Spring 2001

Surveying the Invasion of Smooth Cordgrass, Spartina alterniflora, in Willapa Bay, Washington

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Honors Senior Project
June 2001

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HONORS THESIS

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My introduction to *Spartina alterniflora* growth in Willapa Bay

In late July, I accompanied Keeley O'Connell on a field collection in Willapa Bay, Washington. The goal of our trip was to sample the mudflats invaded by the cordgrass *Spartina alterniflora* as well as the areas unaffected by the grass. Over the course of my senior year at Western Washington University, I have participated in the sorting of these samples and investigation of literature analyzing the effects of *S. alterniflora* in Willapa Bay. The following paper provides a description of what I have learned from the literature reviewed as well as a critique of my biology courses at Western as preparation for this Senior Honors Project.

When looking for possible topics involving science for my project, I came into contact with Keeley O'Connell, a graduate student at Western Washington University. She was just beginning work on her graduate thesis "Effects of Established Atlantic Smooth Cordgrass (*Spartina alterniflora*) and Subsequent Removal on Epifaunal Macroinvertebrates" and suggested I work with her. The agreement was mutually beneficial in that Keeley gained help collected data in the field and sorting through samples in the lab, while I was able to gain background and a topic from which to base my project upon in order to meet graduation requirements.

Initially, I did not have a clear plan regarding the content of my project, so I agreed to assist in lab and fieldwork in order to gain background that I could use later when deciding what I would be doing specifically. I began work on the project in July 2000, with four separate trips to Shannon Point Marine Center in Anacortes. On these days I went through preliminary samples Keeley had previously collected at Willapa Bay. Going through the samples with the use of a dissecting microscope prepared me for later lab work as well as what kind of taxa to expect when looking at a sample. My Biology 403 course, "Physiological Ecology of Animals" offered me the most help at this stage of the project. I was able to apply what I had learned about burrowing worms and other sediment dwellers to my sorting work.

I accompanied Keeley on the field collection in Willapa Bay on August 17, 2000 through August 20, 2000. The fieldwork involved one full day of collecting samples in the mudflat and three days of sieving samples and preparing them for transportation back to the lab at Western. Although my experience with fieldwork is quite limited, I did find the Ecology laboratory (Biology 326) to be helpful. The course familiarized me with the use of transects, PVC corers, and accurate labeling and collection precision necessary when trying to ensure data from fieldwork is applicable to the study being conducted.

The site of our collection was on the southern end of Willapa bay, just east of Porter Point. Substrate content at this end of the bay is muddy and silty in contrast to sandy conditions found in the north. We accessed the site via airboats launched from the Willapa Bay National Wildlife Refuge, which is just south of Pot Shot Slough, an area that has been under investigation in other research projects. From what I have read in the literature, the area we examined has not been the subject of any studies prior to Keeley's thesis research. Research on shorebird feeding activity is tentatively planned for the near future.

The study site was subdivided into three sites: an unvegetated mudflat, an area vegetated as a result of *S. alterniflora* invasion, and a Monsanto clone that had been subject to chemical treatment. All three sites ran perpendicular to the incoming tidal front and were at the same elevational slope and tidal height. Within the unvegetated and vegetated sites, three transects, each 200-meters in length, were set up. All of the transects were 100-meters apart from each other. The chemically treated site only had one transect spanning 100-meters.

S. alterniflora growth was dense enough to be considered a meadow at about 150-meters into the vegetated transects. Prior to this distance, the vegetated sites contained unconnected clones and seedlings. At 0-meters, the vegetated site was basically unvegetated.

In the time between establishment of the plots and collection, there was unexpected mowing of the *S. alterniflora* meadow in the third transect of the vegetated plot. This was determined to be inconsequential to the study because root mass and a large amount of above ground vegetation remained after mowing. In addition, chemical treatment was not applied after mowing as is usually the practice.

