# Grays Harbor Estuary Salmonid Conservation and Restoration Plan

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Wild Fish Conservancy
NORTHWEST
SCIENCE EDUCATION ADVOCACY

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## PURPOSE OF THE REPORT

This plan summarizes three years of sampling data and analysis conducted by the Wild Fish Conservancy (WFC) in the Grays Harbor estuary from 2011-2013, as well as some limited sampling in the lower Chehalis River in 2014. These data, as well as modeling of potential sea level rise due to climate change (SLAMM) conducted by WFC in 2012, are here synthesized to provide citizens and local, state and federal scientists and managers with a method to identify and prioritize habitat acquisition, restoration and conservation projects within the estuary and the tidally influenced portions of its major tributaries in the coming decades. In addition, several specific areas are highlighted as either primary concerns or areas that deserve attention in the short and mid-term. The annual reports, sampling plan, Sea Level Rise (SLR) analysis, and several mapping products (e.g. juvenile salmon and Dungeness crab densities by month for each year, etc.) are also available for download at the WFC web page: http://wildfishconservancy.org/projects/grays-harbor-juvenile-salmon-fish-community-study.

## SUMMARY

Grays Harbor is the second largest estuary in the state of Washington, covering 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 tidal 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.

The following points highlight some of the major findings of this report:

- Various life histories of Chinook and coho salmon were present in the estuary throughout our sampling season (February-September); based on previous studies, some life histories of these species are likely present year-round.
- Unmarked Chinook salmon utilized all areas of the estuary as they moved to the mouth, including South Bay, and were encountered in large numbers both in the Humptulips River and the Hoquiam system (although an accidental early release of juvenile Chinook from the hatchery in 2012 likely inflated this count). Unmarked Chinook were also present in large numbers in Charley Creek (on the South shore), suggesting that the small, tidally influenced creeks feeding into the South channel may play a disproportionately large role in supporting juvenile salmon.
- Large numbers of chum, Chinook and coho salmon were captured in South Bay, even though there is limited adult spawning in the Elk River. The abundant, high-quality habitats here and throughout the lower estuary are being utilized by fish originating in other tributaries of Grays Harbor or from outside the system (Willapa Bay, the Columbia River, Olympic Peninsula, and the Oregon coast, based on genetic analysis).
- The Hoquiam River was very productive for coho salmon and should be protected (via conservation easements, land acquisition, etc.); the Wishkah River is likely similar, though a log jam prevented sampling there in 2012-'13. High concentrations of large woody debris (LWD) in the upper portions of the river are likely a key reason why the Hoquiam River supports large numbers of juvenile coho salmon, although much of the set back forest has been logged. It will be important to prevent future riparian logging both to mitigate temperature increases and to provide a source of replacement LWD, which contributes to pool formation and habitat complexity.
- The Humptulips River was a major producer of unmarked Chinook salmon, as well as coho and chum salmon. Very few hatchery Chinook salmon were captured during the study. Our sampling catches here were likely elevated by the narrow "bottleneck" at the mouth, yielding higher catch efficiencies than at sites in the lower Chehalis River, which is considerably wider and deeper.
- Our modeling showed that young of the year (YOY) coho salmon avoid salinities greater than 5 ppt; salinity was a dominant factor influencing unmarked YOY coho occurrence and abundance. Thus, protection or restoration of freshwater and oligohaline habitats (salinity ranging from 0.5 to 5 ppt) is particularly important for the subyearling (YOY) life

histories of coho salmon. Note that our fyke net samples (2011 only) were excluded from the analysis which produced these results. Estuarine-rearing YOY coho were captured in intertidal sloughs in the main estuary with higher salinities, but salinities in these areas may have been moderated by freshwater input and horizontal salinity gradients.

- Beach seine catches of chum salmon were highest in South Bay (nearly twice as many were caught at sites there than in North Bay) and at Damon Point, where the fish congregate while emigrating to sea. More chum were caught in the Johns River estuary than any other salmonid, suggesting that restoration of the area would be particularly beneficial for this species. However, our fyke-net sampling in a Johns River slough (2011) captured higher densities of juvenile Chinook and coho salmon than at our beach seine site, indicating these species are also present but utilizing different habitats.
- Based on the number of salmon captured and water temperatures and salinities encountered, the critical areas for conservation include the Surge Plain, estuarine tidal sloughs in the main estuary, South Bay, south shore creeks (between South Aberdeen and the Johns River), and the Humptulips and Hoquiam Rivers (upstream tributaries such as the Wynoochee and Satsop rivers, with less tidal influence, were not studied as intensely). The creation of protected areas (through a combination of public and private ownership) in as many of these regions as possible should be a priority, with the goal of protecting existing habitat and allowing increased inundation to lead to the formation of new habitats beneficial for juvenile salmon.
- A number of potential restoration projects beneficial to juvenile salmon and other fishes are outlined near the end of the report.

## FOCUS QUESTIONS

In considering which factors are most important for the protection and restoration of juvenile salmonid and other fish populations within the estuary and tidally influenced portions of its tributaries, we attempted to address the following questions [each numbered question refers to a section of the report with further details and data]:

1. What areas are mostly heavily utilized by the major salmonid species? What are the average water temperatures in these areas when juvenile salmon are present?
2. Which habitat types are “preferred,” or avoided, by juvenile salmon? What time of year are these areas used?
3. Is there evidence of multiple life histories for salmon in the Chehalis basin that will help these populations be resilient in the face of climate change?
4. Where are the critical areas or habitats for juvenile salmonids?
5. What habitat types will be lost first due to SLR? Which habitat types will be most reduced in area due to SLR?

6. What adaptive management actions can be taken to maintain or improve the viability of salmon populations in the Grays Harbor Basin?

**In line with the Washington Coast Sustainable Salmon Partnership's (WCSSP) philosophy of "protect the best, restore the rest", restoration projects in the estuary should be prioritized by a point system incorporating the information presented in this report.**

In addition to the project ranking system currently in use by the Washington state Recreation and Conservation Office (PRISM), a proposed restoration or conservation project should be ranked based on a point system incorporating the following questions (note that this list overlaps in part with existing ranking schemes):

- Does the project occur in an area with high salmon densities (critical areas).
- Is the area used by more than one species of salmon (more points for more species)?
- What is the duration of salmon presence in the area? Is the area used for rearing, or simply as an emigration corridor for juvenile salmon while on their way to sea?
- Does the project conserve salmon and steelhead life history diversity?
- What is the size of the area restored (barrier removals, dike removals, etc.)?
- Does it take SLR into account (height of bridges, culverts, setback dikes, etc.)?
- Does it address a habitat type that will diminish with SLR? (offsets future habitat loss)
- Water temperatures: will the restored habitat still be viable in 20-50 years? Does the project help to mitigate temperature increases?
- Does it follow the guiding principles for conservation outlined at the end of this report (for example, protecting stream headwaters, within the WRIA, to address stream warming)?

***Figure 1: A map of the Grays Harbor estuary, showing the six zones and locations of the core and secondary sites sampled (note that secondary sites differed slightly between years).***

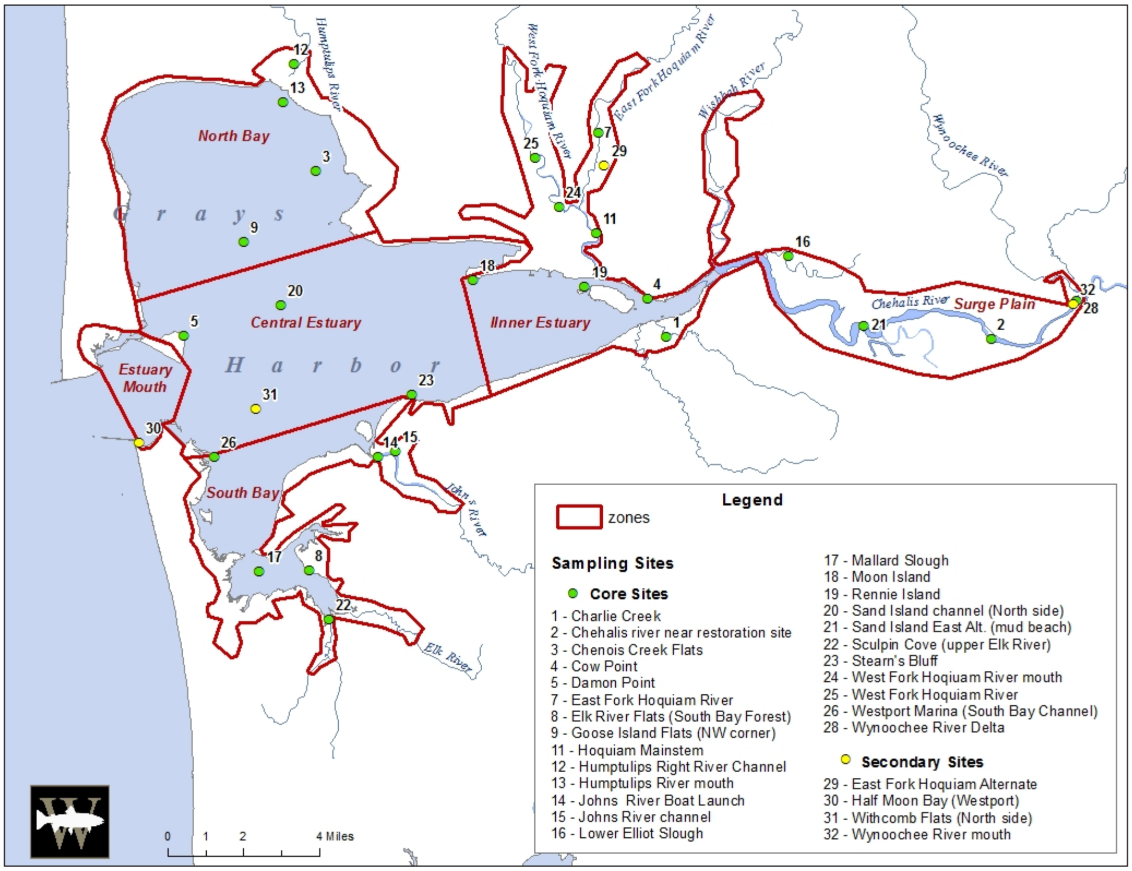



**Table 1**: Summary of Grays Harbor intertidal habitat types by zone (in acres):

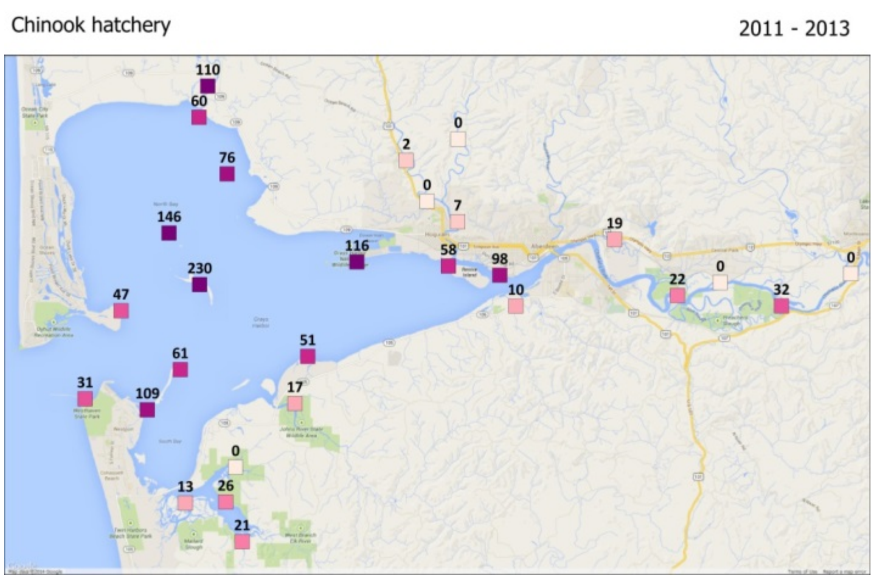
| Habitat Type | Mouth | Central | Inner | North Bay | South Bay | Surge Plain | Grand Total | % of Grand Total |
|---|---|---|---|---|---|---|---|---|
| Open Water/Channel | 2,826.06 | 11,694.93 | 2,860.62 | 2,283.65 | 1,444.27 | 1,599.32 | 22,708.85 | **30.68** |
| Aquatic Vegetation Bed | 53.06 | 7,456.73 | 105.91 | 7,133.70 | 3,834.21 | 0 | 18,583.61 | **25.10** |
| Eelgrass | 0 | 15.62 | 90.47 | 0 | 138.72 | 0 | 244.81 | **0.33** |
| Mud Flat | 0 | 3,664.91 | 4,199.87 | 5,657.43 | 756.69 | 0 | 14,278.89 | **19.29** |
| Sand Flat | 0 | 2,626.21 | 166.60 | 0 | 674.61 | 0 | 3,467.42 | **4.68** |
| Cobble/Gravel/Sand Beach | 141.46 | 211.86 | 0 | 0 | 0 | 0 | 353.33 | **0.48** |
| High Emergent Marsh | 223.53 | 387.08 | 678.99 | 815.36 | 2,789.97 | 832.04 | 5,726.97 | **7.74** |
| Scrub/Shrub Cover | 38.19 | 77.61 | 1,086.87 | 269.38 | 326.72 | 784.97 | 2,583.74 | **3.49** |
| Forested | 0 | 8.33 | 1,386.03 | 390.35 | 341.31 | 3,950.23 | 6,076.25 | **8.21** |
| Total | 3,282.31 | 26,143.28 | 10,575.36 | 16,549.86 | 10,306.49 | 7,166.56 | 74,023.87 | |

## CONSERVATION POINTS ADDRESSING THE FOCUS QUESTIONS

### (1) What areas are mostly heavily utilized by the major juvenile salmonid species? What is the range of water temperatures in these areas when salmon are present?

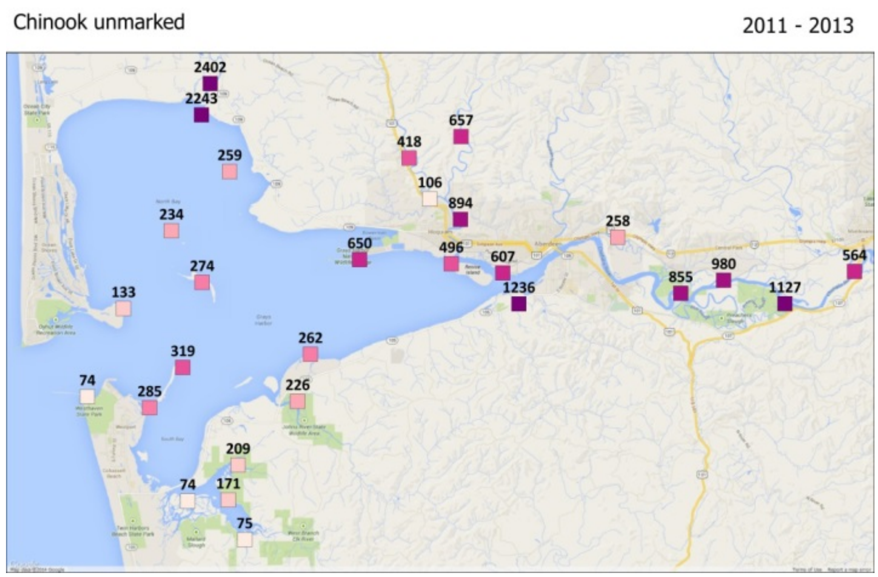
To provide a "first pass" at examining which parts of the estuary are most heavily utilized by juvenile salmon, we plotted the total catch from 2011-2013 at each core site (adjusted for sampling effort) for each species/age class/mark status. Keep in mind that juvenile chum salmon far outnumber both juvenile Chinook and coho salmon (in that order). Note also that these plots (**Figures 2-7**) differ from the density plots (number of fish per hectare) reported in the annual reports for 2011-2013; the density plots extrapolated the catch based upon the size of the net (a fraction of an hectare), and so have higher values. Although our sampling sites (**Figure 1**) were selected to represent all portions of the estuary and the tidally influenced portions of the major tributaries, there were no sampling sites in the northwestern section of North Bay (due to shifting mud flats, shallow water and an abundance of snags) or the Wishkah River, which was sampled only in 2011 and so is not included here (a log jam created in the winter of 2011-2012 blocked access to our sites).

***Figure 2: The total number of hatchery juvenile Chinook captured at core sites, adjusted for sampling effort (2011-2013). Darker colors indicate higher catches.***




For Chinook salmon, the number of unmarked fish (young-of-the-year, or YOY) captured was much larger than that of YOY hatchery fish; hatchery Chinook were mostly found emerging from the Humptulips River (**Figure 2**, North Bay) and were also captured in moderate numbers from the Inner Estuary (i.e. Moon Island) throughout North Bay and the islands to the mouth (few were captured in South Bay). Very few hatchery Chinook were captured in either the Hoquiam or Johns Rivers, but a few (N=10) were captured in Charley Creek (on the South shore, near the mouth of the Chehalis River).

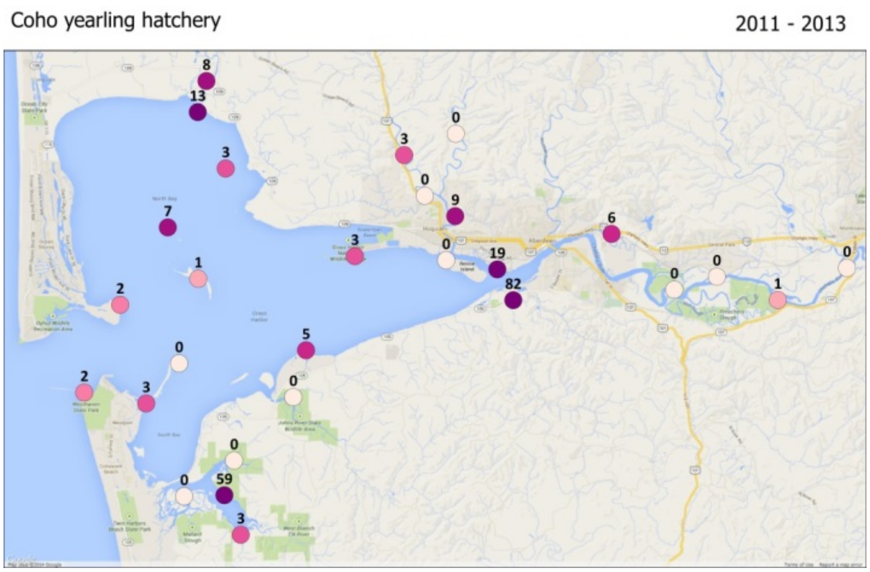
***Figure 3: The total number of unmarked YOY Chinook salmon captured at core sites, adjusted for sampling effort (2011-2013). Darker colors indicate higher catches.***




Unmarked YOY Chinook salmon (**Figure 3**) were found emerging from the Humptulips River in numbers greater than an order of magnitude larger than for hatchery fish. This is surprising, given that the numbers of unmarked Chinook entering the estuary from the main stem Chehalis River and its tributaries, which contain far more habitat, were less than half of that shown entering from the Humptulips River. The explanation is likely that we sampled the lower Humptulips River at a "bottleneck" (the channel is narrow and shallow), inflating catches, while the same sampling technique in the much wider and deeper mainstem Chehalis River was less effective.

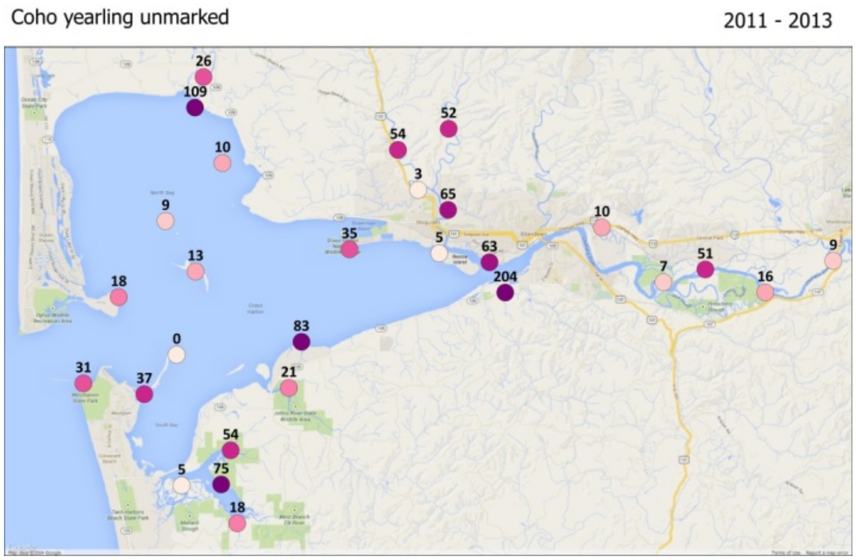
Unmarked Chinook utilized all areas of the estuary as they moved to the mouth, including South Bay, and were encountered in large numbers both in the Hoquiam system (although an accidental early release of juvenile Chinook from the hatchery in 2012 likely inflated this count). Unmarked Chinook were also present in large numbers in Charley Creek (N=1236), suggesting that the small, tidally influenced creeks along the South shore may play a disproportionately large role (with regard to the area of habitat) in supporting juvenile Chinook salmon **(see question #4; Figure 24**). Almost no yearling Chinook salmon were captured in the course of the study, most likely because our method of sampling (beach seining) does not fish the deeper channels that larger fish utilize for emigration.

