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Estuary Habitat Restoration on Union River: A Short-Term Quantitative Analysis

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Abstract. Chum salmon (Oncorhynchus keta) is a species of salmon native to the Pacific Northwest region. In estuary habitats, this salmon spends a significant part of its juvenile life. And in our study, we focus on investigating how the restoration of Union River estuary habitat impacted the presence of native salt-tolerant vegetation species, which indicates the health of potential Chum salmon habitat. To do this, we reviewed vegetation data in Hood Canal restoration and reference estuaries from 2014 to 2018 along six 200-meter transects. Percent growth rate was calculated using arcsine transformed percent cover data and it was determined that the transformed mean percent growth rate of salt-tolerant species was not greater in the restored stand than that in the reference stand using a Welch two sample *t*-test. Overall species composition was produced with the use of a Bray-Curtis dissimilarity matrix and through Analyses of Similarity (ANOSIM) which determined that no significant difference in species composition existed within or between test groups. Similarity Percentages Breakdown (SIMPER) analyses found various native species could recolonize the restored stand along similar distributions in that of the reference stand across all years monitored, such as: baltic rush, pickleweed, eelgrass, brass buttons, sandspurry, and mixed grasses. Additionally, the presence of eelgrass was found to maintain similar distributions within and between the restored and reference estuaries. We have included in our analysis two GIS maps showing the spatial distribution of our restored stand compared to our reference stand and elevation data to show the differences in the tidal channels between our restored and reference stands. Our findings could be used to better assess the usefulness and implementation of estuary restoration in improving habitat that is used by chum salmon.

Keywords. Estuary, salmon, vegetation, habitat, restoration

1. Introduction

The Estuarine System includes waters that are semi-enclosed by land but are partially connected to the ocean [1]. These systems play an important role in chum salmon (Oncorhynchus keta) habitat by providing forage and protection from predators or adverse environmental conditions, making them key sites in chum salmon life history [2]. Chum salmon migrate to the ocean soon after leaving the freshwater gravel banks where they hatch. With little time spent in freshwater streams, Chum salmon need to stay in estuaries for 2 months in early spring [2]. So, estuary habitat is especially important for providing food and protection for these young salmonids.

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It is important to understand what element is attributed to the health of the estuary. Key environmental factors that can affect their survival include water quality, habitat structure, and food presence [3]. Estuary health, including the presence of healthy riparian vegetation, has a large impact on the outcomes of each of these factors by beneficially affecting stream temperatures, O2 concentrations, stream flow, sediment runoff, turbidity, protection, and food sources [3]. The abundance of chum salmon in an area increased significantly when eelgrass was present [4]. Additionally, the presence of eelgrass beds is significant for juvenile sockeye and Chinook salmon [5].

This paper focus on investigation of the terrestrial vegetation effects on estuary health. Terrestrial vegetation should be limited to native species, especially "western crabapple, Hooker's willow, Sitka willow, red Osier dogwood, Pacific ninebark, red alder, western redcedar, Sitka spruce…pickleweed, salt grass, seaside arrowgrass, Jaumea, salt-marsh sandspurry, Olney's Three Square, Lyngby's sedge, redtop, hardstem bulrush, and cattail" [6]. The reason is the exotic species are not part of the salmon's habitat. It should also be noted that salmonid habitat quality increases with the presence of large woody debris, such as fallen trees, because of their ability to create pools and protection within stream systems [7]. The loss of estuarine habitat results in lower survival of chinook salmon [8]. Therefore, we compared estuary habitat health at sites on Union River in Belfair, Washington using data collected along transect lines over 5 years to test the effects of restoration on the native plant species.

Long-term investments in restoring aquatic ecosystems have proven difficult to adequately synthesize and evaluate program outcomes [9], especially to quantify the health of the estuary. Therefore, we compared estuary habitat health at sites on Union River in Belfair, Washington using data collected along transect lines over 5 years to test the effects of restoration on the native plant species. This study uses percent growth rate to calculate the estuary vegetation data, and cross comparing the growth rate between the restored and reference sites. This study can test the estuary health improvement associate with the restoration management, which also provides additional information for salmon conservation that may be used to create conservation plans for each estuary.

2. Methods

2.1. Field Data Collection

The Union River estuary underwent a partial restoration that was completed during the fall of 2013. From 2014 and on, line-transect data was collected within the restored and reference sections of the estuary. Three 200 meter transects were located within each of the reference and restored areas. In total, six 200 meter transects were utilized to gather vegetation data to compare the vegetative compositions of the restored and reference regions.