Four core samples of the mud were taken randomly every 25-meters in each transect. A PVC corer with a diameter of 7.8 cm and a depth of 5 cm was used to extract samples from the mudflat. Following sampling, the mud was placed in marked bags and then brought back to the Refuge to be sieved.

Sieving of samples was done at the study site so that we would not have to bring large quantities back to the University. The smallest sieve used was 0.5mm, so only organisms this size and larger were kept. *S. alterniflora* and eelgrass vegetation were kept in some samples and discarded in others. Even though the vegetation discarded on site was examined carefully, this difference in methods impacted numbers of organisms seen later in the laboratory. After sieving, samples were returned to plastic bags. The samples were then preserved using 10% buffered formalin. Later in the laboratory, samples were transferred from formalin to 70% isopropanol, which is a milder preservative.

I examined the samples using a dissecting microscope. Magnification of the microscope ranged from 7x to 40x. Primarily, I used the 10x to 20x magnification range when extracting invertebrates from the plant material and sediment. This process was tedious, each sample required two to three hours of microscope investigation.

Two of the four samples collected at each 50 meters in each transect were randomly chosen for sorting. Prior to this work, I hadn't done anything similar in any of my courses. Going into this stage of the project, I wasn't prepared for the amount of time required to sort through each sample under a microscope. As a result, I later discovered the expectations for my finished product would need to take into account the time needed in order to sort through one sample in order to have enough data to evaluate in the end.

Beginning Winter Quarter 2001, I went into the laboratory two days a week for three to four hours at a time. My initial goal was to sort through enough samples so that I could key out a particular taxa and subsequently run some data regarding variance of invertebrate density within a transect as a function of distance in the intertidal habitat. As mentioned before, each sample took numerous hours to sort and as the quarter came to an end I realized my expectations seemed unattainable for the amount of time I had available.

At the beginning of this quarter (Spring 2001) I counted the number of amphipods in each sample that had been sorted in the unvegetated transect (a total of 18 samples were available). I was hoping to run statistical analysis on the data thus postulating the degree of density distribution of amphipods within the unvegetated portion of the mudflat as a function of distance. After looking at the data, it became apparent that I didn't have enough samples to make any significant comparisons.

I had a total of eighteen samples, two every 25-meters of one unvegetated transect, from which I could count the number of amphipods. This sample size was too small to arrive at any meaningful conclusions for a number of reasons. There was no distinct pattern of distribution in numbers of amphipods over the range of the transect. Also, the number of amphipods seemed to increase drastically if eelgrass was present in the sample, which incorporates a variable in addition to distance. I didn't have enough other data in order to test the significance of this relationship. Finally, this data would have revealed nothing about my original hypothesis that questioned the significance of *S. alterniflora* growth on invertebrate populations. Instead I could have only addressed the native distribution of benthic invertebrates within the mudflat prior to the invasion of the grass.

The biology 340 course on Biometrics gave me some help in that I knew by looking at my options that I didn't have enough data. I feel the course would have been more helpful if we had covered more non-parametric methods for analyzing data rather than focusing on parametric models. Due to these time constraints, and misunderstanding of expectations going into the project, my final product did not turn out as I had hoped. As a result, I compiled a literature review after discussing my project situation with Dr. Anderson, Chair of the Biology Department. In the following paper I summarize the establishment of *Spartina alterniflora* in Willapa Bay, its effects on the estuary, and what efforts have been explored to eradicate the invasive cordgrass.

Establishment of Spartina alterniflora in Willapa Bay

Spartina alterniflora was first introduced to Willapa Bay, Washington unintentionally in the late 1800's. The cordgrass was used as packing material in the transport of the eastern oyster (*Crassostrea virginica*) to the area for commercial production. When the barrels were unloaded, the hardy cordgrass was discarded and subsequently introduced in the bay (Chew et al. 1998, Sayce 1998, Thom et al. 1997).