***Figure 4: The total number of hatchery yearling coho salmon captured at core sites, adjusted for sampling effort (2011-2013). Darker colors indicate higher catches.***




Far fewer hatchery yearling coho salmon (**Figure 4**) were captured than unmarked (**Figure 5**). These were encountered primarily in four areas: the mouth of the Humptulips River (**Figure 4**, N=13, 8), the Hoquiam River (N=9), Charley Creek (N=82), and in the Elk River estuary (South Bay; N=59). The origin of the fish captured in South Bay is unclear as there is little adult spawning in the Elk River, suggesting that habitats in South Bay are being utilized by fish originating in other tributaries of Grays Harbor (as was also observed in **Figure 4)** or from outside the system (e.g. Willapa Bay, the Columbia River, or the Oregon coast; see 2013 Annual Report, section 3.4: Genetics).

***Figure 5: The total number of unmarked yearling coho salmon captured at core sites, adjusted for sampling effort (2011-2013). Darker colors indicate higher catches.***




Unmarked yearling coho salmon (**Figure 5**) were more widely dispersed throughout the estuary, with moderate catches occurring at the mouth of the Humptulips River (N=109), several sites within the Hoquiam River system (N=52, 54, 65), the Surge Plain (N=51), Charley Creek (N=204), Stearn's Bluff (N=83; at the terminus of the South Channel, which has several tidal creeks entering), and within South Bay (N=75, 54). As with unmarked, YOY Chinook salmon, the small tidal creeks along the South shore of the estuary may be disproportionately important as rearing habitat for yearling coho salmon, based on the catch in Charley Creek.

Note that because we used beach seines to sample, yearling fish are likely underestimated as the beach seines are not as effective at sampling the deeper channels these larger fish tend to utilize (YOY fish are typically in shallow water adjacent to shore).

Young-of-the-year (YOY) coho salmon (**Figure 6**; all unmarked) were more numerous than yearlings and were most abundant in the Hoquiam River system (N= 579, 222, 107), the lower Humptulips River (N=167), the Surge Plain (N=96), and South Bay (N=68). Lower numbers were also present in Charley Creek (N=32) and the Johns River (N=26), which is similar to the Elk River (South Bay) in that there is limited adult spawning in this tributary. Note that very few YOY coho salmon were captured in the central portions of the estuary or near the mouth, where salinities are highest (see section 2). However, fyke netting (2011) in the lower estuary did capture estuarine-rearing YOY coho in intertidal sloughs with higher salinities, although these had some freshwater input and horizontal salinity gradients (meaning the fish could have stayed in the upper, lower salinity gradient) (see **Table 5**).

***Figure 6: The total number of YOY coho salmon (all unmarked) captured at core sites, adjusted for sampling effort (2011-2013). Darker colors indicate higher catches.***

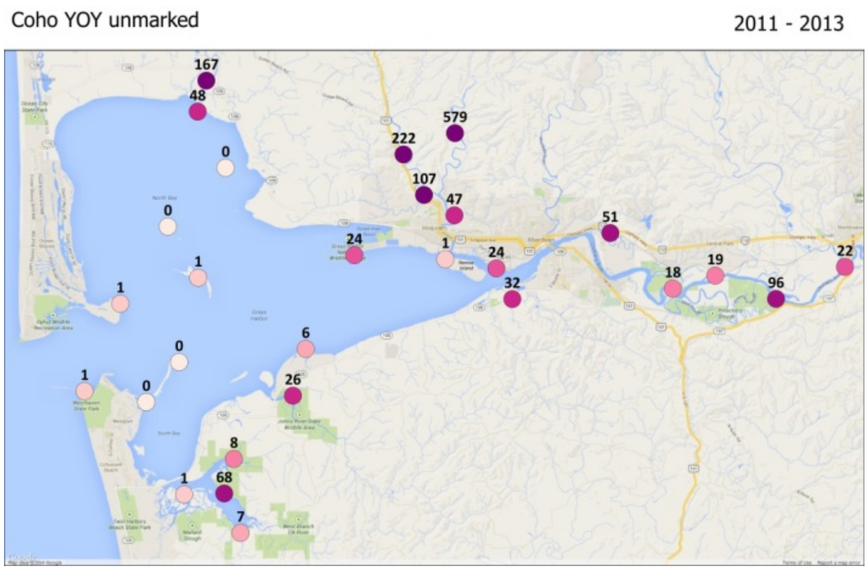
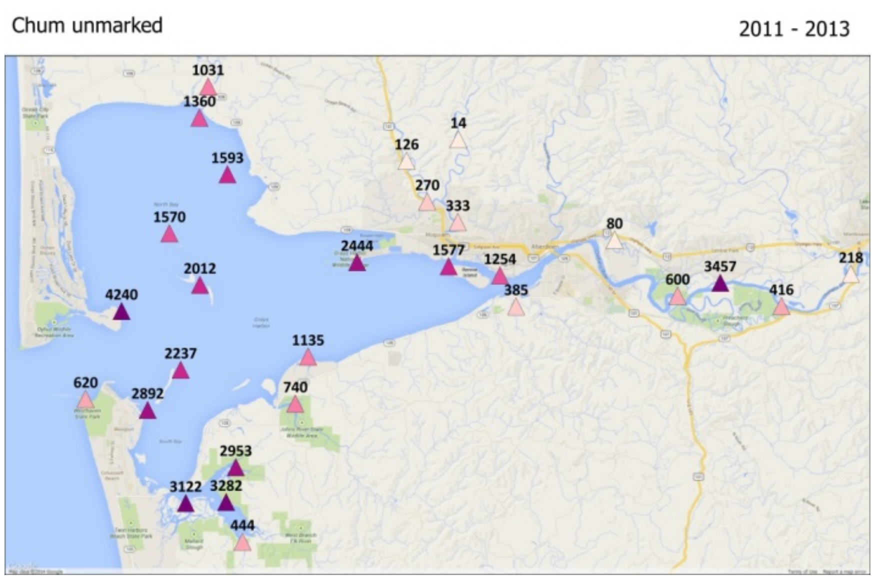



***Figure 7: The total number of chum salmon (all unmarked, YOY) captured at core sites, adjusted for sampling effort (2011-2013). Darker colors indicate higher catches.***




Chum salmon, the most abundant juvenile salmonid in Grays Harbor/Chehalis Basin, were encountered in large numbers throughout the estuary with the exception of the Hoquiam River system, where they were present but at much lower numbers. The relatively low counts in the Surge Plain (with the exception of one site with N=3457; **Figure 7**) were most likely due to the early emigration of chum directly from their redds to the ocean; we commenced sampling in late February or early March (depending on availability of low tides during daylight hours), but most chum salmon were already in the estuary by that time.

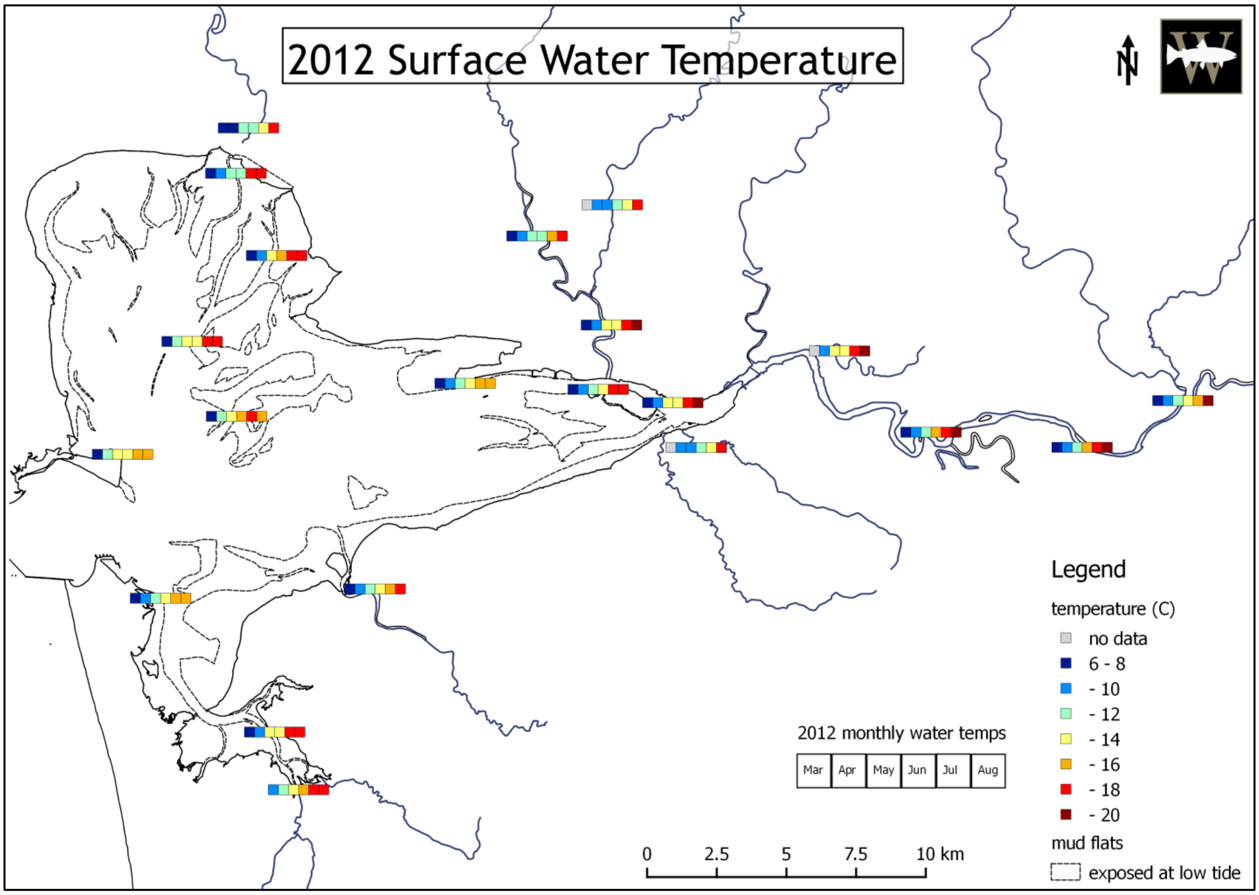
Catches of chum salmon were highest in South Bay (nearly twice as many were caught at sites there than in North Bay, although the catches are biased by limited sampling in North Bay early in 2011) and at Damon Point (N=4240), where the fish congregate while emigrating to sea. More chum were caught in the Johns River estuary (N=740) than any other salmonid, suggesting that restoration of this area would be particularly beneficial for this species.

To investigate why certain areas had higher juvenile salmon catches, we also generated a plot of average temperatures at the sampling sites during the months of peak juvenile salmon residency (presented here for the first time and are not found in the annual reports). The plot shows only 2012, the year with the longest sampling season, but the monthly trends are representative of all years. While temperature data was incorporated into the modeling of occurrence and abundance – and was an important factor in both for unmarked Chinook salmon (negatively associated with temperature) – these plots allow one to visualize the locations and patterns of water temperatures within the estuary (**Figure 8**). Warmer temperatures allow salmon to grow more quickly and may increase food production, but average temperatures in excess of 21°C (70°F) can pose a barrier to migration; prolonged exposure to temperatures at or above this mark can be lethal in both adults and juveniles. Temperatures above 15°C (59°F) can also place salmon at a competitive disadvantage with warm water species (both native and introduced, e.g. largemouth bass) and lead to higher predation (Mantua, Tohver, and Hamlet 2009). Chum salmon, which emigrate to sea earlier in the year, are less affected by water temperatures.

As expected, the pattern at most sites shows warming through the sampling season (**Figure 8**). Notably high temperatures were observed at tidal flat sites in North Bay, Rennie Island, and South Bay, due to the influence of sand or mud flats, which heat up during low tides, when we sampled (fish may utilize areas with warmer than optimal temperatures for foraging, particularly if deeper, cooler water is available nearby). Most other sites were yellow (14°C) on average by May, although the upper Hoquiam River and Charlie Creek (south shore near Aberdeen) were cooler refuges.

The lower Chehalis River sites began to warm by June (**Figure 8**); this coincides with a shift in catch in the lower (non-tidal) portions of the river (below Porter, WA) sampled in 2014 as part of the Lower Chehalis River and Surge Plain Fish Use Assessment Study (Fletcher, Sandell, and McAninch 2015). In that study, juvenile Chinook salmon were the most abundant species (63% of catch) during the late April sampling session, but the composition of the fish assemblage changed dramatically between April and July. During those months, catches of warm water species predominated (mainly 3-spine stickleback, but also juvenile northern pikeminnow, peamouth, red-sided shiner and juvenile starry flounder).

***Figure 8. Average temperature plots at low tide for Grays Harbor surface waters during months of peak juvenile salmon residency (March – August), 2012***




**(2a) Which habitat types are "preferred," or avoided, by juvenile salmon?**

Information on habitat preferences was found primarily in the results of our occurrence and abundance modeling (see the 2013 Annual Report, section 5.2, for more details) and the spatial mapping of catch. 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 zeros where salmon were not present in models of abundance could preclude obtaining informative results. 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 and Wedderbu 1972). For abundance analyses we used GLMs employing a log-link function and assuming a negative binomial distribution, to relate 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, origin (hatchery or unmarked) and year. A negative correlation occurs when lower fish catches are found in areas with higher values of a variable (for example, with unmarked juvenile Chinook salmon and water temperature); positive correlations occur when both increase together (for example, high catches of chum salmon were found to co-occur with the presence of aquatic vegetation). The main results are summarized in the Figures (**2-8**) and Tables (**2, 3**), below; some additional points are highlighted for each species following the tables.

**Table 2**: Summary of modeling results for YOY Chinook and chum salmon

| | ***Unmarked Chinook (YOY)*** | ***Hatchery Chinook (YOY)*** | ***Unmarked Chum*** |
|---|---|---|---|
| *Water Temperature* | o Abundance negatively correlated with temp | | |
| *Salinity* | | | |
| *Habitat* | o Abundance negatively correlated with:<br>▪ intertidal pebble, gravel and sand habitats | | o Abundance positively correlated with:<br>▪ intertidal mixed fines<br>▪ intertidal mixed fines/seasonal aquatic vegetation<br>▪ intertidal pebble/gravel/sand |
| *Timing* | o Present all season<br>o Most abundant April through June<br>o Peak abundance April and May | o Most abundant June through August<br>o Peak abundance July<br>o Presence depends on release dates | o Peak abundance March and April<br>o Absent by June<br>o Rapid outmigration from natal rivers to estuary |
| *Spatial* | o High abundance in the Surge Plain, Inner Estuary and, most notably, the Humptulips River<br>o Relatively low abundance in South Bay | o High abundance in North Bay and the central estuary.<br>o Low abundance in South Bay, the Hoquiam River and Surge Plain | o Most abundant in South Bay, the Surge Plain, Johns River and central estuary near the mouth. |

**Chinook salmon**

- Very few yearling fish caught, so here we focus only on YOY. Most abundant catches varied between years with peaks occurring in June, July and August in 2011, July in 2012 and May, June in 2013. Low abundance after June/July, *but present in the estuary throughout the sampling season (February-September) and most likely year-round.*

- Hatchery Chinook: occurrence is best explained by timing, since the presence of hatchery Chinook in the estuary depends upon release time. Hatchery releases of fall Chinook salmon took place in May and June during the period of this study, which agrees with the observed peak occurrence in the main estuary.

**Chum salmon**

- All chum are YOY, and are present in the estuary from February to May (peak in April in most years); most have emigrated to sea by June. Almost certainly present even earlier, before our sampling started (mid-December or January).
- The best models of chum salmon occurrence all included month, while other explanatory variables, including water temperature, salinity, habitat type, and tide height, varied in significance between years. There was no clear "best" model of chum occurrence, likely because the life history drive for early seaward migration trumps local temperature or salinity conditions.
- Chum abundance in 2011 and 2012 was positively correlated with intertidal habitats which are most common in the main estuary: intertidal mixed fines, intertidal mixed fines/seasonal aquatic vegetation, and intertidal pebble/gravel/sand. Chum abundance was positively correlated with salinity in 2013. Again, this is likely a reflection of the timing of chum emigration- chum were already moving to the ocean when sampling commenced, so they were encountered at lower estuary habitats near the mouth.

**Table 3**: Summary of modeling results for YOY and yearling coho salmon

| | ***Unmarked YOY Coho*** | ***Unmarked Yearling Coho*** | ***Hatchery Yearling Coho*** |
|---|---|---|---|
| *Water Temperature* | | | |
| *Salinity* | o Abundance negatively correlated with salinity<br>o Presence declines rapidly above 5 ppt<br>o Essentially absent above 20 ppt | | |
| *Habitat* | o Presence/abundance positively correlated with:<br>▪ forested mixed fines/mud channels | | |
| *Timing* | o Present all season | o Present mostly April and May<br>o Peak abundance May | o Present April and May<br>o Presence depends on release dates<br>o Peak abundance April |

| | | | |
|---|---|---|---|
| *Spatial* | o Most abundant in the Hoquiam River<br>o Virtually absent from the open waters of the Central Estuary, Inner Estuary and North Bay | o Most abundant in the Hoquiam River, Humptulips river and Charley Creek | |

**Coho salmon**

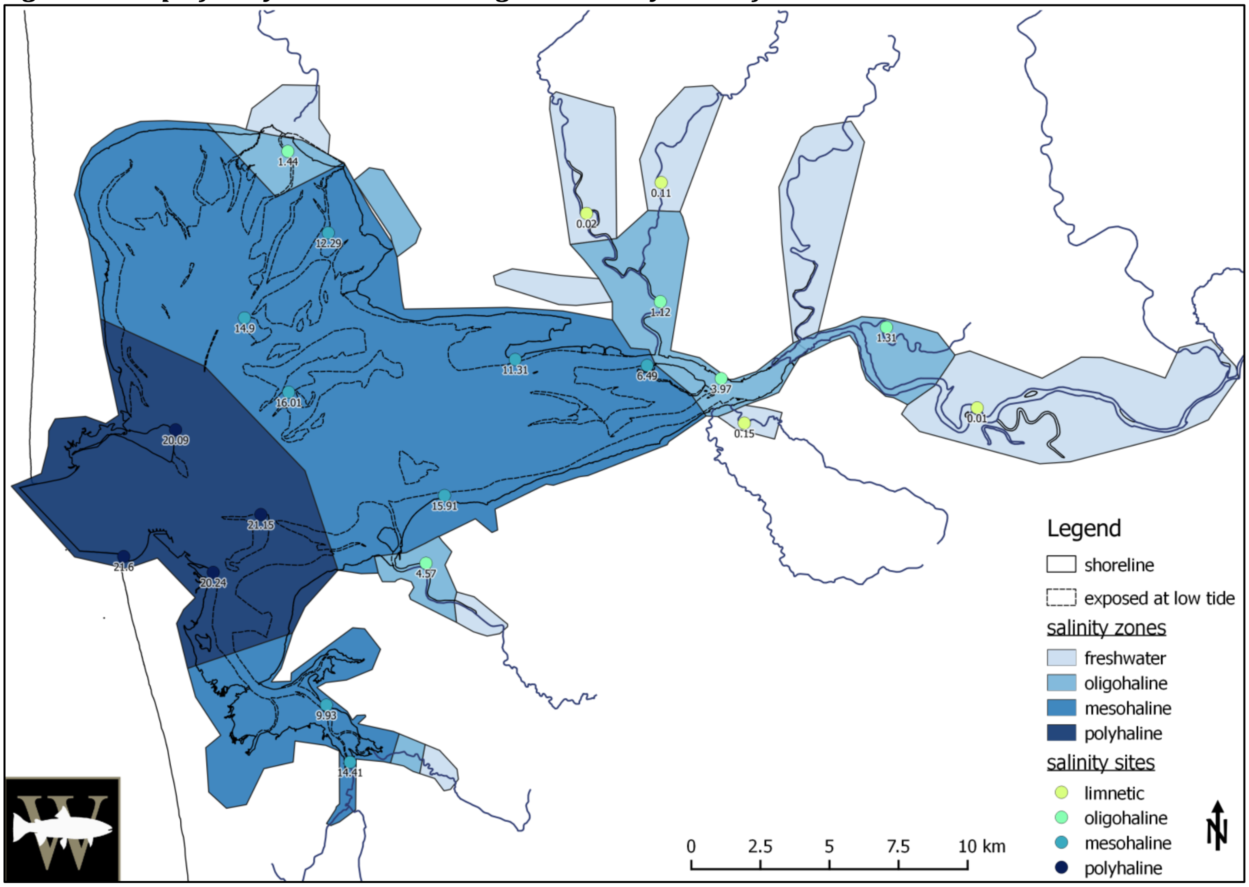
- *Present in the estuary throughout the sampling season and likely year-round.* YOY coho peaked in April in 2011, June in 2012-'13. Yearling coho peaked in May in all years.
- YOY coho abundance was negatively correlated with salinity in all years. Occurrence of unmarked YOY coho was greater in mixed fines or mud channel/forested sites and backshore marsh/forested sites, habitats which are associated with lower salinities (as in the Hoquiam and Wishkah Rivers and the Surge Plain). This suggests that YOY coho are rearing in the estuary for extended periods of time, unlike the yearlings, which quickly migrate to sea. All of the best models included salinity, suggesting that avoidance of salinities greater than 5 ppt was a dominant factor influencing unmarked YOY coho occurrence and abundance. Thus, protection or restoration of freshwater and oligohaline habitats (salinity ranging from 0.5 to 5 ppt) is particularly important for stream-rearing subyearling (YOY) life histories of coho salmon (see **Figure 9**).
- The Hoquiam River was very productive for coho salmon and should be protected (via conservation easements, land acquisition, etc.); the Wishkah River is probably similar, though a log jam prevented sampling there in 2012-'13. High concentrations of large woody debris (LWD) in the upper portions of the river are likely a key reason why the Hoquiam supports large numbers of juvenile coho salmon, although much of the set back forest has been logged. It will be important to prevent future riparian logging both to mitigate temperature increases and to provide a source of replacement LWD.
- Juvenile coho salmon were abundant in eulittoral (5-10 ppt salinity) marsh areas, specifically tidal sloughs with some freshwater input and horizontal salinity gradients (see **Table 5**).
- Unmarked yearling coho: occurrence was highest in April and May before dropping rapidly in June, with wild yearling smolts essentially absent from the sampling sites by July. This short period of estuarine residence was the major factor in the occurrence models.

