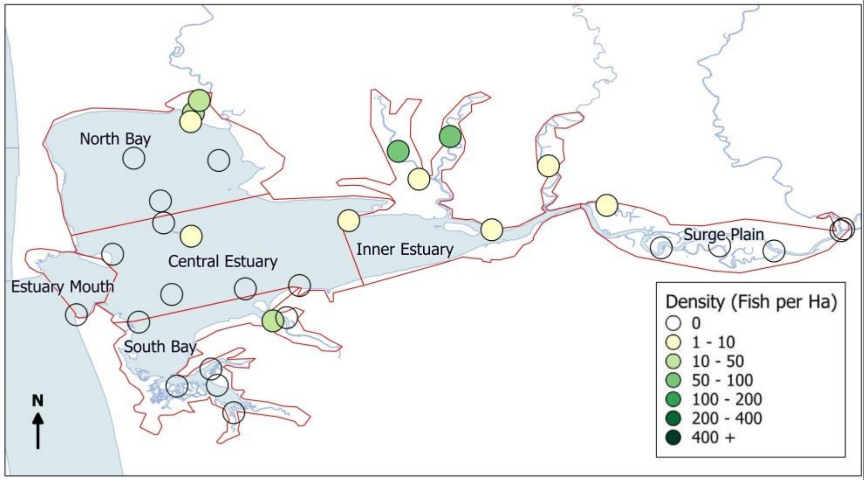
F. September



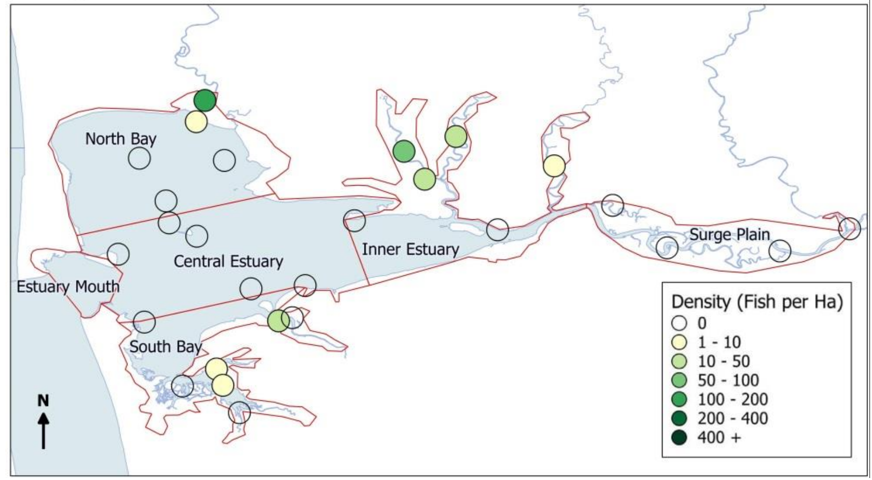
Density and distribution of unmarked YOY coho salmon, 2011