Due to its initial slow rate of growth (the grass actually follows an exponential growth pattern which I will discuss later), *S. alterniflora* went unnoticed for nearly a century (Harrington et al. 1997, Harrington and Harrington 1993). It wasn't until the late 1980's before expansion of the grass was considered a significant threat to the bay. At this point in time, *S. alterniflora* was beginning to show a steep increase in its rate of growth, characteristic of an exponential pattern. By 1992, 2,000 acres of Willapa Bay were covered with *S. alterniflora*, subsequently 1992 labeled the cordgrass labeled a class B noxious weed (Dumbauld et al.1997, Chew 1998). Within the time of just four years (by 1996), around 3,000 acres of *S. alterniflora* had established itself in meadows throughout the bay leading to a drastic change in the nature of Willapa Bay.

Because the grass traps sediment in its root systems and eventually leads to the elevation of tidal mudflats, it poses a huge risk to the commercial, ecological, and recreational aspects of the area. Elevation of tidal mudflats occurs because stout stems and dense root masses promote the accumulation of sediment. With an increase in sediment around the root system, *Spartina* is able to harvest even more nutrients from it surroundings. So, this phenomena encourages continued growth of the plant.

It has been established that the parts of the mudflat now taken over by *S. alterniflora* meadows encourage sediment accumulation at three times the rate than under normal conditions (without the grass) (The Washington State Department of Agriculture 1999). Specific amount of sediment accumulation is dependent upon shoot density and ranges between 0.5 cm/m to 2cm/m (Sayce 1988). When tidal elevation is altered in this way, benthic invertebrate distribution characteristics are altered as well because they now longer experience the same tidal exposure. The exposure to water these invertebrates need for survival becomes less frequent and lasts for a shorter period of time (Zipperer 1996).

Implications of *Spartina alterniflora* establishment

It is important to keep in mind that what may be an essential aspect of one ecosystem can completely destroy another. While *Spartina alterniflora* is key to preserving coastline and offering habitat for local fauna on the East Coast of the United States, it is destroying native flora and fauna assemblages on the West Coast (Lana and Guiss 1991). Estuaries on the East Coast are characteristically saltmarshes and West Coast estuaries are mudflats (Zipperer 1996) Also, native herbivores keep *S. alterniflora* growth in check on the East Coast, while the West Coast lacks such a predator (Chew 1998). When examining the grass invasion in Willapa Bay, it is important to keep these differences in mind. Moreover, there is a high degree of uniqueness even among estuaries on the West Coast, which further emphasizes the need to look at each ecosystem individually.

We can predict potential risks of *S. alterniflora* growth in Willapa Bay from looking at the effects the grass has had on other estuaries around the world. In San Francisco Bay for example, the grass is one of 200 nonindigenous plants, protists, invertebrate, and vertebrate animals drastically changing the estuary. Nonnative species in this area cause an estimated one billion dollars of damage to the area (Cohen 1997). *S. alterniflora* competes with the native *S. foliosa* in San Francisco Bay drastically affecting the ecosystem. This competition and eventual take-over mimics what *S. alterniflora* is doing to the native eelgrass, pickleweed, and other essential vegetation in Willapa Bay.

Spartina alterniflora is so invasive worldwide because it can adapt to and thrive in a variety of intertidal conditions. The grass is able to grow in freshwater as well as saltwater, disperses its seeds and reproduces clones at a rapid rate,and has a dense root mass enabling it to firmly take its place in the estuary (Sayce 1998, Zipperer 1996). Finally, *S. alterniflora* doesn't have many herbivores targeting the grass specifically. The insect, *Prokelisia Marginata* is the only herbivore specifically feeding on this variety of *Spartina* and does not live in many new areas the grass invades.