2.2. Sample Collection

The following parameters were collected within the 200 meter transects: Species, Percent Cover, Stem Count, Canopy Height, and Condition. Transect data collection occurred two times per transect in the summer months. Months in which data were collected were not always congruent across each transect. Some transects were measured in June and

July, while others were measured in July and August. Overall, vegetation data collection occurred in the three summer months of June, July, and August.

2.3. Data Cleaning & Consolidation

We observed that the common names of species varied among sampling instances, and thus we chose a singular common name for each species to identify with. Species that were partially identified and not ecologically significant for salmon habitat were consolidated into more general categories. Sedge, salt sedge, tiny grass, fuzzy grass, gold grass, tan grass, triangle grass, grass ssp. and wispy grass are consolidated under "Mixed Grasses". Items that were not identified or were identified too generally to be categorized, such as anything classified as a "weed", was removed from the dataset.

3. Analyses

Our methods include a t-test, an Analysis of Similarities (ANOSIM) test, and a Similarity Percentages Breakdown (SIMPER) test that we used to analyze the vegetation data. We used R version 4.1.2 [10] for statistical analyses. We grouped species based on their ability to tolerate high levels of salinity with the use of an appendix comparing Pacific Northwest coastal marshlands and the surrounding uplands because salt tolerance is a significant metric to understanding the transformation from agricultural land to natural estuarine habitat [11]. Salt tolerance was consolidated into two groups: salt-tolerant and not salt-tolerant. All tolerant species were considered salt-tolerant and all sensitive species were considered to be not salt-tolerant. We ran a one-tailed Welch two sample *t*-test [10] to determine the difference of the mean percent growth rate of salt-tolerant vegetation species between the restored and reference stands. We transformed the percent cover data with an arcsine square root transformation and calculated growth rate based on the change in the transformed percent cover for each plot across each year sampled. We then produced bar charts in Google Sheets to represent the change in the transformed mean percent growth rate of salt-tolerant species between the restored and reference stands over the five years sampled.

Welch Two-Sample *t*-test Equation is as follows

$$t = \frac{\overline{x_1} - \overline{x_2}}{\sqrt{\left(s^2\left(\frac{1}{n_1} + \frac{1}{n_2}\right)\right)}} \tag{1}$$

where t is the test statistic as Table 1 shows, and x_2 are the means of each group being compared, s^2 is the pooled standard error, and $n_1$and n_2 are the number of observations present within each group.

Table 1. *t*-test hypotheses.

$\boldsymbol{H_\theta}$	Transformed mean percent growth gate of salt-tolerant species is equal in both restored and reference patches.
$\boldsymbol{H_A}$	Transformed mean percent growth rate of salt-tolerant species is greater in the restored patch than the reference patch.

To compare the species composition between sites, we isolated data to only observations made in the month of August, as this month was the most consistent for monitoring between our two stands. With the August percent cover observations, we produced a Bray-Curtis dissimilarity matrix grouped by Treatment, Year, Plot, and Transect to determine the beta diversity between groupings [12]. The dissimilarity matrix was calculated as follows:

Bray-Curtis Equation

$$BC_{jk} = \frac{\sum \left| x_{ij} - x_{ik} \right|}{\sum \left(x_{ij} + x_{ik} \right)} \tag{2}$$

where BC_{jk} is the Bray-Curtis dissimilarity between j and k test groups, x_{ij} is the abundance of species i in community j, and x_{ik} is the abundance of species i in community k.

We utilized the vegan package to produce an Analyses of Similarity with the anosim function to compare the mean of ranked dissimilarity between groups to the mean of ranked dissimilarities within groups [12]. This allowed us to determine statistical dissimilarity within the species composition of the restored and reference stands. The equation for this test is as follows:

ANOSIM Equation

$$R = \frac{r_b - r_w}{M / 2} \tag{3}$$

where r_b is the ranked similarity between test groupings, r_w is the ranked similarity within test groupings, M is $\frac{n(n-1)}{2}$ with n being the number of samples, and R is our test statistic.

We utilized the SIMPER function from the vegan package to produce Similarity Percentages Breakdowns to determine which plant species contribute to at least 70% of the difference in species composition between groups [12]. This allowed us to analyze which species contributed to the most difference between the two sites that were analyzed. The equation for this test is as follows:

SIMPER Equation

$$BC_{ijk} = \frac{\left| x_{ij} - x_{ik} \right|}{\sum \left(x_{ij} + x_{ik} \right)} \tag{4}$$

where BC_{ijk} is the Bray-Curtis dissimilarity between j and k test groups, x_{ij} is the abundance of species i in community j, and x_{ik} is the abundance of species i in community k.