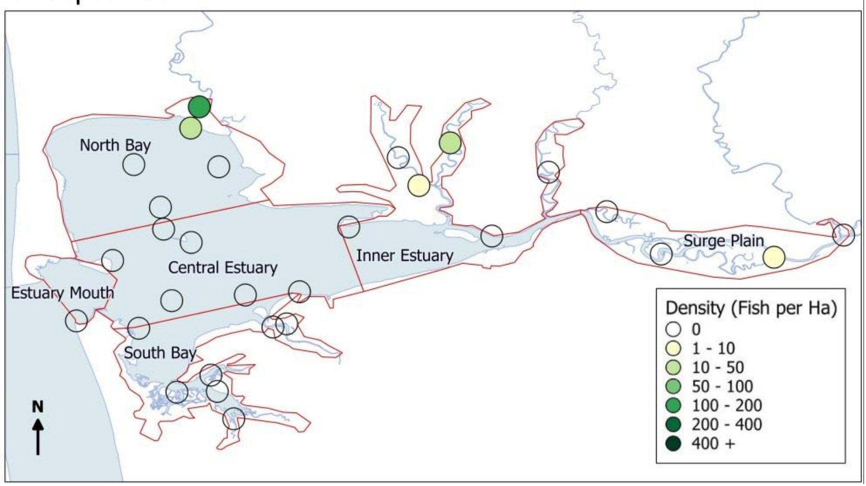
E. July



F. August

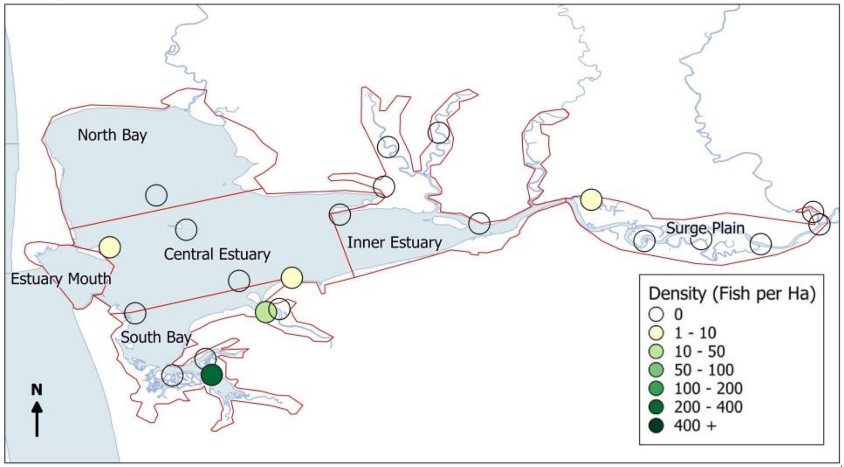


G. September

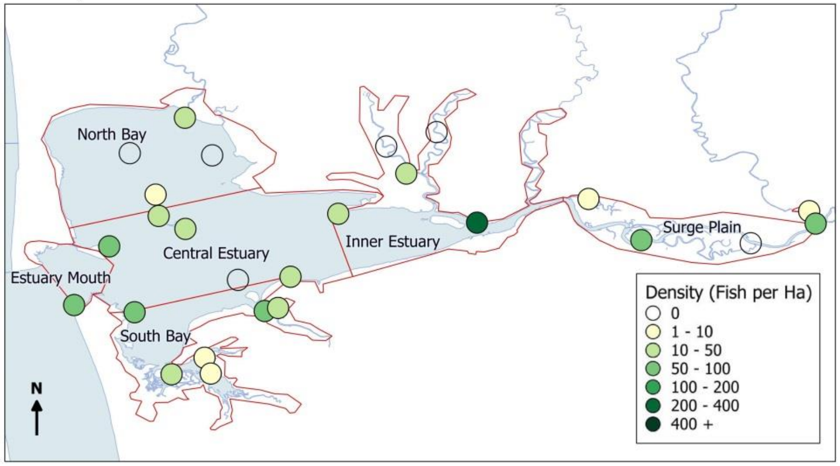


Density and distribution of unmarked yearling coho salmon, 2011