Growth of *S. alterniflora* within the intertidal region of Willapa bay severely changes the mudflat ecosystem, which normally consists of little vegetation besides eelgrass (Zostera) beds (The Washington State Department of Agriculture 1999, Chew 1998). These mudflats are access for feeding on by a variety of shorebirds, marine fish, juvenile salmonids, crabs, and marine mammals (The Washington State Department of

Agriculture 1999). The shorebirds are most likely eating amphipods off the surface of the mudflat as well as small bivalves. Additionally, larger polychaete worms and burrowing shrimp are a potential food source (O'Connell 2001). It is feared that *S. alterniflora*'s ability to establish itself and flourish within an area typically devoid of vegetation will severely limit the feeding activities of the mudflat predators (Thompson 1991, Zipperer 1996). "*Spartina* species are aggressive colonizers that displace native plants and animals historically associated with Willapa Bay intertidal and estuarine environment. Tidal plant species supplanted include two eelgrass species (*Zostera marina* and *Z. japonica*) and macroalgae" (The Washington State Department of Agriculture 1999). Furthermore, it should be noted that biodiversity is negatively affected along with the food chain characteristic of the area. Biodiversity within estuarine communities is a subject I explore in later sections of this paper. Additionally, Willapa Bay is a valuable commercial and recreational asset to residents and visitors.

Because the establishment of *S. alterniflora* meadows led to the overall elevation of the intertidal region, there is a potential risk of flooding in the area. Many regions of the bay, just above the saltmarsh, are occupied by homes, which would experience significant damage if there were indeed a flood. Property values in the area are expected to decrease as the potential of flooding increases.

Willapa Bay is one of the major oyster-producing places in the United States. Just this area accounts for over 50% of the total amount of oysters produced in the state of Washington (Chew 1998). The industry provides numerous jobs and brings an expected $20 million per year to the community (Chew 1998).

Local Native Americans have been dependent upon clams and salmon for centuries.(The Washington State Department of Agriculture 1999). A study by Dumbauld et al. presented at the Second International *Spartina* Conference in 1997 documented "the distribution of adult clams on several beaches where recreational clam harvest was likely to be impacted by *Spartina* encroachment" (Dumbauld et al. 1997). the group found that *S. alterniflora* significantly effects the habitat of intertidal clams in Willapa Bay. Additionally, they noted significance in the change of distribution of the intertidal clams as a result of *S. alterniflora* establishment (Dumbauld et al. 1997).

Besides recreational clamming, fishing and boating are also threatened by *S. alterniflora* in the bay. As the area becomes more terrestrial as a result of spread of the grass into dense meadows, these aquatic activities enjoyed by residents and visitors will no longer be possible. The Willapa Bay modeling study done by Harrington and Harrington clearly shows significant change in environment as a result of exponential grass growth over the next few years (Harrington and Harrington 1993). Their predictions were based upon expectations for growth in particular areas of the bay and did not give an expected acreage count for the future. Although, Kathleen Sayce expects *S. alterniflora* vertical range in Willapa Bay to reach at least 46% of tidal height at its peak point of expansion.

On a larger scale, control of *Spartina* growth is viewed as an essential component for the future of estuarine biodiversity in Willapa Bay. Andrew Cohen, from the San Francisco Estuary Institute, addressed the importance of maintaining biodiversity in estuarine habitats at the Second International *Spartina* Conference in 1997. He explained how estuaries have individual characteristics and therefore shouldn't be viewed as connected via "the world ocean". Furthermore, he noted several benefits resulting from the isolation of estuaries such as: greater number of species possible, parallel study models used by scientists when examining evolutionary implications, and distinct scenic and cultural elements from which humans benefit (Cohen 1997). The invasion of exotic organisms poses a risk on all of these large-scale aspects of an estuary.

In a study completed by Netto and Lana in Paranagua Bay located in southeastern Brazil along the Atlantic Ocean, the researchers found a significant inverse relationship between degree of plant cover by native *S. alterniflora* and densities of macrofauna. The pair note that the "tidal flat is divided into a superior and an inferior zone, characterized by similar species composition in clearly distinct faunal densities" (Netto and Lana 1997, Lana and Guiss 1991). These densities change with the presence of *Spartina*, thus disturbing the natural density distributions. Not only did Netto and Lana find a change in densities of macroinvertebrates associated with the grass cover, they found that these density differences affected the relationships between the invertebrate populations in the mudflat. *S. alterniflora* provides an increase in biomass to areas that are typically devoid of vegetation. This vegetation provides shelter for small bivalves and support for tube-building worms. Moreover, *Spartina* changes the nature of the sediment in the estuary, which will have a major impact on the benthic invertebrates living there. Netto and Lana note that sediment heterogeneity between unvegetated and vegetated areas are caused mainly by *S. alterniflora* (Netto and Lana 1997).