We then produced several GIS maps in ArcGIS Pro Version 2.8.3 [13] to interpret the spatial relationship between our transects in each of our treatment regions. The satellite imagery we used was the base map for ArcGIS Pro, which is updated every 3 years [14] and provided by the United States Geological Survey and MAXAR [15]. This was important to see the transects relative to the Union River, as well as easily see the vegetation surrounding them. The lidar data in the elevation map used was provided by the Washington State Department of Natural Resources Division of Geology and Earth Resources [16]. The digital surface model data used is attached and can be downloaded as a DSM file by clicking the link. We utilized the lidar image to visualize the difference in tidal channels between our restored and reference stands. The transect map is shown in Figure 1, the lidar map is shown in Figure 2. ArcGIS is the intellectual property of ESRI and used within this product under license.

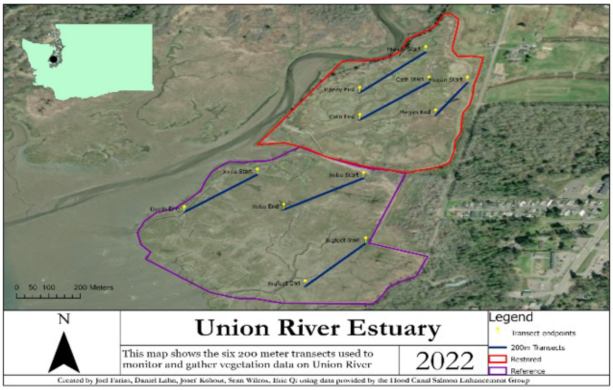

Figure 1. Transect map of Union River Estuary.

Figure 2. Elevation map of Union River Estuary.

4. Results

4.1. T-test

After running the Welch two sample t-test comparing the arcsine transformed mean percent growth rate of salt-tolerant between each treatment, we determined that there was not a greater transformed mean percent growth rate of salt-tolerant species in our restored stand than in our reference stand over the five-year period, $t(7.186) = 1.7083$, $P(1tailed) = 0.065$ as shown in Table 2. The outputs can be found in Figure 3. Some assumptions made by the Welch test are that population variances are unequal, yet the data remains distributed normally because we utilized an arcsine square root transformation to bring the data closer to normality.

Table 2. Welch two sample *t*-test of alternative hypothesis: True difference in means is greater than 0.

Data	*t*	*p*-value	df	95% interval	Sample estimates
ST_rest$mPGR and ST_ref$mPGR	1.7083	0.06511	7.186	-1.150081 Inf	mean of x, mean of y

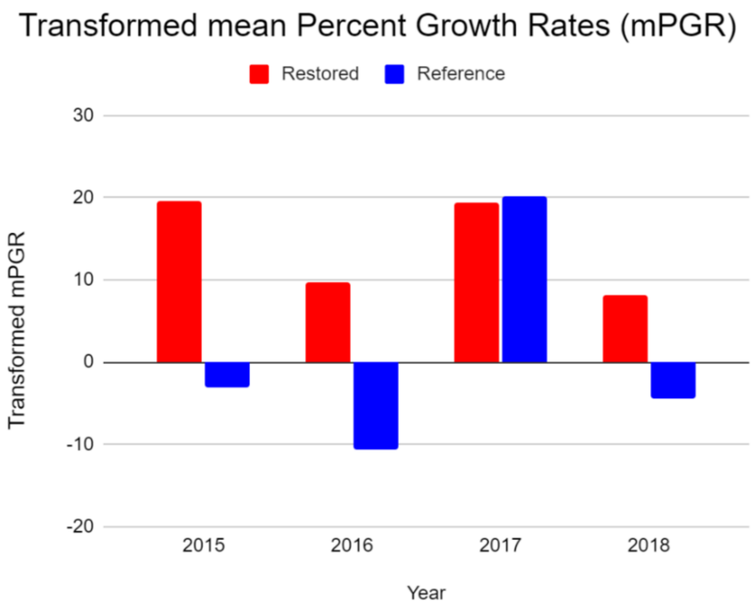

Figure 3. Transformed mean percentage growth rates (mPGR).

