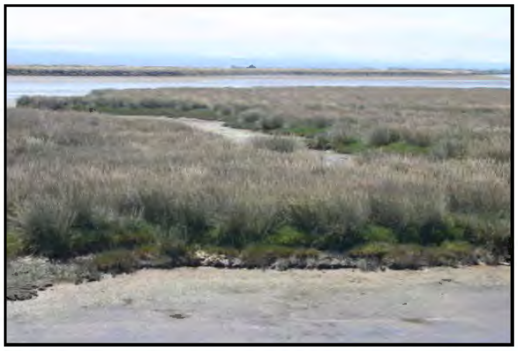



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Humboldt Bay Regional *Spartina* Eradication Plan

Final Report

Project # 3192-01

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Executive Summary

This Draft Humboldt Bay Regional *Spartina* Eradication Plan (Regional Plan) describes an approach for eradicating invasive cordgrass (genus *Spartina*) at a regional scale. In their non-native ranges, invasive *Spartina* species displace native plant species, reduce biodiversity, disrupt natural ecological function, and alter habitats for fish and wildlife species. *Spartina* eradication in the Humboldt Bay region is needed to restore sensitive coastal wetland habitats and to eliminate the threat of spread that untreated *Spartina* poses to other estuaries on the West Coast. This Regional Plan presents a toolbox of control methods to address infested wetlands at different stages of treatment with varying site characteristics. The control methods presented are based on demonstrated effectiveness and ongoing research. We embrace an adaptive management approach, which will allow us to make plan changes in response to new information, treatment successes and failures, funding opportunities, logistical constraints, and other unforeseeable factors.

The region covered in this plan is called the Management Area, and includes Humboldt Bay and the Eel and Mad River Estuaries, on the northern California coast. Regional *Spartina* eradication is part of a larger West Coast collaborative eradication extending from British Columbia, Canada to California. In 2010, the coast-wide *Spartina* Action Coordination Team (ACT) identified *Spartina* eradication in the Management Area as a high priority task, noting that increased focus is needed in this region to achieve eradication success. The importance of coordination, political will, and adequate funding has been demonstrated at several other sites of *Spartina* invasion (such as Willapa Bay, Washington and the San Francisco Estuary, California) where coordinated programs have resulted in nearly complete *Spartina* eradication (Boe et al. 2010).

This Regional Plan is consistent with critical elements that ACT identified as needed for all regions, including eradication of existing *Spartina* infestations, habitat restoration, prevention, early detection, rapid response to new invasions, and communication and outreach. Additionally, this Regional Plan addresses factors unique to the Management Area that affect how *Spartina* can be eradicated, as compared to other eradication methods and efforts on the West Coast. Factors unique to the Management Area include:

- The Management Area currently contains just one species (*S. densiflora*) of the 4 non-native *Spartina* species that have invaded other areas of the West Coast.
- *S. densiflora* has infested 1672 acres since its inadvertent introduction to Humboldt Bay in the 1870s, representing the oldest and most extensive occurrence of this species on the West Coast.
- Approximately 90% of tidal marsh habitat in the Management Area has been invaded by *S. densiflora* to some extent, with evidence that the invasion is still progressing.
- Continuing encroachment by *S. densiflora* threatens high elevation salt marsh, a diverse plant community that provides habitat for rare plant species, and that is already scarce in the Management Area.
- Encroachment into mudflat habitats is becoming evident in some locations within the Management Area. *S. densiflora* does not extend as low in the intertidal zone as the invasive *S. alterniflora*, which

rapidly converted over 9,000 acres of mudflat habitat into dense cordgrass meadows in Willapa Bay before eradication by coordinated regional efforts there.

- No native *Spartina* species occur in the Management Area. The only *Spartina* species that naturally occurs on the West Coast is *S. foliosa*, and its range extends only as far north as Bodega Bay, California. In the San Francisco Estuary, hybrid crosses between *S. foliosa* and invasive *Spartina* species (especially *S. alterniflora*, but also *S. densiflora*) pose a major management challenge.
- *S. densiflora* is less responsive to herbicide treatments then other invasive *Spartina* species, leading ACT to prioritize the development of improved treatment methods for this species (Boe et al. 2010).
- Mechanical treatment methods that effectively kill established stands of *S. densiflora* in 2 years have recently been developed and continue to be refined; substantial recovery by native plant communities following treatment has been documented.
- Various combinations of chemical and mechanical methods are currently under investigation in the Management Area, having been used effectively to treat *S. densiflora* elsewhere.
- Approximately 20% of lands infested by *S. densiflora* in the Management Area have received some level of treatment to date. This Regional Plan is intended to expedite current eradication efforts and provide regional coordination.

This Regional Plan calls for an agency or other entity to be designated to perform regional coordination, appropriately referred to as the Regional Coordinator. The Regional Coordinator will be responsible for coordinated implementation of the Regional Plan, and will provide the long-term presence and commitment needed to eradicate *Spartina*. The Regional Coordinator will coordinate and lead acquisition and administration of funding, permitting, planning, implementation, monitoring, communication, and outreach. Public agencies will support the Regional Coordinator's efforts; private landowners are not expected to fulfill these responsibilities, although willing landowners will be encouraged to participate. The Regional Coordinator will be the main communication conduit and hub among all Management Area parties involved. The Regional Coordinator will share information on work accomplished at the regional level and will collaborate with other West Coast managers who are eradicating invasive *Spartina*.

The Humboldt Bay Harbor, Recreation and Conservation District has been identified as a possible agency to serve as the Regional Coordinator, with support from several additional agencies and non-governmental organizations. The California State Coastal Conservancy (Conservancy) will provide scientific and permitting support and may fund some of the eradication measures and/or help the Regional Coordinator acquire funding for implementation. The Humboldt Bay National Wildlife Refuge will provide scientific and logistical support, and a regional *Spartina* advisory committee may be formed to foster interagency and community communication and participation.

The intended readers and audience for this Draft Regional Plan are resource managers, resource agency staff, landowners, and the local community and public. Sections 1 to 3 provide background information, including an overview and Regional Plan's policy context; a description of the general physical geography of the

Management Area; and information on *Spartina* ecology and the ecological impacts of *Spartina* invasion, with a focus on *S. densiflora*. Sections 4 to 6 present details on how regional *Spartina* eradication can be achieved; readers who are primarily interested in potential *Spartina* control actions in the Management Area should focus on these sections. The eradication strategy includes a discussion of the steps needed to eradicate existing invasive *Spartina* and enhance native plant communities; procedures for minimizing reinvasion; guidelines for monitoring; and means of communication and outreach. An overview of permits that will likely be required to perform eradication work is presented, with discussion of how permitting can be facilitated through coordination at a regional level. Lastly, a characterization of costs associated with plan implementation is provided.

Extensive background information was gathered in the process of preparing this Regional Plan, and much of it is included in appendices (Appendices A to C).

The Conservancy is the lead agency responsible for complying with the California Environmental Quality Act for regional *Spartina* eradication. A Programmatic Environmental Impact Report (PEIR) (CSCC 2012) is being prepared concurrently with development of this Regional Plan to assess potential environmental impacts and recommend mitigation measures to avoid, minimize, or mitigate impacts. Both the Draft Regional Plan and the PEIR will be available for public review and comment.

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List of Acronyms and Abbreviations

Abbreviation or Acronym	Definition
ACT	Action Coordination Team
BOEMRE	Bureau of Ocean Energy Management, Regulation, and Enforcement
CCC	California Coastal Commission
CCMP	California Coastal Management Program
CDFG	California Department of Fish and Game
CDPR	California Department of Pesticide Regulation
CEQA	California Environmental Quality Act
CNPS	California Native Plant Society
Conservancy	California State Coastal Conservancy
CRAM	California Rapid Assessment Method
CSLC	California State Lands Commission
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
EFH	Essential Fish Habitat
EREP	Eel River Estuary Preserve
ESA	Endangered Species Act
Harbor District	Humboldt Bay Harbor, Recreation and Conservation District
HBI	Humboldt Bay Initiative
HBNWR	Humboldt Bay National Wildlife Refuge
LMM	Lanphere-Ma-le'l Marsh
MBTA	Migratory Bird Treaty Act
MCV	A Manual of California Vegetation
MLLW	Mean Lower Low Water
MMMM	Maximum Minus Minimum Method
NCRWQCB	North Coast Regional Water Quality Control Board
NCUAQMD	North Coast Unified Air Quality Management District

Abbreviation or Acronym	Definition
NEPA	National Environmental Policy Act
NHPA	National Historic Preservation Act
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
NPP	Net Primary Productivity
NVCS	National Vegetation Classification System
NWP	Nationwide Permit
PEIR	Programmatic Environmental Impact Report
Regional Plan	Humboldt Bay Regional *Spartina* Eradication Plan
RHA	Rivers and Harbors Act
RMP	Restricted Materials Permit
SHPO	State Historic Preservation Officer
SRERP	Salt River Ecosystem Restoration Project
SWRCB	State Water Resources Control Board
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WCGA	West Coast Governor's Agreement on Ocean Health

Section 1.0 Introduction

1.1 Plan Scope

This Humbold Bay Regional *Spartina* Eradiation Plan (Regional Plan) provides a framework for eradicating invasive *Spartina* at a regional level using a coordinated strategic approach to augment current efforts. The Management Area includes Humboldt Bay, the Eel River Estuary, and the Mad River Estuary. The eradication strategy presented here primarily targets existing populations of *S. densiflora* and secondarily any species of *Spartina* that may invade the Management Area in the future. Regional eradication is part of a larger effort to eradicate all invasive *Spartina* species on the West Coast. The time frame set as a goal for achieving coast-wide eradication is the year 2018 (OGWOC 2008).

It is beyond the scope of this plan to to assess potential environmental impacts or to recommend mitigation measures to avoid, minimize, or mitigate impacts. These concerns are addressed in a Draft Programmantic Environmental Impact Report (PEIR) (H. T. Harvey & Associates and GHD 2012) prepared concurrently with the Regional Plan.

1.2 Goals and Objectives

Goal: Tidal marsh communities in the Management Area will be enhanced through the eradication of invasive *Spartina* and restoration of native vegetation.

- **Objective 1.** By 2013, a regional program will be in place to coordinate efforts to eradicate the invasive cordgrass species *Spartina densiflora* from all lands within the Management Area in collaboration with the larger West Coast invasive *Spartina* eradication program.
- **Objective 2.** By 2018, tidal marshes in the Management Area will be dominated by native tidal marsh plant species.
- **Objective 3.** Tidal marshes in the Management Area will be protected against future *Spartina* invasions by prevention, early detection, and rapid response.

1.3 Need for Invasive *Spartina* Eradication

Successful invasive species are able to effectively reproduce and disperse, often outcompeting local native species, and occupying vacant niches. Non-native invasive species introductions have become increasingly common and are among the most important changes occurring in in marine environments around the world (Carlton and Geller 1993, Grosholz 2002, Ruiz et al. 1997, Silliman et al. 2009). Estuarine environments are one of the most invaded as a result of high levels of human disturbance and inadvertent introductions associated with shipping and aquaculture. The dynamic nature of estuaries can make invasive species management challenging, as new opportunities for colonization arise frequently.

Estuarine habitats perform the essential function of maintaining ecosystem health; they are highly productivity and export organic fuel to nearshore waters (Mitsch and Gosselink 2000, Neves et al. 2010). Significant losses have occurred to estuarine habitat along the West Coast of North America, and it is important to protect remaining habitat from further degradation by invasive species such as non-native *Spartina*.

There are 4 non-native *Spartina* species that have invaded the West Coast. In their non-native ranges, invasive *Spartina* threaten the integrity of estuarine habitats by outcompeting native plant species, including rare plants; reducing biodiversity and disrupting natural ecological functions; producing large amounts of persistent detritus; and altering habitats for fish and wildlife species, including threatened species. These invasions alter ecological processes such as biogeochemical cycling and sediment dynamics (Callaway and Josselyn 1992). Invasive *Spartina* can rapidly expand and spread to new areas, and can act as ecosystem engineers by increasing sedimentation which alters the topography of the marsh. In some locations, invasive *Spartina* has invaded mudflats, eliminating important foraging habitat for shorebirds. In the San Francisco Estuary, California, invasive *Spartina* have hybridized with the native *S. foliosa*, resulting in genetic contamination. *S. foliosa* (California cordgrass) is the only native *Spartina* species on the West Coast of North America, ranging from Bodega Bay in central California south to Baja California.

Coastal invasive species eradication has been identified as a high priority issue by the Ocean Protection Council (COPC 2006), the *West Coast Governors' Agreement on Ocean Health* (WCGA) (OGWOC 2008), *The Draft Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California* (USFWS 2009a), and the *Humboldt Bay Initiative* (HBI) (Schlosser et al. 2009). Control of invasive *Spartina* in the Management Area was specifically recommended in the *Status of Perennial Estuarine Wetlands in the State of California* (Sutula et al. 2008a) and in the WCGA *Spartina Eradication Action Coordination Team Work Plan* (Boe et al. 2010). *S. densiflora* is recognized at the state level (CIPC 2006) and at the regional level (HWMA 2010) as a species that poses a high level threat to wildlands, with severe ecological impacts.

1.4 Need for Regional Coordination

A coordinated, regional approach with local community support is important for successful eradication of invasive *Spartina*, as demonstrated by work in other West Coast estuaries including San Francisco Bay, California (SFEISP 2003), Willapa Bay, Washington (WSDA 2011), and others. In the Management Area, *S. densiflora* eradication efforts are in progress at some locations; however, efforts thus far have addressed less than 20% of the estimated infested acreage in the Management Area. Remaining reproductive populations represent a threat to all treated sites. It is only through eradication of all *Spartina* in the Management Area that the threat of reinfestation can be eliminated. It is therefore critical that *Spartina* eradication be implemented on a regional level, both for the restoration of local tidal marsh communities, and also to eliminate the potential for ongoing spread to other estuaries on the West Coast.

In the Management Area, land infested by *S. densiflora* has both public (local, state, and federal) and private owners, and is under the jurisdiction of multiple regulatory agencies. Interagency collaboration to provide adequate expertise, resources, and focus to sustain long-term efforts is now recognized as important for successful control of invasive species (Boe et al. 2010, Westbrooks and Eplee 2011). The importance of regional coordination in strategic conservation planning was emphasized locally by the HBI. The strategy proposed in the Regional Plan is consistent with the HBI recommendations for controlling invasive species (Schlosser et al. 2009).

An agency or other entitiy will be designated to perform the role of regional coordination and will hereafter be referred to as the Regional Coordinator. The designation of a Regional Coordinator will help ensure comprehensive implementation of the Regional Plan and provide the long-term commitment needed to complete *Spartina* eradication. The Regional Coordinator will be instrumental in acquisition and administration of funding, permitting, planning, implementation, monitoring, and outreach. Private landowners will not be expected to fulfill these responsibilities, although willing landowners will be encouraged to participate in eradication work. Communication with local landowners and regulatory agencies involved will be critical throughout the project. Additionally, the Regional Coordinator will collaborate with other managers on the West Coast working on invasive *Spartina* eradication, stay informed on the status of other invasions, current research and method development, and share information on the work accomplished at the regional level. More details on the role and responsibilities of the Regional Coordinator are discussed in Section 4.2.

The Humboldt Bay Harbor, Recreation and Conservation District (Harbor District) has been identified as a possible agency to fulfill the role of Regional Coordinator, with assistance from other agencies. The California State Coastal Conservancy (Conservancy) will provide scientific and permitting support and may fund some of the eradication measures and/or help the Regional Coordinator to acquire funding for implementation. Humboldt Bay National Wildlife Refuge (HBNWR) will provide scientific and logistical support, and a regional *Spartina* advisory committee may be formed to foster interagency and community communication and participation.

1.5 Collaboration with Coast-Wide *Spartina* Eradication

As part of the WCGA, the Governors of Washington, California, and Oregon (OGWOC 2008) committed to work cooperatively to eradicate invasive *Spartina* coast-wide by 2018:

> Action 2.4: "Focus efforts on eradicating non-native cordgrasses (genus *Spartina*), which are transported between the 3 states (Washington, Oregon, and California) on ocean currents, as a pilot coast-wide eradication."

A *Spartina* Eradication Action Coordination Team (ACT) was formed to implement Action 2.4, and a work plan (ACT Work Plan) developed by Boe et al. (2010). ACT is composed of representatives from each of the 3 states, the federal government, tribal governments, non-governmental organizations and the Province of

British Columbia. The ACT Work Plan supports all ongoing efforts, noting that aggressive eradication programs in the San Francisco Estuary in California; Willapa Bay, Grays Harbor and Puget Sound in Washington; and most infested sites in Oregon have resulted in nearly complete eradication of *Spartina* at these locations. The ACT Work Plan prioritized an increased focus on eradication of existing *Spartina* populations at specific locations, including the Humboldt Bay region, the Siuslaw Estuary in Oregon, and sites in British Columbia, Canada (Boe et al. 2010).

The need for funding, political will, and effective organization was recognized in the ACT Work Plan as paramount for carrying out successful eradication progrms. Six elements were identified that need to be carried out in concert with each other for coast-wide eradication to be successful: 1) prevention, 2) early detection, 3) rapid response, 4) eradication, 5) restoration, and 6) communication and outreach (Boe et al. 2010). The Regional Plan addresses each of these critical elements.

1.6 Challenges of Eradication

Eradication can be defined as "the complete and permanent removal of all wild populations of an alien plant or animal species from a specific area by means of a time-limited campaign" (Genovesi 2011). Eradication of non-native (or alien) species, beginning in the early 1900s, was first triggered by health risks to humans or livestock. Vectors of pathogens, such as the tsetse fly that carried sleeping sickness and mosquitoes that carried malaria, were targeted for eradication. Non-native species that are able to successfully reproduce and spread to the point of becoming pests are referred to as invasive species. Only recently, in the 1980s, did a defined field of invasion biology emerge and with it the justification for eradicating invasive species to protect natural biodiversity, and it was not until the 1990s that eradication was adopted at the highest policy levels as a conservation tool (Davis 2011, Genovesi 2011). The recent advent of an ecosystem-based focus in conservation planning enables the development of a collaborative vision that transcends political and jurisdictional boundaries.

Eradication of aquatic and wetland plant species such as *Spartina* is especially problematic. In general, eradication is more challenging in aquatic than terrestrial environments (Genovesi 2011). The challenges are twofold: 1) Water-related dispersal pathways are numerous and generally difficult to block or contain, and 2) Once a species is established, the constraints associated with working in an aquatic environment can confound implementation of eradication measures (Grosholz 2002, Leishman and Harris 2011).