Paul Snelgrove and colleagues have written a number of papers describing the critical relationship between sediment, what's in the water affecting the sediment, and biodiversity. They characterize the point of exchange between sediment and water as the "marine sediment-water interface". They postulate that marine ecosystems are changing at an alarming rate due to human disturbance affecting the sediment-water interface. When there is a disturbance in either the sediment or in the water, the other is impacted as a result (Snelgrove 2000, Snelgrove et al. 1997).

In the case of *S. alterniflora* in Willapa Bay, Snelgrove's warnings suggest that the growth of the non-native species in the mudflat will alter the native components of biodiversity because particular faunas are associated with certain forms of vegetation. This observation holds true for both above and below the interface point. When a new form of vegetation is introduced to an area, there will be a change in fauna densities both in the water and in the sediment. Furthermore, Snelgrove et al., go on to support this claim by suggesting that the regulation of vegetation growth through environmental conditions may be more important for the regulation of faunal densities rather than the populations of the vegetation itself (Snelgrove 2000). Little is known at this point regarding exactly how *S. alterniflora* in Willapa Bay changes benthic invertebrate densities in the sediment and water, which is unfortunate because the effects of vegetation seem significant.

Exactly how faunal densities are affected by the introduction of vegetation into an estuarine habitat will most likely be different depending on the taxa studied. Because the grain size of sediment is altered (often increased in size) by vegetation in that grasses decrease water flow due to the nature of their dense root systems, there is often a change in the distribution of fauna simply based upon size considerations. Additionally, the vegetated areas usually experience a huge increase in microbial growth around the root clusters. This often results in an increase in nematodes below the sediment-water interface because they utilize the microbes as the predominant food source. In addition, burrowers, and tube-building invertebrates often increase in number with more vegetation because they benefit from the structural stability the plant offers. Finally, above the water-sediment interface, vegetation provides shelter for insects and small bivalves (Thom 1997, Osenga and Coul 1983).

Conversely, vegetation can also have the effect of decreasing particular benthic invertebrate densities in the mudflat. Because the native eelgrass does not have a large root mass like *S. alterniflora*, its effects are much different. Eelgrass will not accumulate sediment because a majority of its growth is above the mudflat. "Large detrital production, combined with the reduced water flow often observed in salt marshes, can lead to organic loading and reduced sediment oxygen availability" (Osenga and Coul 1983). It is unclear exactly which taxa may be affected by this type of scenario. Although, the observation is valuable because it addresses the possibility that vegetation has the potential to change the biodiversity of the water-sediment interface in a number of different ways.

Assessing the potential risks of *Spartina alterniflora*

The growth pattern, rate and means of seed dispersal utilized by *S. alterniflora* must be considered in order to come to an accurate assessment of the significance of its invasion in Willapa Bay. Current efforts to contain and limit the growth of the grass need to be modeled in such a way as to consider the characteristics above otherwise efforts would be futile.

S. alterniflora begins as small patches, which are referred to as clones. Over a period of time, on the order of many years at first and then more rapidly as the individual grass clumps increase in size, the clones will grow to a point where they begin to interconnect. When this dense stage of growth is reached, there is a formation of meadows. These meadows are particularly deleterious to an intertidal ecosystem because they create a habitat that is not suitable for the native biota. Local organisms, previously unable to inhabit the region such as insects and spiders move in while the previous residents are unable to thrive in the region any longer. In most cases, it has been seen that the densities in populations of benthic invertebrates living in the mud increase with the establishment of *S. alternifora* meadows (Zipperer 1996). *S. alterniflora* provides the benthic invertebrates with protection from predators, increased food availability, and stable homogeneous sediment (Lana and Guiss 1991). This phenomenon is a disastrous scenario because it suggests that predators such as migratory waterfowl are not able to access the needed food source. Subsequently, the entire ecosystem sees a dramatic and sudden shift in population dynamics of many species.