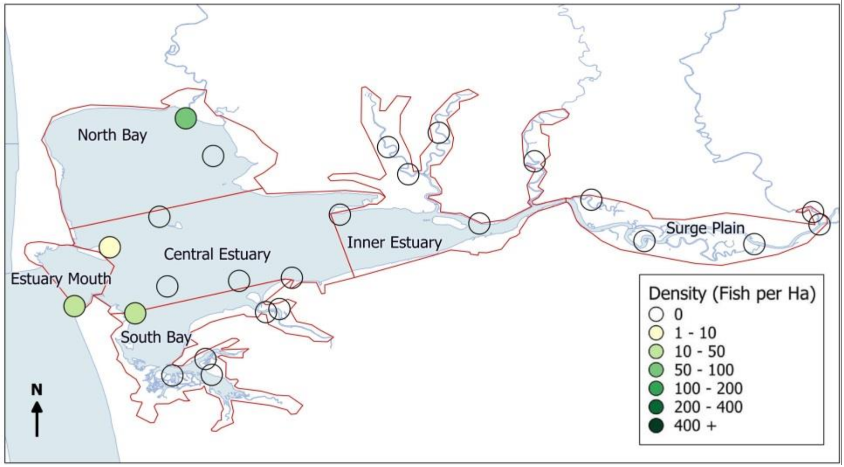
A. April



B. May

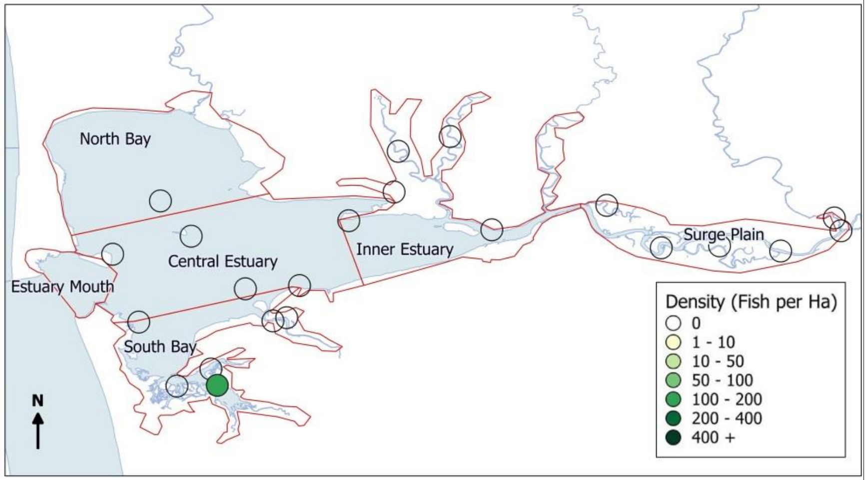


C. June

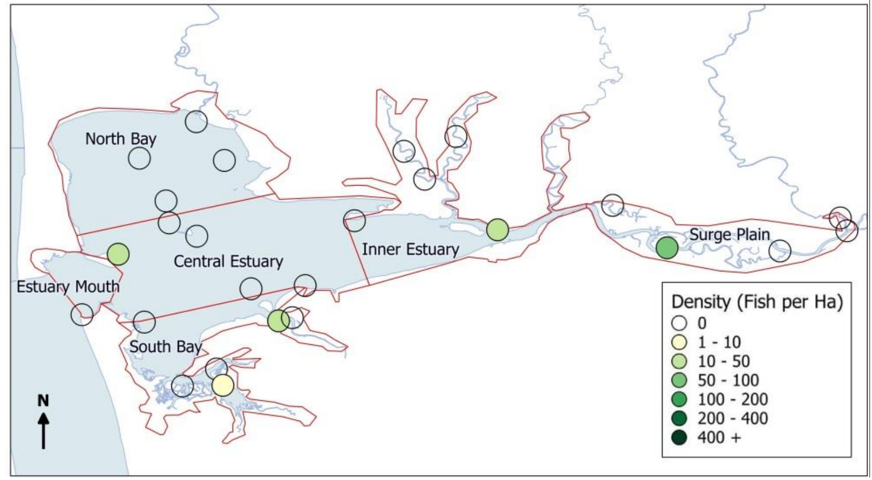