**Steelhead**

- Not many steelhead were captured in our study (a few large hauls of hatchery fish were captured; not very informative), so we were unable to model them effectively.

- Summer steelhead will be among the most affected by reduced water flows and higher water temperatures.

***Figure 9. Map of Grays Harbor showing the salinity zones for 2011-2013.***




There is a strong seasonal component to the surface salinities that we encountered; early in the sampling year, when rainfall and river flows are elevated (February through May), surface salinities are low at many estuarine sites, but these rapidly increase in July and remain elevated until the fall.

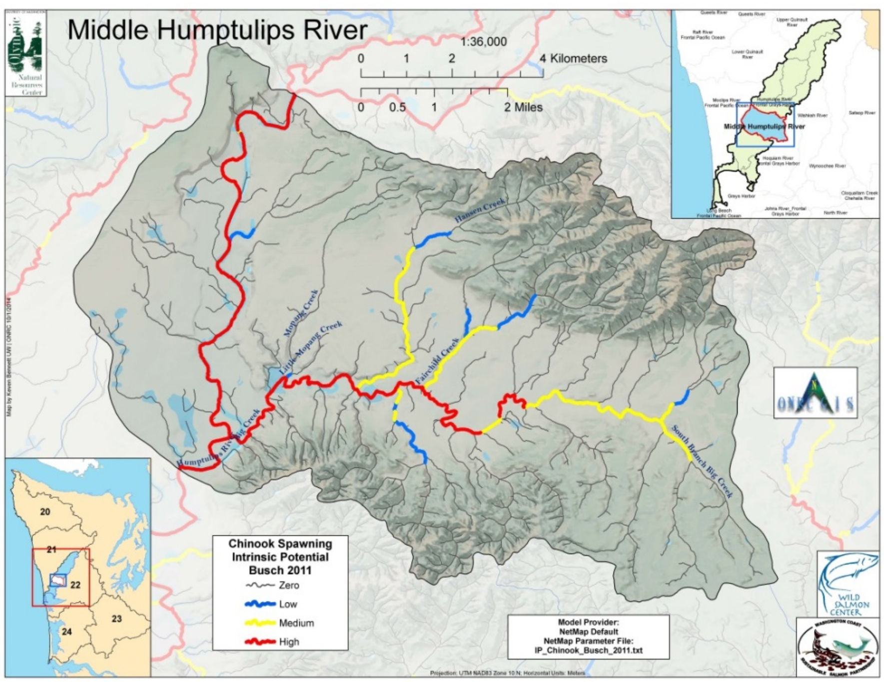
**Table 4**: Percent of total area of each habitat type in each salinity zone

| Percentage | Salinity zones | | | |
|---|---|---|---|---|
| Habitat Type | High | Medium | Low | Fresh |
| Openwater | 74.7 | 11.8 | 6.1 | 7.4 |
| Aquatic vegetation bed | 89.3 | 6.5 | 4.1 | 0 |
| Mud flat | 62.9 | 34.9 | 2.2 | 0 |
| Sand flat | 60.5 | 39.5 | 0 | 0 |
| Emergent Marsh | 31.7 | 42.4 | 9.8 | 16 |
| Scrub/Shrub | 13.5 | 11.4 | 19 | 56.1 |
| Forested | 1.6 | 3.2 | 24.2 | 71 |

From **Table 4**, showing the percentage of each habitat type occurring in the different salinity zones, it is apparent that the majority of aquatic vegetation beds (89.3%), mud flats (62.98%) and sand flats (60.5%) occur in the polyhaline ("high") salinity zone, while the majority of forested (71%) and scrub/shrub (56.1%) habitats occur in the freshwater salinity zone. Emergent marsh habitats are the most evenly spread habitat type, occurring most commonly in the mesohaline (medium) zone (42.4%) but also common in the polyhaline zone (31.7%) and to a lesser extent in the freshwater (16%) and oligohaline (9.8%) zones.

**Note:** Our study focused on the tidally influenced portions of the main tributaries. To see maps delineating specific freshwater river reaches with habitat for the various salmon species, we now have access to the mapping portal: http://www.onrc.washington.edu/MarinePrograms/IPOuterCoast/PostPhaseII_MapPortal.html

An example for the Middle Humptulips River is below:




**(2b) What time of year are these areas used? Does this information inform work windows for in-water projects such as channel dredging?**

As mentioned in the modeling summary above, both Chinook and coho salmon juveniles were present throughout the sampling season (February-September; see **Figures 10, 11**) and, according to previous studies, are likely present in the estuary year-round.

Yearling Chinook and coho had briefer periods of estuarine residence as this life history moves to sea in the late spring/summer. Other, alternative life histories appear to be present (see section 3, below). Chum salmon are likely only in the estuary from December or January (our sampling started in February or March) through late May; a few fish may persist until June (**Figure 12**).

***Figure 10: Unmarked Chinook salmon catch by month in Grays Harbor, 2011-2013 (sampling during February only occurred in 2012)***

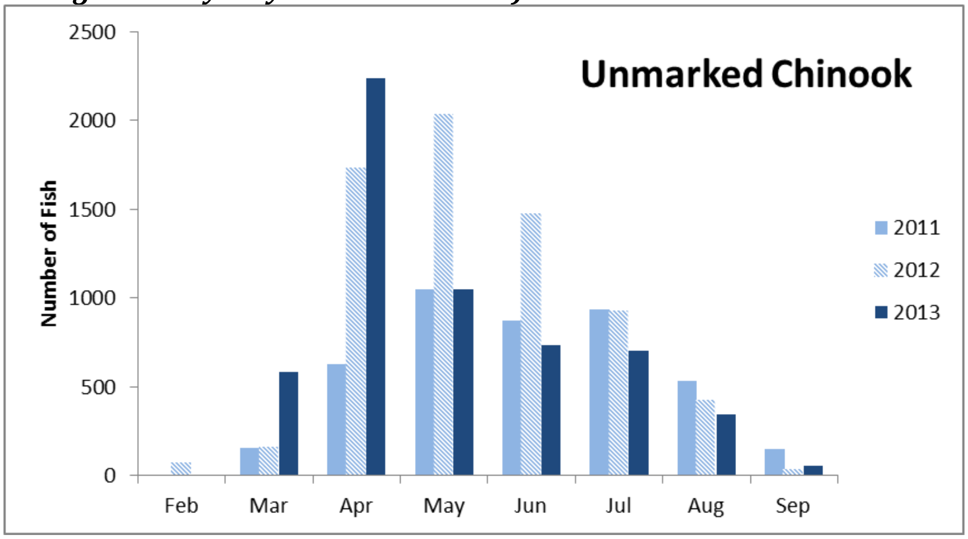



***Figure 11: YOY Coho salmon catch by month in Grays Harbor, 2011-2013 (sampling in February only occurred in 2012, when a few yearling coho were captured)***

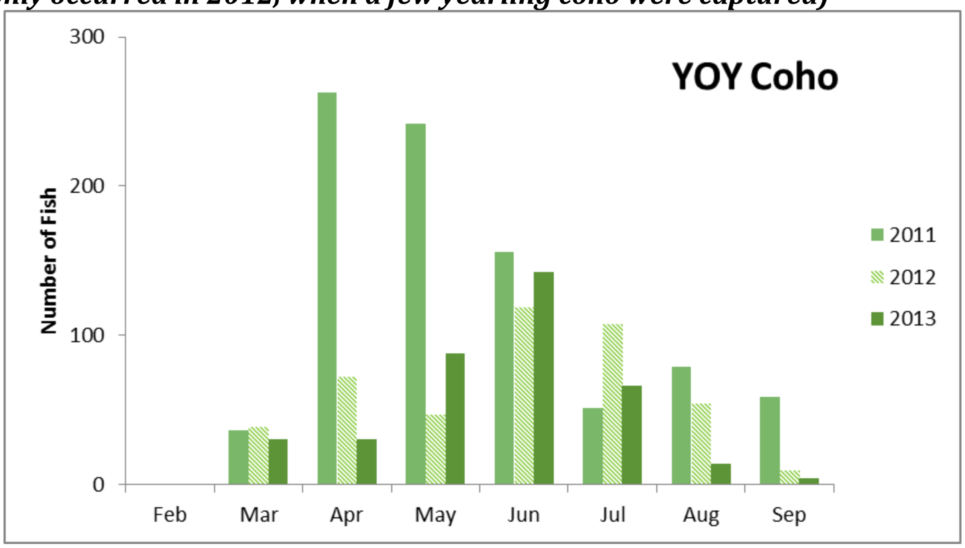
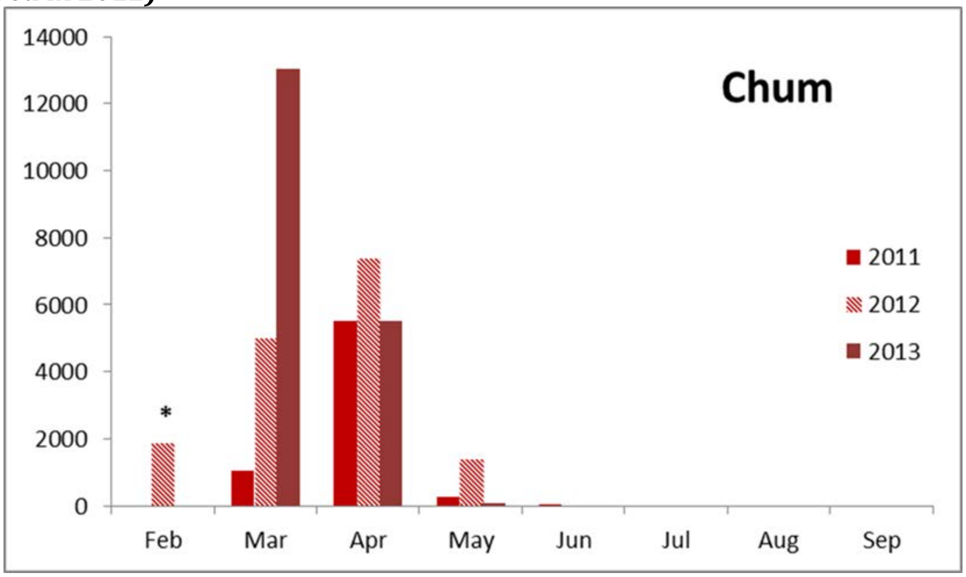


***Figure 12: Chum salmon catch by month in Grays Harbor, 2011-2013 (*sampling in February only occurred in 2012)***




Catches of other salmonids (steelhead, bull trout, cutthroat trout) were insufficient to draw conclusions, although all bull trout were captured between March and early June, when water temperatures were low (see **Figure 8**). While bull trout may have remained in the estuary beyond June in deeper, tidally cooled channels, they avoided shallow channel margins and tributaries where they may have been captured via beach seining. Based on the native char (bull trout) study authored by (Jeanes and Morello 2006), the current in-water work window for dredging of the shipping channel now begins 15 July through 15 February. However, this time period still encompasses the residency of juvenile Chinook and coho salmon (fall) and chum salmon (winter); a better work window would be from mid-September through mid-January.

*For more specific mapping of juvenile salmon densities by month for each year, download the pdf "Grays Harbor Juvenile Salmon Density Plots 2011-2013" at:* http://wildfishconservancy.org/projects/grays-harbor-juvenile-salmon-fish-community-study.

It is important to remember that salmon make up only a fraction of the estuarine fish community (**Figure 13**), and many other species rely on estuarine habitats for spawning and rearing. Chum salmon dominate the estuarine fish community early in the year, but as the water warms the relative abundance of surf smelt, surf perch, 3-spine stickleback and northern anchovy is much higher than that of salmon (**Figure 14**). These "forage fish" and other fish species provide food for juvenile salmon (if of appropriate size), supply alternative targets for piscine and avian predators that might otherwise eat juvenile salmon, and form the base of an intricate food web that supports everything from migratory and resident waterfowl to seven gilled sharks and marine mammals.

***Figure 13: Bar plot showing the three year totals of the most abundant fish species caught in the Grays Harbor estuary, 2011-2013***

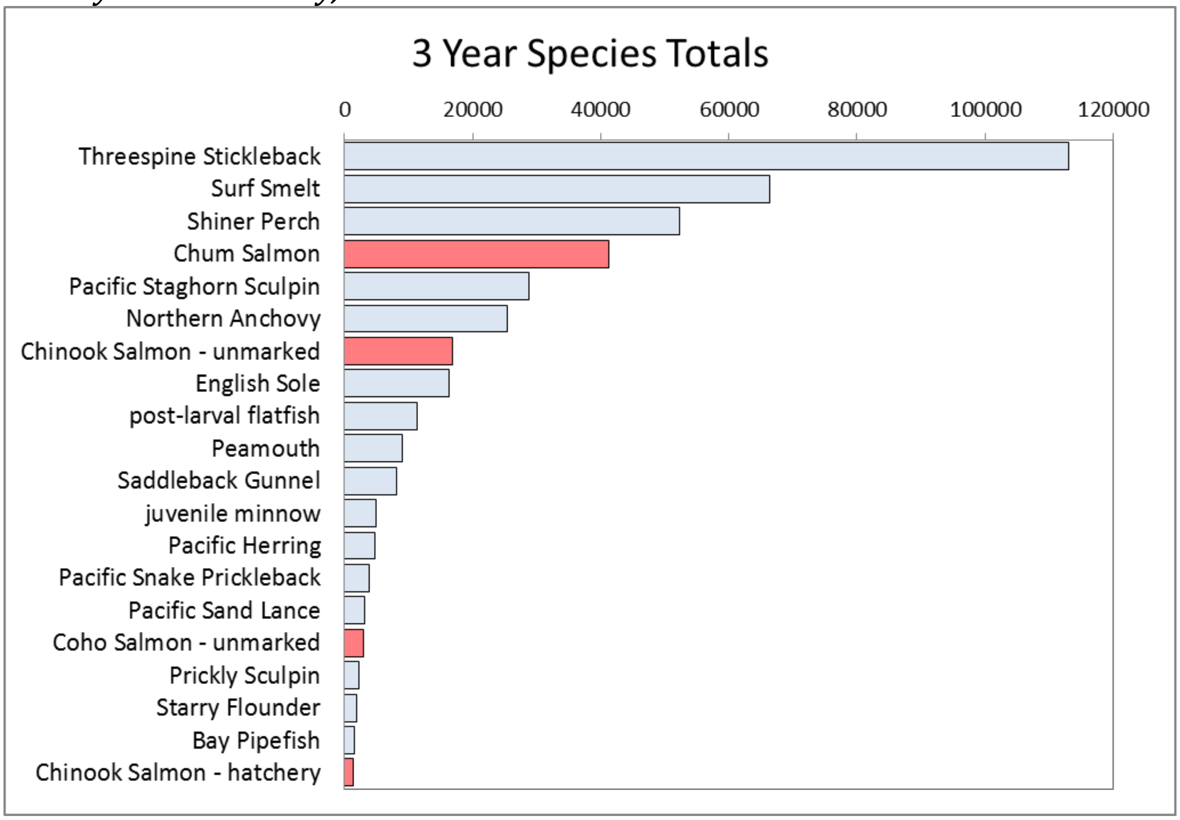
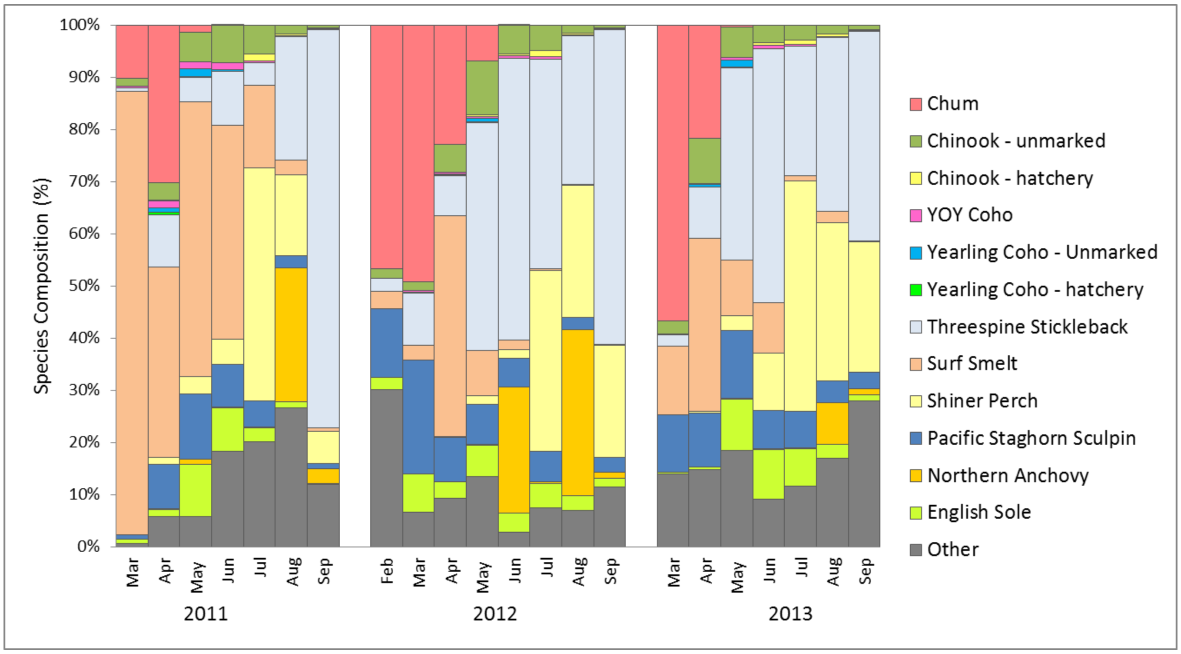


***Figure 14: Seasonal composition (%) of salmon and the most abundant non-salmonids, 2011-'13.***




**(3) Is there evidence of multiple life histories for salmon in the Chehalis basin that will help these populations be resilient in the face of climate change?**

Although estuarine dependence and residence times differ among salmonid species, the identification of diverse life history types both within and between various species was pivotal in promoting our understanding of the importance of estuaries for salmonids. In theory any genetically robust Chinook or coho salmon population can potentially produce all life history strategies, but some strategies will be more abundant than others within a population. Chinook salmon have the greatest degree of documented life history variation, with residence times ranging from a few weeks to several months (Levy and Northcote 1982; Simenstad, Fresh, and Salo 1982; Thorpe 1994; Beamer et al. 2005; Bottom et al. 2005; Hering et al. 2010). A study in the Sixes River, Oregon (Reimers 1973) identified five Chinook salmon life history types, with scale analysis indicating that fish with the longest estuarine residence times contributed 90% of the adult spawning population. Other studies, conducted from northern California to southeast Alaska, have also shown that estuarine residence is beneficial for juveniles and eventual adult recruitment of Chinook salmon (Neilson *et al.*, 1985; Macdonald *et al.*, 1988; Levings *et al.*, 1989; Sommer *et al.*, 2001; Magnusson and Hilborn, 2003; Bottom *et al.*, 2005a; Greene *et al.*, 2005) and coho salmon (Solazzi *et al.*, 1991; Linley, 2001; Magnusson and Hilborn, 2003).

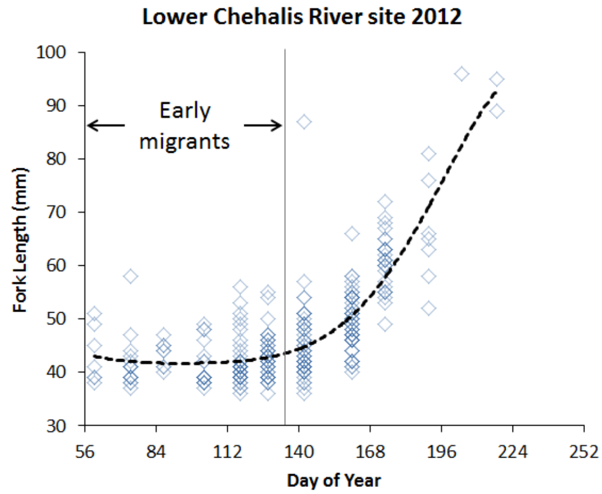
The timing of entry into the estuary may influence the length of estuarine residence (Simenstad, Fresh, and Salo 1982); an ongoing study in the Skagit River system (Beamer et al. 2005) has found that early migrating Chinook salmon fry in the Skagit River marsh/delta use a different suite of habitats than fish migrating later in the year. The proportion of the population that exhibited early migration may be a result of overall population size and a limitation in freshwater habitat capacity; as freshwater habitat fills up, the excess fish respond by moving downstream (although river and nearshore water temperatures may also be a factor). Given that juvenile Chinook salmon are present in the Skagit River system from February through October, different life history strategies appear to have adapted to seasonal changes in flow/inundation, temperature and foraging opportunities. There is also evidence that wild Chinook salmon juveniles have longer estuarine residence times in comparison with hatchery origin fish (Levings, McAllister, and Chang 1986; Beamer et al. 2005), which may be due larger size at release of hatchery fish.