Studies on the transport of *S. alterniflora* seeds reveal wind and water as the three major mechanisms used. In the Pacific Northwest, seeds of *S. alterniflora* are primarily dispersed via waterways. The initial establishment of *S. alterniflora* in Willapa Bay however, is attributed to human influence (Chew 1998). The seeds of *S. alterniflora* may be carried within a patch of uprooted grass material for several miles where it can reestablish itself quite successfully in new areas (Sayce et al. 1997).

Because the invasive weed may be transported many miles at a time by water, *S. alterniflora* in Willapa Bay poses a potential threat to other local coasts such as inland waters and outer coasts of Washington as well as parts of British Columbia (Sayce et al. 1997). Sayce has speculated from looking at the path of the Columbia River that dispersal of *S. alterniflora* southward is unlikely (Sayce et al. 1997). However, *S. alterniflora* has already become previously established along coastal areas of California, particularly San Francisco (Daehler and Strong 1996, Levin and Hewitt 1998). Not only do control efforts need to stop spread in Willapa Bay, recognition of *S. alterniflora*'s ability to spread over a wide geographical area needs to be addressed when formulating eradication plans.

Spartina alterniflora grows in dense patches that congregate to form thick meadows. This pattern of growth in the upper intertidal mudflat is disastrous because it changes the ecosystem into a terrestrial habitat. Unfortunately, due to its exponential pattern of growth once its been established, *S.alterniflora* invasion in Willapa Bay was not noticed as a significant threat until after the cordgrass was well established and spreading rapidly. Harrington and his colleagues support their conclusion of exponential growth with data taken in 1982 and 1988 that corresponded with a sigmoidal growth curve. The group of researchers then went on to further postulate the growth patterns of *S. alterniflora* in Willapa Bay. They suggest that the presence of eelgrass (*Zostera*), a native grass species to Willapa bay, does not curb the establishment of new shoots nor does it limit the growth of new clones. In addition they noted that the majority of new *S. alterniflora* clones were growing in the upper tidezone regions, areas if the mudflat natively unvegetated.

An observable decay effect in relation to distance as you move away from plants acting as a seed sources was also noticed. New establishment of *S. alterniflora* clones becomes less likely as distance increases between the area designated for new growth and the grass that is acting as the source of seeds (Harrington et al. 1997). As the number of potential seed sources increase with the spread of the grass, its potential for seeding new areas increases as well because seed travel is limited by distance.

Control efforts: past and present

Efforts to control the growth of *S. alterniflora* in Willapa Bay began with the declaration of the grass as a Class B noxious weed. In 1992, there was an official assessment of the invasion in Washington State's Environmental Impact Statement (EIS) and the federal "Environmental Assessment" (EA), which addressed the impacts of the grass as well as options for its control as part of the State Environmental Protection Acta (SEPA). This document was especially beneficial because it coordinated various state agencies and designated responsibilities that each would take on in the eradication effort. Seven state agencies decided on "integrated pest management" as their approach. "Integrated pest management (IPM) is defined to mean the coordinated use of multiple biological, mechanical/physical, and chemical treatment methods to control, contain, reduce, and/or eradicate *Spartina*." (Chew 1998)

Although this initial organization and allocation of tasks was needed in the early 1990's, actual efforts to contain the spread of the weed had not begun. In 1995, *S. alterniflora* in Willapa Bay was seen as an emergency situation, prompting the Washington State Legislature to initiate a more direct form of action. The Legislature subsequently declared the Washington State Department of Agriculture (WSDA) as the group responsible for the grass eradication. Soon after, $1 million was allocated to the control effort (Chew 1998, Bishop 1997).