Density and distribution of hatchery yearling coho salmon, 2011

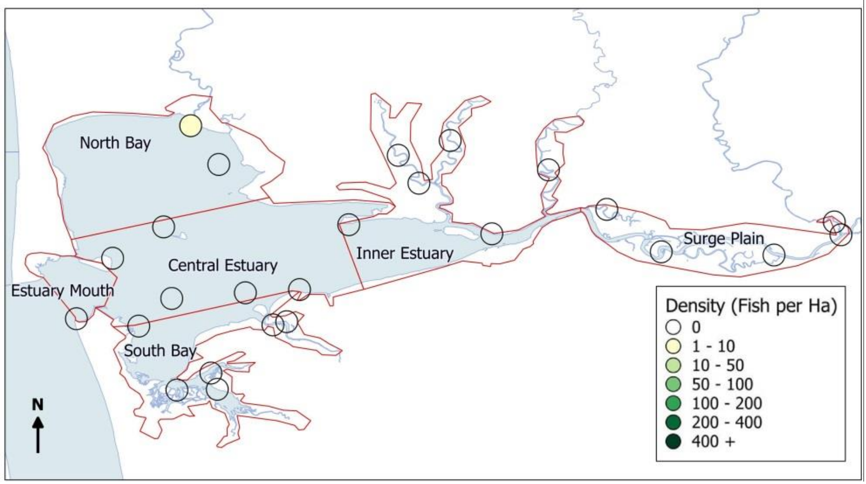
A. April



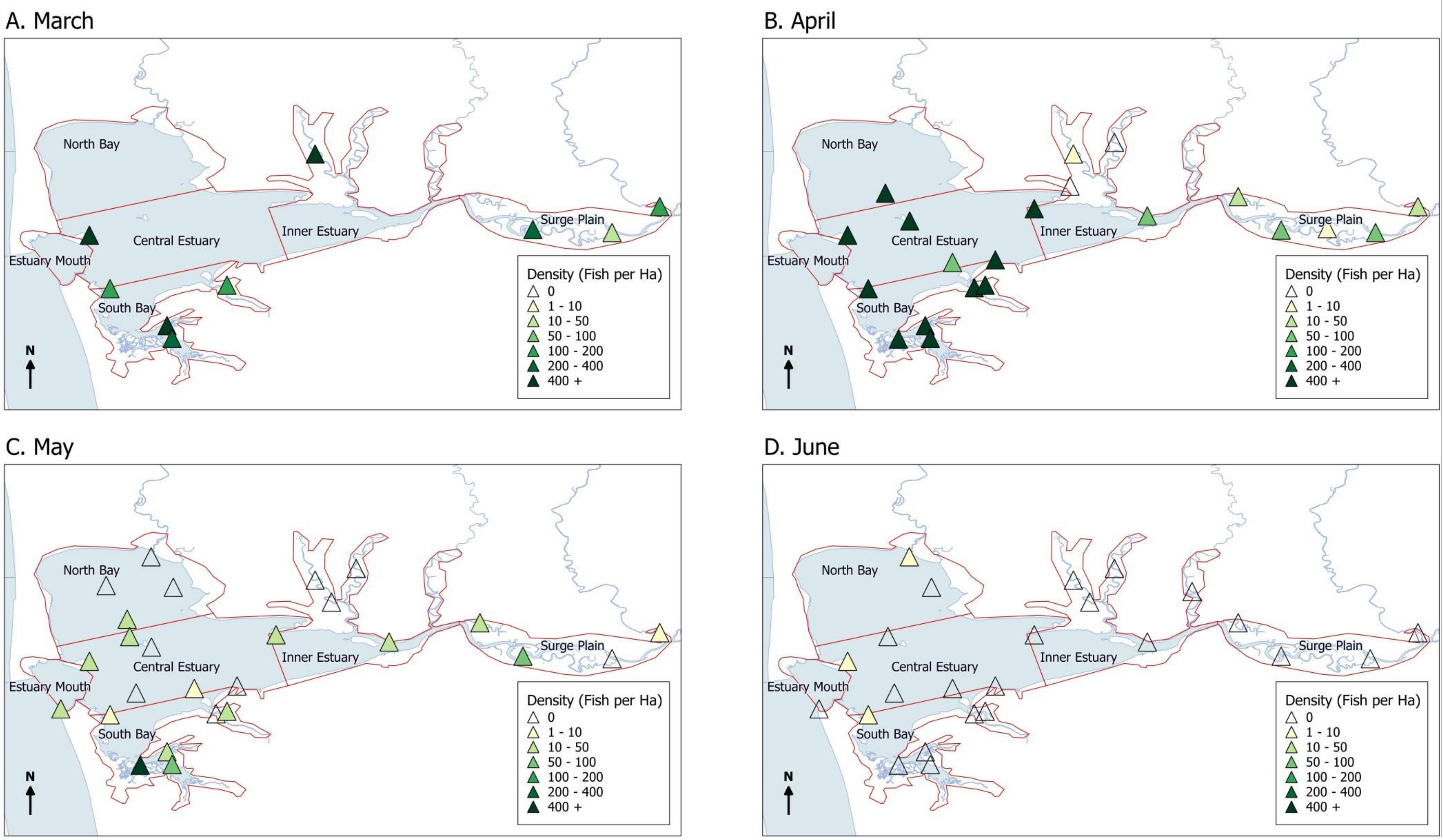
B. May



C. June



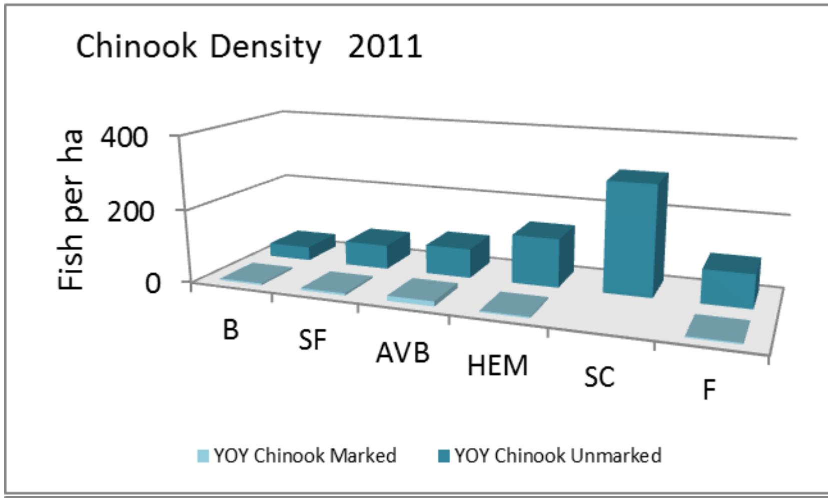