In contrast, a study by Chittenden *et al*. (Chittenden et al. 2008) used acoustic tagging to show that wild coho salmon juveniles in the Campbell River system (British Columbia) spent less time in the estuary than hatchery reared smolts, though estuary rearing was important for both. Coho salmon may have different life histories and migration patterns according to their region of origin (Weitkamp and Neely 2002). Coho salmon typically enter the estuary as yearlings after rearing in rivers for one year, with residence times ranging on scales from days to weeks (common) up to three months (rare) (Durkin 1982; Healey 1982; Thorpe 1994). An alternative life history, the coho salmon "nomad", may enter estuaries as subyearlings and spend the entire summer (mainly in shallow intertidal habitats) there before returning to fresh water to overwinter, emigrating to sea the following year (Koski 2009). Even when certain life histories have "disappeared," the restoration of tidal wetlands can allow those life histories to re-emerge, as demonstrated in the Grays River, Washington (a tributary of the Columbia River) (Craig, Simenstad, and Bottom 2014).

The life histories of pink and chum salmon, which tend to emigrate directly to sea after emergence, makes these two species less dependent on estuary residence, although some variation still exists. Mark – recapture studies of chum salmon residence showed a range from 1.7 - 4 days in the Skagit River marsh to 2 - 3 months in the Yaquina River estuary (Oregon) (Healey 1982; Thorpe 1994).

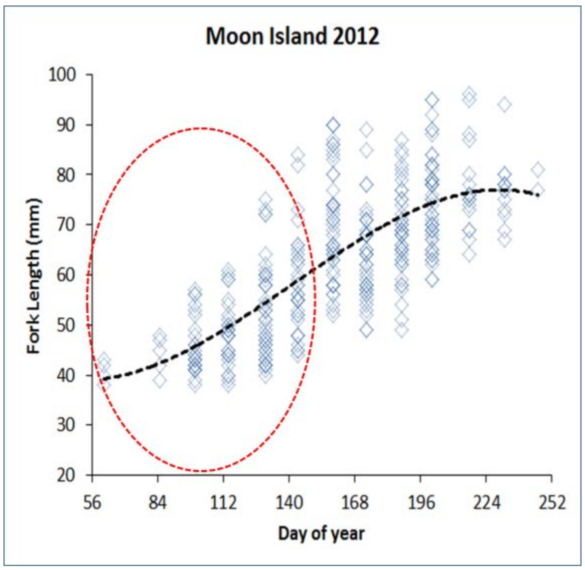
Our data from 2011-2013 reveals several life history strategies for both Chinook and coho salmon in Grays Harbor, primarily by analysis of fork length variation through the sampling season (patterns were similar in all years). For Chinook salmon, we saw the presence of "fry migrants" (very small fish that move to the estuary early in the year, with little growth while in freshwater) at some of the Surge Plain sites where salinities are low (oligohaline). Chinook similar in size are also present at lower estuary sites with higher salinities (mesohaline), where some fish move through (migrants) while others stay and grow (**Figures 15-17**).

***Figure 15. Length trend of subyearling Chinook salmon moving through a sample site in the lower Chehalis River in 2012. Fish captured before day 128 (early May) were similar in size, reflecting a population that migrated relatively quickly following emergence. After day 128 the length of juvenile Chinook salmon steadily increased, reflecting the arrival of later migrants with varying degrees of river rearing.***




At sites in the Inner estuary (e.g. Moon Island, **Figure 16**) sites, a different pattern of residency was noted. All the fish circled ion the figure are early fry migrants that have stayed near this site to rear; after day 140 the catch was a mix of estuarine rearing migrants and recruitment from later migrants which display varying degrees of river rearing.

***Figure 16: Fork length of juvenile Chinook salmon in 2012 at the Moon Island site; fish within the red circle are early migrants which may be rearing at the site, while after day 140 recruitment of later migrants occurs, although migration is not abrupt and occurs along a gradient.***



In addition, an analysis of variance (ANOVA) of fork lengths by site revealed a pattern of groupings by sites/regions that shows the different timing of migrant arrival at lower river versus estuarine sampling sites. In 2012 (representative of all years), fry migrants compose the first group (smallest fork lengths, upper left, oligohaline sites), and a larger group (later migrants) are in the lower right (mesohaline sites) (**Figure 17**). The first (upper left) group are sites where little rearing takes place; these sites are part of the migration corridor. The next group (lower right) are sites where increased rearing takes place; the further to the bottom and right, the more rearing and growth. However, there is a continuum of migration over time, and these groups are not necessarily as isolated as they appear in the figure.

***Figure 17: Results of a post-hoc Tukey test on unmarked Chinook fork length showing which site pairings differed significantly ($p < .05$) in 2012 (representative of all years). Site pairings which were not significantly different are marked (X); site pairings which were not significant but close to the alpha level are marked (•); and sites which differed significantly are blank. Sites are listed in order of mean fork length from low to high.***

| 2012 | Sand Island east (surge plain) | Chehalis River restoration site | Wynoochee River delta | Humptuplips River mouth | East Fork Hoquiam River | Lower Elliot Slough | Humptulips River right channel | West Fork Hoquiam River | Cow Point | Hoquiam River mainstem | Charlie Creek | Damon Point | Moon Island | Rennie Island | Chenois Creek flats | Sculpin Cove | Goose Island flats | Johns River channel | Elk River flats | Sand Island channel | Westport Marina |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sand Island east (surge plain) | | X | X | | | | | | | | | | | | | | | | | | |
| Chehalis River restoration site | X | | X | X | X | X | X | X | | | | | | | | | | | | | |
| Wynoochee River delta | X | X | | X | X | X | X | X | | | | | | | | | | | | | |
| Humptuplips River mouth | | X | X | | X | X | X | X | | | | | | | | | | | | | |
| East Fork Hoquiam River | | X | X | X | | X | X | X | | | | | | | | | | | | | |
| Lower Elliot Slough | | X | X | X | X | | X | X | | | | | | | | | | | | | |
| Humptulips River right channel | | X | X | X | X | X | | X | | | | | | | | | | | | | |
| West Fork Hoquiam River | | X | X | X | X | X | X | | | | | | | | | | | | | | |
| Cow Point | | | | | | | | | | X | X | X | | | | | | | | | |
| Hoquiam River mainstem | | | | | | | | | X | | X | X | | | | | | | | | |
| Charlie Creek | | | | | | | | | X | X | | X | X | X | • | X | | | | | |
| Damon Point | | | | | | | | | X | X | X | | X | X | X | X | | | | | |
| Moon Island | | | | | | | | | | | X | X | | X | X | X | | X | | | |
| Rennie Island | | | | | | | | | | | X | X | X | | X | X | | X | | | |
| Chenois Creek flats | | | | | | | | | | | • | X | X | X | | X | X | X | • | | |
| Sculpin Cove | | | | | | | | | | | X | X | X | X | X | | X | X | X | X | |
| Goose Island flats | | | | | | | | | | | | | | | X | X | | X | X | X | |
| Johns River channel | | | | | | | | | | | | | X | X | X | X | X | | X | X | X |
| Elk River flats | | | | | | | | | | | | | | | • | X | X | X | | X | X |
| Sand Island channel | | | | | | | | | | | | | | | | X | X | X | X | | X |
| Westport Marina | | | | | | | | | | | | | | | | | | X | X | X | |

Data showing diverse coho salmon life histories are less clear, but we did observe subyearling (YOY) and yearling fish throughout the sampling season. Most of the fish captured were early fry migrants moving to the Surge Plain (particularly the Lower Elliot slough site in 2011; data not shown) or the estuary (for example, at Cow Point). The exception was in the Hoquiam River, where juveniles resided and added length in all years

(**Figure 18;** only 2012 is shown). A similar trend was seen in the lower Humptulips River in 2012 (data not shown). The data for total coho salmon catch in 2013 are shown in **Figure 19**; other years showed similar patterns (all the annual plots are available in the 2013 Grays Harbor report). The fyke netting, which was only conducted in 2011, showed a different pattern. Estuarine-rearing YOY coho were captured in intertidal sloughs with higher salinities (**Table 5**), although these had some freshwater input and the fish may have been utilizing the surface waters, where salinities were lower.

The “nomad” coho salmon life history is likely present in Grays Harbor as well, with subyearling coho moving to the estuary in their first summer for feeding opportunity and (potentially) to escape warm river temperatures, then returning to the Surge Plain or lower tributaries during the winter before emigrating to sea the following year. However, due to funding constraints we were unable to confirm this by sampling in the Surge Plain in the fall of 2014.

***Figure 18: Fork length of juvenile coho salmon in 2012 at the East Fork Hoquiam River site.***

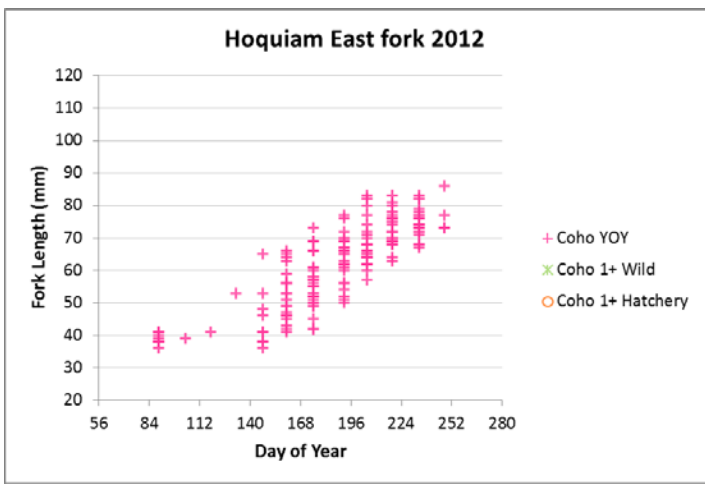
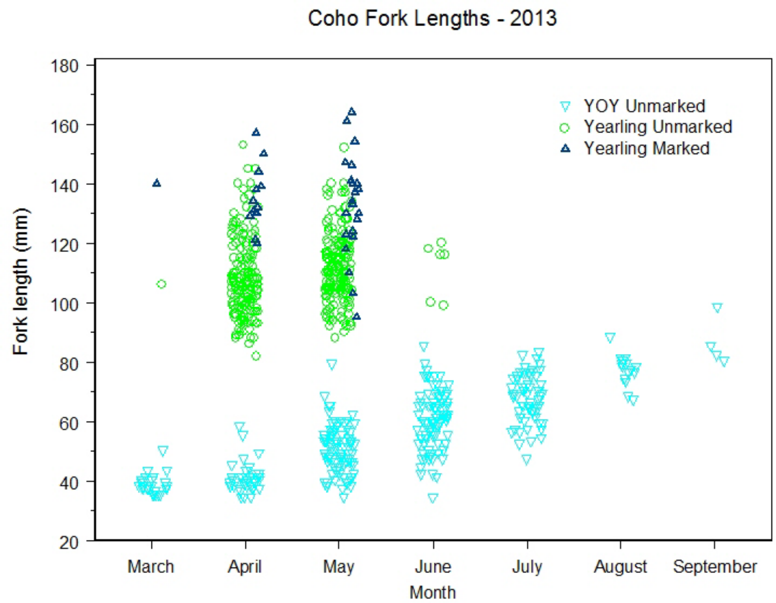


***Figure 19: Coho salmon fork lengths (mm), by month, showing age class designations***




As the climate changes, certain life history strategies – particularly those that have late juvenile emigration or summer adult returns – will be most severely affected. In the basins of Grays Harbor, the adult stocks most affected include one stock of summer Chinook and two stocks of summer steelhead trout, although juveniles of all stocks and species will also be affected. The expected reduction in summer rainfall (resulting in reduced summer river flows), decrease in snowpack (already limited in the Humptulips and Satsop drainages), and increased water temperatures will stress fish and allow for the earlier arrival of warm water fish predators, among other effects. According to the University of Washington's Climate Impacts Group, "The combined effects of warming stream temperatures and altered stream flows will very likely reduce the reproductive success for many salmon populations in Washington watersheds" (Mantua, Tohver, and Hamlet 2009; Abdul-Aziz et al. 2011). The presence of multiple life history strategies for the various species of salmonids in the Grays Harbor basin allows for the best chance of persistence, supplying the genetic variation that will hopefully maximize adaptive capacity (Greene et al. 2010). For more information on climate impacts and management alternatives, see #6, below.

**(4) Where are the critical areas or habitats for juvenile salmonids?**

*The information on salmon catches and water temperatures presented in focus question #1 form the basis for the selection of the following areas as priorities for conservation.*

### Surge Plain

The Surge Plain (head of tidal influence on the lower Chehalis River) is one of the most important intact habitats in the basin, providing winter refugia from high river flows and oligohaline (low salinity) habitat, which is particularly important for juvenile coho salmon (see #2, above). This tidal swamp contains numerous sloughs and remains heavily forested (with some native Sitka spruce, *Picea sitchensis,* already present), containing an estimated 198km (123 miles) of shoreline (**Figure 20**). Because of its significance as off-channel rearing habitat and refugia from high winter flows for juvenile salmon, 3,018 acres have been designated a Natural Area Preserve (NAP) by the Washington State Department of Natural Resources.

Our sea level rise (SLR) modeling suggests this area could be impacted by 2025 (under all scenarios), and intrusion of salt water (esp. in summer, lower river flows) has the potential to kill most of the salt-intolerant tree species in the forest, destabilizing the numerous sloughs through the action of flooding and tidal surges. While there is a great deal of uncertainty in the projections of sea level rise globally, changes in the volume and temperature of the river water entering the estuary will clearly modify the extent of salt water intrusion and stratification in the estuary, with the less dense freshwater overlaying the denser salt/brackish component. The frequency and magnitude of "king" tides is also expected to increase. However, a warmer ocean could also result in a less dense salt wedge that would not intrude as far into the estuary, even as water levels rise (ISAB 2007).

Planting of additional Sitka spruce (a salt resistant species) in the current Surge Plain offers one way to offset the loss of other tree species in the forest in this region, stabilizing the banks. However, another concern is the migration of the head of tide upstream as sea and estuary water levels rise as predicted. To answer the question "is there an area upriver that may serve as the 'future' Surge Plain?," we mapped the expected inundation levels under a variety of SLR magnitudes (up to 2 meters increase; **Figure 21**), as well as plotting river elevations (**Figure 22**) in this stretch from two different data sources. The elevation gradient between the Satsop River and the Wynoochee River is low, suggesting this area was originally an active floodplain prior to being diked. The future head of tide under scenarios of 1 meter or more of SLR will likely be downstream of the Satsop River (**Figure 29**). See also the Restoration Projects Section, "Lower Chehalis River: Flood Plain Connectivity."

***Figure 20: A map of the Chehalis River Surge Plain, with sloughs outlined in blue. It is estimated that the sloughs in the region contain 198 km (123 miles) of shoreline. The red line is the railroad track that passes through the area (created by and used with the permission of Jarred Figlar-Barnes).***