Within the last six years, many different approaches, with varied degrees of success, have been experimented with in Willapa Bay. Although the idea of a biological control seemed like the most promising method of eradication from the very beginning, other strategies were practiced until recently. The worry about and delay in use of a biological control was that is required the introduction of a non-native insect into the area, which could cause further ecological damage. Agencies needed time to estimate the insect's potential benefits and threats. In the meantime, other methods were employed in order to buy time and possibly act as an alternative to the introduction of a new species.

In August 1992, a group of researchers forming the Wetland Ecosystem Team conducted a study in an effort to determine the effects of the herbicide RODEO and the associated surfactant X-77 on the benthic invertebrate populations in Willapa Bay. In prior studies by Major and Grue it was determined that RODEO would be the most effective herbicide for eradication of *S. alterniflora* in Willapa Bay. In order for this chemical treatment to be effective, a surfactant must be applied as well. Various combinations of herbicides and surfactants were tested with the RODEO and X-77 proving to be the best balance between maximum *S. alterniflora* death, and minimum harmful side effects on the native flora and fauna in the bay (Major and Grue 1997).

With this combination of herbicide and surfactant already predetermined, the Wetland Ecosystem Team tested its effectiveness as well as its impact on the bay. Specific taxa were chosen for the experiment based upon their importance in the food web of the bay. The research group also followed the observed changes in microalgae density after application of the chemical treatment relative to untreated areas nearby due to its important role in providing diatoms in the sediment. These diatoms are believed to be the largest source of food utilized by the primary consumers in the estuarine community (Atkinson 1992, Chew 1998, Simenstad et al. 1996).

Upon conclusion of their 17-week experiment the group detected no significant effects on the benthic invertebrate and microalgae densities as a result of arial application of RODEO and X-77. The group noted three reasons that may have influenced the lack of noticeable responses: the conditions of the test, the large amount of variation in organismal distribution within the mudflat, and the time scale used for the experiment. The significant amount of invertebrate distribution variability among sites concerned the Wetland Ecosystem Team the most of all three testing considerations. Specific characteristics they found that varied among sites and may explain the invertebrate and microalgae density differences were tidal elevation, substrate structure, and natural disturbance. Although the group verified that the chemical treatment regimen that they tested seemed to have no significant risks to the area, they advised extreme caution before increased concentrations were used and treatment sites approached with identical methods (Simenstad et al. 1996).

This study should not be used in support of the use of this chemical treatment. The short time period used by the researchers fails to consider seasonal and year-to-year consequences of RODEO and X-77. Also, the group did not look at changes in the quantity of eelgrass after chemical treatment application. This is a problem because it was observed in our research that a large number of polychaete worms, potential food for shorebirds, live in the native grass.

A study conducted by Frid, Davey, and Chandrasekara examined the effects of using tracked vehicles in the control of *Spartina alterniflora*. They noted the success of an earlier study determining the effectiveness of physical disturbance in destroying *S. alterniflora*. They noted that such success is largely dependent on two variables 1) the extent to which the cordgrass growth is reduced 2) the ability of the method to cause *Spartina* destruction without disturbing the benthic fauna.

Frid and colleagues concluded that the benefits to bird populations resulting from the removal of *Spartina* outweighed the effects physical disturbance caused to the invertebrate populations. In fact, the small changes in benthic fauna density seen directly after the tracked vehicle treatment disappeared in less than 12 days.

An initial mud sample was taken and then examined for specific taxa and numbers of benthic invertebrates. Two days later, the tracked vehicle was repeatedly driven over the sample plat until the grass was completely uprooted or buried under the sediment. Sampling methods were repeated 12, 31, 92, and 383 days after the vehicle treatment. There was no significant decrease in the number of organisms, nor the taxa identified even after the area had only 12 days to recover according to univariate statistical methods.