Eradications are generally more challenging for plant species than animal species. The presence of a dormant life stage, including a soil seed bank; prolific reproduction rates; and high dispersal capacity are some of the characteristics that make plant species more problematic (Genovesi 2011). For example, *Spartina* species reproduce both vegetatively and sexually and have mechanisms for both short-range and long-range dispersal via tides and oceanic currents (Bortolus 2006, Kittelson and Boyd 1997, Sayce et al. 1997).

Furthermore, the fact that *S. densiflora* is widespread and well established as a dominant species in tidal marshes throughout the Management Area and that it has spread to other locations on the West Coast make eradication even more challenging. Attempts at eradication at this scale are hindered by high cost, the need for interjurisdictional coordination and collaboration, long-term commitment and the perception of infeasibility (Holt 2011, Westbrooks and Eplee 2011).

No standardized definitions of success exist for the eradication of invasive species. Genovesi (2011) distinguishes eradication from permanent control, which is defined as a reduction but not elimination of a species. Nearly complete eradication of invasive *Spartina* has been achieved at several other West Coast locations; however continued monitoring and treatment is ongoing (Boe at al. 2010). The Washington State Department of Agriculture categorizes the reduction of invasive *Spartina* from 9000 ac (3642 ha) in 2003 to 12 ac (5 ha) in 2011 as a success, but recognizes that eradicating the remaining acres will be challenging and require long-term efforts (WSDA 2011). In the San Francisco Estuary, the acreage requiring *Spartina* treatment decreased from 2000 acres in 2006 to 144 acres by the end of the 2011 treatment season (Kerr, pers. comm., August 2012). The results of these eradication efforts indicate that dramatic reductions of invasive *Spartina* are quite feasible in the short term, but a long-term effort will be needed to achieve the goal of total eradication of invasive *Spartina*.

Section 2.0 Management Area

2.1 Geographical Setting

Section 2.1 provides an overview of the 3 estuaries comprising the Management Area (Figure 2-1). For greater detail, refer to Appendix A.

2.1.1 Humboldt Bay

Humboldt Bay (40° 44' 59", -124° 12' 34"), situated on a low-gradient alluvial plain at the base of the Coast Ranges, is a tidally driven coastal lagoon with limited freshwater input (Costa 1982, Emmett et al. 2000). It is California's 2nd largest estuarine system after San Francisco Bay, which is located 231 miles (mi) (371.8 km) to the south. Humboldt Bay is about 14 mi (22.5 km) long and its width varies from 0.5 mi (0.8 km) in Entrance Bay to 4.3 mi (6.9 km) across the widest part at North Bay. At high tide, the bay occupies an area of 24.1 mi^2 (62.4 km2), which is reduced to 10.8 mi^2 (27.97 km2) at low tide (Proctor et al. 1980). At low tide, extensive intertidal mudflats are exposed, comprising about 2/3 of the bay area (Gast and Skeesick 1964, Proctor et al. 1980).

The mouth of Humboldt Bay has been stabilized by jetties since the late 1800s. Two barrier beaches on either side of the entrance, the North and South Spits, shelter the estuary. The 3 regions of Humboldt Bay are defined as: 1) North Bay: the basin north of the Highway 255 Samoa Bridge, 2) Entrance Bay: the channel from the Highway 255 bridge south to the South Jetty, and 3) South Bay: the basin south of the South Jetty. Major tidal sloughs associated with the North Bay include Mad River, McDaniel, Gannon, Freshwater and Eureka Sloughs. White and Hookton Sloughs are associated with the South Bay. Two islands, Indian Island and Woodley Island, are located at the north end of Entrance Bay.

The Humboldt Bay watershed is 223 mi2 (577.6 km2) (HBWAC and RCAA 2005), which is relatively small for a bay its size. Discharge from Elk River is Humboldt Bay's largest freshwater source. Other major tributaries include Jacoby Creek and Freshwater Creek (via Eureka Slough) both of which empty into North Bay, and Salmon Creek, which empties into South Bay. The freshwater input to the bay varies with season and is largely governed by storm events. While its overall flow contribution is relatively small, the freshwater input has important localized effects on sedimentation rates and patterns, nutrient flux, and productivity (Barnhart et al. 1992).

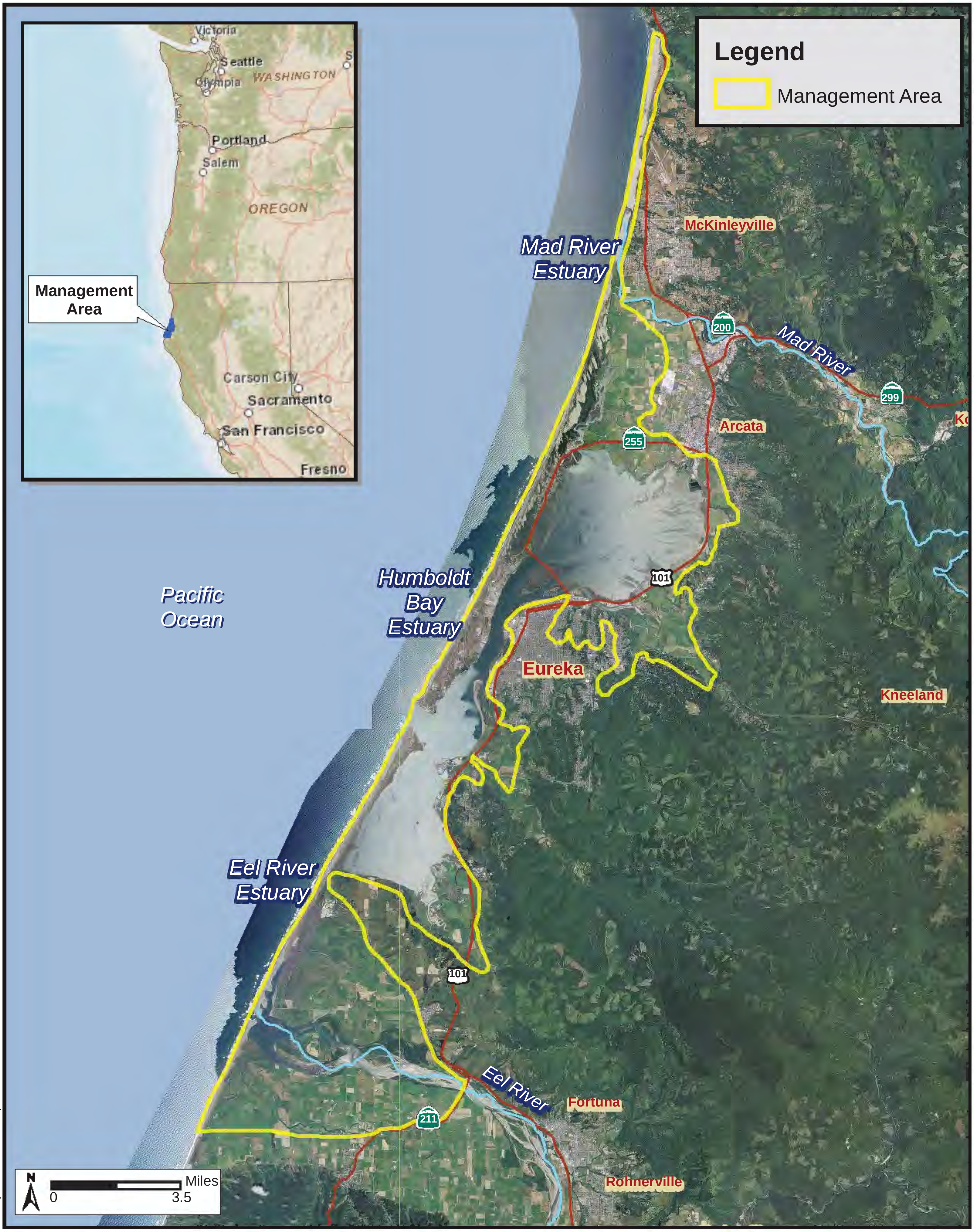

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Figure 2-1. Map Showing the Location and Boundaries of the Management Area

Figure 1: Vicinity Map

Humboldt Bay Regional Invasive Spartina Management Plan (3192-01)
March 2012

2.1.2 Eel River Estuary

The Eel River Estuary is the 4th largest estuary in California. The mouth of the Eel River (40° 38' 29", -124° 18' 44") is approximately 9 mi (14.5 km) south of the Humboldt Bay mouth; however the wetlands associated with these 2 estuarine systems are only narrowly separated by Table Bluff, which is less than 1 mi (1.6 km) wide. Tidal influence in the Eel River extends approximately 7 mi (11.3 km) upstream. At high water, the estuarine area of the river is estimated at 9.3 mi^2 (24.1 km^2).

The river mouth of the Eel River Estuary remains open to tidal exchange year round but migrates north and south, likely due to variations in longshore transport of sands from ocean currents, but also related to debris accumulations, tides, and flood flows (CDFG 2010). The mouth is bordered by sandy beaches composed of marine shoreline deposits and sand dunes. The estuary is divided into 5 zones based on channel characteristics and mixing regimes of tidal marine water and river freshwater: 1) North Sloughs: channels north of the river mouth, 2) North Bay: embayment extending from the river mouth upstream to near Cock Robin Island bridge, 3) Middle Estuary: main channels from Cock Robin Island bridge to Fulmor Rd, 4) Upper Estuary: main channel from Fulmor Rd to Fernbridge, and 5) South Sloughs: channels south of the river mouth, including the Salt River. Tidal sloughs north of the Eel River mouth include McNulty, Hawk, Quill, Hogpen, Sevenmile, Mosley and Ropers Sloughs. Sloughs south of the river mouth include Morgan and Cutoff Sloughs and the Salt River.

The Eel River Estuary experiences a much larger freshwater influence than Humboldt Bay, has a smaller tidal prism, and has greater seasonal variability. The Eel River Estuary receives runoff from over 800 tributary streams, collectively 3500 mi (5632.7 km) long, draining 3700 mi^2 (9582.9 km^2) of the mountainous Eel River watershed. Mean annual discharge from the Eel River Basin is approximately 5.4 million acre-feet (CDFG 2010). In the Eel River Estuary, salinity is strongly related to seasonal discharge and daily high and low tides (Cannata and Hassler 1995). Flood flows due to large winter rainstorms can temporarily inundate the estuary with freshwater. After peak flows subside, high tides move a mass or wedge of seawater back into the lower estuary. During the spring-summer period, the lower estuary has vertical density variation and is partially or moderately stratified. There is daily variation in the degree of stratification in the lower estuary during the summer and rapid shifts in stratification with the tides in both temperature and salinity (H. T. Harvey & Associates 2009).

2.1.3 Mad River Estuary

The Mad River (40° 56' 31", -124° 8' 6") is located north of Humboldt Bay. The mouth of the river is continually migrating, and is currently located approximately 14 mi (22 km) north of the mouth of Humboldt Bay. The Mad River is a freshwater-dominated system, with tidal influence extending approximately 5 mi (8 km) upstream to the Highway 101 Bridge. The estuary sub-basin drains 17 mi^2 (44 km^2), while the watershed drains 497 mi^2 (1287 km^2). Major tributaries that flow into the estuarine portion of the river are Widow White Creek and Mill Creek (Stillwater Sciences et al. 2010).

2.2 Land Use

Management of tidal waters in the Eel River and Mad River estuaries is the primary responsibility of the California State Lands Commission (CSLC), but in Humboldt Bay this responsibility has been transferred to the Harbor District. The incorporated cities of Eureka and Arcata, which are adjacent to Humboldt Bay, also have tideland jurisdiction over areas of Humboldt Bay. Land use management in unincorporated areas remains the responsibility of the County of Humboldt.

Agricultural Land Use Bordering Tidal Slough

Land use in the Management Area includes agriculture, marine dependent industrial uses, conservation management, urban, and residential. In Humboldt Bay, the Harbor District (HBHRCD 2007) identified geographic areas where different kinds of activities are expected to occur. These geographic distinctions provide a broad policy framework for the Harbor District's management decisions. The central part of the bay is associated with commercial and coastal-dependent industrial uses while the northern and southern parts are considered to have greater importance as habitat or natural areas. However, there are some portions of Central Bay, such as the beaches and marshes along the south end of the North Spit that are of high biological sensitivity.

Humboldt County's economy has historically depended on fishing, logging, agriculture and associated milling and shipping. However, according to statistics available from the U.S. Census Bureau (USCB 2009), employment in the farming, fishing and forestry sector has declined by half since 1990. Mariculture, primarily the cultivation of oysters (producing about 70% of the oysters grown in California), remains a major industry in the North Bay, with some limited shoreside facilities. In coastal Humboldt County, the largest employers are currently in the education, health and social services sectors (EDD 2010).

2.3 Tidal Marsh Resources

Section 2.2 provides a description of the existing conditions of tidal marsh resources in the region, with reference to historical conditions. For greater detail, refer to Appendix A.

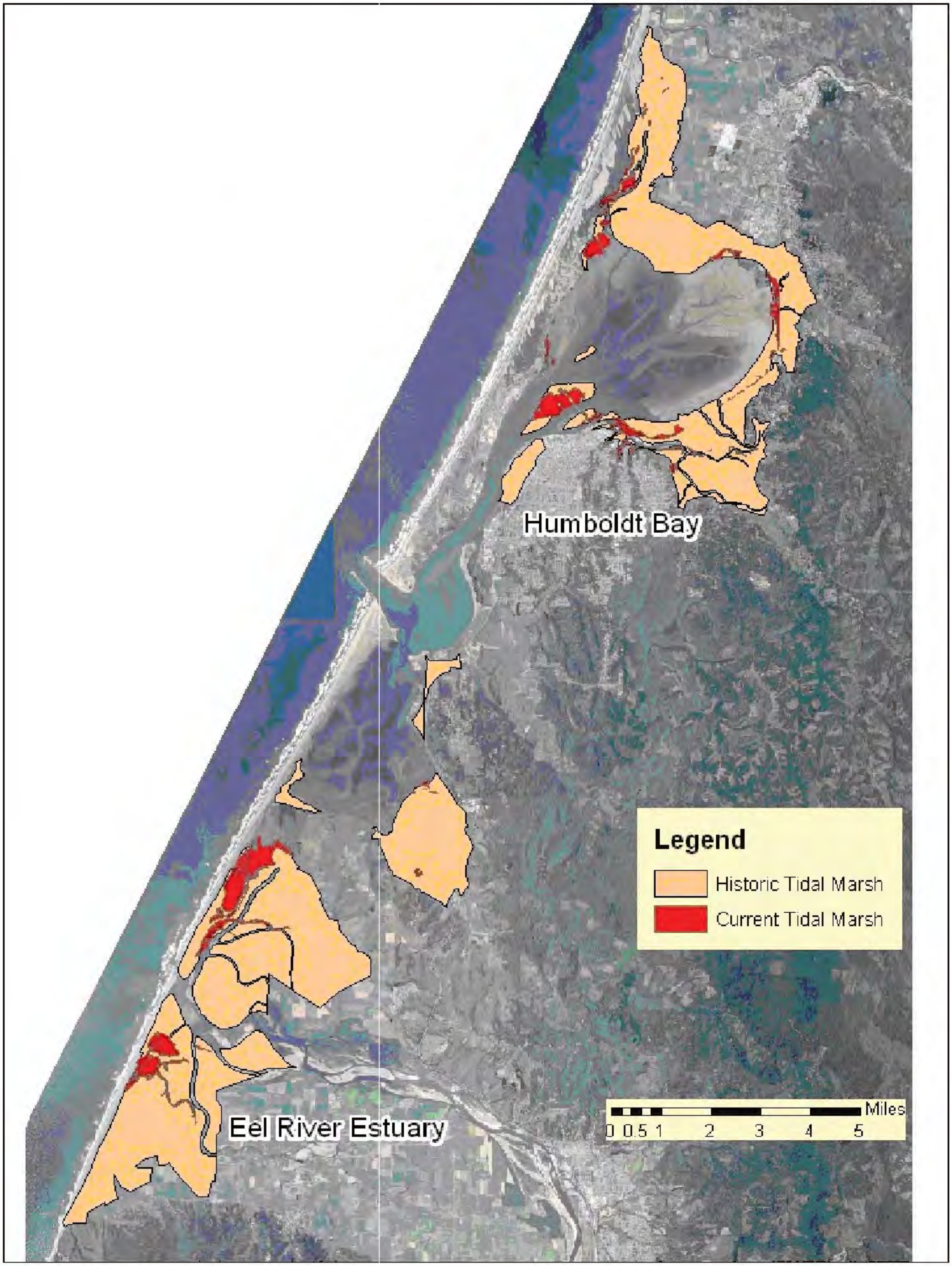
2.3.1 Historical and Current Extent

Most of the historical tidal marshes in the Management Area were diked for agriculture in the late 19th and early 20th centuries, and have been reduced to less than 10% of their estimated historical extent (Borgeld et al. 1993, Laird et al. 2007, Schlosser and Eicher 2012, USFWS 2009b) (Figure 2-2). Today, significant portions of tidelands and former tidelands in the Management Area are protected as part of the California Department of Fish and Game's (CDFG) Mad River Slough, Fay Slough, Elk River, and Eel River Wildlife Areas; the U.S. Fish and Wildlife Service's (USFWS) HBNWR; the Bureau of Land Management's South Spit Cooperative Management Area; the City of Eureka's Elk River Wildlife Sanctuary and PALCO Marsh; the City of Arcata's Arcata Marsh and Wildlife Sanctuary; and The Wildlands Conservancy Eel River Preserve.

In Humboldt Bay, the extent of tidal marsh is approximately 905 ac (366 ha) (Schlosser and Eicher 2012). In North Bay, tidal marsh occurs on interior islands; the islands and banks of Mad River Slough; bordering the channels of McDaniel, Butcher, Gannon, Eureka, Freshwater, and Fay Sloughs as well as smaller secondary sloughs; near the mouth of Jacoby Creek and Rocky Gulch; and as an interrupted fringe around the bay perimeter. At the north end of Entrance Bay, Indian Island supports one of the largest contiguous areas of tidal marsh remaining. The shoreline of Entrance Bay is extensively developed, with only a narrow and intermittent remnant fringe of marsh remaining. In South Bay, small amounts of tidal marsh occur in association with White Slough and Hookton Slough, and tidal connectivity has recently been restored to portions of Salmon Creek (Laird et al. 2007, Pickart 2001, Shapiro and Associates 1980, USFWS 2009c) (Figure 2-2).