4.2. Analysis of Similarities (ANOSIM)

We produced four ANOSIM analyses along four different groupings: Treatment, Transect, Year, and Plot. All four of the analyses produced an ANOSIM R statistic which was less than 0.05 (Treatment: 0.03553, Transect: 0.04249, Year: 0.01852, and Plot: 0.02023). Each test maintained the same significance of 0.01. With an R value which is very close to zero and a significance of less than 0.05, these outputs determine that there is no significant differentiation of the high and low species composition values within and among our four test groups. The output for this test is shown in Table 3. The key assumption of this test is that the ranges of dissimilarity are equal between groups.

Table 3. ANOSIM analyses of treatment, year, plot, and transect.

	Grouping: treatment	**Grouping: year**	**Grouping: plot**	**Grouping: transect**
ANOSIM statistic R	0.03553	0.01852	0.02023	0.04249
Significance	0.001	0.001	0.001	0.001
Permutation	free	free	free	free
Number of permutations	999	999	999	999
90% quantiles of permutations	0.000449	0.000695	0.00203	0.000576
95% quantiles of permutations	0.000615	0.000912	0.00266	0.000765
97.5% quantiles of permutations	0.000760	0.001059	0.00324	0.000923
99% quantiles of permutations	0.000979	0.001280	0.00366	0.001231

4.3. Similarities Percentage Breakdown (SIMPER)

We produced a SIMPER analysis grouped by our two treatments, restored and reference, in order to determine which species were responsible for at least 70% of the differences in species composition between the two sites. Our first test grouping compared the restored and reference stands across all years sampled. We analyzed the species responsible for 90% of the sites' compositions. Baltic rush, pickleweed, eelgrass, brass buttons, sandspurry, mixed grasses, and mud were all found to have similar compositions between each site. Cordgrass, saltmarsh rush, seashore saltgrass, triangle orache, seaside arrowgrass, fleshy jaumea, and sea milkwort were all found to contribute to at least 70% of the dissimilarity between the two sites. The output is shown in Table 4.

We analyzed the species responsible for 90% of the species composition within the year grouping of 2017 and 2018, this compared which species are responsible for 70% of the overall dissimilarity during the most recent monitoring sessions. Cordgrass, Baltic rush, mud, pickleweed, mixed grasses, saltmarsh rush, brass buttons, seashore saltgrass, triangle orache, seaside arrowgrass, fleshy jaumea, eelgrass, and sea milkwort were the species which made up 90% of the species composition of both sites between 2017 and 2018. The species composition within and between groups that were found to contribute to 70% of the dissimilarity were cordgrass, Baltic rush, pickleweed, and brass buttons. Those species which contributed to 90% of the overall composition but were not responsible for 70% of the overall dissimilarity were mud, mixed grasses, saltmarsh rush, seashore saltgrass, triangle orache, seaside arrowgrass, fleshy jaumea, eelgrass, and sea milkwort.

Since the presence of eelgrass has been found to be a significant indicator of chum salmon abundance, we analyzed the contribution of eelgrass to the overall dissimilarity of species between various years [4]. The first grouping we analyzed was 2014 and 2015. Between these two years, eelgrass was found to contribute to at least 70% of the dissimilarity within and between this grouping. In the subsequent grouping of 2015 and

2016, eelgrass was not found to contribute to at least 70% of the dissimilarity within and between groups. With the final two groupings of 2016 & 2017 and 2017 & 2018, eelgrass was not found to contribute to at least 70% of the dissimilarity within and between groups.

Table 4. SIMPER analysis of restored and reference.