Density and distribution of unmarked YOY chum salmon, 2011

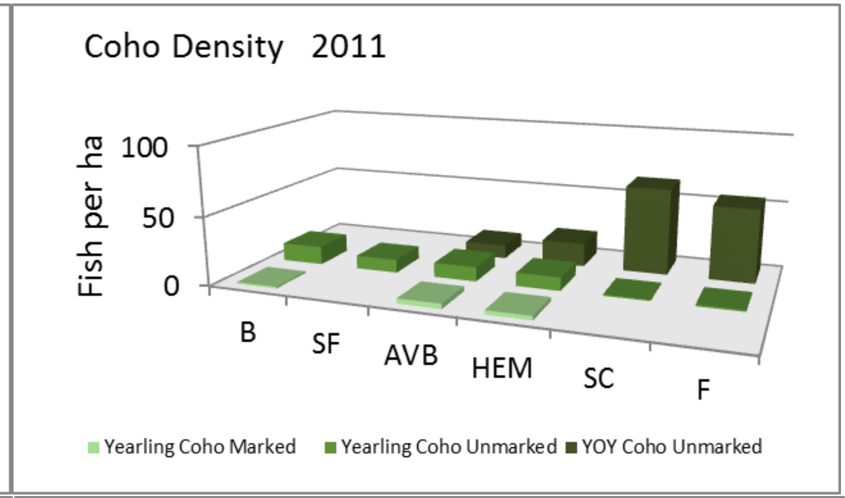


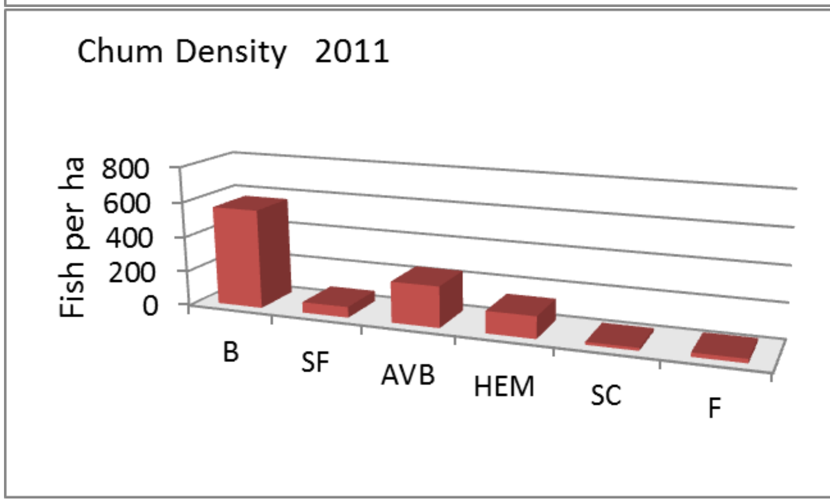
Appendix 4: Online resources for estimating the tidal heights