In the Eel River Estuary, tidal marsh is currently about 639 ac (259 ha), less than 10% of the estimated historical extent (Schlosser and Eicher 2012). The majority of existing tidal marsh is found in the Centerville Slough area of the Salt River drainage (south of the Eel River mouth) and the recently breached area adjacent to McNulty Slough (north of the Eel River mouth). Tidal marshes also occur on the banks of tidal sloughs and sporadically on the banks of the main channel and Cock Robin Island (Laird et al. 2007, Roberts 1992) (Figure 2-2).

The extent of tidal marsh in the Mad River Estuary has not been mapped, but is relatively small compared to the other 2 estuaries in the Management Area. Channel dynamics, bank stabilization, and the predominance of freshwater influence in the system are all factors that contribute to the relative scarcity of estuarine marsh in the Mad River system. Estimating historical extent is difficult, but early descriptions indicate that the floodplains were dominated by coniferous forests.



(Adapted from Laird et al. 2007)

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H. T. HARVEY & ASSOCIATES
ECOLOGICAL CONSULTANTS

Figure 5: Historic & Current Extent of Tidal Marsh

Figure 2-2: Historic and Current Extent of Tidal Marsh in Humboldt Bay and the Eel River Estuary

Humboldt Bay Regional Invasive Spartina Management Plan (3192-01)
March 2012

2.3.2 Habitat Condition

The Management Area was included in a statewide assessment of the health of perennial, saline estuarine wetlands of California (Sutula et al. 2008a). For purposes of comparison, the state's coastline was divided into 4 regions based on eco-regional boundaries developed by Hickman (1993): the North Coast, San Francisco Estuary, Central Coast, and South Coast. Field data were collected for 30 randomly selected sites within each region. Most of the estuarine wetlands that represent the North Coast region were located within the Management Area. Sutula et al. (2008a) described ambient conditions at representative assessment sites and discussed how conditions vary by region within the state. Major stressors were identified for each region, and the ambient conditions assessments utilized the California Rapid Assessment Method (CRAM, Version 5.0.2) (Collins et al. 2008).

CRAM uses field indicators to assess wetland attributes within 4 categories: Landscape Context, Hydrology, Physical Structure, and Biotic Structure. A series of metrics was developed to provide scores that measure wetland health. The Landscape Context attributes measure the degree of aquatic connectivity and the size and condition of natural buffers that border the wetland. Hydrology attributes include freshwater source, hydrologic connectivity, and hydroperiod. Physical Structure attributes include structural patch richness and topographic complexity. Biotic Structure attributes include plant community composition, vertical vegetation structure, and horizontal zonation and interspersion of plant species or assemblages. Scores are reported as a percentage of the maximum possible CRAM points that can be assigned for each attribute category. Higher scores represent better condition and higher potential to provide wetland functions. Scores are ranked as follows: greater than 82 = Category 1; scores between 63 and 82 = Category 2; scores between 44 and 63 = Category 3; and scores less than 44 = Category 4 (Sutula et al. 2008a, b).

In terms of overall CRAM index scores, North Coast perennial, saline estuarine wetlands scored the highest of all California regions (averaging 4-15 points higher than other regions), especially with regards to Physical Structure (25-27 points higher). Mean ambient scores for North Coast wetlands fell within Category 1 for all attribute categories except Biotic Structure, which fell within Category 2. The reason for the relatively low score in Biotic Structure is attributed to the predominance of *S. densiflora* in North Coast marshes. Lack of treatment of invasive plant species was identified as the most frequent stressor, occurring at 88% of North Coast sites, and it was also considered to be the most severe stressor present at 70% of the sites. North Coast CRAM index scores were significantly lower for individual sites where the invasive plant stressor was severe.

Following invasive species, other top stressors identified for North Coast wetlands were: excessive sediment from local watersheds (occurring at 20% of sites), dikes and levees (20%), non-point source pollution (13%), and mosquito ditching (13%). Sutula et al. (2008a) recommended that *S. densiflora* in North Coast estuarine wetlands be controlled to improve overall species richness and biotic structure.

2.3.3 Plant Communities

Little historical botanical information is available for the region and preinvasion floristic descriptions of Management Area tidal marshes are lacking (Clifford 2002). Today, tidal marshes in the Management Area share a number of floristic features with other West Coast marshes. Plant species that range from British Columbia to Baja California include perennial pickleweed (*Salicornia pacifica* Standl.), (synonyms: *Sarcocornia pacifica* [Standl.] A. J. Scott: *Salicornia virginica* L., [misapplied]) (Baldwin et al. 2012), saltgrass (*Distichlis spicata* [L.] E. Greene), marsh jaumea (*Jaumea carnosa* [Less.] A. Gray), arrowgrass (*Triglochin* spp.), and saltmarsh dodder (*Cuscuta salina* Engelm.). Approximately 200 miles and further south, the native species *Spartina foliosa* is an important component of the low elevation salt marshes. Tidal marshes to the north generally occur in association with larger rivers and therefore have a greater freshwater influence. Lyngbye's sedge (*Carex lyngbyei* Hornem), a species typically associated with brackish conditions, is locally abundant in the Management Area, but it is a dominant species in tidal marshes further north (FNAEC 1993+, Grewell et al. 2007, Leppig and Pickart 2009, Macdonald 1977, Macdonald and Barbour 1974). On the West Coast of North America, the predominance of *S. densiflora* is unique to Management Area tidal marshes, although it has also been introduced to San Francisco Bay and has spread to a few locations in Washington and British Columbia.

The tidal elevation range of salt marsh in Humboldt Bay is from about 5.4 ft (1.7 m) MLLW (slightly below the level of MLHW) to about 8.8 ft (2.7 m) MLLW, or potentially higher where not truncated at its upper limit by levees. The transition from low/mid-elevation salt marshes to high salt marshes occurs at about 7.3 ft (2.2 m) MLLW (Claycomb 1983, Eicher 1987, Falenski 2007). Slight variations in marsh elevation influence length and duration of tidal inundation, which in turn influence the distribution of marsh plants (Figure 2-3). Low tidal elevations tend to have higher soil and water salinity and higher soil organic matter but lower soil aeration (Clarke and Hannon 1969, Zedler 1977).

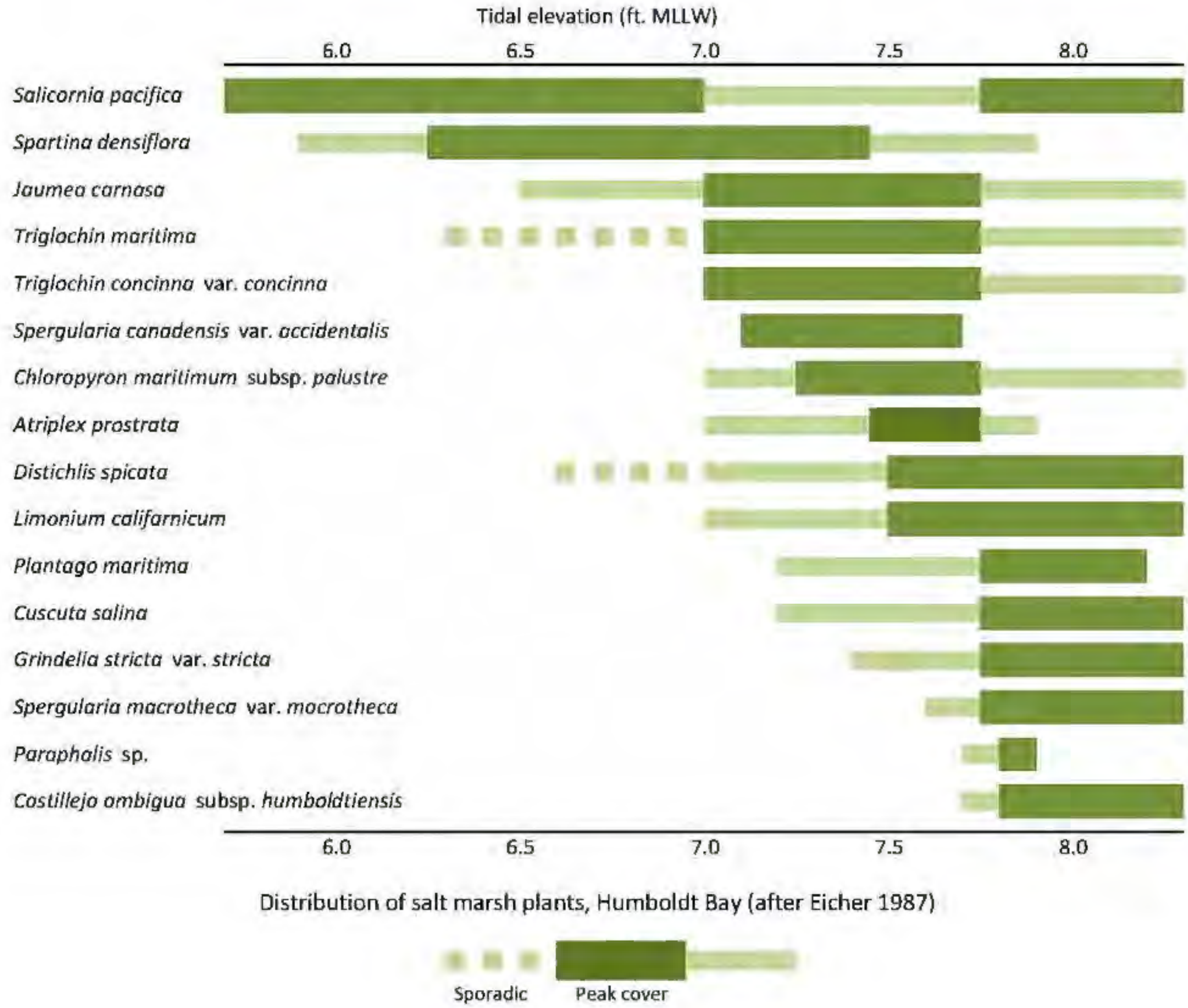

Figure 2-3. Salt Marsh Plant Species Tidal Elevation Range in North Humboldt Bay

Tidal marsh vegetation types within Management Area are classified and presented in Table 2-1, following *A Manual of California Vegetation* (MCV) (Sawyer et al. 2009). Most of these vegetation types were previously described by Pickart (2006) for diked wetlands of HBNWR. Pickart (2006) collected elevation, salinity, and soil moisture data to characterize the alliances. It should be noted that no regional classification for tidal marsh vegetation occurring outside diked areas has been completed for the North Coast, so the classification used here is likely incomplete and subject to change.

Table 2-1. Tidal Marsh Vegetation Types in the Management Area

Marsh Nomenclature Based on Salinity[1]	Manual of California Vegetation Type[2]	Alliance Common Name[2]
Slightly brackish marsh	*Juncus lescurii* Herbaceous Alliance	Salt Rush Herbaceous Alliance
Brackish marsh	*Deschampsia cespitosa* Herbaceous Alliance	Tufted hairgrass Herbaceous Alliance
	Potentilla anserina subsp. *pacifica* (Baldwin 2012) Herbaceous Alliance	Pacific silverweed Herbaceous Alliance
	Carex lyngbyei Herbaceous Alliance[3]	Lyngbye's sedge Herbaceous Alliance
	Distichlis spicata Herbaceous Alliance	Saltgrass Herbaceous Alliance
	Bolboschoenus maritimus Herbaceous Alliance	Alkali bulrush Herbaceous Alliance
	Atriplex prostrata-Cotula coronopifolia Semi-natural Herbaceous Stands	Triangle orache-brass buttons Semi-natural Stands
Salt marsh	*Salicornia pacifica* (Baldwin 2012) Herbaceous Alliance	Pickleweed Herbaceous Alliance
	Spartina densiflora Semi-natural Herbaceous Stands	Dense-flowered cordgrass Semi-natural Herbaceous Stands

[1] Vegetation types listed in order of increasing salinity (adapted from Pickart 2006)
[2] Sawyer et al. (2009) classification, modified with Baldwin et al. (2012) scientific nomenclature as noted
[3] Alliance not represented in MCV, but recognized locally and by the National Vegetation Classification System (NVCS) (NatureServe 2009)

A brief description of tidal marsh vegetation types is presented below. For detailed descriptions of alliances, including photos of each type, refer to Appendix A.

S. densiflora has invaded multiple tidal marsh vegetation types throughout the Management Area, primarily salt marshes but also brackish marshes. Subsequent to invasion of salt marshes, *S. densiflora* typically displaces native species and rises to a position of dominance. Once this has occurred, the vegetation type is classified as *S. densiflora* Semi-natural Herbaceous Stands. As a result, *S. densiflora* Semi-natural Herbaceous Stands are the most prevalent salt marsh vegetation type in the Management Area.

***Spartina densiflora* Marsh**

Low Elevation Pickleweed Marsh

High Elevation Pickleweed Marsh

The most common native salt marsh vegetation type is the Pickleweed Herbaceous Alliance. Perennial pickleweed is the dominant species, with 30% or more cover. This vegetation type occurs throughout the full range of intertidal elevations, but with different associated species occurring at different elevations. At the lowest tidal elevations, perennial pickleweed grows in dense monotypic mats (Eicher 1987); however, low elevation pickleweed marsh is now relatively rare in Humboldt Bay due to continuing encroachment by *S. densiflora* (Pickart 2001). Plant species diversity is highest in high elevation pickleweed marshes. Perennial pickleweed is the dominant species, with saltgrass and/or fleshy jaumea as frequent co-dominant species, and with a diverse assemblage of other plant species also occurring, including several rare plants (Figure 2-3) (Eicher 1987).

Saltgrass Marsh

Alkali Bulrush Marsh

The Saltgrass Herbaceous Alliance is found at intermediate to high elevations, typically in areas with somewhat muted tidal action. Saltgrass is the dominant species and pickleweed has <30% cover.

The Alkali Bulrush Herbaceous Alliance occurs at the upper edges of salt marshes and bordering tidal channels. The Lyngbye's Sedge Herbaceous Alliance is common along the lower banks of tidal creeks. The Tufted Hairgrass Herbaceous Alliance is found at the highest margins of salt marshes and on dikes. The Salt Rush Herbaceous Alliance is slightly brackish, occurring in seasonally inundated areas or at the upper margins of salt marshes. The Pacific Silverweed Herbaceous Alliance is only found in areas where there is significant freshwater influence.

2.3.4 Animal Communities

Animal communities in the Management Area have been described in numerous reports (Barnhart et al. 1992, CDFG 2010, Monroe 1973, Monroe et al. 1974, Roberts 1992, Schlosser and Eicher 2012, Stillwater Sciences et al. 2010, USFWS 2009c). Brief descriptions are provided here, grouping animal communities into the broad categories of invertebrates, fish, birds, mammals, and amphibians.

Invertebrates occupy several major habitat niches in estuarine marshes. Benthic fauna comprise both infauna, invertebrates that live under the soil surface, and epifauna, that live on the surface of the mud or on other organisms or plants. In addition to these aquatic invertebrates, terrestrial invertebrates, including flying insects, spiders, and mites, utilize the marsh at low tides or seek refuge on unflooded portions of the plants. Tidal creeks and salt pannes also have their own distinct fauna.

Diverse fish fauna, most of which are native species, inhabit the Management Area. Tidal sloughs are utilized by the endangered Tidewater goby (*Eucyclogobius newberryi*) and 3 threatened salmonid species: Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Oncorhynchus mykiss*) (discussed in more detail in Section 2.2.5). Estuarine habitat in the Management Area provdes a nursery for other species that are important to recreational and commercial fisheries including rockfish (*Sebastes* spp.), kelp greenling (*Hexagrammos decagrammus*), cabezon (*Scorpaenichthys marmoratus*) (Schlosser and Bloeser 2006) and Dungeness crab (*Metacarcinus magister*). Dungeness crab use salt marshes as habitat to escape predators during molting. Dungeness crab also use salt marshes as nursery habitat for larva which has been deposited into the estuary and transported shoreward by tidal currents (Lellis-Dibble et al. 2008). Additionally, there is a recreational fishery within Humboldt Bay that focuses on rockfish, lingcod (*Ophiodon elongates*), cabezon and kelp greenling at the jetties near Humboldt Bay's entrance; California halibut (*Paralichthys californicus*) and leopard sharks (*Triakis semifasciata*) in bay channels; and surfperches (Embiotocidae) throughout the bay. Clamming is also popular, particularly in south Humboldt Bay mudflats. Commercial fisheries focus on Pacific herring (*Clupea pallasii*) roe as well as northern anchovy (*Engraulis mordax*), which are captured to support live bait fisheries in the Pacific Ocean.

Numerous bird species use the Management Area marshes as a location to roost at high tide and/or as a place to forage. The Management Area is located on the Pacific Flyway, a major north-south travel route for migratory birds extending from Alaska to Patagonia. The Humboldt Bay, Eel River, and Mad River estuaries are major foraging and resting grounds for numerous species of migratory birds, particularly shorebirds and waterfowl that use the Pacific Flyway (Monroe 1973, Monroe et al. 1974, Springer 1982). For a list of bird species that commonly use Management Area tidal marshes to forage or roost, refer to Appendix A.

Mammals that use the Management Area marshes include raccoon (*Procyon lotor*), black-tailed deer (*Odocoileus columbianus*), river otter (*Lutra canadensis*), striped skunk (*Mephitis mephitis*), and mink (*Neovison vison*). Small rodents such as the California vole (*Microtus californicus*), white-footed mouse (*Peromyscus maniculatus*), vagrant shrew (*Sorex vagrans*), and house mouse (*Mus musculus*) are known to forage and breed in high elevation tidal marshes. Bats such as yuma myotis (*Myotis yumanensis*) forage over the marshes for insects (Springer 1982).

Amphibians such as Pacific tree frogs (*Pseudacris regilla*) and northern red-legged frogs (*Rana aurora*) occur in vegetated tidal marshes in the Management Area. However, while these species occur in Management Area marshes, they probably do not use these areas for breeding, because both these species of frogs have a low tolerance for salinity. Jennings and Hayes (1989) reported that exposure of pre-hatchling red-legged frog embryos to salinity greater than 4.5 parts per thousand caused 100% mortality and larvae will only tolerate salinities up to 7 ppt. However, these species may breed adjacent to the salt marshes in areas with freshwater inflows.