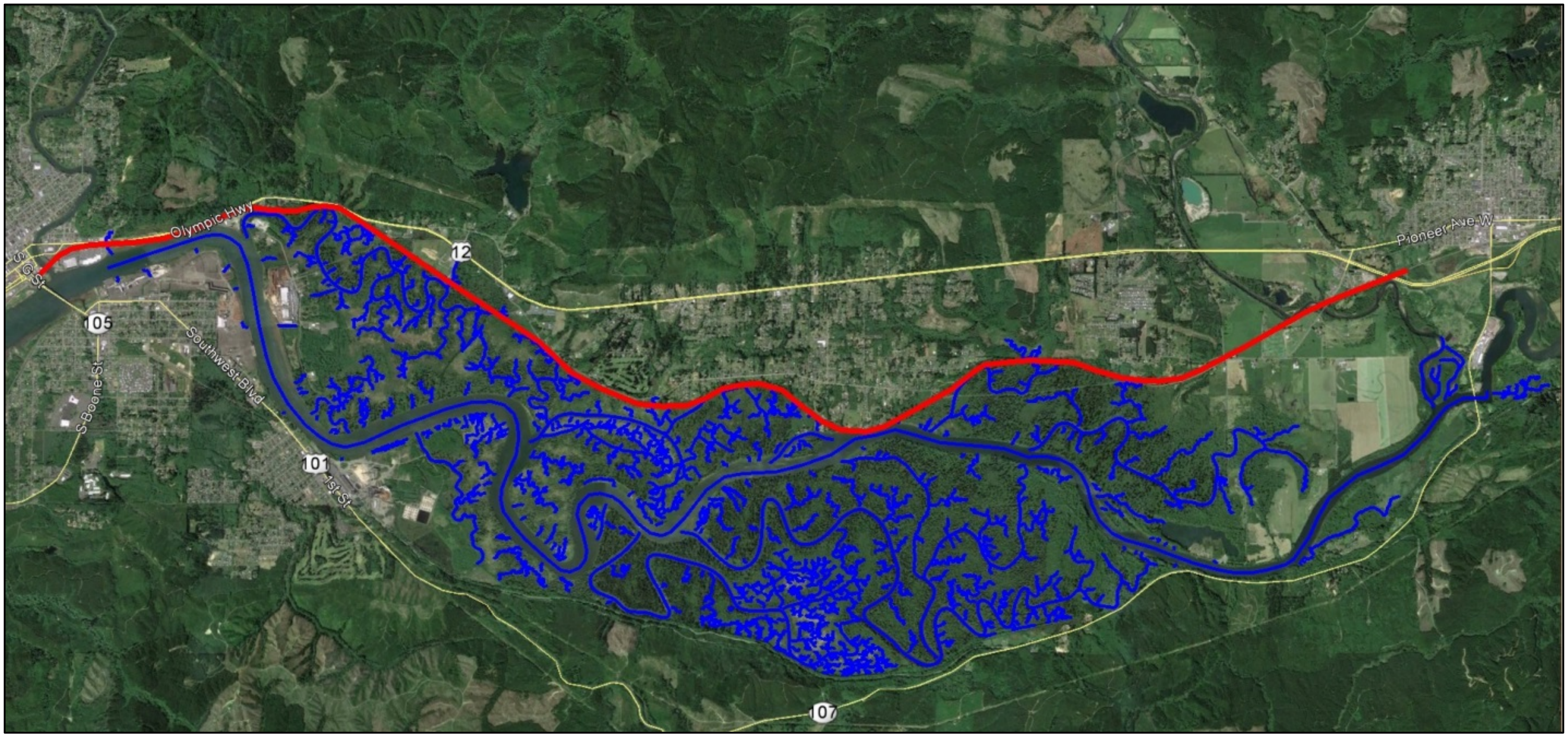


***Figure 21: Map of projected head of tide (Surge Plain) under various sea level rise scenarios.***

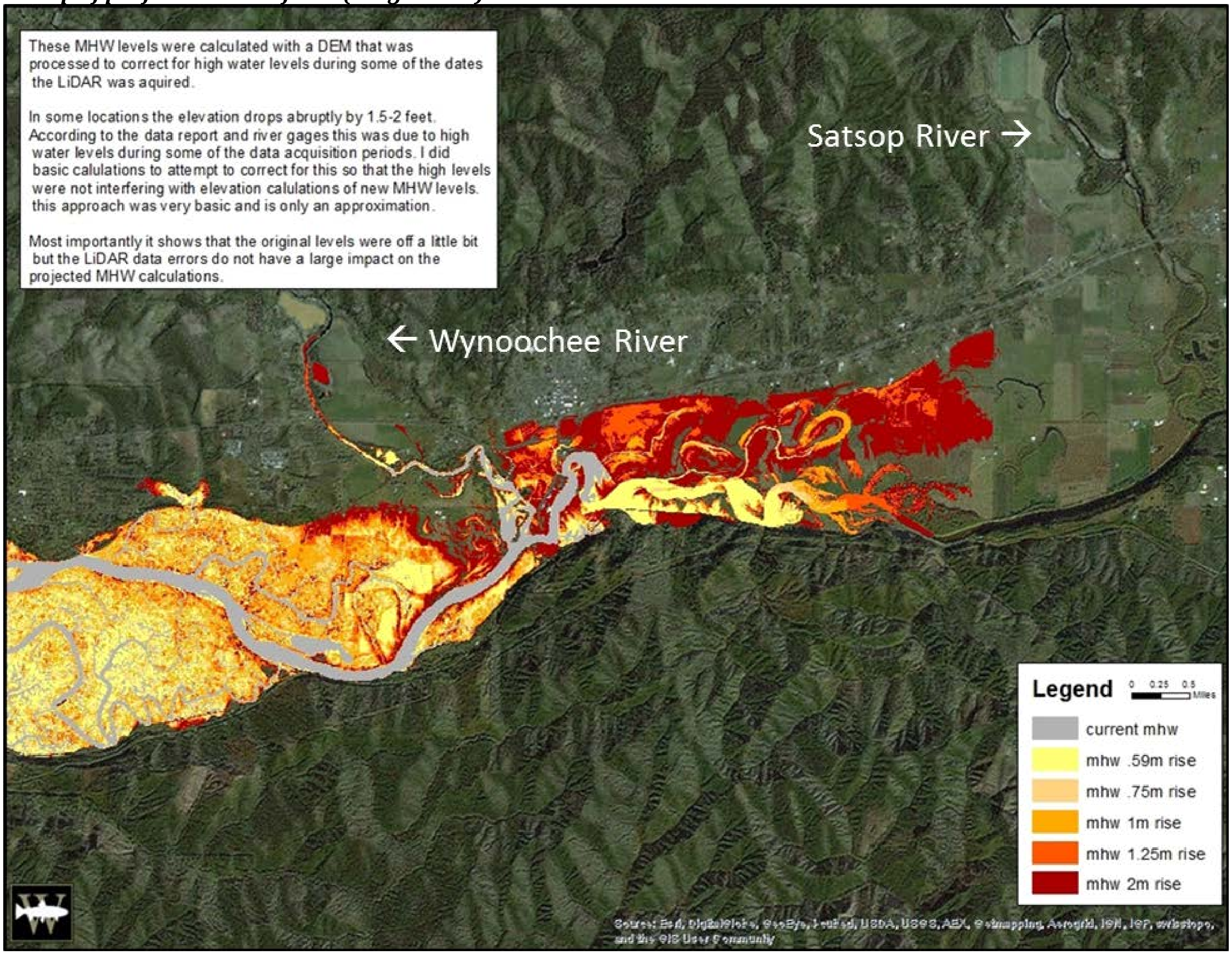
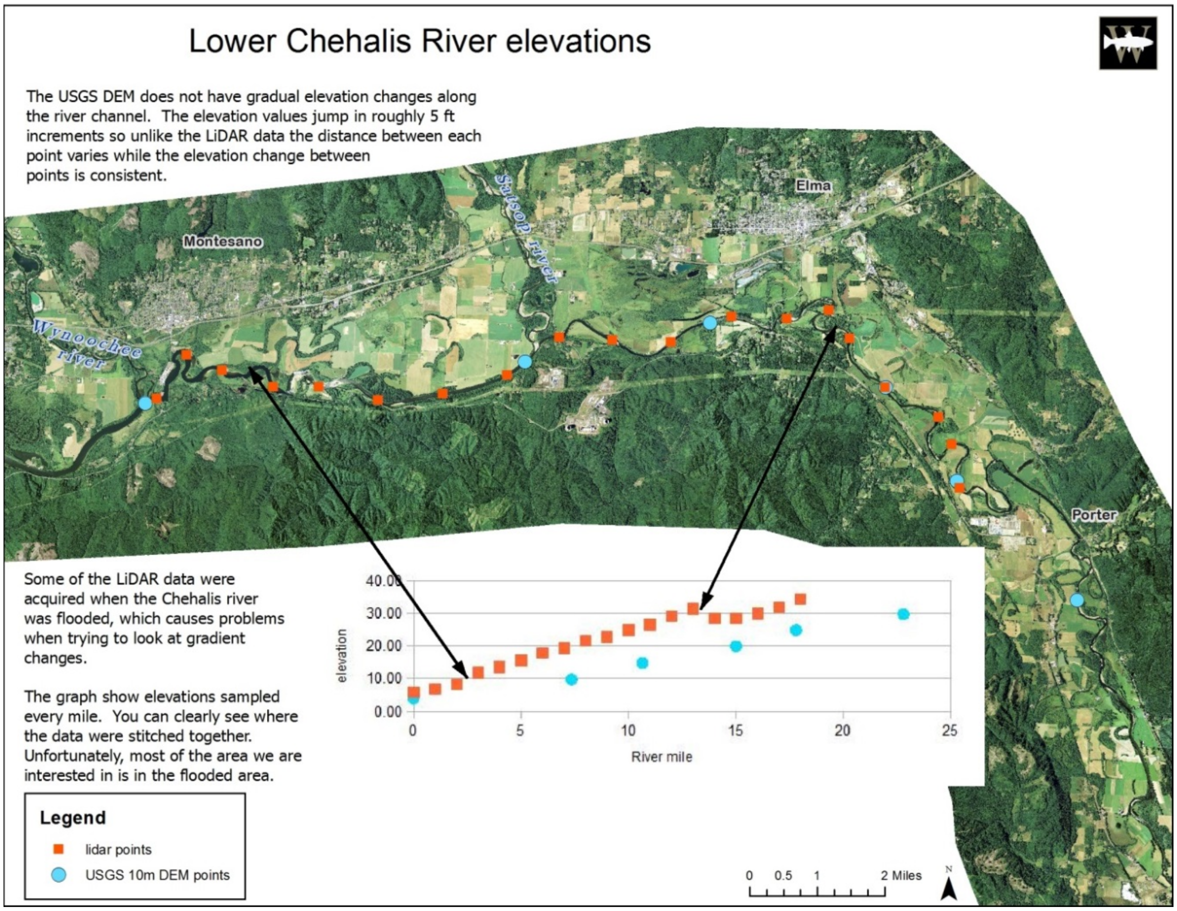


***Figure 22: Map showing elevation changes in the lower Chehalis River, based on USGS digital elevation models (DEM) and LiDAR data, by river mile. Note that some of the LiDAR flights were conducted during river flooding, creating a "jump" in the trend line when stitched together (red squares).***



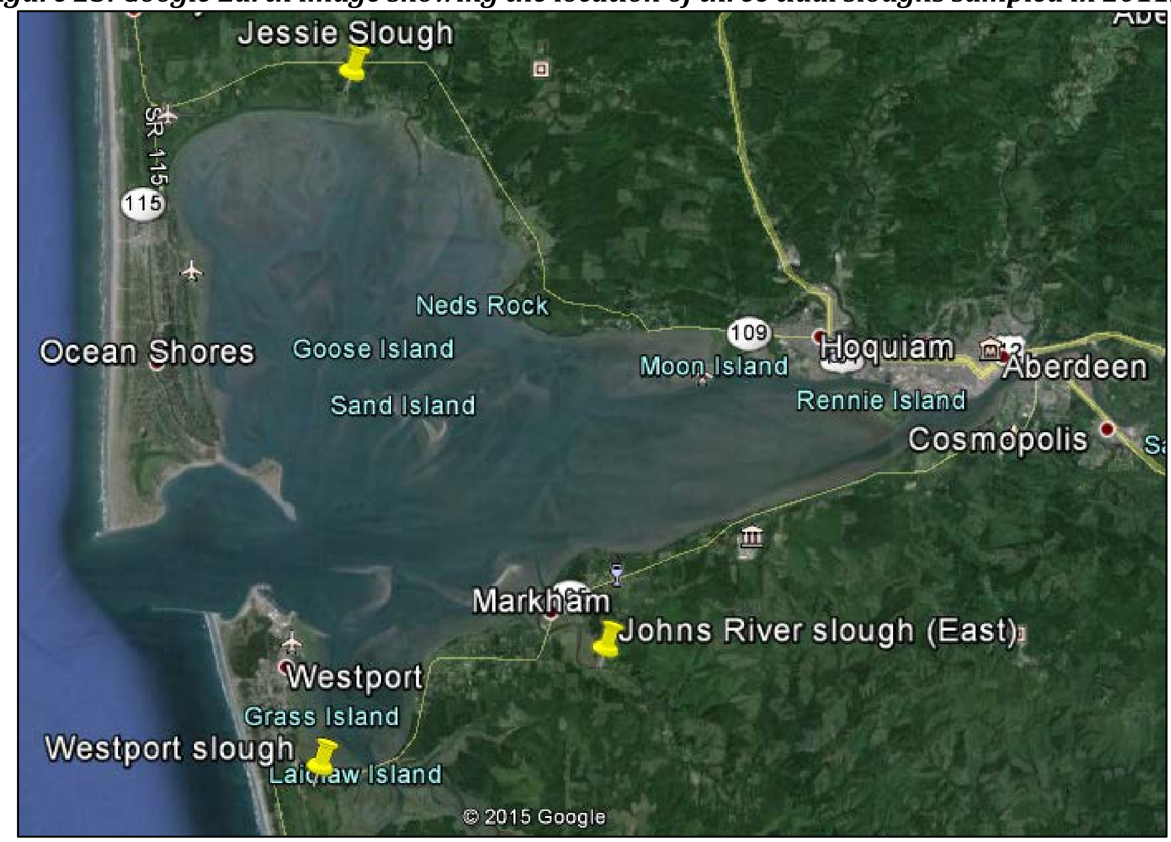

## Estuarine tidal sloughs (outside of the Surge Plain)

A number of other "blind" (dead end) tidal sloughs off the main estuary were sampled via fyke netting in 2011. These sloughs, though generally small in area, harbored relatively high numbers of juvenile Chinook and coho salmon (**Table 5**), suggesting that tidal sloughs are also a good candidate for protection (Jessie Slough, on the North shore, is intact and the land is already owned by Grays Harbor Audubon; the Johns River slough is on WDFW land) or restoration (South Bay bridge slough ("Westport slough")). Coho were present in all of these, even as mid-range salinities approached 10 ppt (although it is likely that horizontal salinity gradients were present), and these may be important for juveniles adapting to higher salinity water before they emigrate to sea. **Figure 23** shows the location of these sloughs; both the Johns River slough (East shore) and the Westport slough are detailed further in the section "Restoration Site Recommendations", below.

**Table 5**: Tidal sloughs sampled via fyke net in 2011 with juvenile Chinook and coho salmon catch and fyke net and slough area (in hectares).

| Site | Fyke net area (Hectares) | # of sampling events | Total Chinook salmon | Total Coho | Total Area (Hectares) |
|---|---|---|---|---|---|
| Johns River slough | 0.8126 | 8 | 25 | 79 | 6.5008 |
| Jessie Slough | 0.2011 | 6 | 51 | 213 | 1.2066 |
| Westport Slough | 0.332 | 1 | 1 | 8 | 0.332 |

***Figure 23: Google Earth image showing the location of three tidal sloughs sampled in 2011.***




**South Bay**

Given that South Bay (Elk River estuary) has limited adult spawning habitat, the area supports surprisingly large numbers of juvenile unmarked Chinook, YOY and yearling unmarked coho and chum salmon (all YOY) (**Figures 2-7**). The presence of both adipose fin clipped salmon (there is no hatchery on the Elk River) and salmon from outside of the Grays Harbor basin (based on genetics; see the WFC 2013 annual report) show that the area is utilized for rearing by juvenile salmon arising from diverse areas, including the Olympic Peninsula, Willapa Bay, Columbia River, and Oregon coast. The area is largely intact and is surrounded by both public (WDNR, Grays Harbor County) and timber lands (**Figure 27)**, providing excellent tidal flat, marsh, and forested habitats for juvenile salmon.

**Humptulips, Hoquiam and Wishkah Rivers**

The Humptulips River is a major contributor of juvenile chum, coho, and especially, unmarked Chinook salmon (**Figures 2-7**); it also serves as a cool water input to the tide flats of the main estuary and provides a temperature refugia in late summer (**Figure 8**). Very few hatchery (adipose clipped) juvenile Chinook were captured in the three years of our study. The mouth of the Humptulips River has excellent marsh, tidal flat, and forested habitat and is protected in ownership by Grays Harbor Audubon.

Despite its smaller size, the three forks of the Hoquiam River provided the largest catches of YOY coho salmon to the estuary (as an example, see **Figure 3**), as well as moderate numbers of Chinook and chum salmon. The Hoquiam system contains excellent forested and scrub/shrub habitat, is extensively influenced by the tidal surge, and in its upper reaches has enormous quantities of large woody debris both on the banks and imbedded in the river bottom which provide good rearing habitat. However, the watershed is logged and replenishment of LWD may be a problem in the future; riparian logging buffers should be protected and enlarged if possible.

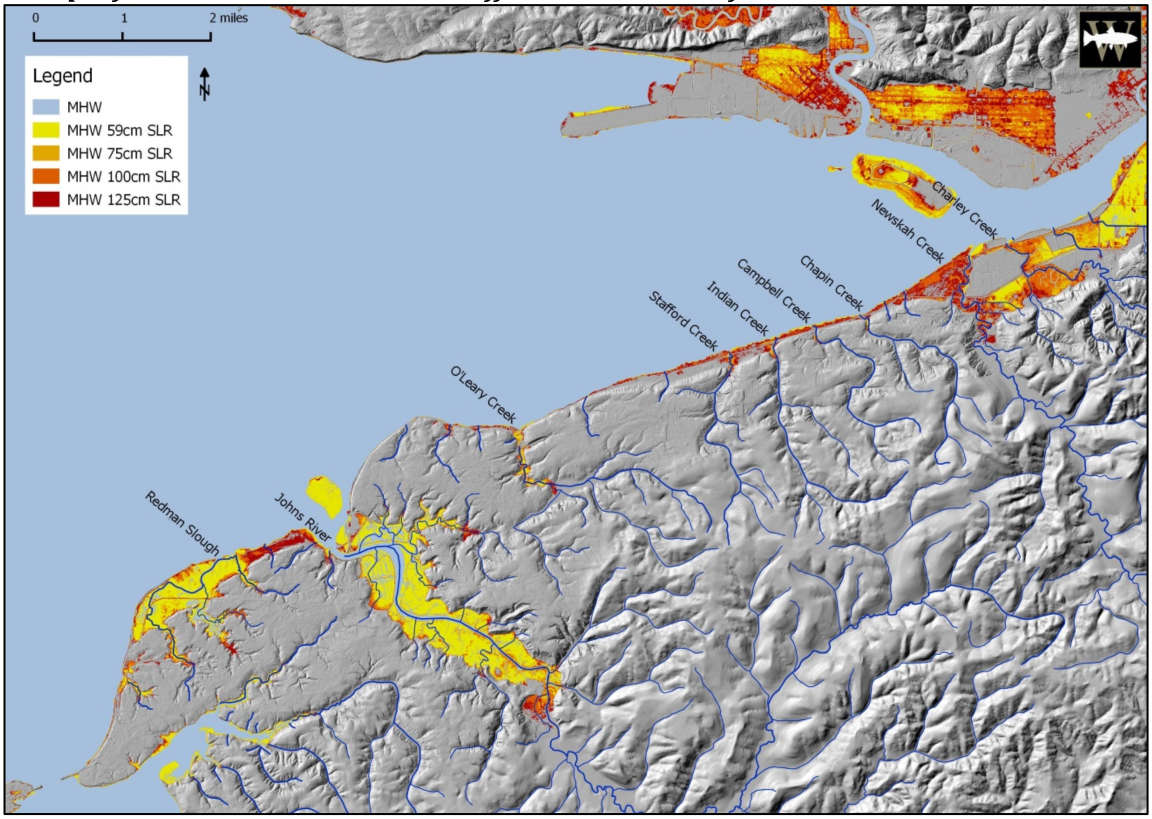
The Wishkah River is similar to the Hoquiam River in many respects, although we were only able to sample it in 2011 due to the arrival of a large logjam in the winter of 2011-2012. Catches of unmarked YOY Chinook salmon in the Wishkah River were similar to those in the Hoquiam River, as were catches of YOY coho by fyke netting (slough), but not by beach seining (river). The Wishkah should be sampled further to clarify its role in salmon production in the basin. The other major tributaries to the Lower Chehalis River (Wynoochee and Satsop Rivers) were not sampled as intensely in this study because, being farther upstream, they had fewer tidally influenced portions.

In 2014, our sampling in the lower Chehalis River (above tidal influence) showed that YOY coho, essentially all of which are unmarked in the Chehalis Basin, were encountered occasionally and usually in low densities with one exception, the sampling site "Cow Run" near the mouth of Delzene Creek on June 16 (>800 fish/ha) (Fletcher et al., 2015). <u>This high density coincided with a notably cooler water temperature at this site</u> (14.1°C) <u>compared to the average water temperature of 8 other locations sampled that day</u> (17.1°C ± 0.25). Cooler water temperature may indicate the presence of hyporheic groundwater upwelling which might be actively sought after by juvenile coho during summer months (cold groundwater may be a limiting resource in summer, and resource managers should consider prioritizing such areas for protection and restoration). By late July, coho were absent from all sites except for 3 individuals at the mouth of the Satsop River, which is also a source of cooler than average water.

#### South Shore Tidally Influenced Creeks

The South shore of the estuary will see the largest impacts of SLR due to lower, gradual increases in elevation (in comparison with most of the North shore). The area contains a series of 7 small tidal creeks from south Aberdeen to Markham (mouth of the Johns River) that are utilized for rearing (even if there is minimal adult spawning) by juvenile salmon (**Figures 2-7**), based on our data for Charley Creek (see **Figure 24** for location). These creeks and associated wetlands will likely become increasingly inundated with sea level rise (**Figure 24**) and will remain a key habitat for juvenile salmonids. Charley Creek is also a source of cool water in comparison to the adjacent South channel (**Figure 8**), although it and Newskah Creek have larger catchments than the other creeks in this area. Additional sampling to clarify the role of the smaller creeks would be beneficial.

***Figure 24: Map of the south shore of the main estuary, showing the locations of tidal creeks and the projected inundation under 3 different scenarios of sea level rise.***




**(5) What habitat types will be lost first due to sea level rise (SLR)? Which habitat types will be most reduced in area due to SLR?**

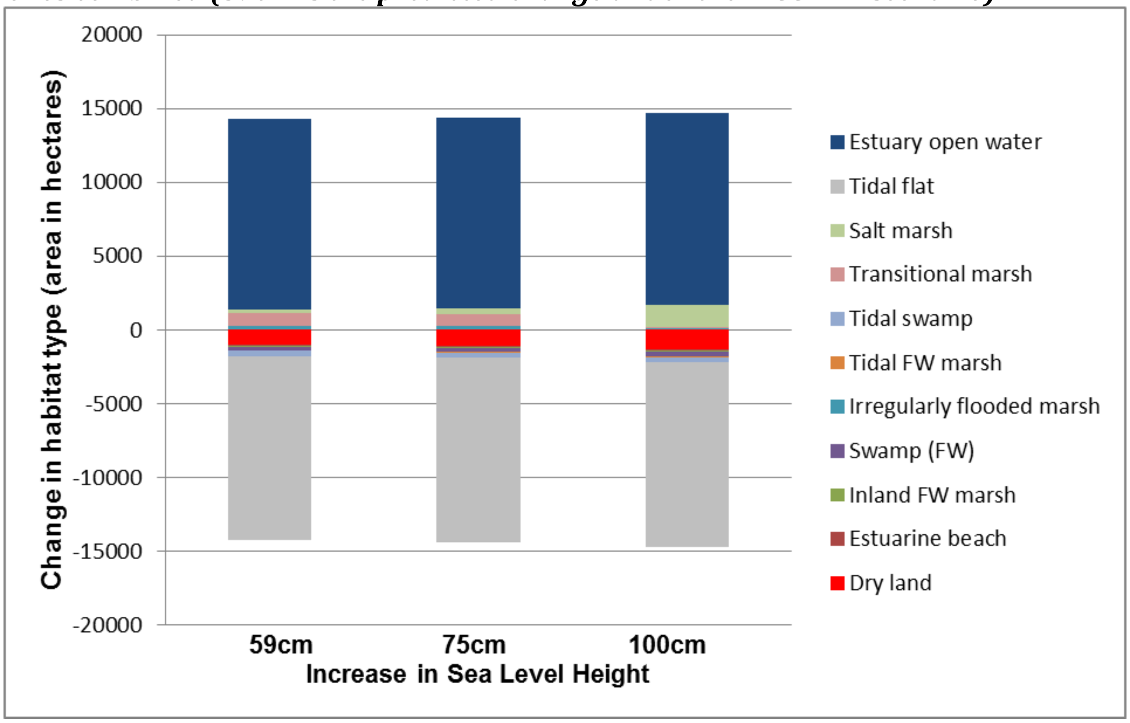
The good news for the Chehalis Basin is that, as a "rain dominant" system, it will be among the least impacted in the state of Washington. However, significant changes are expected, including an increase in the magnitude and frequency of extreme winter precipitation events (which will increase winter stream flows and may increase flooding), an increase in the frequency and magnitude of extreme tides, warming air and water temperatures, increases in inundation due to sea level rise, ocean acidification and reduced summer river and stream flows. The magnitude and timing of these changes are uncertain, but the most recent reports by the Intergovernmental Panel on Climate Change (IPCC; http://www.ipcc.ch/report/ar5/syr/) suggests that SLR is proceeding "ahead" of schedule; the A1B scenario of 59cm of SLR used as a benchmark in earlier reports now appears increasingly conservative (see also (Rahmstorf 2012)). To date, SLR in the Grays Harbor area has been minimal in comparison with other parts of the world, but sea levels are predicted to accelerate their increase in the coming decades (for more information, see the WFC 2012 report on Climate Change in the Chehalis River and Grays Harbor). The timing of these changes can be inferred from **Table 6** by following the trends from 59cm to 100cm of SLR, which shows the percentage of each habitat remaining under the different scenarios; no yearly targets are provided because of the uncertainty in the models. ). *As a disclaimer, the model outputs are only projections and should not be used for specific predictions at any one area or point in time.* Despite this uncertainty, the modeling is useful because it highlights which habitats will change first (and to what extent), and where those habitats are found in the estuary.