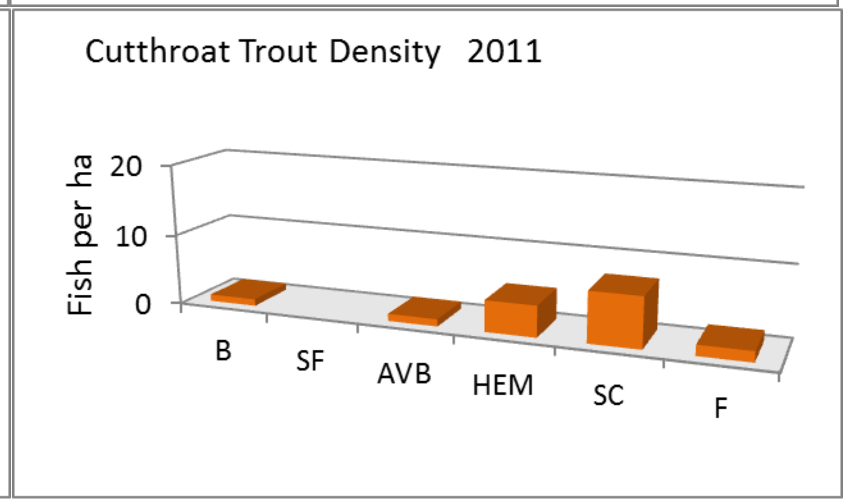
Site name	Zone	Tide predictor	Website
Half Moon Bay [aka Westport ocean side]	Mouth	Westport	http://www.protides.com/washington/2964
Westport Marina (South Bay Channel)	South Bay	Westport	http://www.protides.com/washington/2964
Elk River Flats (aka South Bay Forest)	South Bay	Bay City	http://www.protides.com/washington/164/
Beardslee Slough	South Bay	Bay City	http://www.protides.com/washington/164/
Beardslee Slough Mouth	South Bay	Bay City	http://www.protides.com/washington/164/
Mallard Slough	South Bay	Bay City	http://www.protides.com/washington/164/
John's River channel	South Bay	Markham	http://www.protides.com/washington/1592/
John's River slough	South Bay	Markham	http://www.protides.com/washington/1592/
Ocean Shores Flats 1	North Bay	Westport	http://www.protides.com/washington/2964
North Bay Flats 1 (aka Humptulips flats 1)	North Bay	Westport	http://www.protides.com/washington/2964
North Bay Flats 2 (aka Humptulips flats 2)	North Bay	Westport	http://www.protides.com/washington/2964
Campbell Slough	North Bay	Westport	http://www.protides.com/washington/2964
Humptulips River mouth	North Bay	Westport	http://www.protides.com/washington/2964
Jessie Slough	North Bay	Westport	http://www.protides.com/washington/2964
Chinois Creek Flats Alternate	North Bay	Westport	http://www.protides.com/washington/2964
Chinois Creek Flats Alternate 2	North Bay	Westport	http://www.protides.com/washington/2964
Chinois Creek Flats 1	North Bay	Westport	http://www.protides.com/washington/2964
Chinois Creek Flats 2	North Bay	Westport	http://www.protides.com/washington/2964
Sand Island channel (North side)	Central estuary	Westport	http://www.protides.com/washington/2964
Sand Island Flats (South side)	Central estuary	Westport	http://www.protides.com/washington/2964
Goose Island Flats (NW corner)	Central estuary	Westport	http://www.protides.com/washington/2964
North Bay Bar (Goose Island Alt.)	Central estuary	Westport	http://www.protides.com/washington/2964
Damon Point	Central estuary	Westport	http://www.protides.com/washington/2964
Bar off John's River	Central estuary	Markham	http://www.protides.com/washington/1592/
Withcomb Flats	Central estuary	Westport	http://www.protides.com/washington/2964
Stearn's Bluff	Central estuary	Markham	http://www.protides.com/washington/1592/
Moon Island	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
Cow Point	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
West Fork Hoquiam River	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
West Fork Hoquiam River Mouth	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
Hoquiam River	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
Hoquiam River slough	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
East Fork Hoquiam River	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
Wishkah River Channel	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
Wishkah River Slough	Upper estuary	Aberdeen	http://www.protides.com/washington/11/
Lower Elliot Slough	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Preacher's Slough (corner)	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Sand Island East	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Preacher Slough Restoration	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Wynoochee River	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Chehalis near Friends landing	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Chehalis restoration site	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/
Chehalis River surge plain	Surge Plain	Cosmopolis	http://www.protides.com/washington/616/