2.3.5 Sensitive Species

2.3.5.1 Sensitive Plant Species

Humboldt Bay Owl's Clover

Sensitive plant species that occur in intertidal coastal marshes in the Humboldt Bay/Eel River region include Humboldt Bay owl's clover (*Castilleja ambigua* Hook & Arn. subsp. *humboldtiensis* (Keck) Chuang & Heckard), Point Reyes bird's beak (*Chloropyron maritimum* (Benth.) A. Heller subsp. *palustre* (Behr) Tank & J.M. Egger, formerly *Cordylanthus maritimus* subsp. *palustris*) (Behr) T.I. Chuang & Heckard), western sand spurrey (*Spergularia canadensis* (Pers.) G. Don var. *occidentalis* R. Rossbach), Lyngbye's sedge, seacoast angelica (*Angelica lucida* L.), and dwarf alkali grass (*Puccinellia pumila* (Vasey) A. Hitch.) (CNPS 2012, Grewell et al. 2007, Leppig and Pickart 2009).

Humboldt Bay owl's clover and Point Reyes bird's beak are discussed together here because they are related taxa that co-occur in similar habitat and have similar growth characteristics. Both are ranked by the California Native Plant Society (CNPS) with a California Rare Plant Rank of 1B.2, fairly endangered in California (CNPS 2012). Neither have state or federal listings. Humboldt Bay owl's clover has a limited distribution, occurring only from Humboldt Bay south to Tomales Bay, California (Grewell et al. 2007). Point Reyes bird's beak's range extends northward into Oregon, where it is endangered. In California, the subspecies has been reported as far south as Santa Clara County (CNPS 2012). Both taxa are small annuals and they are both facultative hemi-parasites; they parasitize other plant species by root connections called haustoria, but also derive some of their energy through photosynthesis. Both Humboldt Bay owl's clover and Point Reyes bird's beak occur in high-elevation salt marshes (Eicher 1987). The life histories of these 2 rare annuals have been studied in high elevation salt marsh on islands of the intertidal coastal marsh at Mad River Slough and on the mainland of Mad River Slough in north Humboldt Bay (Bivin et al. 1991).

Pickart (2001) mapped Humboldt Bay owl's clover in May-June 1998 and Point Reyes bird's beak in June 1999 in salt marshes throughout Humboldt Bay. USFWS maintains an ongoing monitoring program for these species on HBNWR lands. Both species have exhibited high annual fluctuations in population numbers in over a decade of monitoring in Mad River Slough (Pickart 2001, Pickart 2012, Pickart and Miller 1988). Both species are locally abundant, but are rare across their range because of a drastic habitat decline. At the Lanphere and Ma-le'l Dunes Refuge Units, removal of *S. densiflora* from these species' habitat resulted in an explosive population increase of both Humboldt Bay owl's clover and Point Reyes bird's beak (Pickart 2011a). In a 2-year study at Humboldt Bay on Humboldt Bay owl's clover, no significant impacts associated with application of a mechanical *Spartina* treatment were detected in terms of plant abundance, vigor, or reproductive output (Eicher and Pickart 2011).

Pt. Reyes Bird's Beak

Western sand spurrey has a CNPS rank of 2.1, seriously endangered in California, but more common elsewhere (CNPS 2012). The plant grows in Oregon and Washington intertidal coastal marshes, but in California it is known only in Humboldt Bay/Eel River estuarine marshes. Western sand spurrey is a tiny annual plant that occurs in high elevation salt marshes. Eicher (1987) found *S. canadensis* var. *occidentalis* ranging from 7.1 to 7.7 ft (2.2 to 2.3 m) MLLW in North Humboldt Bay, typically associated with arrowgrass, common pickleweed, and marsh jaumea, whereas the more stout perennial sticky sand spurrey (*S. macrotheca* (Hornem.) Heynh. var. *macrotheca*) tended to grow at higher elevations (7.6 to 8.4 ft (2.3 to 2.6 m) MLLW), often in association with saltgrass.

Lyngbye's Sedge

Lyngbye's sedge has as CNPS Rank of 2.2, fairly endangered in California, but more common elsewhere (CNPS 2012). Lyngbye's sedge is locally abundant in intertidal coastal marshes along the coasts of Alaska, Washington, and Oregon. In California, the species extends as far south as Bolinas Lagoon, just north of San Francisco Bay, California (CNPS 2012). In Management Area tidal marshes, Lyngbye's sedge is typically found bordering sloughs near river mouths and where there are other freshwater inputs.

Seacoast angelica has a CNPS rank of 4.2, limited distribution (Watch List); the species appears to be fairly endangered in California but more common elsewhere (CNPS 2012). Seacoast angelica occurs in Oregon, Washington, Alaska, and on the east coast of North America. In California, seacoast angelica extends from

Del Norte County south to Mendocino County. In Humboldt Bay and the Eel River Estuary, seacoast angelica occurs in brackish marshes, usually at the upper margin of the marsh or growing on adjacent levees.

Dwarf alkali grass has a CNPS rank of 2.2 as fairly endangered in California, but more common elsewhere (CNPS 2012). Dwarf alkali grass is currently known from only 2 occurrences in California, one in the Eel River Estuary and the other in Fort Bragg, Mendocino County (CNPS 2012). This species occurs in Washington and in Oregon, where it is on a watch list. It has also been introduced to the Northeastern United States, and is found in Maine.

2.3.5.2 Sensitive Animal Species

Humboldt Bay, the Eel River Estuary, and the Mad River Estuary are utilized by 3 salmonid species that are listed as threatened under the Federal Endangered Species Act (ESA): Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Oncorhynchus mykiss*). Estuaries are known to be important rearing areas for juvenile salmonids before they enter the ocean (Healey 1980). Small Chinook salmon often occupy salt marshes, tidal creeks, intertidal flats, and other shallow nearshore habitats. Marsh habitats may be of particular importance to subyearling salmonids because of the high insect and invetebrate prey resources and potential refuge from predators (Bottom et al. 2005). Wallace (2006) found significant use of the tidal portions of Freshwater Creek, Elk River, and Salmon Creek (Humboldt Bay tributaries) by juvenile Chinook salmon, coho salmon and steelhead trout. Pinnix et al. (2008) found that in Humboldt Bay, juvenile coho salmon also utilize deep channels, channel margins and floating eelgrass mats.

Tidewater goby (*Eucyclogobius newberryi*), a species listed as endangered under the Federal ESA, has been found in Humboldt Bay's off-channel habitats that are only reached by very high tides, including areas behind tide gates. Tidewater gobies also occur in the Eel River Estuary (Chamberlain 2006, 2011). In both Humboldt Bay and the Eel River Estuary, substantial potential habitat for tidewater goby is likely on privately owned land that has not been surveyed. Longfin smelt (*Spirinchus thaleichthys*), which are listed as endangered under the State of California ESA, has been identified in the Eel River Estuary (Puckett 1977) and Humboldt Bay (CDFG 2009). Green sturgeon (*Acipenser medirostris*), which is listed as threatened under the Federal ESA, also occur in Humboldt Bay (Fritzsche and Cavannagh 2007).

Several additional sensitive wildlife species forage in or use the Management Area marshes and immediately adjacent areas. California Species of Special Concern that are known to use the area include northern harrier, short-eared owl (*Asio flammeus*), and northern red-legged frog. The western red bat (*Lasiurus blossevillii*) may also use the marshes (Johnston and Whitford 2009).

Section 3.0 Regional *Spartina* Ecology and Impacts

3.1 Overview

Section 3.1 provides an overview of *Spartina* species, with an emphasis on the West Coast invasions. For greater detail, refer to Appendix B.

The genus *Spartina* consists of 17 species of perennial cordgrass in the Poaceae family, with native ranges in North, Central, and South America; Europe; and North Africa (Mobberley 1956). Most of the species grow in coastal areas or on riparian stream banks. *Spartina* species possess specific adaptations to tolerate seasonally freezing temperatures, frequent inundation, and varying salinities (Daehler and Strong 1996). A number of *Spartina* species have expanded outside their native ranges into other marine systems. Non-native *Spartina* species have invaded salt marshes around the world including the west coast of North America from California to British Columbia, China, North Africa, Australia, New Zealand, and Europe (United Kingdom, France, Denmark, Germany, Spain, and the Netherlands) (Morgan and Sytsma 2010).

3.1.1 West Coast *Spartina*

The only species of *Spartina* that is native to the Pacific Coast of North America is *S. foliosa* (Daehler and Strong 1996, Mobberley 1956). *S. foliosa* ranges from Bodega Bay in central California south to Baja California with some gaps in between: it is absent in Monterey Bay and Morro Bay. The largest populations are found in San Francisco and San Pablo Bays, California (SFEISP 2003).

***Spartina foliosa* in San Francisco Estuary**

Four non-native invasive *Spartina* species have been documented on the West Coast: 1) *S. densiflora*; 2) *S. alterniflora*; 3) *S. patens*; and 4) *S. anglica* (Figure 3-1). All of these species have the potential to invade the Management Area, and managers are advised to be on the alert for spotting them.

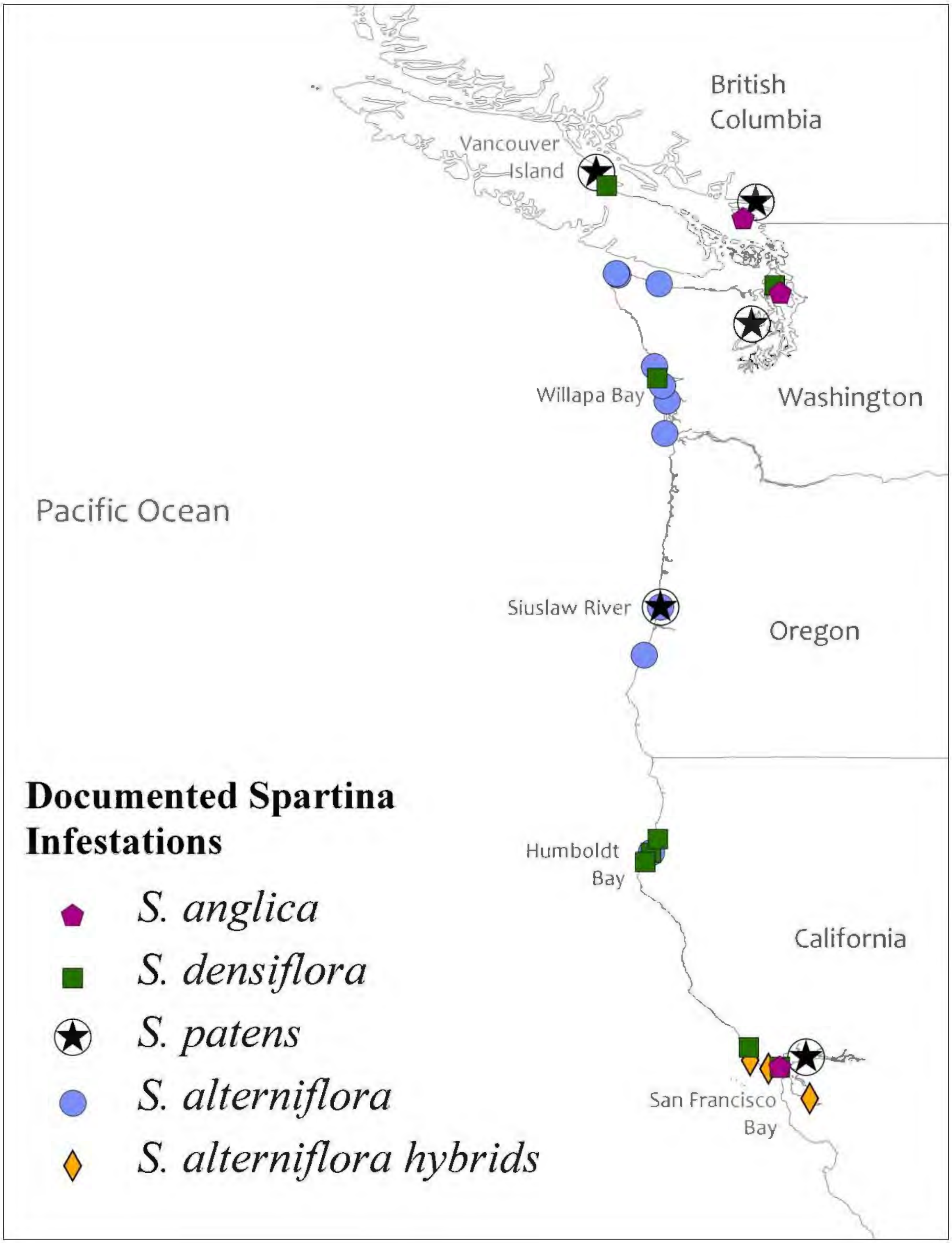

Figure 3-1. Distribution of Invasive *Spartina* on the West Coast of North America (courtesy of PSU 2012)

Spartina densiflora
(Photo by Andrea Pickart)

***Spartina alterniflora* Clone**
(Photo courtesy of San Francisco Estuary Invasive Spartina Project)

S. densiflora (dense-flowered cordgrass) is distinctive from other *Spartina* on the West Coast by its bunchgrass growth form; its short, shallow, creeping rhizomes; narrow, firm, in-rolled leaves that are grayish green; and its compact inflorescences. The bunchgrass habit is most apparent when the grass is interspersed with other species, and not as evident when the plants grow close together in dense stands.

S. alterniflora (Atlantic smooth cordgrass) is a tall, wide leaved grass with stems solitary or forming small clumps. Initially, the invasion appears as a round clone, eventually developing into dense stands or meadows. *S. alterniflora* has a relatively wide elevation range and can invade both tidal marsh and mudflat habitats. *S. alterniflora* spreads vigorously by rhizomes that are longer and grow deeper than *S. densiflora*. The leaf sheaths are often a reddish color. Inflorescences are open.

Spartina anglica
(Photo courtesy of San Francisco Estuary Invasive Spartina Project)

S. anglica (English cordgrass) is a hybrid between *S. alterniflora* and England's native *S. maritime*. *S. anglica* exhibits high morphological variability. It has solitary stems that can grow in small clumps or form monospecific stands. Like its parent *S. alterniflora, S. anglica* can spread vigorously by creeping rhizomes into marsh and mudflat habitats. It has wide leaves that often protrude at a right angle to the stem. Inflorescences are erect and dense.

Spartina patens

(Photo courtesy of San Francisco Estuary Invasive Spartina Project)

S. patens (salt meadow cordgrass) grows as a dense turf or sod, with fine, matted, decumbent stems. *S. patens* is intolerant of waterlogged mud, but invades high salt marsh with sufficient drainage. It has fine stems and the narrow, green leaves are soft and strongly inrolled. The inflorescence is open with spreading, narrow spikes.

3.1.2 *S. densiflora* Distribution on the West Coast

S. densiflora is currently the only species of *Spartina* occurring in the Management Area. The Humboldt Bay population represents the oldest *Spartina* invasion on the West Coast, traced back to the late 19th century. Other sites of *Spartina* invasion are much more recent (San Francisco Bay in 1980, Washington in 2001, and British Columbia in 2005). Currently, populations of *S. densiflora* occur on Vancouver Island in British Columbia, Canada (Dresen et al. 2010); in Grays Harbor and Puget Sound, Washington (WSDA 2011); in the Humboldt Bay region, California (Grazul and Rowland 2010) and in San Francisco Bay, California (Hogle and OEI 2011) (Figure 3-1), although *S.densiflora* populations in San Francisco Bay and Grays Harbor have been nearly eradicated. No populations of *S. densiflora* have yet been detected in Oregon (Howard et al. 2007) or Alaska (Morgan and Sytsma 2010).

S. densiflora has the potential to invade other estuarine environments along the West Coast given its ability to colonize a variety of substrates with varying salinity regimes (Bortolus 2006), and the potential for long range dispersal of seed by tides or inadvertent transport on equipment such as nets, cords, etc. via boats to other harbors and ports of the West Coast.

The potential for *Spartina* to disperse between West Coast estuaries is supported by a drift card study conducted by Portland State University (Morgan and Sytsma 2010). During a one-year period in 2004 and 2005, drift cards were released monthly from Willapa Bay, Washington, and Humboldt and San Francisco Bays in California, to determine the relative risk of major infestations colonizing other locations along the west coast. Drift cards released from Humboldt Bay were found within a month of their release at locations along the Oregon Coast and in southwest Washington. Observed seasonal trends were related to nearshore ocean currents that flow predominantly northward along the Oregon and Washington coasts in the fall and winter. During the fall and winter, drift card releases traveled northward 15.2 mi/day (24.5 km/day) and 22.9 mi/day (36.8 km/day) from Humboldt Bay and Willapa Bay, respectively. During the spring drift card release, drift cards from Willapa Bay were recovered in Oregon. Drift cards released from San Francisco Bay traveled northward at approximately 9.9 mi/day (16 km/day) (Morgan and Sytsma 2010). Isolated plants have been found on the outer coast of California north of San Francisco Bay suggesting that populations from San Francisco Bay could provide seed source to other estuaries along the California and the Pacific Coasts (Strong and Ayres 2005).

3.2 *Spartina densiflora* in the Management Area

Section 3.2 provides a summary of the regional invasion and spread of *S. densiflora* in the Management Area and current extent in regional tidal marshes. For greater detail, including a description of past and recent regional mapping, refer to Appendix B.

3.2.1 Invasion and Spread

S. densiflora is believed to have been transported to Humboldt Bay in ballast of returning ships transporting lumber to Chile (Spicher and Josselyn 1985), possibly following the 9.0 magnitude earthquake of 1868 that destroyed many Chilean coastal towns (Billings 1915). It was not until 1984 that *Spartina* in the Management Area was recognized as *S. densiflora* as the result of genetic testing (Spicher 1984, Spicher and Josselyn 1985) and later confirmed by Faber (2000). Prior to that discovery, Humboldt *Spartina* was thought to be a northern ecotype of the native *S. foliosa*. Under that erroneous assumption, plant material from Humboldt Bay was transplanted to a marsh restoration site in San Francisco Bay in 1976, the initial introduction of the species to that region (Faber 2000).

By the 1960s, *S. densiflora* had become a dominant species in the flora of tidal marshes in the Management Area (Macdonald 1967). In Humboldt Bay, historical photographs from the 1970s show that large areas of Indian Island and Jacoby Creek marsh remained free of *S. densiflora*. In a 1985 investigation at Humboldt Bay, Eicher (1987) found *S. densiflora* occurring from 5.9 to 7.9 ft (1.8 to 2.4 m) MLLW, almost the full range of tidal elevations at which salt marsh vegetation occurred (5.7 to 8.4 ft (1.7 to 2.6 m) MLLW. *S. densiflora*-dominated marsh was most prevalent from 6.9 to 7.3 ft (2.1 to 2.2 m) MLLW. Since that time, *S. densiflora* distribution and abundance has expanded into the lowest marsh elevations, with clumps of *S. densiflora* observed encroaching onto intertidal mudflats below the elevation of existing salt marsh vegetation, and into the highest marsh elevations, including high diversity marshes that support rare plant species (Pickart 2001). The frequency of *S. densiflora* measured in high salt marshes at the Mad River Slough showed a 50-fold increase between 1989 and 1997 (Pickart 1997). By 1999, Pickart (2001) estimated that over 90% of salt marshes in Humboldt Bay had been invaded by *S. densiflora,* with over half characterized as having dense cover (≥70%) by *S. densiflora.*

Little historical information is available documenting the invasion and spread of *S. densiflora* in the other 2 estuaries in the Management Area. In the Eel River Estuary, *S. densiflora* prevalence in tidal marshes was noted previously by Eicher and Bivin (1991), H. T. Harvey & Associates (2008), and Roberts (1992). It appears that relatively recent sedimentation and accretion in the the Eel River Estuary has resulted in *S. densiflora* colonization and expansion in the newly accreted areas.