	Average	sd	Ratio	ava	avb	Cum sum	*p*
Mud	0.13059	0.296398	0.44059	1.39E-02	9.63E-02	0.134	1
Cordgrass	0.123078	0.282442	0.43576	6.30E-02	1.01E-02	0.2603	0.001
Saltmarsh rush	0.102079	0.265831	0.384	6.81E-02	1.39E-03	0.365	0.001
Mixed grasses	0.083604	0.232369	0.35979	1.36E-02	3.32E-02	0.4508	1
Baltic rush	0.083444	0.233139	0.35791	2.21E-02	2.81E-02	0.5365	0.981
Pickleweed	0.079867	0.211268	0.37804	5.71E-03	2.33E-02	0.6184	0.999
Seashore saltgrass	0.059775	0.201848	0.29614	2.57E-02	8.14E-03	0.6798	0.003
Triangle orache	0.056978	0.161271	0.35331	6.10E-03	6.54E-03	0.7382	0.001
Seaside arrowgrass	0.036938	0.138707	0.2663	6.41E-03	7.40E-04	0.7761	0.001
Fleshy jaumea	0.0332894	0.136646	0.24362	7.12E-03	1.36E-03	0.8103	0.001
Eelgrass	0.029135	0.114329	0.25483	1.13E-03	3.98E-03	0.8402	1
Brass buttons	0.027532	0.119902	0.22962	0.00E+00	6.63E-03	0.8684	1
Sea milkwort	0.02746	0.121229	0.22651	5.22E-03	2.99E-04	0.8966	0.001
Sandspurrey	0.02209	0.101861	0.21687	5.71E-05	3.49E-03	0.9193	1
Saltmarsh plantain	0.010539	0.074569	0.14133	1.81E-03	2.00E-04	0.9301	0.001
Hardstem bulrush	0.010051	0.080991	0.1241	0.00E+00	4.60E-03	0.9404	1
Lyngby's sedge	0.008803	0.077344	0.11381	1.79E-03	1.89E-03	0.9494	0.948
Bare ground	0.0076336	0.071454	0.10683	1.29E-03	1.59E-03	0.9573	0.264
Silverweed	0.00729	0.063328	0.11512	3.71E-04	1.33E-03	0.9648	0.977
Oregon gumweed	0.005928	0.050352	0.11774	5.33E-04	1.50E-04	0.9708	0.002
Common rush	0.0057568	0.06467	0.08902	0.00E+00	3.29E-03	0.9767	1
Curly dock	0.003038	0.035205	0.08629	0.00E+00	3.49E-04	0.9799	1
Saltmarsh bulrush	0.002164	0.038294	0.05651	0.00E+00	7.07E-04	0.9821	0.999
Toad rush	0.002062	0.037697	0.05469	0.00E+00	1.12E-03	0.9842	1
Broadleaf plantain	0.002009	0.030764	0.06529	0.00E+00	2.83E-04	0.9863	1
English plantain	0.001795	0.031718	0.05659	0.00E+00	4.82E-04	0.9881	0.999
Douglas aster	0.001759	0.035142	0.05005	0.00E+00	8.48E-04	0.9899	1
Creeping thistle	0.001736	0.026655	0.06513	0.00E+00	2.00E-04	0.9917	1
Meadow barley	0.001229	0.02447	0.05023	1.62E-04	0.00E+00	0.993	0.001
Pacific silverweed	0.001229	0.02447	0.05023	1.62E-04	0.00E+00	0.9942	0.001
Reed canary grass	0.001212	0.025754	0.04705	0.00E+00	2.25E-04	0.9955	0.999
Seaside buttercup	0.001085	0.021089	0.05145	0.00E+00	1.25E-04	0.9966	1
Lwd	0.001074	0.02843	0.03779	0.00E+00	5.49E-04	0.9977	0.993
Dandelion	0.000868	0.018868	0.046	0.00E+00	9.98E-05	0.9986	1
Chickweed	0.000534	0.015046	0.03551	5.71E-05	0.00E+00	0.9991	0.001
Needle spikerush	0.000434	0.013348	0.03251	0.00E+00	4.99E-05	0.9996	1
Hairy cat's ear	0.000217	0.009441	0.02298	0.00E+00	2.50E-05	0.9998	1
Red clover	0.000217	0.009441	0.02298	0.00E+00	2.50E-05	1	1

We analyzed the eelgrass within our Treatment grouping, which includes our reference stand and restored stand, and eelgrass was not found to account for at least 70% of the dissimilarity within and between the two groups across all years sampled. This indicates that between the two treatments, the proportion of eelgrass to the overall species composition is similar. This shows that eelgrass has begun to recolonize the restored stand as expected.

5. Discussion

Our results indicate that restoration efforts positively benefit the growth of native salt-tolerant species in estuary habitat. Alternative publications have found tidal wetland restorations to have significant benefit to juvenile salmonids in the Columbia River estuary system [9]. Although we were unable to reject the null hypothesis that the transformed mean percent growth rate was greater in the restored stand than in the reference stand, our t-test provided a *p*-value of 0.065 which very closely approached statistical significance. The average transformed mean percent growth rate for the restored stand across all year sampled was 11.34 whereas for the reference stand it was only 0.40. It would be misguided to determine that the growth rates between the two sites are equal, so therefore, we determined that the recolonization of salt-tolerant species into the restored stand led to a successful restoration.