Appendix 5: Habitat usage by species density, 2011



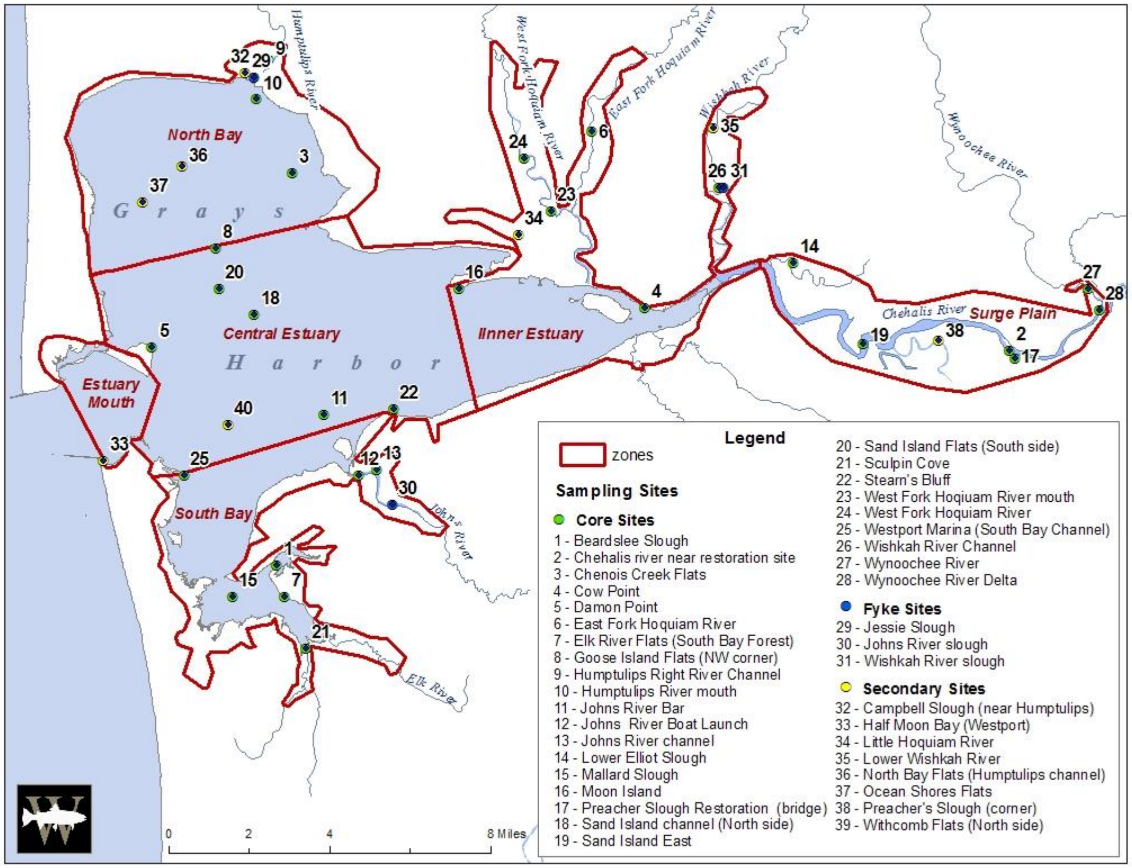






Appendix 6: A map of the Chehalis River estuary (2011)

[showing the six zones and locations of the core, secondary, and fyke net sites sampled in 2011]