3.2.2 Current Extent

S. densiflora is now a dominant species in salt marshes throughout the Management Area. It has also invaded adjacent seasonally flooded brackish marshes and in some places it is encroaching onto intertidal mudflats.

Substrates are typically mud or sand, but *S. densiflora* sometimes occurs on gravel substrates such as riverbars on the lower Mad River. It is also found growing on artificial substrates such as rip-rap levees.

Regional *S. densiflora* mapping was completed in 2011 by HBNWR staff through an agreement with the Harbor District and was funded by the Conservancy and the Federal Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE). The density of *S. densiflora* was categorized according to 3 cover classes: 1-25%, 26-60%, and 61-100% cover (Grazul and Rowland 2011). A total of 1671 acres on land in the Management Area are infested with *S. densiflora*, with 1008 ac (408 ha) occurring in Humboldt Bay, 656 ac (265 ha) in the Eel River Estuary, and 7.4 ac (3.0 ha) in the Mad River Estuary. Approximately 37% of this acreage was characterized as having high density *S. densiflora* (>60% cover) (Grazul and Rowland 2011) (Table 3-1; Figures 3-2 through 3-4).

Table 3-1. Acres Infested by *S. densiflora* in the Management Area (Grazul and Rowland 2011)

		Cover Class			
Sub-Region	**Total Acres**	**91-100%**	**26-60%**	**1-25%**	**Linear Features**
Mad River Estuary	7.36	1.88	0	5.47	0.16
North Humboldt Bay[1]	867.50	314.94	243.37	308.18	14.43
South Humboldt Bay	140.21	26.71	45.17	68.31	8.57
Eel River Estuary	656.42	278.96	171.78	205.66	2.61
Total Infested Acres	1,671.49	622.49	460.32	587.62	25.77

[1] includes Entrance Bay

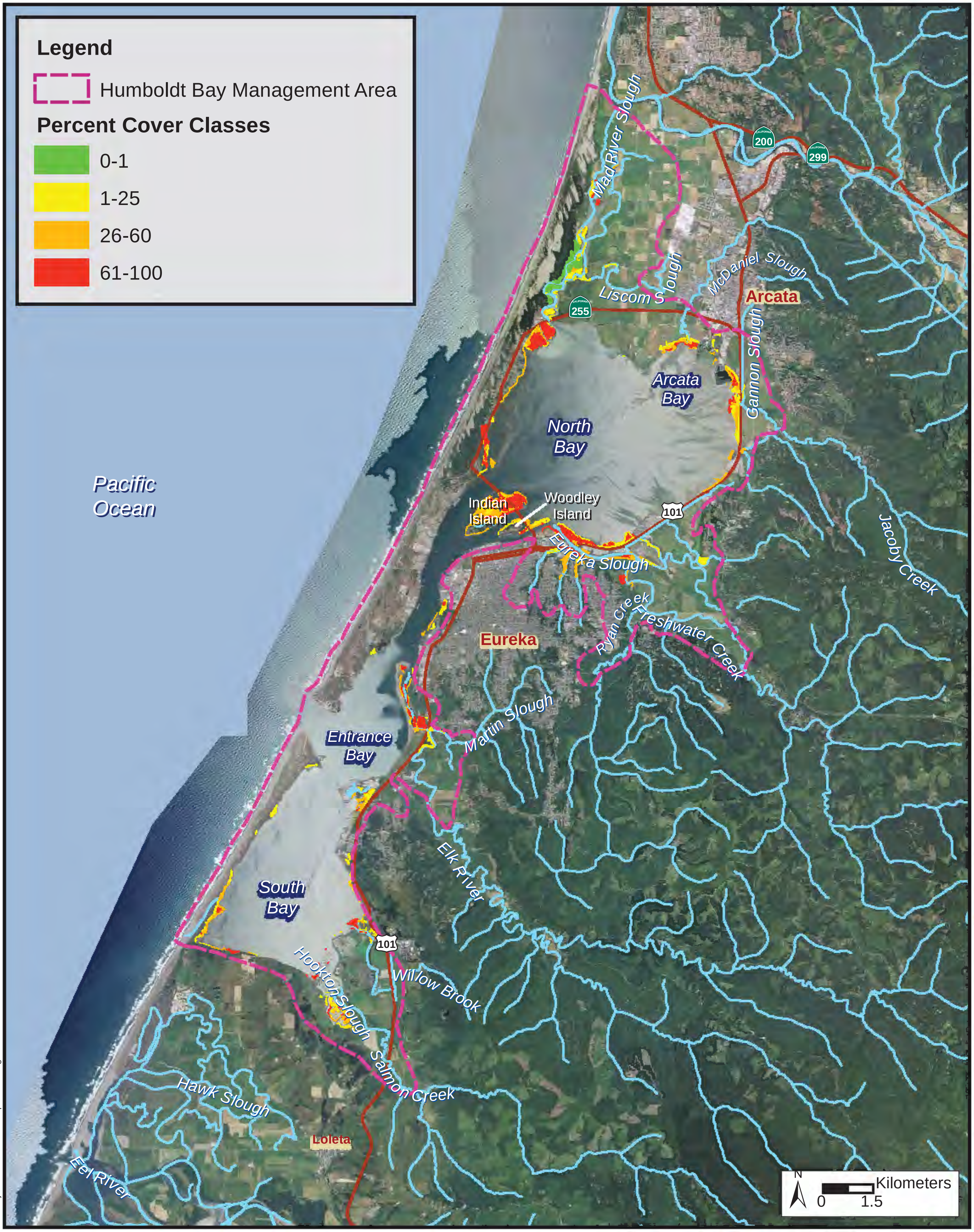

Figure 9: Humboldt Bay Spartina Densiflora Distribution
Figure 3-2. *S. densiflora* Distribution in Humboldt Bay

Humboldt Bay Regional Invasive Spartina Management Plan (3192-02)
March 2012

H. T. HARVEY & ASSOCIATES
ECOLOGICAL CONSULTANTS

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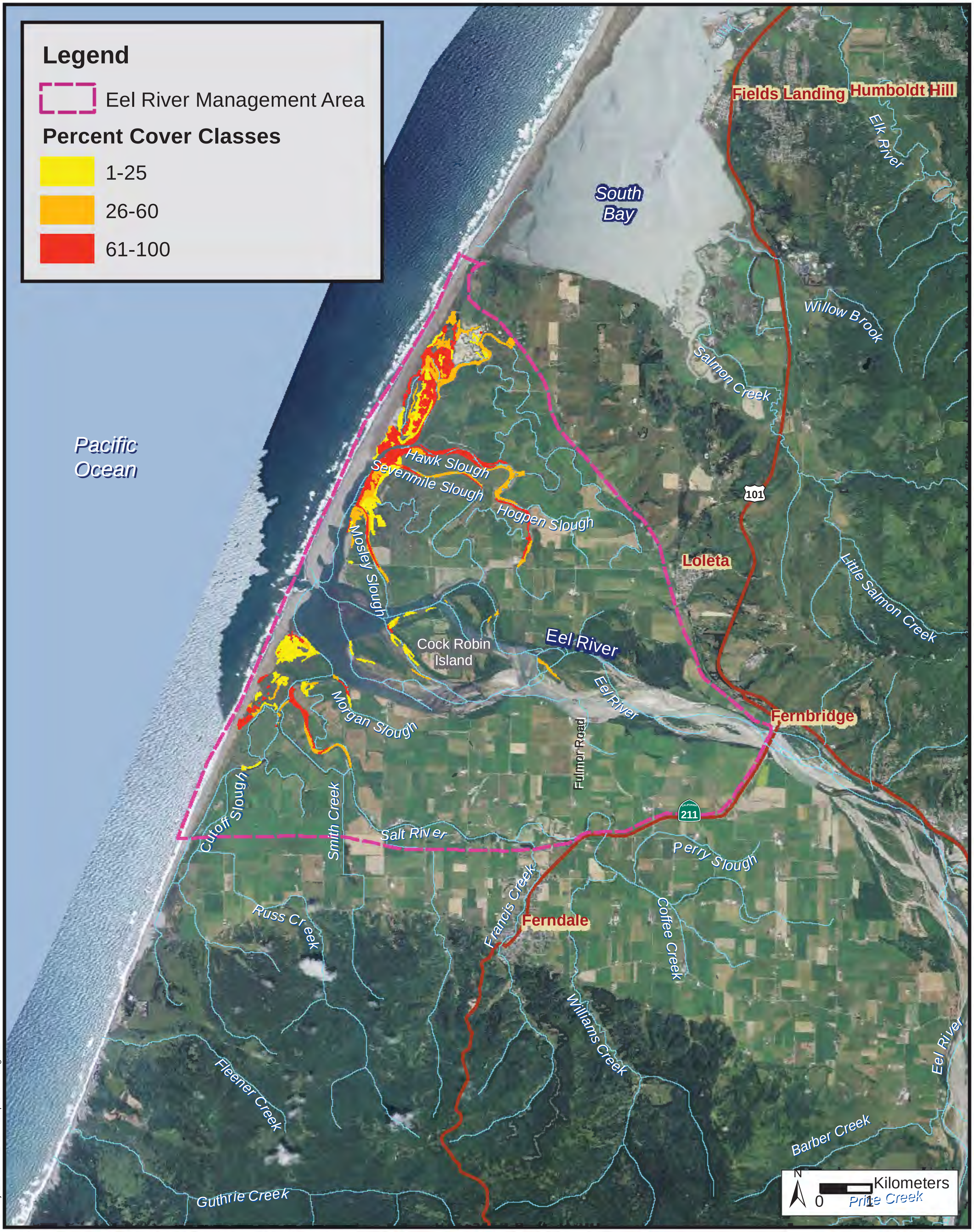

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Figure 3-3. *S. densiflora* Distribution in the Eel River Estuary

Figure 7: Eel River Spartina Densiflora Distribution

Humboldt Bay Regional Invasive Spartina Management Plan (3192-01)
March 2012

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Figure 3-4. *S. densiflora* Distribution in the Mad River Estuary

Figure 4. Mad River Management Area

Humboldt Bay Regional Invasive Spartina Management Plan (3192-01)
March 2012

3.3 Ecology of *Spartina densiflora*

Section 3.3 provides a summary of the ecology of *S. densiflora*. For greater detail, refer to Appendix B.

S. densiflora is a long-lived perennial species with a bunchgrass growth form, short creeping rhizomes, and stiff in-rolled leaves (Boe et al. 2010, Bortolus 2006, Spicher 1984). Based on biogeographical (Bortolus 2006) and molecular evidence (Fortune et al. 2008), *S. densiflora* is believed to be native to the southeastern coastal marshes of South America, where it ranges from Sao Paulo, Brazil to Rio Gallegos, Argentina. From its native range, *S. densiflora* spread by various means to Chile, the USA, Spain and Morocco (Bortolus 2006). The tiller density, biomass production, flowering period, and phenotype of *S. densiflora* are highly variable among the regions where it occurs (Bortolus 2006). Differences in plant vigor between locations where the plant is native and where it is introduced are the subject of current studies (Bortolus 2010).

There are some important differences in characteristics of *S. densiflora* compared to other *Spartina* species that have invaded the West Coast. *S. densiflora* does not grow at tidal elevations as low as most other invasive *Spartina*. *S. densiflora* has less developed aerenchyma tissue, which may in part explain why the plant favors slightly higher elevations where inundation is less frequent. *S. densiflora* has short rhizomes and the root system is relatively shallow. In studies of *S. densiflora* in a variety of marsh types in Spain, Nieva et al. (2001) found that most of the below ground biomass was concentrated in the upper 20 cm of soil. *S. densiflora* has narrow, inrolled leaves. It has a slower growth rate and does not spread as aggressively by rhizome as *S. alterniflora*. Additionally, the wrack generated by *S. densiflora* is not as abundant as that produced by *S. alterniflora* (Bortolus 2006).

In the Management Area, *S. densiflora* exhibits different growth forms and density levels, apparently in response to a combination of environmental factors and interspecific competition. It is most robust in mid to low tidal elevation marshes with ample tidal flushing. Plants occurring at lower tidal elevations in the Mad River Estuary, where freshwater influence is relatively high, have wider and less inrolled leaves. Pure stands of the dense clumped grass can cover large areas of low or mid-elevation marsh or occur as a fringe bordering tidal channels in higher marsh. On mature, well drained marsh plains with relatively high salinities, *S. densiflora* generally grows at lower densities interspersed with other marsh species, or as linear stands bordering tidal creeks and salt pannes. In brackish marshes, *S. densiflora* is sometimes mixed with other tall graminoids such as the native hairgrass (*Deschampsia cespitosa* L.) and can be hard to discern.

3.3.1 Reproduction

S. densiflora is a perennial grass that can reproduce both sexually and by vegetative expansion. *S. densiflora* spreads vegetatively by the formation of belowground rhizomes and tillers which grow laterally and can result in the growth of plants distant from the original plant (Nieva et al. 2001). The production of annual tillers from short rhizomes each year results in expansion and competition with existing salt marsh plants and gives the plant the characteristic 'tussock' look (Kittelson 1993).

S. densiflora establishment and spread is typically lower in undisturbed marshes (Eicher 1987, Kittelson and Boyd 1997) than in disturbed areas, such as patches of open space created by storm damage, wrack accumulation, or human disturbance. In the field, Kittelson and Boyd (1997) found the vegetative growth of *S. densiflora* to be greater in plants surrounded by bare space than in those with neighboring vegetation. Plants growing in association with competitors produced tightly packed tillers, but plants growing in the absence of competitors produced tillers that expanded farther away from the plant, resulting in vegetative expansion over a greater area.

In the Management Area, *S. densiflora* flowers in Humboldt Bay from June through August, with seed maturation and dispersal occurring in September through October (Kittelson 1993). *S. densiflora* has extremely high fecundity. Kittelson and Boyd (1997) estimated that each plant produces a total of 2512 ± 105 seeds, of which 78.7%, or 1977 ± 80 seeds, are viable. In that study, the mean number of inflorescences produced by each plant was 28.7 ± 16, which equates to approximately 88 seeds/inflorescence. A more recent study by HBNWR found a mean of 112 (SE 5.5) seeds produced per inflorescence, but did not assess viability. HBNWR measured density of inflorescences, finding approximately 7.9 inflorescences/ft^2 (85/m^2) in low to moderate density *Spartina* and 10.2/ft^2 (110/m^2) in high density *Spartina*. This represents a range of seed production between 35-47 million seeds/acre (88-118 million/ha) (Pickart 2012). Applying the viability rate of 78.7% determined by Kittelson and Boyd (1997), the estimated production by *S. densiflora* in the Management Area is 27-37 million viable seeds per ac (67-93 million/ha).

Mature inflorescences are shattered by wind and wave action, and seeds are either deposited in the vicinity of parent plants or dispersed by tides. Seed dispersal is undocumented but presumably begins at seed set and may continue throughout the winter. Patterns and range of seed dispersal are unknown. Seed produced in the fall may germinate the following spring-summer or be stored in the soil seed bank. In a recent study, Pickart (2012) confirmed that *S. densiflora* has a persistent seed bank lasting at least 2 years. Seed viability in the seed bank declined at most study sites after 2 years (seed replenishment was prevented to derive this assessment), but remained the same in the site characterized by the densest seed bank. HBNWR plans to continue these seed bank studies to determine longevity. Seed bank density, ranging from 0.4-15 million seeds/acre (1-38 million/ha) in the 1st year, was strongly correlated to aboveground abundance of *Spartina*, suggesting that seeds are primarily entering the bank at the site of seed production. It is also possible that seed deposition rates are higher in dense *S. densiflora* stands because the dense tall plants may be better able to trap seeds than native vegetation (Pickart 2012). An additional study to measure the relative contributions of seed produced on-site and dispersal from seeds produced off-site is scheduled to start in fall 2012 (Pickart, pers. comm., September 2012). Bortolus et al. (2004) found that plants in undisturbed marshes have a lower reproductive effort than plants in highly disturbed marshes, and that increased disturbance resulted in increased seed production in *S. densiflora*.

Each seed-bearing *S. densiflora* plant represents a source of propagules that may reinfest treated sites. Evidence suggests that this threat is greatest in proximity to the parent plant and diminishes with increasing distance. Quantitative data are needed to gauge the relative degree of threat at various distances. It may be possible to place seed traps in tidal slough channels at various distances from known *S. densiflora* stands.

Monitoring conducted before and after fall high tides could yield quantitative data on seed dispersal rates (Pickart, pers. comm., November 2011).

Spicher and Josselyn (1985) found that the seeds of *S. densiflora* are tolerant of long storage periods in dry or moist conditions. However, HBNWR staff has found that seed kept dry was dead after 6 months. Seed germination and seedling survival occur at salinities less than 11% as determined in experimental trials (Kittelson and Boyd 1997). In salinities of 4%, seedling survival and growth was higher than in salinities of 11% to 26% (Clifford 2002). Seedling recruitment is generally highest during the spring, especially associated with rain events that lower soil salinity. Seedling establishment is lower during years of lower rainfall and in soils with higher salinities (Kittelson and Boyd 1997). Once plants are established, growth and expansion easily occur at higher salinities.

3.3.2 Productivity

In Humboldt Bay, Rogers (1981) found that S. *densiflora* displayed higher aboveground primary productivity than pickleweed or saltgrass, but did not measure belowground primary productivity or the primary productivity of non-vascular autotrophs. Lagarde (2012) used aboveground and belowground biomass measurements coupled with paired closed chamber carbon dioxide flux measurements to compare primary productivity of *S. densiflora* dominated marsh to that of marsh dominated by native vegetation. While net primary productivity (NPP) of *S. densiflora* marsh was higher for aboveground biomass, it was lower for belowground biomass and total NPP was lower overall (Table 3-2). *S. densiflora* marsh also exhibited lower net ecosystem exchange measurements (gross primary productivity minus ecosystem respiration rate), presumably as a result of shading and subsequently lower production by benthic macroalgae. Benthic macroalgal cover was a good predictor of net ecosystem exchange (Lagarde 2012).