**Table 6**: Comparison of percentage of habitat types remaining in the Grays Harbor estuary under varying model predictions of sea level rise (SLR). The A1B model (~59cm SLR max) is the moderate climate change scenario from the 2007 IPCC report; also shown are changes if sea level rises 75cm and 100cm by 2100 compared to 1981 data. Both the NWI habitat categories and the approximate equivalent habitat from our sampling plan are provided. Note that percent changes >100% (increases) are listed as multiples (e.g. "3x"); percentages of less than 100% indicate a net loss in that habitat type.

| **Amount of change** | | **Sea Level Rise** | | |
|---|---|---|---|---|
| NWI habitat categories | Our Habitat Category | A1B | 75cm | 1m |
| Dry Land | Dry Land | 88% | 87% | 86% |
| Nontidal Swamp | Forest | 43% | 41% | 34% |
| Inland Fresh Marsh | Scrub/Shrub Cover | 45% | 44% | 39% |
| Tidal Fresh Marsh | High Emergent Marsh | 11% | 10% | 6% |
| Transitional Marsh / Scrub Shrub | Scrub/Shrub Cover | 265x | 263x | 199x |
| Regularly Flooded Marsh (Saltmarsh) | High Emergent Marsh | 2.4x | 2.6x | 4.1x |
| Estuarine Beach | Cobble/gravel/Sand beach | 67.7% | 66.7% | 49.5% |
| Tidal Flat | Mud Flat/Sand Flat | 16.6% | 16.7% | 17.1% |
| Inland Open Water | Open Water | 53.1% | 51.9% | 48.6% |
| Riverine Tidal Open Water | Open Water | 7.5% | 7.4% | 7.0% |
| Estuarine Open Water | **Aquatic Vegetation Beds?** | 2.5x | 2.6x | 2.6x |
| Irregularly Flooded Marsh | High Emergent Marsh | 6x | 6.1x | 5.8x |
| Inland Shore | | 91.2% | 90.4% | 77.7% |
| Tidal Swamp | Forest | 3.1% | 2.7% | 1.6% |

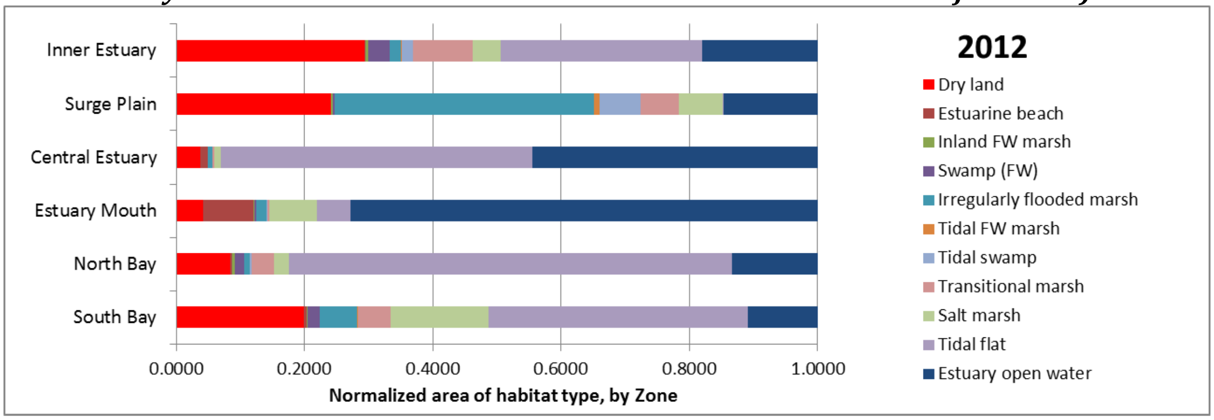
The initial projected losses in aquatic habitats are greatest for tidal swamps (forested; most of this is in the Surge Plain; 3.1% remaining), tidal freshwater marshes (11% remaining), tidal mud and sand flats (much of this is located in North Bay; 16.6% remaining), non-tidal swamps (43% remaining), and inland freshwater marshes (45% remaining) (see **Appendix** 1 for the raw numbers in hectares). The loss and gains of the various habitats are plotted in **Figure 25**, which highlights the conversion of tidal flats to estuarine open water (because of a lack of bathymetry (water depth) data to input into the model, it is unclear how much of this would convert to shallow water aquatic vegetation beds, an important habitat type for juvenile fish, and how much would become deeper, open water). In general, the trends for each habitat type hold as one moves from 59cm of SLR to 100cm of SLR, although the magnitudes increase (**Figures 25, 26**).

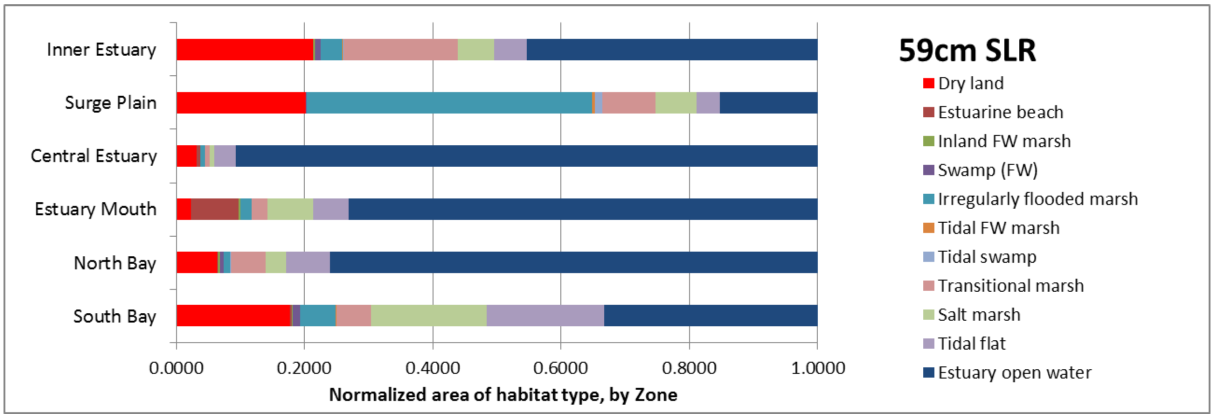
***Figure 25: Expected change in habitat types under three different scenarios of sea level rise, all zones combined (59cm is the predicted change under the IPCC A1B scenario).***

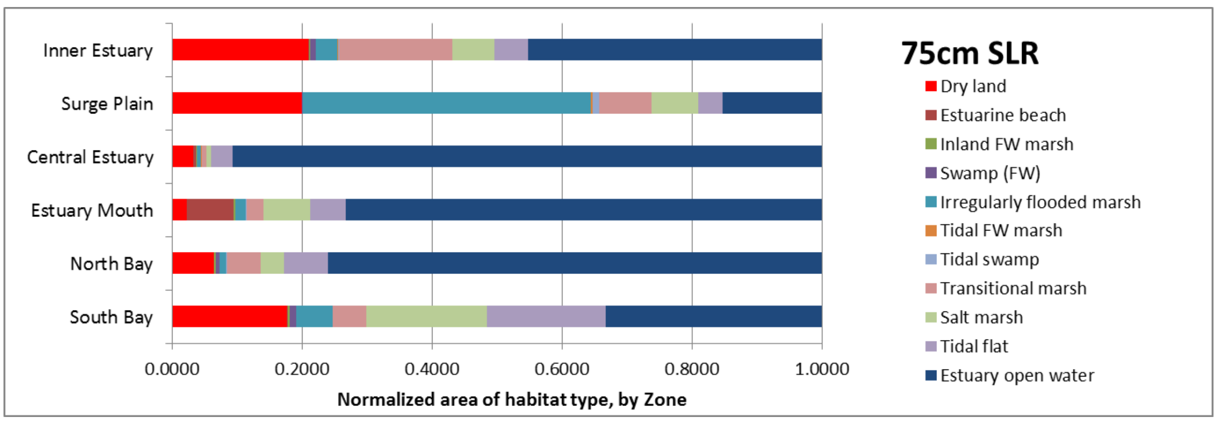



Both Goose and Sand Islands are submerged by increasing sea levels by 2100 (A1B and 75cm scenarios) or 2075 (1 meter scenario). In the Inner Estuary zone, the extensive mud flats around Moon Island (near the airport) and Rennie Island are submerged by 2075 in all three scenarios, although complete inundation of Rennie Island itself is not predicted. In the surge plain (as previously mentioned), the predicted changes in SLR will result in a rapid transition from forested tidal swamp to irregularly flooded marsh by 2025 even in the most conservative scenario (A1B). Under the higher SLR predictions, the area around Cosmopolis (some of which is currently protected by tide gates) will also transition from dry land to transitional marsh by 2025 (all scenarios) and eventually to tidal fresh water marsh (by 2050 under the 75cm scenario and between 2025 and 2050 under the 1 meter scenario). Aberdeen is predicted to undergo a similar, but less dramatic, transition, with transitional marsh beginning to appear around 2050 under the 1 meter scenario.

***Figure 26: Habitats by zone in 2012 and after SLR under three different scenarios of inundation (note that these data were normalized by dividing the area of each habitat type in hectares by the total area in each zone to better show the breakdown of habitats).***



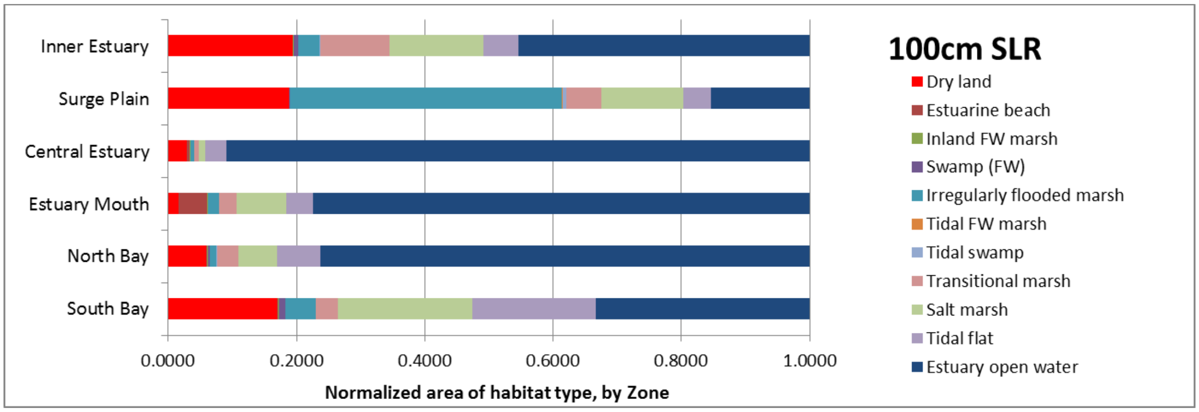



**Figure 26** shows the habitat availability in each of the six zones in 2012 and under the three different scenarios of SLR (the data are normalized to better show the distribution of habitats). The changes between the three SLR scenarios are subtle, as the initial inundation of 59cm generates much of the change, but a comparison against conditions in 2012 highlights the major changes. Most notable is the loss of tidal flats in all zones except the Surge Plain, with most of the habitat converting to estuarine open water (some of which will be aquatic vegetation beds). South Bay is expected to have the most remaining tidal flats because it has slightly higher elevations than North Bay. As noted previously, the Surge Plain is expected to convert from forest/swamp to various types of marsh land (while this is a relatively small area, it represents the majority of this habitat in the estuary), and the Inner Estuary converts from tidal flats (Moon Island, Rennie Island flats), swamp, and marsh land to open water.

In North and South Bays, SLR will have less dramatic effects. Some areas of tidal flats will be lost and there will be a reduction in the amount of forested area in the headwaters of the Elk and Johns Rivers. However, most of these areas are expected to transition from one type of marsh currently present (e.g. tidal fresh or transitional marsh) to salt marsh. In the estuary as a whole, rising sea levels are predicted to dramatically increase the amount of the various types of marsh land; for transitional marsh (scrub/shrub cover), over 200-fold; for regularly flooded salt marsh, 2.5-4 fold; for irregularly flooded marsh, roughly 6 fold under all scenarios (**Table 6**). The increase in salt water levels will result in a decrease in freshwater marsh habitat, with inland fresh water marsh declining to ~45% of 1981 levels and tidal fresh marsh declining to roughly 10% of 1981 levels (**Table 6**).

These trends assume that no extensive diking is built around the estuary, as this would limit the shoreward expansion of seawater and would eventually “drown” the shallow shoreline habitats that are critical for YOY salmon and other fishes. The preservation of these habitats is essential, so it is critical that as sea level rises, new areas of habitat are available as the waterline migrates landward (Shaughnessy et al. 2012).

Extensive armoring of shorelines (dikes, levees, etc.) against sea level rise may prevent this process from occurring, leading to the loss of wetlands and undermining the biological and chemical processes that allow estuaries to be such productive ecosystems (Scavia et al. 2002). To this end, development of vulnerable areas should be prevented or discouraged, and setback lines from the coast and wetland margins should be increased. Another option is the establishment of “rolling easements” which allow for development that does not lead to the destruction of wetlands and beaches and are adjusted according to local sea level rise over time.

*For more information on climate change, including map projections of where habitat will change due inundation, see the WFC 2012 report, “Climate Change in the Chehalis River and Grays Harbor Estuary.”*

**(6) What adaptive management actions can be taken to maintain or improve the viability of salmon populations in the Grays Harbor Basin?**

As the climate changes, conditions for salmonids in the Grays Harbor estuary will become more challenging, particularly for stocks of salmon with extended freshwater rearing periods (including steelhead, coho and subyearling (ocean type) Chinook salmon). These conditions can be offset, or delayed, by making investments to protect habitat and limit the detrimental effects of warmer water temperatures and altered river and stream flows, allowing the species in question to maximize their adaptive capacity (for example, by altering life histories to avoid extended summer river residency of adults prior to spawning). For salmonids in particular, management strategies will also have to adapt. In theory, harvest management is designed to produce sustainable yields, which are directly linked to the productive capacity of the environment. As the environment is altered by climate change in ways that do not favor salmon recruitment (e.g. warmer water temperatures, loss of thermal refugia, decreased summer stream flows, etc.), harvest must be adaptively managed to maintain sustainability. Exploitation and environmental change must be considered together to produce strategies that allow these fish populations to remain sustainable (Scavia et al. 2002).

For over a century, hatchery production has been utilized as a primary tool for fishery enhancement and habitat mitigation in the Pacific Northwest. Unfortunately, hatchery practices have resulted in unintended genetic, ecological, and fishery related consequences which have degraded wild salmonid populations, compromised the public’s substantial investment in habitat protection and restoration, and undermined the long-term sustainability of regional fisheries. Despite recommendations from leading fishery scientists for meaningful hatchery and harvest management reform, our society continues to depend on conventional methods of artificial propagation in efforts to improve short-term commercial and recreational fishing opportunities. For example, the authors of *Upstream*, published by the National Research Council, explained in 1996 (NRC 1996) that hatcheries "have resulted (among other effects) in reduced genetic diversity within and between salmon populations, increased the effect of mixed-population fisheries on depleted natural populations, altered the behavior of fish, caused ecological problems by eliminating the nutritive contributions of carcasses of spawning salmon from streams, and probably displaced the remnants of wild runs." Specifically, the Hatchery Scientific Review Group (HSRG) emphasizes that local adaptation of fish populations is fundamentally important to hatchery reform (HSRG 2014: http://hatcheryreform.us/hrp/welcome_show.action):

> 3.2.6 "… a major concern with many current hatchery programs is that they have been operated in a manner that disrupts natural selection for population characteristics that are tailored to local environmental conditions. Proper integration or segregation of harvest augmentation programs is the recommended means to minimize the adverse effects of hatcheries on local adaptation of natural populations. Local adaptation of hatchery populations is achieved by using local broodstock (of natural-origin, in the case of integrated programs; of local hatchery-origin in the case of segregated programs) and avoiding transfer of hatchery fish among watersheds. It is important to promote local adaptation because it maximizes the viability and productivity of the population over time and maintains biological diversity within and between populations. Local adaption is also critical to enable populations to adjust to changing environmental conditions, for example, through climate change." [emphasis added]

In the face of diminished abundance and changing selective pressures, the preservation of wild salmon and steelhead populations' genetic integrity remains the best tool to enable the rapid adaptation and evolution required to maintain or recover salmonid populations for future generations (Greene et al. 2010). Without significant and timely hatchery and harvest reform, the potential for wild salmonid recovery will be further compromised, risking the loss of otherwise renewable resources and associated long-term economic and cultural benefits. In order to address these issues, the best approach going forward is to:

- Implement the Hatchery Scientific Review Group's (HSRG) recommendations
- Implement the state's own policy on hatchery and harvest reform: http://wdfw.wa.gov/commission/policies/c3619.html
- Discontinue the management of all Grays Harbor chum salmon as one of two large stocks- this overlooks individual stock variations (e.g. Satsop River, etc.) that may be critical for providing adaptive capacity
- Oppose the proposed Chehalis River Dam, which would further diminish salmon and steelhead runs in the upper river and would decrease the input of sediment transported to the estuary, potentially accelerating the loss of tidal sand and mud flats

- Focus on "restoring floodplain functions that recharge aquifers, identifying and protecting thermal refugia provided by ground-water and tributary inflows, undercut banks and deep stratified pools, and restoring vegetation in riparian zones that provide shade and complexity for stream habitat. Restoring, protecting, and enhancing instream flows in summer are also key" (Logerwell et al. 2003).
- Cease operating hatcheries that violate the Endangered Species Act (in the absence of NOAA-approved Hatchery and Genetic Management Plans (HGMPs; http://wdfw.wa.gov/hatcheries/esa.html), which would examine the effect of hatcheries on a local scale).

## RESTORATION SITE RECOMMENDATIONS

To assist with restoration planning efforts, current land ownership in the Grays Harbor estuary is mapped in **Figure 29**. This information is provided to assist with planning, under the assumption that public lands may be easier to protect or restore, and may therefore take priority.

The projects outlined here provide examples of actions that would benefit juvenile salmon by increasing habitat availability, based on the data contained in this plan, but does not approach a complete list of available projects in the estuary. Although these are considered priorities, they may not necessarily be the highest priority projects- issues with the ability to complete a project quickly, or budget restrictions, may take precedence, and the final decisions will have to be made by the Chehalis Lead Entity and other partners in the watershed. The project scoring sheet used by the Recreation and Conservation Office offers a way to rank future projects' value based on the list provided in the initial section, "Purpose of the Report," and is intended to be complementary to the ranking systems currently in use by PRISM, WCSSP, etc. In addition to restoration, protection of existing high quality habitats, through conservation easements or land acquisition, should be considered as a priority under the WCSSP's policy of "protect the best, restore the rest."

The restoration areas highlighted below are presented in two groups; the first identifies beneficial restoration projects without regard to sea level rise (SLR), while the second focuses on projects that will help offset SLR or encourage the transition of habitat from one type to another that will be beneficial to juvenile salmon and other fishes primarily under increasing sea level heights. An additional section identifies projects that include changes to infrastructure and roads that will provide long-lasting benefits.

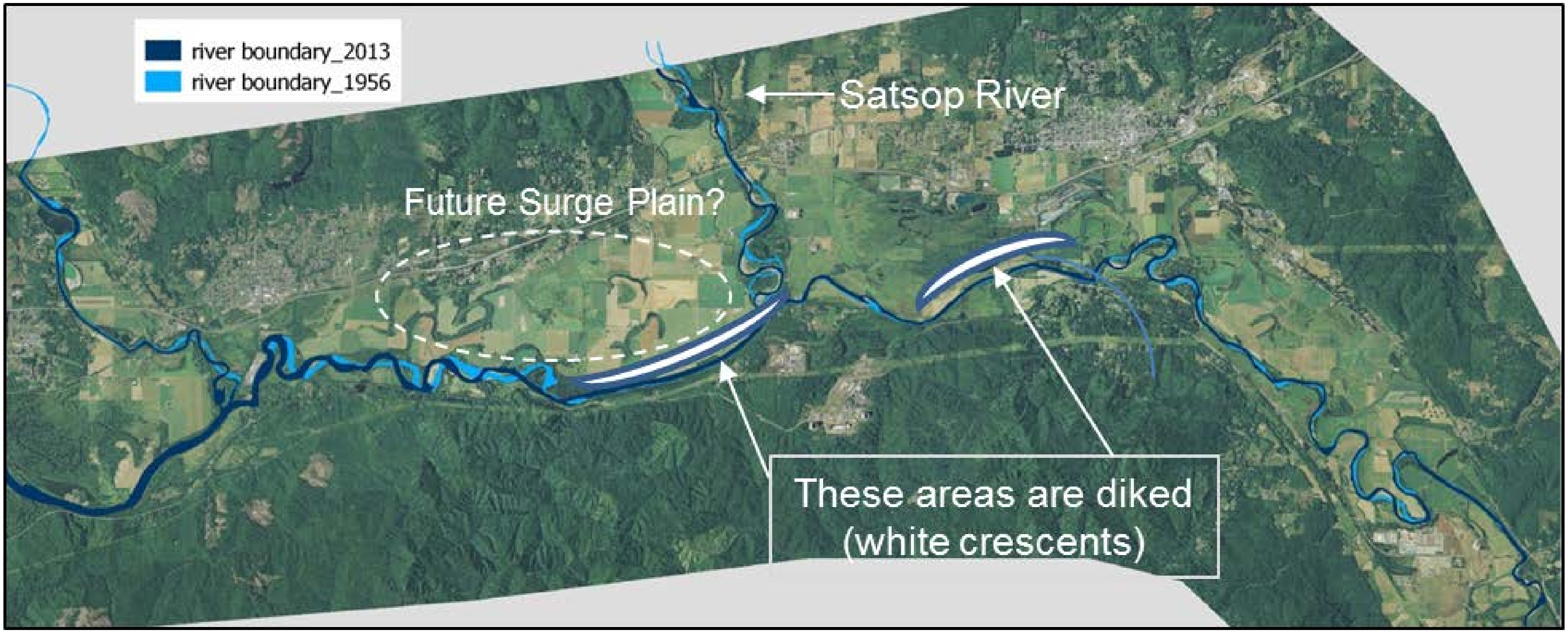
## Group 1

### Lower Mainstem Chehalis River: Flood Plain Connectivity

The stretch of river between Elma and Montesano has numerous side channels, gravel pit ponds (which may harbor introduced, warm-water species) and marshes that are no longer connected to the mainstem river, which has been diked against the southern wall of the flood plain and channelized (straightened). The banks are armored with rocks and plastic sheeting buried in soil most of the way upstream to Elma; based on the earliest aerial photographs, dating from the 1940's, the dikes have been present in some form for >70 years. Poor floodplain conditions exist in the stretches between Montesano and the Satsop River (one of the largest sub-basins in the drainage) and between the Satsop confluence and Elma due to bank protection (levees) and channelization. The upper extent of most of the chum spawning habitat is in this region, near the mouth of Cloquallum Creek. The causes of floodplain impacts, such as channel incision or loss of side-channel habitat, are poorly documented, but likely causes include bank hardening, filling and draining of wetlands, increased sediment transport (leading to channel incision), and the loss of large wood.