Appendix 7: List of core, secondary and fyke sites sampled in 2011

Site Name	latitude	longitude	habitat	zone	type
Beardslee Slough	46.867158	-124.038720	Aquatic Vegetation Bed	South Bay	core site
Campbell Slough (near Humptulips)	47.044676	-124.058826	Scrub/Shrub Cover	North Bay	secondary site
Chehalis river near restoration site	46.947571	-123.654645	Scrub/Shrub Cover	Surge Plain	core site
Chenois Creek Flats	47.009079	-124.033366	Aquatic Vegetation Bed	North Bay	core site
Cow Point	46.961900	-123.847065	High Emergent Marsh	Upper estuary	core site
Damon Point	46.945315	-124.105779	Cobble/Gravel/Sand Beach	Central estuary	core site
East Fork Hoquiam River	47.025343	-123.875533	Forested	Upper estuary	core site
Elk River Flats (South Bay Forest)	46.856100	-124.034283	Forested	South Bay	core site
Goose Island Flats (NW corner)	46.981537	-124.073087	Aquatic Vegetation Bed	Central estuary	core site
Half Moon Bay (Westport)	46.904246	-124.130385	Cobble/Gravel/Sand Beach	Mouth	secondary site
Humptulips Right River Channel	47.049975	-124.046594	Forested	North Bay	core site
Humptulips River mouth	47.035434	-124.052548	Aquatic Vegetation Bed	North Bay	core site
Jessie Slough	47.043077	-124.053996	Scrub/Shrub Cover	North Bay	fyke
Johns River Boat Launch Seine Site	46.899973	-123.996389	High Emergent Marsh	Central estuary	core site
Johns River Bar	46.921800	-124.015204	Aquatic Vegetation Bed	Central estuary	core site
Johns River channel	46.902084	-123.987036	High Emergent Marsh	South Bay	core site
Johns River slough	46.889758	-123.978253	High Emergent Marsh	South Bay	fyke
Little Hoquiam River	46.987709	-123.913718	Scrub/Shrub Cover	Upper estuary	secondary site
Lower Elliot Slough	46.978491	-123.768695	Forested	Surge Plain	core site
Lower Wishkah River	47.027065	-123.811352	Forested	Upper estuary	secondary site
Mallard Slough	46.855625	-124.061887	High Emergent Marsh	South Bay	core site
Moon Island	46.968083	-123.944742	Aquatic Vegetation Bed	Upper estuary	core site
North Bay Flats (Humptulips channel)	47.010698	-124.091296	Aquatic Vegetation Bed	North Bay	secondary site
Ocean Shores Flats	46.997688	-124.111703	Aquatic Vegetation Bed	North Bay	secondary site
Preacher Slough Restoration (bridge)	46.944667	-123.651644	Forested	Surge Plain	core site
Preacher's Slough (corner)	46.950953	-123.691820	Forested	Surge Plain	secondary site
Sand Island channel (North side)	46.957501	-124.052176	Aquatic Vegetation Bed	Central estuary	core site
Sand Island East	46.949635	-123.731544	Aquatic Vegetation Bed	Surge Plain	core site
Sand Island Flats (South side)	46.966641	-124.070969	Aquatic Vegetation Bed	Central estuary	core site
Sculpin Cove	46.837546	-124.023062	High Emergent Marsh	South Bay	core site
South Bay Bridge	46.862984	-124.065418	Aquatic Vegetation Bed	South Bay	secondary site
Stearn's Bluff	46.924029	-123.978258	Aquatic Vegetation Bed	Central estuary	core site
West Fork Hoqiuam River mouth	46.996364	-123.896837	Scrub/Shrub Cover	Upper estuary	core site
West Fork Hoquiam River	47.015359	-123.910941	Forested	Upper estuary	core site
Westport Marina (South Bay Channel)	46.899119	-124.087932	Eelgrass	South Bay	core site
Wishkah River Channel	47.005423	-123.808460	Forested	Upper Estuary	core site
Wishkah River slough	47.005423	-123.805846	Scrub/Shrub Cover	Upper estuary	fyke
Withcomb Flats (North side)	46.917876	-124.065249	Sand Flat	Central estuary	secondary site
Wynoochee River	46.969991	-123.613493	Scrub/Shrub Cover	Surge Plain	core site
Wynoochee River Delta	46.962568	-123.607227	Forested	Surge Plain	core site

Core sites are produced in **bold** font in the above table.