Table 3-2. NPP in Native and Invaded Marsh in the Management Area

Marsh Type	Aboveground NPP (g C/m²/year)[1]	Belowground NPP (g C/m²/year)[1]	Overall NPP (g C/m²/year)[1]
Native Marsh	194/459	5169/4168	5363/4491
S. densiflora Marsh	628/680	1749/1732	2377/1917

[1] The 1st number shown was derived using the Maximum Minus Minimum Method (MMMM) and the 2nd number using Smalley's Method (Lagarde 2012)

3.3.3 Adaptive Advantages

A number of *S. densiflora* characteristics give it a competitive advantage over native tidal marsh plants in the Management Area. Physical characteristics include a tall canopy and production of abundant aboveground biomass, which can reduce light availability and limit photosynthesis for shorter stature species; the reduced light and shading from the tall canopy can also alter sediment temperature (Bortolus et al. 2002). Physical structures such as aerenchyma in leaves, rhizomes, and roots allow *S. densiflora* to gather available oxygen in oxygen limited environments. Salt secreting glands on leaves allow the plant to excrete excess salt to maintain cellular ionic balance (Rozema et al. 1981). Physical processes such as C_4 metabolism give *S. densiflora* a competitive advantage over C_3 salt marsh plants, such as pickleweed, in conditions of low water availability, and allow it to photosynthesize more readily.

Different growing strategies enable *S. densiflora* to adapt to local environmental variables and microhabitat conditions (Kittelson and Boyd 1997, Nieva et al. 2005). Once established, *S. densiflora*'s dense tussocks and dense root systems limit colonization by other species. Bare areas resulting from wrack deposition favor dominance by *Spartina* over other salt marsh species by restricting native species establishment and smothering established species (Kittelson and Boyd 1997). This creates a negative feedback look that promotes further colonization by *Spartina*.

S. densiflora does not go completely dormant, allowing it to be an effective competitor year round, whereas many salt marsh plants such as pickleweed, jaumea, and saltgrass have dormant periods in the winter (Kittelson and Boyd 1997, Trilla et al. 2010, Vicari et al. 2002). Abundant seed production and a persistent seed bank allow the species to be reproductively competitive, especially in open or disturbed areas. High seedling flushes have been observed occurring in bare areas where *Spartina* has been removed from HBNWR treatment sites (Pickart 2012). Seedlings are not as competitive in established marshes as in bare areas (Falenski 2007, Kittelson 1993, Kittelson and Boyd 1997, Rogers 1981).

3.4 Ecological Impacts of *Spartina densiflora*

3.4.1 Ecosystem Level Impacts

Salt and brackish marshes in the Management Area are valuable components of local estuarine ecosystems, and are intricately linked to other estuarine habitats such as mudflats, subtidal channels, and native eelgrass (*Zostera marina*) beds. Therefore, impacts of *S. densiflora* invasion are not only detrimental to marsh communities but the entire ecosystem. Rejmanek et al. (1988) demonstrated a positive correlation between plant biomass and sediment deposition. The cespitose nature of *S. densiflora*, high stem densities, and stout leaves effectively trap nutrient-laden sediment particles suspended in the water column. The resulting increase in sediment deposition favors further establishment of *S. densiflora* and encroachment into other habitats such as mudflat. Pickart (pers. comm., October 2012) noted that there has been about 4 in (10 cm) or more of accretion around the plants growing on the lower elevation mudflat at the Mad River Estuary between 2010 and 2012. *S. densiflora* marshes have a lower NPP than native tidal marshes in the region (Lagarde 2012).

S. densiflora has colonized some mudflats in the Management Area, although it is not as big a threat to mudflat habitats as *S. alterniflora* is at other locations such as Willapa Bay. Within the boundaries of HBNWR, 4.9 ac (2.0 ha) of *S. densiflora* was documented growing directly on mudflat with no other salt marsh vegetation nearby (Grazul and Rowland 2010). It has been observed growing on mudflats in other areas of the world where it has invaded (Bortolus 2006, Clifford 2002). Mudflat communities include several species of algae, invertebrates such as polychaete worms, ghost shrimp, and clams, and native eelgrass (*Zostera marina*). Eelgrass is a large contributor to estuarine primary productivity and eelgrass habitat also functions as nursery, feeding, and refuge areas for juvenile invertebrates, Dungeness crab, and many bird species (Dean et al. 1998, Pfauth et al. 2003).

Climate change and associated sea level rise are expected to impact coastal marshes, and the results are hard to predict. Local resource managers are working to investigate opportunities for intertidal marshes to migrate inland as sea level rises. Dense monocultures of *Spartina* have little morphological or genetic diversity to allow adaptation to changing conditions, whereas restored marsh communities dominated by native marsh species will be more resilient to these changes.

3.4.2 Threats to Plant Communities

In low and mid-elevation salt marshes throughout the Management Area, *S. densiflora* commonly forms dense monocultures that have displaced native plant species such as pickleweed, fleshy jaumea, and seaside arrow grass. Continuing encroachment by *S. densiflora* in already scarce high elevation salt marshes within the region threatens a diverse plant community that provides habitat for the rare plant species Humboldt Bay owl's clover, Point Reyes bird's beak, and western sand spurrey.

Salt Marsh Dominated by *S. densiflora* in Humboldt Bay

Brackish Marsh Invaded by *S. densiflora* in the Mad River Estuary
(Photo by Andrea Pickart)

In addition to colonizing salt marshes, *S. densiflora* is also invading brackish marshes in the Management Area, including tidal areas with strong freshwater influence (Grazul and Rowland 2011) and areas with muted tidal action near open or leaking tide gates (Pickart 2001, Pickart 2006). These brackish communities support the special status species Lyngbye's sedge and sea watch angelica, and also include seacoast bulrush (*Bolboschoenus maritimus* (L.) Palla subsp. *paludosus* (A. Nelson)), tufted hairgrass, and salt rush. Encroachment of *S. densiflora* is also evident on mudflats, where invasion causes a reduction in cover and diversity of algal functional groups (Augyte and Pickart In Prep).

Mudflat Encroachment by *S. densiflora* in the Eel River Estuary

The ability of *S. densiflora* to colonize newly disturbed or bare areas poses threats to restoration projects, areas for *Spartina*. This may result directly from earthwork or contouring of the site. Invasion pathways may also be indirect, such as when a levee is breached and the new tidal influx results in die-off of the existing vegetation. In Humboldt Bay, including *Spartina* treatment sites. Areas newly opened to tidal influence and without established vegetation are prime colonization examples of *Spartina* colonizing restoration project sites have been documented for the Park Street Restoration Project (Claycomb 1983, Clifford 2002, Springer et al. 1984); the King Salmon Slough Restoration Project (Eicher 1993); the Palco Marsh enhancement project (Eicher et al. 1995); the Butcher's Slough Restoration Project, and at *Spartina* treatment sites (Pickart 2012).

3.4.3 Threats to Animal Communities

Reduced diversity and abundance of terrestrial invertebrates and changes in representation of functional groups were observed in a *S. densiflora* invaded marsh in the Mad River Slough in Humboldt Bay (Mitchell 2010). Removal of *S. densiflora* has been demonstrated to result in a trophic shift in invertebrate communities, resulting in increased species richness and an increased abundance of the native snail *Littorina subrotundata* (Mitchell 2012).

Fish may be impacted by changes to ecosystems, geomorphology and hydrology that are a result of *S. densiflora* invasion. Native fishery species in the Management Area that may be affected by these changes include Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), Dungeness crab (*Metacarcinus magister*) and tidewater goby (*Eucyclogobius newberryi*). Potential impacts to these species from a *Spartina* invasion in lower elevations may include barriers to movements in tidal waters as the edges of the channels are vegetated, and potentially reducing some foraging habitat on mudflats or along the edges of channels. These species have both ecological and economic value and depend on habitats within the Management Area to complete critical portions of their life cycle. If *S. densiflora* becomes more prominent at lower elevations (i.e., in mudflats and tidal channels), more significant effects to fish communities could occur in the Management Area.

Few shorebird species currently forage in salt marshes around Humboldt Bay; however, it is possible that shorebird usage of the marshes might increase following restoration of native salt marsh plant communities. A current study is underway comparing avian use in marshes dominated by *S. densiflora* with restored marshes dominated by native tidal marsh plant species (Johnson, pers. comm., August 2012). Should *Spartina* expand further into unvegetated mudflat areas, the primary potential impact on habitat quality would be loss of mudflat habitat. The most significant impacts would be to shorebirds such as dunlin, western sanpiper, least sandpiper, and others that congregate and feed on intertidal mudflats throughout the winter each year (Danuvsky and Colwell 2003, Harris 2006).

3.5 Other *Spartina* Species in the Management Area

Aside from *S. densiflora*, the only other invasive *Spartina* species that has ever been documented in the Management Area is *S. alterniflora*. Native to the eastern and Gulf coasts of North America, *S. alterniflora* was first detected in Humboldt Bay in 1985 at a salt marsh in Samoa, on the eastern shoreline of Humboldt's North Bay. *S. alterniflora* initially colonized unvegetated mudflat that occurred at lower intertidal elevations than *S. densiflora* marsh (Eicher and Sawyer 1989). Over 3 years, the *S. alterniflora* stand increased from 10 ft^2 to 5,000 ft^2 and spread upward into vegetated salt marsh. CDFG effectively eradicated the species by diking the area, cutting the grass to grade, removing all cuttings from the site, applying salt, covering it with black semi-permeable geotextile fabric, and weighing down the fabric and seams with sand bags. Around the same time, *S. alterniflora* was detected in the Eel River Estuary, within vegetated salt marsh but along an eroding edge of the marsh. This population was washed away by winter floods, covered by a subsequent layer of deposited alluvial sand, and did not reestablish (Kovacs, pers. comm., February 2010). Without the control efforts by CDFG, it is likely that *S. alterniflora* would have spread widely onto the mudflats. *S. alterniflora* and/or other species of *Spartina* could invade restored areas, and land managers need to stay alert for early detection and rapid response should invasion occur.

Section 4.0 Regional *Spartina* Eradication Strategy

4.1 General Strategic Approach

Section 4.1 provides a general strategic approach that is consistent with coast-wide *Spartina* eradication efforts while addressing conditions unique to the Management Area. Major objectives are to provide regional coordination, to help expedite ongoing efforts to eradicate *S. densiflora* in the Management Area, and to be prepared to respond to other invasive *Spartina* species that may invade in the future. The foundation for this strategy is based on lessons learned from other West Coast invasive *Spartina* eradication efforts and from ongoing research and eradication work specifically with *S. densiflora* in Humboldt Bay. For greater detail on lessons learned, refer to Appendix C.

As part of the coast-wide effort, a *Spartina* Eradication ACT was formed and a work plan (ACT Work Plan) developed by Boe et al. (2010). The regional eradication strategy presented here is consistent with the critical elements outlined by the ACT Work Plan, including coordinated eradication of existing invasive *Spartina* populations, restoration of native plant communities, procedures for minimizing reinvasion, long-term monitoring to detect and treat new infestations, and extensive communication and outreach.

The ACT Work Plan recognized that adequate funding, political will, and coordinated efforts are needed for effective *Spartina* eradication, as demonstrated by successful programs thus far, such as in San Francisco Estuary in California; Willapa Bay, Grays Harbor and Puget Sound in Washington; and most infested sites in Oregon. Based on these successes, key lessons that have been incorporated into the regional *Spartina* eradiaction strategy for the Management Area include:

- Regional coordination provides a framework for long-term funding, permitting, planning, implementation, monitoring, evaluation, communication and outreach
- Community and agency support are paramount for success
- The use of integrated management techniques can improve effectiveness and offer flexibility
- An adaptive management approach will allow periodic re-evaluation of treatment strategy based on monitoring results and on new research findings
- Maintaining a database is important for housing regional and site-specific data
- Annual reports are important for describing the progress of eradication efforts

While these elements have coast-wide applicability, each region faces unique challenges, considering individual *Spartina* species characteristics, site conditions, and community dynamics. Factors unique to the Management Area were considered in developing the eradication strategy for our region. As the current sole invasive *Spartina* species occurring in the Management Area, *S. densiflora* is the major focus of the treatment strategy presented and treatment methods discussed. The *S. densiflora* infestation here is by far the oldest *Spartina* invasion on the West Coast, with ample time to have become widespread and well-established as a dominant species in tidal marshes throughout the Management Area. The strategy used to launch eradication of a widespread, well established plant population, at least initially, is different than that for nascent or satellite infestations. It also represents the largest *S. densiflora* population anywhere on the West Coast, and most of the treatment method development specific to this species has been conducted in the Management Area over the past 10 years.

S. densiflora has shallow rhizomes (relatively easier to treat with mechanical techniques than other invasive *Spartina*) and inrolled leaves (less responsive to chemical treatments than other invasive *Spartina*). Noting the observed herbicide resistance by this species, the need for further development of methods specific to *S. densiflora* was recognized in the ACT Work Plan (Boe et al 2010). Control method development for *S. densiflora* in the Management Area thus far has focused on mechanical treatments, although chemical treatment and combined chemical and mechanical treatment methods are currently also under investigation, and information available to date for all are presented here. *S. densiflora* grows at higher elevations than most other invasive *Spartina,* and while there is evidence of encroachment onto mudflats in the Management Area, it is not as big a threat in this regard as other species (such as the rapid and expansive *S. alterniflora* invasion of mudflats in Willapa Bay, WA). Since the native range of *S. foliosa* does not extend this far north, hybridization is not one of the challenges faced in this region (a major challenge in the San Francisco Estuary, primarily the hybrid cross *S. alternifora* x *S. foliosa*, but *S. densiflora* x *S. foliosa* also occurs there).

The regional eradication strategy was developed based on the best currently available data. Recommendations are intended as guidelines and not as constraints for those involved in implementation of regional *Spartina* eradication. An adaptive management approach will allow the flexibility to make adjustments as new information becomes available, facilitating plan changes in response to new research results, the outcome of treatments employed, funding opportunities, logistical constraints, new challenges, and other unforeseeable factors.

4.2 Regional Coordination

One of the 1st steps in establishing a regional *Spartina* eradication program will be to designate a regional coordinating agency or other entity (Regional Coordinator) to help ensure comprehensive implementation of the Regional Plan and provide the long-term commitment needed to complete *Spartina* eradication. The Regional Coordinator will serve as: 1) the applicant/holder of region-wide permits; 2) the applicant/administrator for region-wide funding; 3) the coordinator for site-specific planning, implementation, and monitoring throughout the region. Individual landowners will not be expected to take on any of these responsibilities, although willing landowners will be encouraged to participate in planning, eradication, and monitoring. The Regional Coordinator will work with land managers already engaged in *Spartina* eradication and establish contact with all other relevant landowners to develop suitable site-specific plans for eradicating *Spartina*. Communication among all landowners and regulatory agencies involved will be critical throughout project planning and implementation. The Regional Coordinator will also work to provide information to the local community and engage participation. Decisions regarding *Spartina* control priorities and optimal control methods will be made in collaboration with other entities participating in the project.

The Regional Coordinator will establish, update, and maintain a spatially explicit database containing relevant information. The database will serve as a mechanism for tracking *Spartina* treatment and native marsh recovery in the Management Area. The database will incorporate the information contained in this plan and the regional geodatabase established by HBNWR. Key elements of the regional *Spartina* database include:

- A library of information pertaining to *Spartina* ecology and control methods
- Maps and data on regional *Spartina* distribution and abundance
- Land ownership and landowner contact information
- Jurisdictional boundaries
- Site-specific evaluations and treatment plans
- Monitoring data
- Treatment records and photodocumentation for all sites
- Annual progress reports summarizing regional accomplishments
- Performance evaluations
- Budget and cost records for monitoring and treatment
- Status of coast-wide *Spartina* eradication efforts

The Regional Coordinator will establish and maintain a system to track implementation of *Spartina* eradication measures. As work is performed at each site, it is important to document information such as implementation dates for each treatment stage; methods, equipment, and labor sources used; the time and funds spent on implementation; special circumstances and/or any particular challenges that may have been encountered. Forms can be prepared to facilitate consistent reporting for entry into the regional database.

Annual progress reports will be prepared to summarize work accomplished during the year, including a list of sites where work was performed, the number of acres treated, the funds expended, and other pertinent information. Treatment maps can be generated by updating the regional geodatabase with entries recording when particular treatment stages were completed at each site.

4.3 Work-to-date in the Management Area

Regional coordination of *Spartina* eradication is intended to support and augment current efforts. Experimental work on eradicating *S. densiflora* in the Management Area was initiated by HBNWR in 2002 and method research and development has been ongoing since that time, with active treatment in progress on all HBNWR lands. Several additional land managers have treated *S. densiflora* and/or have treatment in progress using various methods (Table 4-1). This work has provided valuable information used to develop the regional eradication strategy.

In addition to the past and ongoing treatments presented in Table 4-1, *S. densiflora* control measures are planned for several additional sites within the Management Area:

The Eel River Estuary Preserve (EREP), located south of the Eel River mouth, is managed by The Wildlands Conservancy, a 501(c)(3) non-profit public benefit corporation. The EREP encompasses approximately 1300 ac (526 ha), including approximately 300 ac (121 ha) of tidal salt marsh habitat. The northern salt marshes on the EREP are severely infested with *S. densiflora*. Most of the early stage invasion areas pose a threat to populations of Humboldt Bay owl's clover. *S. densiflora* eradication is a priority management goal at the EREP; these efforts began on a small scale during summer 2011 using subsurface mowing with brushcutters. Site treatment is contingent on the acquisition of funding (Clendenen, pers. comm., April 2011).

The Salt River Ecosystem Restoration Project (SRERP) is designed to restore ecologic, geomorphic and hydrologic function within the Salt River watershed. The project includes restoration of approximately 7.7 mi (12.4 km) of the Salt River channel and over 400 ac (162 ha) of tidal marsh (Riverside Ranch). Areas of dense *S. densiflora* line the lower reach of the Salt River channel and the confluence of the Salt River channel with Cutoff Slough. Most of the eastern edge of the infestation will be removed during clearing and grubbing operations in preparation for restoration. This material will be removed off-site or deeply buried on-site so that *Spartina* does not have an opportunity to spread vegetatively or by seed. However, large areas of *Spartina* will remain along the western edge outside the limits of the restoration grading. Planning is currently in progress for these areas, with potential control methods including mechanical removal where practical, and mowing (brushcutters) for seed suppression.