The stretch of river from the mouth of the Satsop to Montesano is of particular interest because the low gradient of the river here suggests a previously active floodplain connection (**Figure 22**); the area may also be inundated by SLR (with the potential to become the future Surge Plain if restored) in the coming decades (see #4 and **Figure 21**). While it is likely that the Satsop naturally pushes the Chehalis against a rock outcropping on the southern side of the valley, the area downstream of the confluence appears to once resembled the Surge Plain further downstream (historical aerial photos show traces of channel braiding or sloughs). Juvenile salmon would benefit by restoration of this area via removal the dike (restoring floodplain connectivity), planting of native trees and shrubs, and through the creation of artificial sloughs in the area to increase habitat, refugia from high river flows, nutrient transport, and river sinuosity. **Figure 27** shows the remnants of the original river channel and the location of the dikes; note that upstream of Elma, the river retains a more natural sinuosity. This would be one of the largest and most beneficial restoration projects in the basin and will require the gradual acquisition of land for conservation purposes prior to active restoration projects. Planting of native trees and shrubs should be a priority to allow these to become established before the arrival of the predicted tidal surges. Land acquisition might fall under "Acres for America" program by the NFW: http://www.nfwf.org/acresforamerica/Pages/2014rfp.aspx#.U-k4r2NO1vI.

***Figure 27: Map showing the prior and current location of the lower Chehalis River channel, from historic photographs and current satellite images. Note that the earliest aerial photos date from the 1940's, after the river channel had already been significantly altered by diking.***



**Johns River dike**

The large dike on the eastern shore of the lower Johns River partially breached in 2011; since that time the gap has widened, several other gaps have formed, and the area is reverting to a natural state (the appropriate number of tidal channels should be estimated following the technique of (Hood 2015)). WFC sampled in the newly inundated area in 2012 and found that juvenile salmon and other fish were already utilizing the habitat, which was transitional marsh at the time. An area on the western shore (south of the waterfowl hunting area) remains diked and should be considered for a restoration project. Although natural production of salmon from the Johns River is relatively low, this area contains excellent rearing habitat, high numbers of juvenile chum salmon, and could aid salmonid recovery in the basin (**Figure 28**). In addition, our fyke sampling of a slough on the Johns River estuary found usage by juvenile Chinook and coho salmon to a much greater extent than the riverine habitat.

***Figure 28: Google Earth image of the lower Johns River, showing the area of the 2011 breach and remaining dike on the western shore (inset photograph of the breach).***

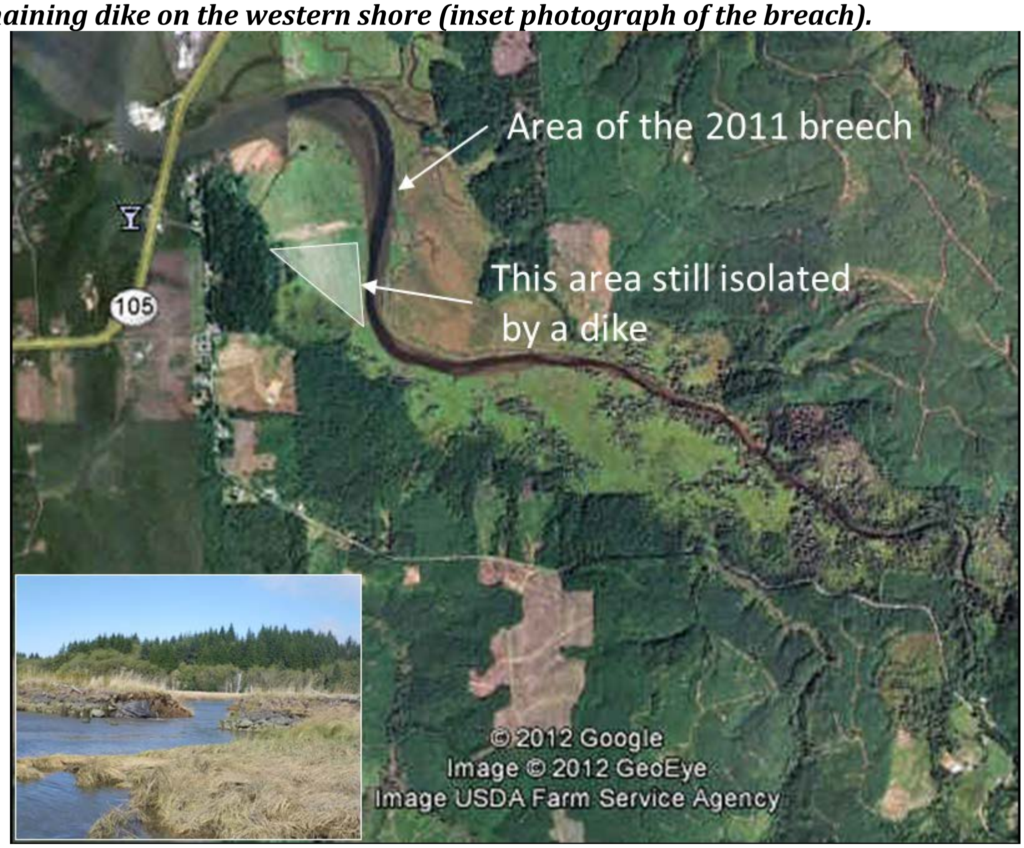
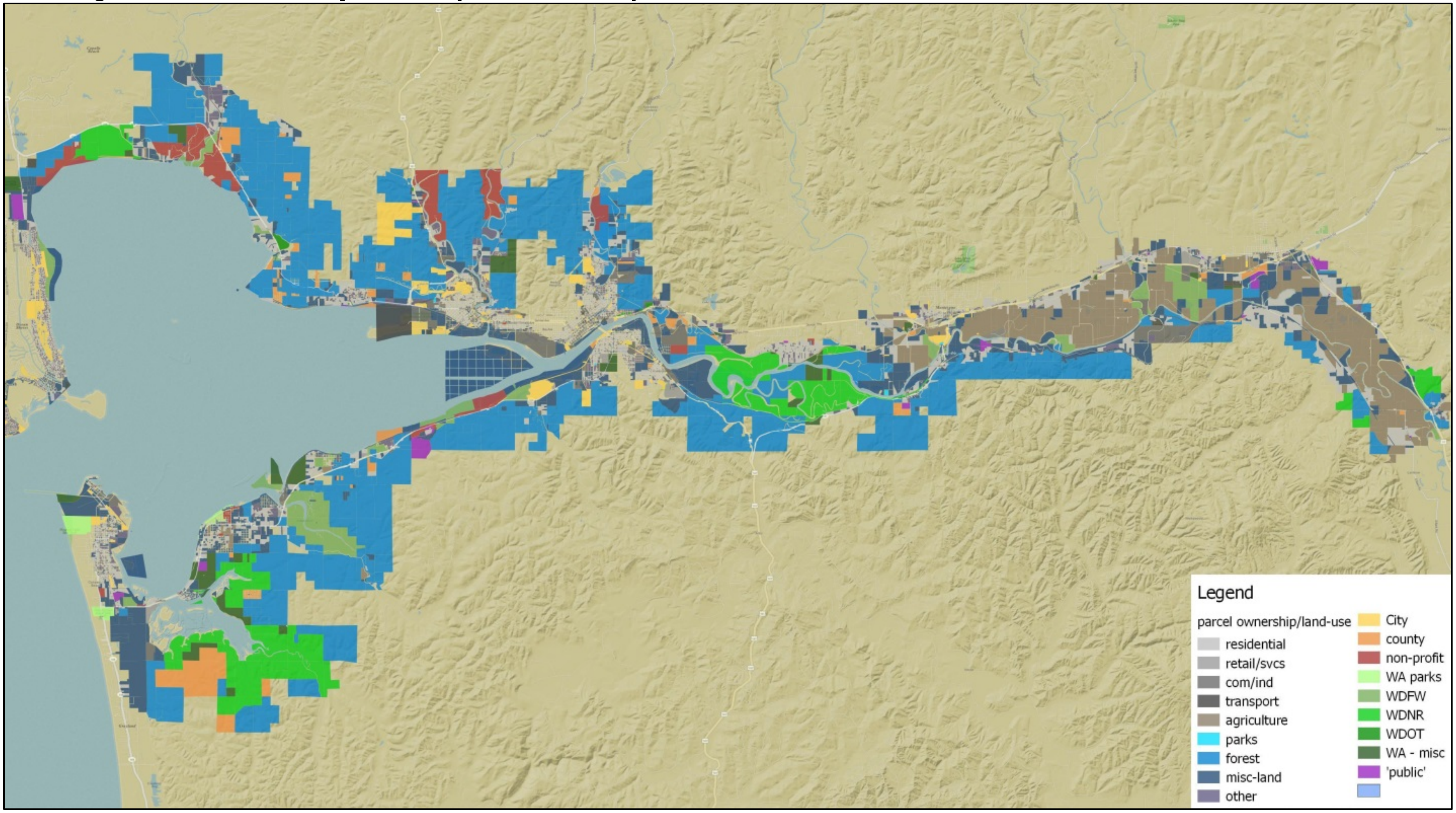


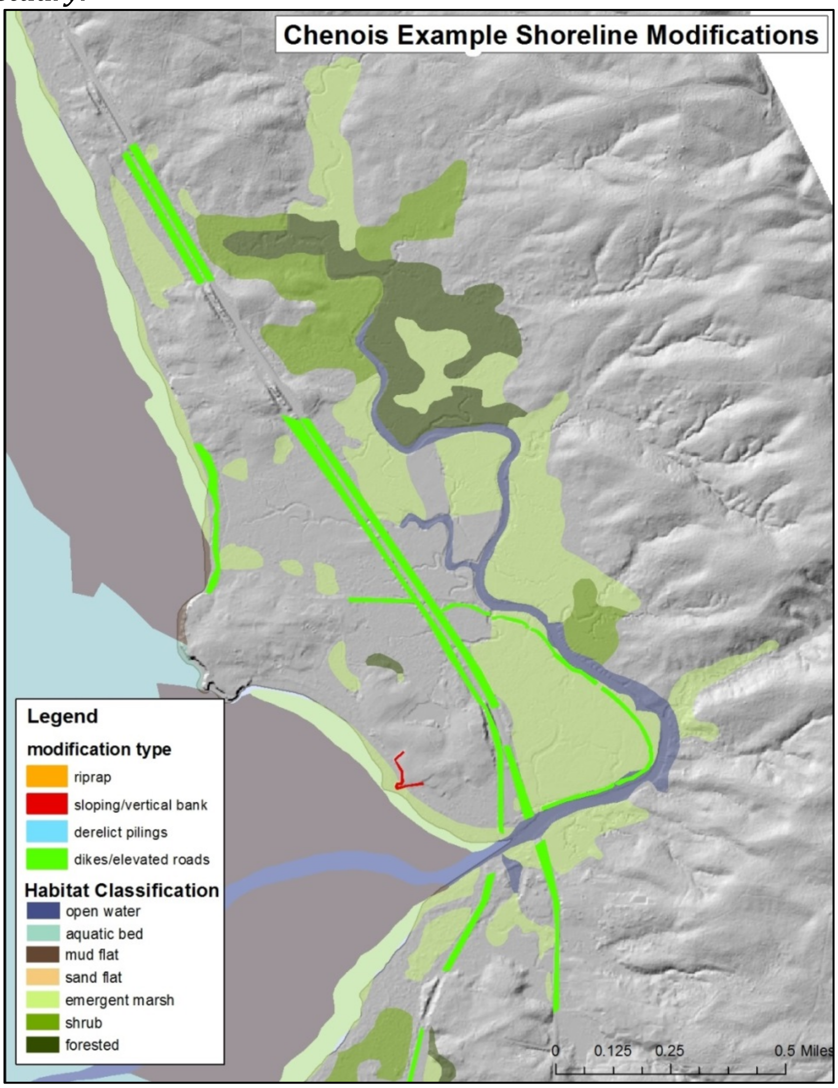
***Figure 29: Land ownership in the Grays Harbor estuary.***



**Dikes near Chenois creek**

The dikes near the mouth of the tidally influenced Chenois Creek isolate some meandering tidal channels and limit access to the wetlands East of the road. Our sampling westward of the mouth, on the tidal flats, found that both Chinook and chum salmon utilize the area, with coho salmon present but at lower abundance, suggesting that the creek may be a rearing area for these species. The Grays Harbor Audubon has expressed interest in dike removal in this area and closer to the mouth of the Humptulips River; these efforts should be encouraged.

***Figure 30: Shoreline alterations in the vicinity of Chenois Creek, northwest shore of North Bay, Grays Harbor estuary.***



### Tide gate on "Westport Slough", just West of the South Bay Bridge

The flap style tide gate in this area is under state route 105, just west of the Elk River bridge, and isolates the area highlighted in green in **Figure 31**). The tide gate excludes juvenile salmon from reaching high quality marsh fringe rearing habitat adjacent to the South Bay zone. Removal of this tide gate would result in access to an estimated 40 hectares of additional habitat for juvenile salmon. The tide gate does not prevent tidal inundation of the area because the water seeps through the gate and gravel substrate under the roadway; a culvert would be a better solution.

***Figure 31: Map of the Westport Slough, just West of the South Bay bridge (area highlighted in green).***


## Group 2

### Cosmopolis area

Under the higher SLR predictions, the area around Cosmopolis (partly isolated at present by tide gates) will also transition from dry land to transitional marsh by 2025 (all scenarios) and eventually to tidal fresh water marsh (by 2050 under the 75cm scenario and between 2025 and 2050 under the 1 meter scenario). **Figure 32** details land ownership in the area, and **Figure 33** shows the areas of interest. The shoreline areas have been isolated by industrial development and could be restored via the removal of pavement (northeast corner) or riprap (western edge; this area is the lowest priority of the three). The third area, in the southeast corner, is an inland marsh that appears to be isolated from the lower Chehalis by tide gates. Removal of the gates would allow the area to become transitional or tidal marsh as waters rise due to SLR. Of the habitat restoration projects outlined here, this is the lowest priority due to the limited amount of habitat available for recovery.

***Figure 32: Land ownership in the Cosmopolis area.***

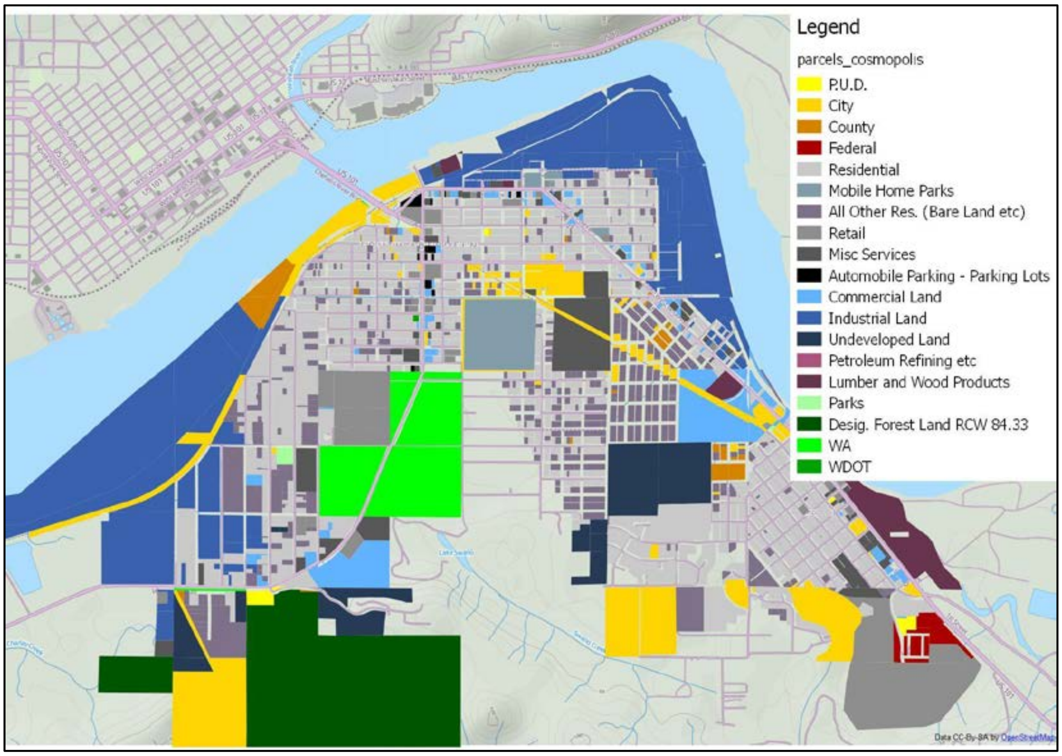
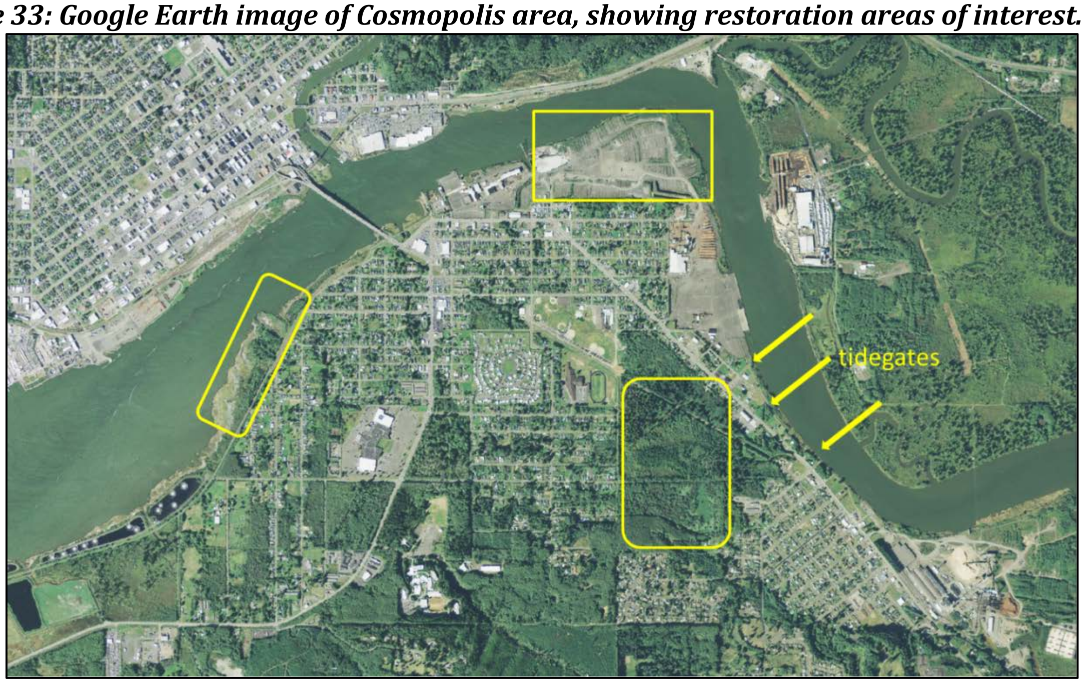



***Figure 33: Google Earth image of Cosmopolis area, showing restoration areas of interest.***



**Roads/Infrastructure**

***Tide gates in Ocosta***

Two tide gates near Ocosta (Bottle Beach state park) block salmon entry to this potentially productive marsh rearing habitat. The area that would become tidally influenced if a modern tide gate was put in place (or, preferably, if the old "flap" style gate were simply removed) is estimated at 56 hectares; the estimated area that was historically inundated prior to development is in excess of 100 hectares (**Figures 34, 35**). Currently, this area is active marsh land (and poor farmland), with three small creeks and numerous springs in the area already causing road closures due to standing water. The area is at very low elevation and will be one of the first shorelines to become inundated under all three scenarios of sea level rise, and should be one of the top priority projects in the main estuary.