There was some speculation by the researchers themselves that the conclusion is flawed. This speculation stems from the invertebrates high rate of decomposition (invertebrates decompose in a matter of days) in addition to a fast rate of re-establishment via migration by adult populations. In fact, the researches postulated that these two phenomena may be correlated. When intertidal invertebrates are killed due to disturbance from the tracked vehicle, their remains along with the churning of the sediment stimulates bacterial activity. Furthermore, the increased bacterial growth provides a larger incentive for adult populations of invertebrates to move into the area. Deposit feeding infauna will move in to feed upon the abundant bacteria. Despite these speculated disturbances, the group reaffirmed their position that this mechanical approach ultimately has more positive than negative results. They advise the tracked vehicle as an effective approach for the management of *Spartina* in tidal regions (Frid et al. 1997, Chew 1998).

After nearly ten years of laboratory testing, the planthopper *Prokelisia marginata* has just recently been released in a limited region of *S. alterniflora* meadow in Willapa Bay. I t has long been speculated that the insect, a biological control, is the best method for controlling the fast spread of *Spartina*. Because such a control effort involves the introduction of a non-native species to the area, great effort was put into testing before the method was first employed in the field this past summer (Chew 1998).

Testing of the biological control involved the identification of a herbivore that is specific to *Spartina*, while avoiding other grasses that are native to the area. Testing began in 1993 and continues currently. A study completed by Daehler and Strong in 1996 documents the susceptibility of *Spartina* to the planthopper. The researchers tested the responses of *Spartina* in San Francisco Bay as well as in Willapa Bay to the herbivore. Before tests were done, they suspected the cordgrass in Willapa Bay would be especially harmed by the biological treatment. Over the 100 years that *S. alterniflora* has inhabited the bay, it has had no exposure to insect predators. Additionally, earlier tests revealed that the cordgrass has an unusually low resistance to *Prokelisia marginata*, the specialized insect who feeds upon *Spartina* in its native East Coast habitats (Daehler and Strong 1996).

The two researchers found that the "growth of the Willapa Bay plants was greatly reduced by the planthopper, with the plants exposed to planthopper herbivory averaging only 30% and 12% of the aboveground biomass of herbivore-free controls after the first and second seasons of herbivory, respectively." The *Spartina* in Willapa Bay is significantly more susceptible to the planthopper than the *Spartina* in San Francisco Bay exposed to the same treatment. This difference is believed to be due to the fact that the grass in SFB has been exposed to herbivory while the Willapa Bay plants have not (Daehler and Strong 1996, Levin and Hewitt 1998).

Daehler and Strong have hypothesized that in its move to Willapa Bay, *S. alterniflora* lost its resistance to *Prokelisia marginata* in some sort of evolutionary trade-off. Resistance is costly to the plant, so if it is not needed in a particular habitat, resistance will be lost in exchange for increased growth. In addition, it is believed that the *Spartina* in Willapa Bay initially established itself as a single clone. As a result, there was extensive inbreeding, which lead to a homogenous population. If the initial clone was intolerant to herbivory, this trait would have thus remained in the establishing population making the plant susceptible to biological control (Daehler and Strong 1996).

Major advancement in the implication of the biological control happened in 1997 when The University of Washington's Olympic Natural Resource Center and the Columbia Pacific Resources Center joined efforts. They pulled cash from various other agencies, private donations, and redirected $80,000 that was initially allocated for research of other grass control methods. Research made possible by this funding established that there are no closely related plants to *Spartina* that would be impacted by *Prokelisia marginata* (Chew 1998). These finding spurred effort to release the herbivore, although many researchers still feel there are many additional questions that were left unanswered.

Besides the risks associated with the introduction of a non-native species to Willapa Bay, there is concern that *Spartina* will evolve to become resistant to the planthopper in a short period of time, leaving the area with a stronger weed as well as a new insect. The use of the insect may place selective evolutionary pressure on S. alterniflora, thus making it so the resistant plants survive and go onto reproduce. Current research has not revealed how long it may take the weed from achieving resistance to the insect, nor do researchers reveal a method for controlling the cordgrass once the new population of new *Spartina* plants proliferates within the estuary. Even the most hopeful control effort available currently has many holes and potential for risk in the near future.

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