Table 4-1. *S. densiflora* Eradication Work-to-Date in the Management Area

Location, Size, and Setting	Eradication Methods	Outcomes
HBNWR experimental treatment, 10 ac (4 ha) of high-elevation salt marsh on an island in Mad River Slough (North Humboldt Bay), relatively low infestation along the island margins and edges of tidal channels (2002-2004) (Pickart 2005a)	Handheld corded weedeaters used to repeatedly top mow mature *S. densiflora* plants	High mortality (80%) was achiedved by the end of the 2nd year, with up to 11 treatments over a 2-yr period
HBNWR – Lanphere and Ma-le'l Marsh Pilot Restoration Project, North Humboldt Bay, 31 ac (12.5 ha), mainland site with high densities of *S. densiflora* (2006-2007, with maintenance ongoing) (Pickart 2012)	'Grind' treatment: 3-pronged metal-bladed brushcutters applied several inches below the soil surface to target shallow rhizomes Wrack raked and burned or hauled off-site for disposal Handheld propane torches used to flame seedlings during the 1st spring post-treatment; brushcutters subsequently used to selectively remove sparse seedlings that continued to emerge through August Resprouts treated with brushcutters or shovels 1-2 times per year for 2 years Revegetation experiments using volunteer labor to plant plugs of salvaged native salt marsh plants	Mature plants were killed in 1-2 years, with high intensity initial reatment followed by 1-3 lower intensity resprout treatments over a 2-yr period Grind treatment of dense *Spartina* stands in the summer resulted in a flush of *Spartina* seedlings the following spring Flame treatments and brushcutters were both effective in treating seedlings Natural recolonization by native salt marsh species occurred within 2 years of initial treatment; experimental planting of native salt marsh species was successful but not necessary Af 5 years following initial treatment, *S. densiflora* individuals continued to invade, but at a very low level (<1% *Spartina*, which can be maintained with minimal effort) Rare annual plant populations on-site increased dramatically following removal of *Spartina*
HBNWR *Spartina* Eradication Project, approximately 289 ac (117 ha) of infested marsh, North and South Humboldt Bay (2010–-2012)(Check HBNWR website for updates (http://www.fws.gov/humboldtbay/spartina.html)	'Grind' treatment: 3-pronged metal-bladed brushcutters applied several inches below the soil surface to target shallow rhizomes Wrack eliminated by using bruscutters to finely chop aboveground material into a mulch that is left in place Manual excavation with shovels used where brushcutters are not effective, including rocky substrates and locations that are too wet *Spartina* seedlings treated by flaming with propane torches or removing with brushcutters Backhoes used where accessible (eg, bordering levees) Experimental trials in progress with mini-tillers Amphibious vehicular equipment used experimentally to top mow dense *Spartina* stands, and may be used for tilling and/or crushing treatments Volunteer labor has been used to hand dig *Spartina*	This project is a further progression of the 2006-2007 HBNWR pilot project (see above) Grind treatment is being refined to minimize resprout treatments and to maximize efficiency Grind treatment can be effective in reducing the seed bank in addition to killing established plants The Marsh Master II (amphibious vehicle) successfully maneuvered tidal channels in dense *Spartina* stands in fall 2011 trials, and continuing trials are in progress Volunteer events helped engage the community and garner public support Quantitative data on treatment times, efficacy, and native vegetation recovery will be made available upon project completion
Arcata Marsh and Wildlife Sanctuary, City of Arcata, in North Humboldt Bay, includes Butcher's Slough Enhancement Project (2009--2012) (Neander, pers. comm., March 2011)	Top mows using handheld brushcutters, repeated approximately annually	Top mow treatments have reduced the vigor of *S. densiflora* (but not eliminated it) and increased the cover by native marsh species
McDaniel Slough Tidal Marsh Restoration Project, City of Arcata, North Humboldt Bay, 10 ac (4.0 ha), (2009) (Benson, pers. comm., June 2011)	Dense stands excavated using hand shovels and pulaskis Grind treatment used to treat individual plants Wrack initially disposed of off-site; subsequently, wrack and excavated plants stockpiled on-site and covered with tarps	Covering with tarps was effective in killing stockpiled plants in 6 months; decomposition of stockpiled material is slow-mounds remain after 2 years Sufficient resources need to be allocated for future removal of the plastic covering

Location, Size, and Setting	Eradication Methods	Outcomes
Freshwater Farms Reserve, Northcoast Regional Land Trust, North Humboldt Bay, including a 35-ac (14.2 ha) tidal marsh restoration project located on Wood Creek and land bordering Freshwater slough where *S. densiflora* occurred in a narrow fringe (2009) (Wells, pers. comm., April 2011)	Bordering Freshwater Slough, *S. densiflora* was excavated using shovels; material was stockpiled on-site and covered with tarps on an upland berm At the Wood Creek Tidal Marsh enhancement Project, the few *S. densiflora* occurring at the site were removed	All *S. densiflora* on NRLT property has been removed; measures are in place to prevent reinfestation
Salt Marsh Mitigation for the Elk River Wildlife Trail Improvement Project, Eureka, California, City of Eureka, pocket marsh in Entrance Bay (Humboldt Bay), 0.21 ac (0.084 ha). (2011-2012) (SHN 2011, Slattery, pers. comm., October 2011)	Plants were excavated manually using shovels and disposed of off-site Treatment was conducted in conjunction with plans to create 1.1 ac (0.45 ha) nearby salt marsh	All *S. densiflora* was removed. The site is being monitored
PG&E Buhne Point Power Plant Entrance Bay (Humboldt Bay), 3 ac (1.2 ha) (2009-2010) (Benson, pers. comm., January 2011)	Manual excavation using shovels; material stockpiled and covered with tarps on-site Grind treatment in selected portions of the site Individual plants cut and covered with black plastic; some small areas top mowed, then covered	All methods used, with follow-up treatments, were effective in killing *S. densiflora*

4.4 Regional Phasing Approach

A phased treatment approach is proposed to address a number of ecological, logistical, and budgetary factors. Phasing will allow both temporal and spatial partitioning of available resources, and it will allow the process of habitat recovery to keep pace with the temporary site disturbance inherent with treatment. Dividing the Management Area into Management Units would facilitate phasing. Factors to consider in delineating Management Units include proximity and hydrologic connectivity to sites that have previously been treated or have treatment in progress, land ownership and management, logistical considerations, and funding opportunities.

4.4.1 Site Prioritization

A mechanism for prioritizing sites for *S. densiflora* treatment is shown in Table 4-2. Sites can be prioritized based on these attributes: 1) Maintenance Level Status, 2) Vulnerability, 3) Propagule Pressure, and 4) Containment.

Table 4-2. Attributes Used to Prioritize Sites for *S. densiflora* Treatment

Attribute	Definition	Priority level	Strategy
Maintenance Level Status	Sites that have received intensive *Spartina* eradication treatment	High # acres restored marsh → High Priority	It is a high priority to continue maintenance level treatments on all restored lands to prevent *Spartina* reinvasion
Vulnerability	Vulnerability of habitat to invasion by *Spartina*	High # acres with restoration in progress → High Priority	Site disturbance associated with restoration (including primary treatment for *Spartina*) increases vulnerability to reinvasion, especially from on-site seed bank. It is a high priority to maintain treatment throughout the vulnerable period until native vegetation recovers, with resulting canopy closure and reduction in site vulnerability
Propagule Pressure	Level of threat posed by *Spartina* populations to vulnerable sites	Close proximity to vulnerable sites → High Priority	The higher the proximity to vulnerable sites, the greater the threat posed by remaining *Spartina* stands. It is a high priority to reduce this threat through treatment (or temporarily through seed suppression measures)
Containment	Ability to contain an infestation	Low # infested acres remaining → High Priority	The lower the infested acreage remaining within a Management Unit, the higher the potential for containing the infestation. Containment is a high priority interim goal until regional eradication can be achieved

The status of recent and ongoing *Spartina* eradication projects is important to consider in site prioritization. Sufficient resources should be allocated for maintenance level treatments of all treated sites to prevent reinvasion. Sites undergoing active *Spartina* treatment are highly vulnerable to infestation because of the open space created by *Spartina* removal. Colonization of vegetated marsh by *S. densiflora* seedlings is low, while colonization of treated sites can be very high due to the open space created by treatment (Kittelson and Boyd 1997, Pickart 2012). Recently treated sites are therefore considered at high risk and of need for immediate protection. Implementing *S. densiflora* treatment in phases would limit the extent of vulnerable sites present in the Management Area at any one time.

Containment refers to the ability to completely remove *Spartina* populations within specific geographic locations. Containment is most feasible for relatively small and/or isolated poulations and when there is little remaining in an area as a result of *Spartina* treatment on neigboring lands. The lower the infested acreage remaining within a Management Unit, the higher the potential is for containing the infestation, and the higher the priority for treatment. Containment for specific locations can be viewed as an interim goal until regional eradication can be achieved.

Propagule pressure is a term referring to the number of propagules present and their ability to reach new locations. Propagule pressure is a major factor influencing biological invasions of natural communities (Davis 2011, Fridley 2011, Leishman and Harris 2011). Based on current HBNWR research on *S. densiflora* seed dynamics, it appears that on-site regeneration from a persistent seed bank poses the greatest threat to treated sites, followed by on-site or nearby reproductive populations. In a recent HBNWR study, *S. densiflora* exhibited extremely high fecundity (35-47 million seeds/ac) (88-118 seeds/ha), and a persistent seed bank lasting at least 2 years. In research plots, viable seed in the seed bank declined after 2 years (exclosures prevented seed replenishment in research plots) at most study sites, but remained the same at one site, which had the densest seed bank. Studies will continue to determine how long seeds remain viable in the seed bank. Seed bank density, ranging from an average of 1111 to 42,278 seeds/ft^2 (100 to 3,805 seeds/m^2) of surface area in the 1st year, was strongly correlated to above ground abundance of *S. densiflora*, suggesting that seeds may primarily enter the bank at the site of seed production (Pickart 2012).

The influx of tidally dispersed seed is also a threat, though apparently secondary to on-site seed sources. An ongoing study by HBNWR will provide quantitative data on the relative contribution of seed from off-site sources. Seed dispersal distances and patterns are speculative but can be inferred to some degree from circulation patterns within the Management Area, which are primarily affected by tides, wind, waves, bathymetry, and variations in density (salinity) and temperature. Wind direction shifts with the season and plays an important role in determining circulation patterns (Anderson, pers. comm., August 2011, Costa 1982). This is particularly significant when *S. densiflora* seeds are being dispersed (primarily fall and perhaps through winter).

Dispersal of *Spartina* seed from the Eel River to Humboldt Bay likely poses more of a threat than the reverse. Sediment transport studies have documented the longshore transport of sediments from the Eel River into Humboldt Bay. Seed dispersal from Humboldt Bay into the Eel River Estuary is less likely considering oceanic currents and the fact that the Eel River has substantial volume and velocity of freshwater outflows. Within Humboldt Bay, suspended particles tend to concentrate and deposit along the northeast shore of North Bay. This may result in the northeast corner of Humboldt Bay getting the most seed influx from other areas, however, this needs to be confirmed (Anderson, pers. comm., August 2011, Costa 1982).

Based on circulation modeling (Anderson 2010), it appears that the residence time of suspended particles (e.g., tidally dispersed seeds) within Humboldt Bay varies by region. In a summer 2009 model of Humboldt Bay, the flushing rate was approximately 1.6 days for Entrance Bay, 14 days for South Bay, and over 30 days for North Bay In some situations, North Bay waters may flow into the South Bay, or visa-versa, as a function of tides, wind and weather. However, more data is needed to clarify the situations in which this may occur (Anderson, pers. comm., August 2011). Future research could investigate the degree of buoyancy of *S. densiflora* seeds and the length of time seeds may remain suspended in tidewaters.

Until additional quantitative data on *S. densiflora* seed dispersal becomes available, it is presumed that proximity and hydrologic connectivity increase the level of threat posed by an existing stand to recently treated sites. Therefore, initial resource allocation should focus on completing *S. densiflora* treatment within Management Units where significant work has already been performed before moving into new regions (notwithstanding overriding logistical or budgetary considerations).

4.4.2 Timeline for Implementation

An illustration of how a phased approach could be used to treat all *S. densiflora* in the Management Area by 2018 is presented here (Figure 4-1). Each year, specific sites would be targeted to receive initial treatment, with diligent follow-up the 2nd year, and maintenance treatments thereafter. In this illustration, the entire region would reach maintenance level status by the end of the 2018 treatment year, with all infested lands having received at least 2 years of focused treatment. This illustration is presented as a general example; the specific number of acres to be treated each year will depend on a number of factors, including acquisition of all relevant permits and the availability of sufficient funding and other resources. The phased timeline depicted in Figure 4-1 is based on the following assumptions:

- An estimated 1672 acres of land in the Management Area have been infested by *S. densiflora* (Grazul and Rowland 2011)
- Approximately 20% of these lands have either been restored or have treatment in progress
- The 2013 treatment year will include maintenance of restored lands, 2nd year follow-up for lands where treatment has already been initiated, and initiation of treatment on some new lands (permits and funding either already in place or pending for this work)
- At any one site, 2 years of focused treatment are required to kill established *S. densiflora* stands and address recruitment from the seed bank, with treatment intensity and resource investment higher in the 1st year than the 2nd year
- Maintenance of sites after the 2nd year will include monitoring and spot treatments as needed, but the resources required are expected to be dramatically less those required for the 1st 2 years

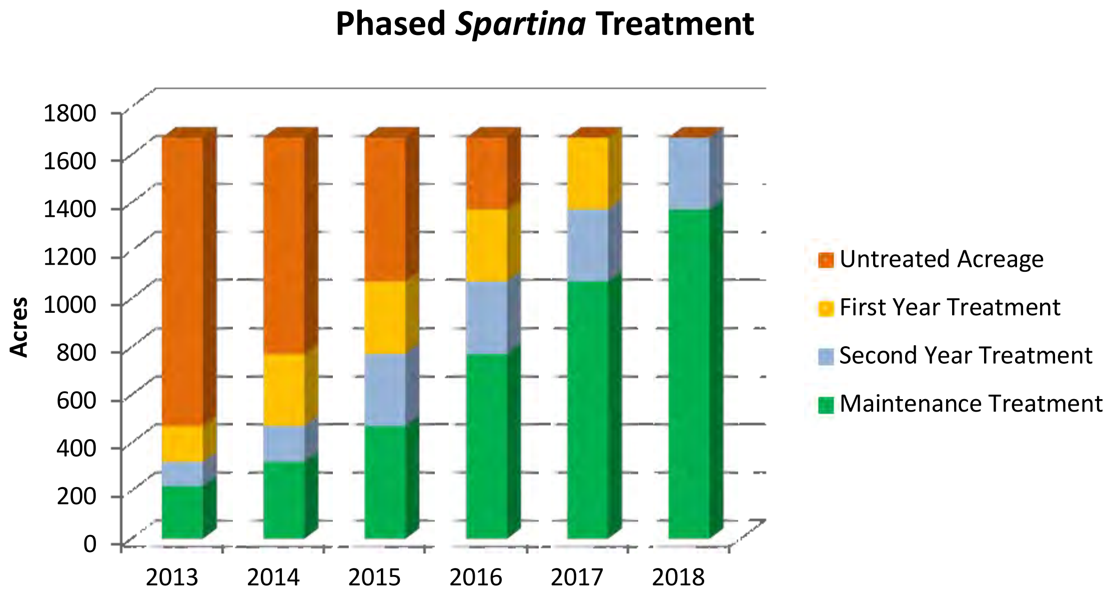


Figure 4-1. Illustration of Phased Approach to Treating *S. densiflora* in the Management Area

Based on the guidelines presented above, considerations for the development of a general phased treatment strategy for the 3 estuaries covered in this plan are provided below:

In Humboldt Bay, a considerable amount of *Spartina* eradication work has been performed. A strategic approach would include prioritizing maintenance of restored sites, completing treatment in progress, then focusing on neighboring sites, and finally moving into remaining areas based on defined Management Units. In North Bay, maintenance level treatment of lands restored by HBNWR, including Jacoby Creek and portions of Mad River Slough are high priority, as is completion of intensive treatment in progress at Eureka Slough. Increased intensity of efforts on City of Arcata lands would augment the work initiated in these areas. The total infested acreage is lower for South Bay than North Bay (140 ac and 868 ac) (57 ha and 351 ha) respectively, and 65% of the land infested by *Spartina* in South Bay is contained within HBNWR boundaries, while this figure is much lower (23%) for North Humboldt Bay. Augmenting work already performed by HBNWR by treating all remaining infested areas in the South Bay would help achieve containment in this basin. Also, it has been suggested that proximity to the mouth of Humboldt Bay is a consideration for prioritizing work to minimize release of *S. densiflora* seed into oceanic waters that could be transported to other estuaries on the West Coast.

The Eel River Estuary contains areas with high densities of *S. densiflora* that can spread locally and that can provide seed sources into Humboldt Bay and the Mad River. SRERP is scheduled to begin work in 2013, and restoration plans include *Spartina* treatment at this site. Prioritization of lands in the vicinity of Salt River would help lead to containment in this area. Treatment of remaining areas would follow, within defined Management Units and using the guidelines presented in this section.

The *Spartina* infestation in the Mad River Estuary constitutes only a small portion of the total in the Management Area and would require a relatively small investment of resources for eradication. Containment is a reasonable goal to achieve with 2 years of intensive treatment. Minimal resources would be required thereafter for follow-up monitoring and maintenance, considering the small overall acreage and the relatively low level of propagule pressure in this area. Reports that *Spartina* is spreading from the relatively limited salt marsh in the Mad River Estuary to the more extensive brackish marsh areas increase the urgency of eradication in this area. Prioritizing and completing *Spartina* eradication work in the Mad River Estuary would provide a successful eradication model that could serve as a demonstration tool for public outreach.

4.5 Site-Specific Plans

The Regional Coordinator will take a lead role in preparing site-specific plans, with landowner permission and coordination throughout all stages of the process. A 'site' will be defined based on ecological and logistical criteria. In general, land ownership will not serve as a basis for delineating sites; therefore multiple landowners may be involved. Treatment coordination is important at the site-specific level as well as regionally. Each site-specific plan will clearly specifiy contact information for all site partners, including landowners, managers, contractors, and any other partners to help facilitate good communication and coordination throughout the treatment process. Required landowner permission or notification prior to accessing the site should be noted. Neighbors and any other stakeholders identified who may directly or indirectly be affected by *S. densiflora* treatment at a particular site may need to be contacted to make access arrangements or notified prior to implementation of treatment measures.