While removal of the tide gates would be beneficial, a wider angle on the area shows that the most economically and environmentally rational solution is to move the location of state route 105. A natural bluff (where most of the homes are located) is set back from the marsh, providing an area of high ground for SR 105 to run behind the existing neighborhood. Most of this land is timber/forest land or is owned by the Washington Department of Natural Resources (**Figure 29**). **Figure 35** shows the proposed new route (straight yellow line), as well as the perpendicular side roads (running towards the estuary) that would provide access for homeowners near the shore (the dashed red line shows an alternative route if the Johns River bridge needs to be replaced at some point in the future; the blue arrows indicated the movement of estuarine water). If SR 105 is left in its current location, it will necessitate continual investment of public funds to raise the dike that SR 105 runs along and to maintain the tide gates as sea levels rise, while preventing fish access to the marsh habitat. The movement of SR 105 would be a one-time investment that solves both problems.

***Figure 34. Map of parcels in the Ocosta area, South shore or the grays Harbor estuary. The green line is state route 105; red shaded polygons are spring fed creeks, green shaded areas are wetlands  of interest.***

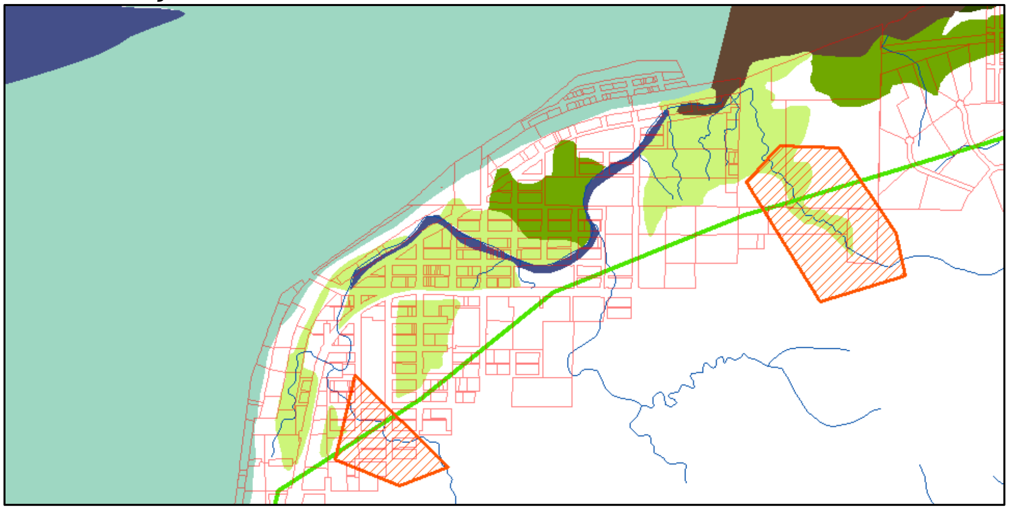
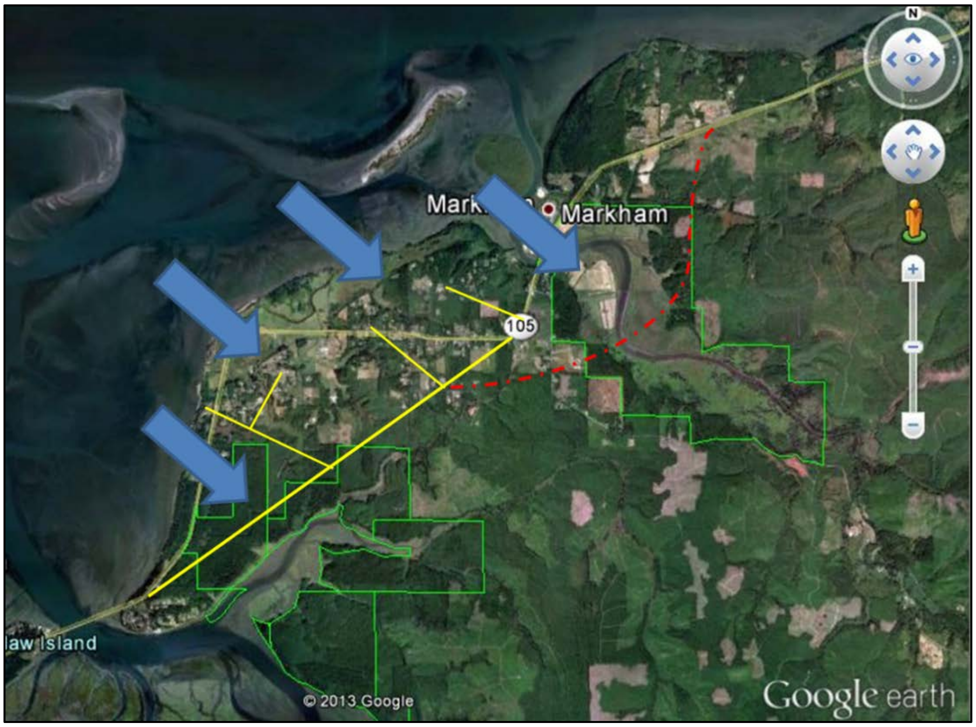


***Figure 35. Google Earth images of the South shore, showing current location of state route 105 (top) and proposed new route (bottom, straight yellow line) to alleviate the need for continued dike maintenance and improve fish habitat accessibility in the area.***



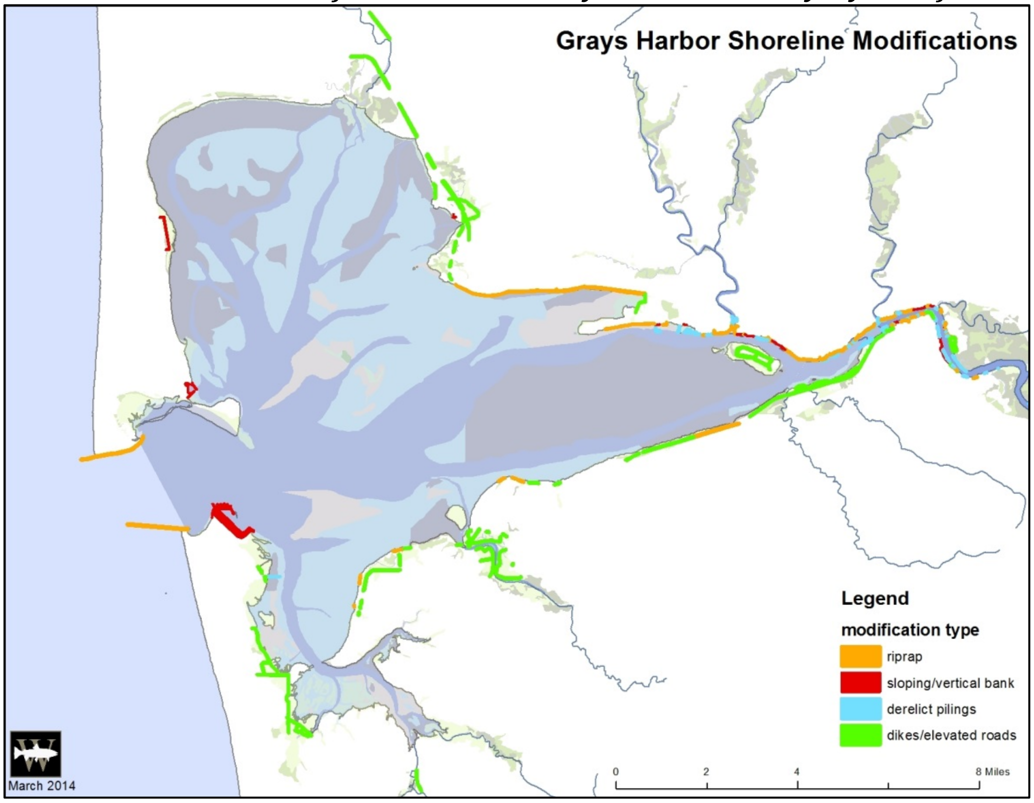

Other infrastructure concerns include:

- Auto wrecking yards near Charley Creek and along the south shore: these should be moved to higher ground to prevent inundation and limit the risk of spilled chemicals seeping into the creeks and South channel of the estuary
- The holding ponds on Rennie Island (Rayonnier) will need to be shored up to protect against SLR. This is predicted to be an issue by 2050 depending on which scenario of inundation we encounter.

### Habitat modifications

The map below shows shoreline modifications for the entire estuary (**Figure 36**), the majority of which are riprap (shoreline armoring) and dikes. The derelict pilings common in the lower river and Surge Plain are mostly cedar logs and do not pose a threat to wildlife. These plots highlight other areas in the estuary where restoration projects may be targeted.

***Figure 36. Shoreline habitat modifications in the Grays Harbor estuary, by modification type.***




## GUIDING PRINCIPLES FOR RESTORATION AND CONSERVATION

a) Mitigate increases in water temperature to help preserve summer run salmon and steelhead populations in the basin and to provide more time for these species to adapt to changing conditions. Water temperature should be monitored in freshwater portions of the estuary (tidally influenced portions of the tributaries) and in headwater streams that will serve as thermal refugia for salmonids. In addition, tributaries should be investigated (ideally using Forward-Looking Infrared cameras (FLIR) or Infrared Themrography (IRT) overflights to map the tributaries in the basin) for areas with springs or groundwater seeps that will provide cool water in an increasingly warm climate; these areas should be prioritized for protection with riparian buffers, land acquisition, etc. Where possible, riparian harvest buffers should be expanded and deforested reaches should be replanted along the lower Chehalis River and the major tributaries to increase shading and moderate water temperature increases.

b) Preserve life history/genetic diversity. Forecast reductions in summer water flow and increased water temperatures will adversely impact summer run fish the most; genetic diversity will help all species adapt and increase resiliency. Hatchery stocking practices and harvest need to be re-examined in light of recent scientific advances to limit the loss of genetic diversity among salmonids in the basin.

c) Plan ahead for the effects of Sea Level Rise (SLR) on salmon and steelhead by increasing fish access to headwaters via the removal of migration barriers, and resist the urge to "fight" SLR by diking, which will ultimately reduce habitat availability and diversity for all estuarine species (including migratory birds, shellfish, etc.).

d) Help mitigate for potential loss or reduction of the existing Surge Plain (a unique tidal surge marsh on the lower Chehalis River) and other tidal sloughs due to sea level rise; these areas are heavily utilized by juvenile salmonids. Our modeling efforts show that the current surge plain may move upstream as sea levels increase; under the scenario of 1 meter (~3 feet) of sea level rise by 2100, the head of tidal influence (upriver end of the surge plain) will occur in the region below the confluence with the Satsop River.

e) Restore flood plain connectivity in the lower mainstem Chehalis River (especially from Elma to Montesano) to increase rearing habitat for salinity averse species (coho salmon) and the varied life history stages of Chinook, coho and chum salmon and steelhead and cutthroat trout. Stretches of the river (for example, the 3.8 km (2.6 miles) below the confluence of the Satsop River) are entirely confined by diking and riprap.

f) Maintain water quality gains and track plankton blooms. Apart from harmful algal blooms (HABs), algal blooms may lead to loss of eelgrass/aquatic vegetation beds by reducing light penetration in the photic zone (the upper water column), reducing nutrient inputs into the food web and areas of predation refuge for juvenile fishes and other organisms. Changes in the frequency and duration of plankton blooms may also affect oyster and crab production in the estuary (numerous red algal blooms were observed in 2011-2013; for more information see: http://www.ecy.wa.gov/programs/eap/mar_wat/trends.html).

g) Anticipate how SLR will affect the impact of human activity in the basin. Water treatment plants, pulp mill holding ponds (e.g. Rennie Island), roads and other development may need to be moved or altered so that higher water levels, and an increase in flooding frequency and height due to climate change, do not adversely affect the availability of habitat and water quality in the basin. Culvert, bridge and tide gate replacements should incorporate predicted SLR changes through 2050 if not 2100, and acknowledge the uncertainty in these projections (i.e. the rate of change may exceed current predictions).

h) Continue to support periodic monitoring of salmonid usage of the estuary and tributaries. With the present study, Grays Harbor has one of the longest monitoring histories on the West coast (Simenstad and Eggers 1981; Schroder and Fresh 1992);

these efforts should be continued to provide information on shifting life histories, stock status, the effects of climate change, and the results of restoration actions.

i) Invasive species, though outside the scope of this report, need to monitored and addressed. While we noted the presence of some invasive species during sampling (smallmouth bass, yellow perch, sunfish/bluegill, shad; high densities of knotweed along the lower Chehalis and Wynoochee Rivers), there is limited information available on invasive plants. Efforts to monitor the spread of *Spartina* and Japanese eelgrass in the estuary should be continued.

j) Our study would benefit by a comparative study in Willapa Bay, a largely undisturbed estuary with the same climate and a similar history of resource extraction (mainly logging), but without a legacy of industrial pollution. Willapa Bay could serve as a "control" estuary for studies in Grays Harbor and the Columbia River estuary (Gleason et al. 2011).

**In the interest of furthering informed planning and decision making in the Grays Harbor estuary, WFC is committed to sharing all of the data generated in this study with the public in the fall of 2015; for access, visit the WFC website and select the "Project Data Portal" tab (www.wildfishconservancy.org).**

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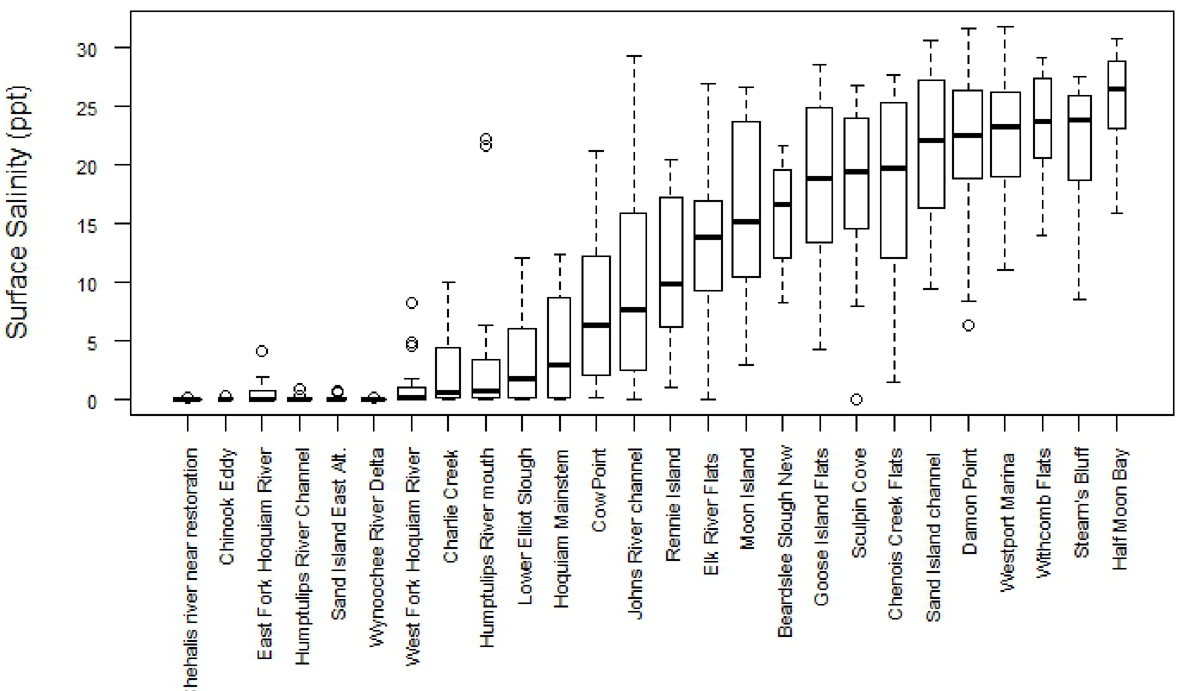
# APPENDICES

1. *Comparison of habitat area (in hectares) in the Grays Harbor estuary under varying model predictions of sea level rise (SLR). The A1B model (~59cm SLR max) is the moderate climate change scenario from the 2007 IPCC report; also shown are changes if sea level rises 75cm and 100cm by 2100 in comparison to the 1981 data.*

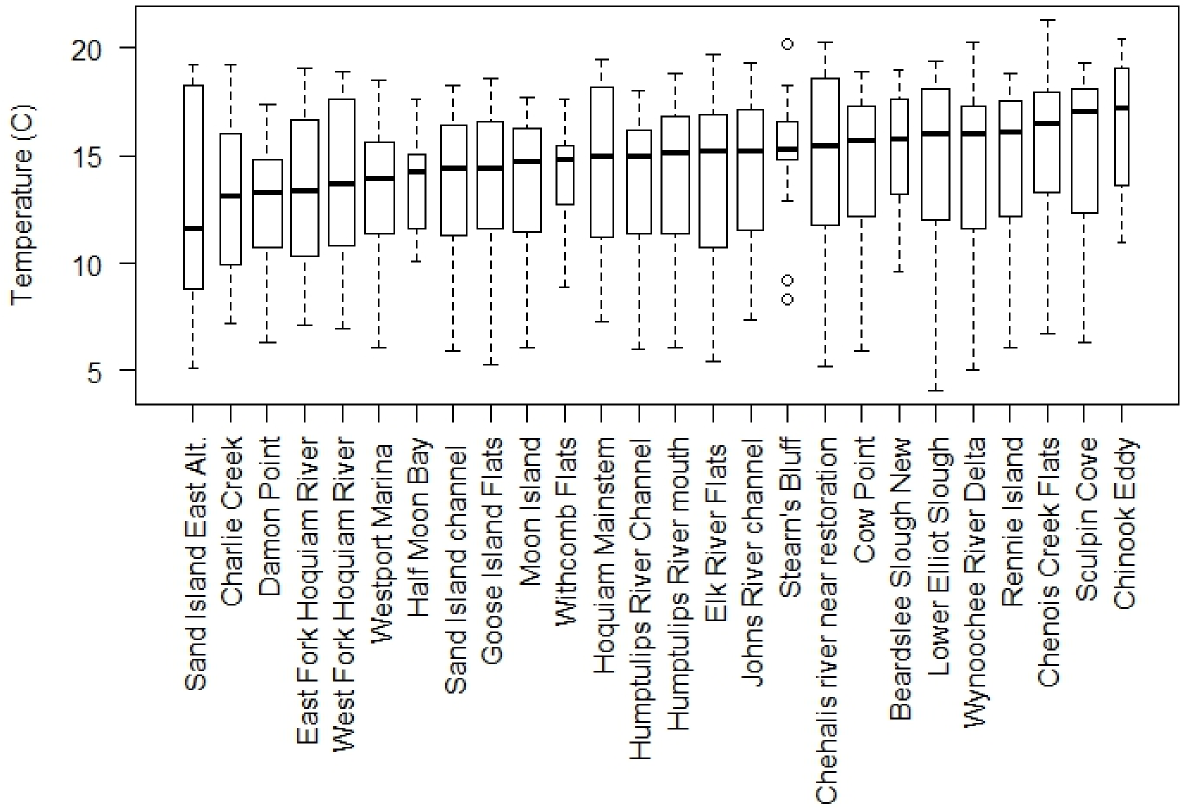
| **Area in Hectares (Ha)** | **Sea Level Rise** | | | | | | |
|---|---|---|---|---|---|---|---|
| NWI habitat categories | 1981 (Ha) | A1B (Ha) | % of 1981 | 75cm (Ha) | % of 1981 | 1 m (Ha) | % of 1981 |
| Dry Land | 32,788.9 | 28,802.9 | **88** | 28,665.2 | **87** | 28,101.0 | **86** |
| Nontidal Swamp | 1,544.0 | 660.3 | **43** | 635.7 | **41** | 529.2 | **34** |
| Inland Fresh Marsh | 788.3 | 355.6 | **45** | 346.3 | **44** | 306.1 | **39** |
| Tidal Fresh Marsh | 327.3 | 36.2 | **11** | 31.6 | **10** | 18.3 | **6** |
| Transitional Marsh / Scrub Shrub | 13.9 | 3,692.6 | **26532** | 3,671.4 | **26380** | 2,773.4 | **19928** |
| Regularly Flooded Marsh (Saltmarsh) | 1,109.5 | 2,674.1 | **241** | 2,873.3 | **259** | 4,523.6 | **408** |
| Estuarine Beach | 265.3 | 179.6 | **68** | 176.9 | **67** | 131.4 | **50** |
| Tidal Flat | 14,926.6 | 2,481.3 | **17** | 2,489.4 | **17** | 2,554.7 | **17** |
| Inland Open Water | 106.3 | 56.4 | **53** | 55.2 | **52** | 51.7 | **49** |
| Riverine Tidal Open Water | 656.5 | 49.3 | **8** | 48.8 | **7** | 45.9 | **7** |
| Estuarine Open Water | 8,664.5 | 22,260.0 | **257** | 22,274.4 | **257** | 22,392.1 | **258** |
| Irregularly Flooded Marsh | 408.7 | 2,497.6 | **611** | 2,487.8 | **609** | 2,361.5 | **578** |
| Inland Shore | 67.6 | 61.6 | **91** | 61.1 | **90** | 52.5 | **78** |
| Tidal Swamp | 2,209.3 | 69.2 | **3** | 59.7 | **3** | 35.2 | **2** |

2. *Map of known tide gates in the Grays Harbor Estuary.*

3. *Box plots of salinities encountered during sampling in 2013.*



4. *Box plots of water temperatures encountered during sampling in 2013.*



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