All four of our Analyses of Similarity (ANOSIM) tests determined that there was very little to no difference in the species composition between our four test groupings (Treatment, Transect, Year, Plot). With growth of salt-tolerant plant species in the restored stand and no statistically significant differences in the vegetative species composition between the two sites, we determined that this restoration effort was successful in restoring this land to its pre-agricultural use condition. Although the results of our ANOSIM provide that there is little to no difference in the species composition between sites, our Similarities Percentage Breakdown (SIMPER) tests provided a clearer understanding about which species were most similar between groupings and which were most different. The analysis of the treatment grouping provided a comparison of the species composition within our restored and reference stands across all years sampled. The species which cumulated to 90% of the total composition between both sites across all years sampled included Baltic rush, pickleweed, eelgrass, brass buttons, sandspurry, mixed grasses, mud, cordgrass, saltmarsh rush, seashore saltgrass, triangle orache, seaside arrowgrass, fleshy jaumea, and sea milkwort. Our analysis provided insight to support the notion that this was a successful restoration effort because a large portion of these species have been documented as being important native species [6]. Of the species which contributed to 90% of the total composition for our treatment test grouping across all years sampled; cordgrass, saltmarsh rush, seashore saltgrass, triangle orache, seaside arrowgrass, fleshy jaumea, and sea milkwort were all found to contribute to at least 70% of the dissimilarity between our restored and reference stands.

We then analyzed the species composition between years. We selected the grouping which compared 2017 and 2018 to interpret the species composition between the most recent years sampled. The species which made up 90% of the species composition between this grouping were: cordgrass, Baltic rush, mud, pickleweed, mixed grasses, saltmarsh rush, brass buttons, seashore saltgrass, triangle orache, seaside arrowgrass, fleshy jaumea, eelgrass, and sea milkwort. Of these species, only cordgrass, Baltic rush, pickleweed, and brass buttons contributed to 70% or more of the dissimilarity between and within 2017 and 2018. We compared the results of our SIMPER analyses from the treatment grouping and the year grouping to conclude that the number of species contributing to the dissimilarity of the species composition reduced over the sampled time period of 2014 to 2018. One important consideration about SIMPER analyses is that they tend to confound the means within and between test groupings and skew towards highly abundant species [17].

Native eelgrass species have been found to be statistically significant to the abundance of Chum salmon [4]. For this reason, we focused on eelgrass for some of our SIMPER tests. When comparing the 2014 and 2015 groupings, eelgrass was found to be dissimilar between the years, as it was recorded significantly more in 2014. During the years of 2015 through 2018, eelgrass was observed to be statistically similar when comparing the species composition between our restored and reference stands. The disproportionate counting of eelgrass in 2014 may have been due to eelgrass breaking off at another location and pooling in the estuary. Overall, this produced supporting evidence to determine that eelgrass was capable of recolonizing our restoration area and providing necessary habitat for juvenile salmonid species. Growth of healthy riparian vegetation may positively impact habitat functions that chum salmon are more dependent on, such as food presence and stream conditions [3]. If this is the case, restoration projects such as this will likely improve the survivability of salmonid populations, especially that of juvenile Chum salmon.

Although this estuary restoration project was considered to be successful in restoring thirty acres of tidal marshland habitat for salmon populations, there are several factors that could contribute to more significant analyses for future restoration efforts. In order to better couple these types of research projects with the desired species, i.e. Chum salmon, it would be beneficial to monitor multiple estuary systems with census population surveys as well as quadrat vegetation monitoring in the Hood Canal region in order to directly compare the impacts of estuary restoration on the focal species. With another river system to compare population census surveys, determinations could be made regarding the direct effects of this estuary restoration on the summer-run Chum salmon population in the Union River. These results that were achieved could be improved through a more consistent monitoring protocol. Some recommendations we have for improving this are to decide on one acceptable common name identification for each plant species, label unidentifiable species by their genus or family, and monitor a given transect in the same month each year. Identifying all species present within a quadrat is important because it strengthens potential results and prevents inaccuracy. Consistent temporal monitoring limits the impact of confounding variables on the collected data.

6. Conclusion

This paper utilized the transect vegetation data from Union River estuary to analyze the salt tolerant plant species data. The t-test, the Analysis of Similarities (ANOSIM) test, and the Similarity Percentages Breakdown (SIMPER) test returned results that indicate that restoration efforts positively benefit the growth of native salt-tolerant species in estuary habitat. Native eelgrass species have been found to be statistically significant to the abundance of Chum salmon. Restoration projects such as this will likely improve the survivability of salmonid populations, especially that of juvenile Chum salmon populations.

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