Information which should be included in site-specific plans is shown in Table 4-3. This information will all be incorporated as part of the regional database. The site-specific plan will include a site evaluation describing existing conditions and special considerations; a plan outlining a specific treatment approach, a timeline for implementation; and information needed for treatment coordination including contact information for site owners, managers, and other partners.

Table 4-3. Site-Specific Plan Information

General Information	Specific Information
Site Description	Location, size, ownership, land use history, current management, adjacent land use, accessibility
Site Conditions	Topography, hydrology, substrate, vegetation types, sensitive resources
Extent of *Spartina*	Abundance and distribution on-site, threats from off-site *Spartina*
Treatment Approach	Methods, equipment, access, limiting factors, labor, safety, timeline
Treatment Coordination	Coordination plan, contact information for all affected parties
Revegetation	Potential for natural recovery/need for planting

General Information	Specific Information
Monitoring	Photodocumentation, assessment of need for follow-up treatments, evaluation of treatment success
Environmental Compliance	Permits, mitigation measures, notification process
Reporting	Documentation of treatment implementation and monitoring
References	Use existing data/science reports to inform planning

4.5.1 Site Evaluation

Site-specific evaluations will be conducted as a basis for determining the best method, or suite of methods to provide successful eradication. Each evaluation will describe the current condition of the site including land ownership and management, a description of the vegetation and the extent of the *Spartina* infestation, the presence of sensitive resources, topography, hydrology, substrate, accessibility, and other site-specific limiting factors or special considerations. Much of this information can be compiled from existing data, such as APN maps, the regional *Spartina* geodatabase (Grazul and Rowland 2011), mapping of intertidal coastal marsh habitats throughout the Management Area (NOAA 2011, Schlosser and Eicher 2012), local planning documents, and sensitive species occurrence records maintained by CDFG and USFWS. Goldsmith and Golightly (2007) provide an inventory of tide control structures for Humboldt Bay. One or more field visits will be required to verify or update available data.

Past and current land uses and management of the site may influence the treatment approach selected, including potential seasonal restraints such as hunting. Management status may also determine how long-term maintenance will be carried out following *Spartina* eradication. Any previous or current on-site treatment of *Spartina* should be noted.

The tidal elevation range and topographic complexity should be described. Plant species may be used as indicators of tidal elevation. Dense *Spartina* stands typically occur at low to mid elevations, while higher diversity plant communities characterize high elevation marshes. Low elevation marshes are inundated more frequently, which affects work schedules. Generally, the marshes in the Management Area are inundated by tides of about 6.0 ft. MLLW, but each location is different, and each site has topographic variability, so observing the site through a tide cycle can be helpful in planning field work. Mudflats are typically inundated at about 3.0–4.0 ft. MLLW, which also needs to be considered in access planning. The presence, location, and specific characteristics of tidal channels on-site or bordering a site affect how the site will be accessed and may prove limiting for some treatment techniques.

Accessibility needs to be examined both with regards to potential access by vehicular equipment and to determine logistics for access by labor crews. *Spartina* on islands may need to be accessed by boat or by traversing intertidal mudflats. Floating docks that serve as bridges may be used to allow field crews to cross wide tidal slough channels and mudflats. Sites adjacent to busy roads or the Railroad Right-of-Way may require special permits and/or safety provisions such as road shoulder closures while equipment and/or crews are working on the site. Some roads may have seasonal limitations, such as roads that become too muddy during the rainy season to support vehicular traffic.

The type of substrate(s) present will affect the treatment approach including appropriate equipment selection. Most infested sites in the Management Area are characterized by soft mud substrates; however *S. densiflora* can also be found on sandy soils, on gravelly or rocky flats, and along rock or rip-rap levees. The presence and condition of tide control structures, especially if hydrology is actively manipulated at the site, may affect selection of treatment techniques.

Vegetation types present at the site should be described, including dominant plant species and relative abundance. The abundance and diversity of native plant species on-site and at neighboring locations with hydrologic connectivity to the site will be used to estimate whether sufficient natural colonization can be expected following *Spartina* treatment. The presence of anoxic conditions at a site can inhibit colonization by native plant species, and revegetation measures may need to be included in site-specific plans in these areas.

All sensitive resources present on the site should be noted, with information on sensitivity status (federal, state, or other listing). Sensitive resources include rare species, special status wildlife species habitat, research plots or data gathering devices, or cultural resources. Sensitive species occurrence records are maintained by CDFG and USFWS. Additional site-specific data may be available for the site. References and dates should be provided for site-specific surveys, including surveys that document the absence of potentially occurring sensitive species or other sensitive resources. Maps showing the location of sensitive resources are helpful, and it may be appropriate to place field markers prior to implementation to avoid disruption of resources such as study plots or data-gathering devices. If sensitive resources are present, measures needed to avoid, minimize, and/or mitigate impacts associated with the proposed treatment must be addressed and documented (H. T. Harvey & Associates and GHD 2012). The procedure for notification if sensitive resources are discovered during treatment implementation should also be noted.

4.5.2 Treatment Approach

Based on the site evaluation, the site-specific plan will determine the best treatment approach, which will typically include a combination of techniques and may vary according to treatment stage. The size and density of the infestation and accessibility are key determinants of which techniques to use. Feasibility, cost, logistics, and site-specific factors are additional considerations. If several sites are within close geographic proximity, it may make sense to develop a site specific plan for a complex of adjacent sites using a combination of methods that address varying habitats and severities of invasions. Overall, the treatment approach will strive to maximize efficacy while minimizing adverse impacts.

One of the 1st considerations will be the suitability of the site for treatment with heavy equipment. The inability of soft marsh substrates to support heavy weight limits the use of standard and low ground pressure heavy equipment; however these may be used to treat *S. densiflora* growing on the sides and at the base of levees, which are common at the upper margins of tidal marshes throughout the Management Area. A backhoe can be used to excavate *S. densiflora,* but a suitable nearby upland location will be required for disposal of the excavated material. Temporary drainage of an infested site may also enhance accessibility by standard heavy equipment.

Amphibious tracked vehicular equipment has much greater versatility and can be used on marshes throughout much of the Management Area. It may be necessary to stage the equipment during high tide. Amphibious vehicles are self-propelled through water, providing there is little current. Heavy attachments, as used for mechanical treatments, weigh down the vehicle and in this case, it can be helpful to push the vehicle using an airboat. In September 2011 and again in September 2012, an amphibious vehicle was used with success to mow several acres of low marsh at HBNWR's Eureka Slough unit, demonstrating that at least in relatively flat areas without extensive dissecting tidal creeks, the use of this type of eqyuipment is viable and efficient (Pickart, pers. comm., October 2012).

While treatment of large dense stands by equipment may be the most cost-effective, the use of hand tools has advantages for sites or portions of sites containing low density *Spartina* interspersed with native plants and/or small, scattered *Spartina* individuals or patches, and at sites that are difficult to access by heavy equipment. Handheld tools such as bruscutters have been used extensively with successful results in the Management Area. Handheld tools and are relatively easy to transport and can be highly selective, thereby minimizing non-target impacts. Field crews using handheld tools will also be valuable at all sites for follow-up treatment stages.

As part of developing the treatment approach, the time required to complete primary and follow-up treatments will be estimated and labor sources identified. The use of heavy equipment and chemical applications require licensed, skilled operators. Large labor crews require training and supervision. Volunteer labor, including community groups, school groups, and the general public, can provide educational and community building benefits. Often, labor crews must walk through areas containing sensitive resources (e.g., high elevation marshes that support a high diversity of native species including rare plants) to access *Spartina* invasion sites. A pathway can be delineated (with pinflags, etc) to restrict the trampling impact to a small area.

Each site plan will also briefly review and assess the potential environmental effects of implementing the control program and will include the status of compliance with environmental regulations. Sensitive resources such as rare plants, special status wildlife species habitat, research plots, or cultural resources will require measures to avoid, minimize, and/or mitigate impacts associated with the proposed treatment, and must be included in treatment plans. The Conservancy is the lead agency responsible for compliance with the California Environmental Quality Act (CEQA) for regional *Spartina* eradication. Potential environmental impacts and recommended mitigation measures to avoid, minimize, or mitigate impacts are addressed in the Draft PEIR (H. T. Harvey & Associates and GHD 2012) prepared concurrently with the Regional Plan.

4.6 Treatment Stages

Comprehensive *S. densiflora* eradication and restoration of native plant vegetation will require several treatment stages, regardless of which treatment methods are selected. Different strategies and techniques or combinations of techniques may be used for different treatment stages. In discussing treatment stages, it is useful to define several terms. Established *Spartina* populations are referred to as "mature" plants or stands; these are the target of initial or "primary" treatment, but will typically require some form of secondary treatment to achieve complete plant mortality. Plant response to primary treatment depends on the type of method used. Mechanical treatments that target the shallow belowground rhizomes without completely removing them may result in "resprouts," which are new upright stems generated from remaining rhizomes or rhizome fragments with intact nodes. Other methods of primary treatment may result in the need to secondarily treat "regrowth" of aboveground stems not fully killed by primary treatment. In addition to ensuring complete mortality of established *S. densiflora* plants, it is also important to address new plants that grow from seed; these are referred to as "volunteers" – "seedlings" when young and "juveniles" when older. If left untreated, juvenile plants will mature and develop rhizomes, making them hard to distinguish from resprouts in the field; these 2 groups may be treated collectively the 2nd year following initial treatment.

Treatment stages are summarized below and discussed in greater detail thereafter. Not all treatment stages will be required at every site, and the need will also vary depending on the method(s) selected for treatment. A full discussion of various mechanical and chemical control methods available as treatment options is presented in Sections 4.7 to 4.9.

1. **Primary Treatment:** the 1st action taken at a site aimed at killing established *S. densiflora* plants (most intensive)
2. **Resprout Treatment:** resprouts may need to be treated for 1-2 years following primary treatment to ensure mortality of established *S. densiflora* plants (less intensive than primary treatment)
3. **Seedling Treatment:** may be required the 1st and 2nd spring-summer seasons following primary treatment to help prevent reinvasion of the site by *S. densiflora* seedlings (highly variable)
4. **Maintenance Treatment:** by the 3rd year, treatment intensity required drops substantially, needing 1(-2) treatments per year to address volunteer *S. densiflora* plants that reinvade the site
5. **Revegetation**: if warranted, active revegetation measures can be taken, although it is expected that at most sites the native salt marsh plant community will recover naturally
6. **Seed Suppression Treatment:** can be used as an interim measure to halt seed suppression and reduce the threat of spread from targeted populations into highly vulnerable sites

The optimal timing for each stage of treatment is shown in Table 4-4, although in practice, scheduling may vary based on logistical or other considerations. Maintenance level treatments will be required throughout the period of native community recovery, with a diminishing need for funding, labor, and other resource allocation. This timeline was developed primarily for the mechanical methods currently practiced in the Management Area, but could be adapted for use of a combination of mechanical and chemical methods.

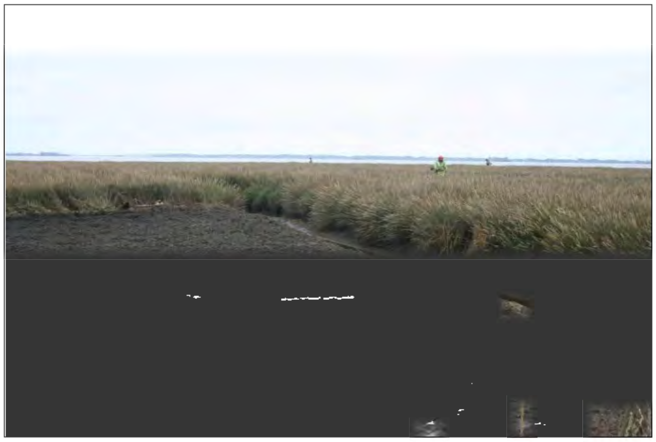
Table 4-4. Example of Site-specific Treatment Stages over a 5-yr Treatment Period

<table>
<tr><th></th><th colspan="12">Year 1</th><th colspan="12">Year 2</th><th></th><th></th><th></th></tr>
<tr><th>Treatment Stage[1]</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Apr</th><th>May</th><th>Jun</th><th>Jul</th><th>Aug</th><th>Sep</th><th>Oct</th><th>Nov</th><th>Dec</th><th>Jan</th><th>Feb</th><th>Mar</th><th>Year 3</th><th>Year 4</th><th>Year 5</th></tr>
<tr><td>Primary Treatment</td><td colspan="5">First attack when fieldwork most conducive and before seed set</td><td colspan="22"></td></tr>
<tr><td>Resprouts (1st pass)</td><td colspan="5"></td><td colspan="7">Easiest to see when native plants are dormant and easiest to treat if done first season after primary treatment</td><td colspan="15"></td></tr>
<tr><td>Seedlings</td><td colspan="11"></td><td colspan="6">Seedling flush in early spring, continue to emerge through summer; best to treat when young</td><td colspan="10"></td></tr>
<tr><td>Resprouts (2nd pass)</td><td colspan="12"></td><td colspan="12">Second pass for resprouts plus young plants missed as seedlings</td><td colspan="3"></td></tr>
<tr><td>Seed Suppression</td><td colspan="3"></td><td colspan="2">High threat stands</td><td colspan="10"></td><td colspan="2">High threat stands</td><td colspan="10"></td></tr>
<tr><td>Natural Recolonization</td><td></td><td colspan="26">No resource allocation needed other than monitoring to determine sufficiency of natural process, which starts soon after bare ground is exposed: succession from algal mats to emergent vegetation dominated by native plant species</td></tr>
<tr><td>Revegetation Measures</td><td colspan="7"></td><td colspan="5">Areas with need; plant during rainy season</td><td colspan="7"></td><td colspan="5">Areas with insufficient natural recolonization</td><td colspan="3"></td></tr>
<tr><td>Maintenance Treatments</td><td colspan="24"></td><td colspan="3">Treat volunteer Spartina plants as needed; will likely be needed until regional eradication achieved</td></tr>
</table>

[1] Developed primarly for use with mechanical methods currently in practice in the Management Area, but could be adapted for use of a combination of mechanical and chemical methods. The optimal season for each treatment stage is shown as a guideline, although treatments are not necessarily restricted to these times; see text for additional detail

4.6.1 Primary Treatment

Primary treatment refers to the 1st action taken at a site aimed at killing established *S. densiflora* plants. This effort requires the greatest investment of resources and has the highest potential for non-target impacts. The optimal timing of primary treatment varies depending on the control technique(s) used, equipment and/or labor availability, and site-specific characteristics. The April-September period has fewer tidal and weather-related constraints and more hours of daylight.



Primary Treatment in Progress

(*S. densiflora* has been removed using the grind method from the left bank of the channel; dense stands remain on the right bank)

Mechanical control of *S. densiflora* has been documented as an effective primary treatment technique in the Management Area (Pickart 2012). A technique referred to as the "grind" method using handheld brushcutters to target plant rhizomes is the main method currently in practice, and research on the use of mini-tillers and amphibious equipment to apply various mechanical treatments is ongoing (Pickart 2012) (See Section 4.7 for more information). Chemical control and combinations of chemical and mechanical control have been used as primary treatment for *S. densiflora* in other West Coast estuaries (Hogle and OEI 2011, WSDA 2011) and is currently under investigation in the Management Area (Gerwein, pers. comm., October 2012) (See Section 4.8 for more information).

4.6.2 Resprout Treatment

Intact rhizomes or rhizome fragments left behind can regenerate following primary treatment using belowground mechanical methods; therefore, resprout treatments may be needed over a 1-2 year period following primary treatment to ensure the mortality of all existing plants. During the 1st resprout treatment, small plants missed during primary treatment can also be treated. During the 2nd treatment, juveniles (i.e., plants that were missed as seedlings or in areas not treated for seedlings) can also be treated.

***S. densiflora* Resprouts**

(6 months following primary treatment using the grind method)

Resprout treatments require considerably less expenditure of resources than primary treatment. Resprout treatments are best scheduled for late fall through early spring, when native salt marsh plants undergo winter dormancy, and *S. densiflora* resprouts are more readily visible. Treating *S. densiflora* at this time also allows easier detection and removal of any small plants missed during primary treatment.

4.6.3 Seedling Treatment

***S. densiflora* Seedling Flush**
(first spring following primary treatment)
(Photo by Andrea Pickart)

Seedling treatments may be required the 1st and 2nd spring-summer seasons following primary treatment to help prevent reinvasion of the site. The open space created as a result of primary treatment can be readily colonized by *S. densiflora* seedlings, although there appears to be a great deal of variation among sites. Seed sources include the seed bank (seeds produced in previous years that are stored in the soil until conditions are suitable for germination) and seed rain (seeds produced and deposited during the current year). Seedlings start emerging in March-April and can continue emerging through August. The density of the spring seedling flush is hard to predict, as it varies depending on site-specific characteristics, seed dispersal patterns, and weather patterns.

The season in which primary treatment is applied can affect seedling emergence the following spring. In experimental plots, summer treatment using the grind method resulted in significantly higher seedling emergence than the same treatment applied during the winter. The summer plots had a longer period of exposure between treatment time and the spring timing of germination which may have accounted for greater input of seeds. Additionally, a longer period of exposure provides a greater opportunity for the establishment of algal mats, which are positively correlated with high seedling emergence (Pickart 2012).

Seedlings are most easily treated early, before they become well established. At the Refuge's Lanphere-Ma-le'l Marsh (LMM) restoration site, a combination of flaming and brushcutter treatments was used effectively to treat seedlings. A single spring flaming treatment conducted after the 1st spring flush resulted in 80% mortality of seedlings. Subsequently, brushcutter treatments were preferred for selective removal of the seedlings that emerged through summer. A sweeping motion with the brushcutter was used to nick out the tiny blades with minimal disturbance to surrounding vegetation. *Spartina* seedling density the 1st spring following primary treatment was over 5.6/ft^2 (60.6/m^2) reduced to 0.2/ft^2 (2.4/m^2) by the 3rd spring (similarly low the 2nd spring, though not quantitatively measured) and has remained low, with spot treatments conducted 1-2 times each year (Pickart 2012). Using propane torches to flame seedlings takes significantly longer than using brushcutters, while both methods are completely effective if applied carefully (Pickart, pers. comm., October 2012). Hand pulling or digging can also be used to selectively remove older seedlings. For more information on application of these methods, see Section 4.7.

4.6.4 Maintenance Treatment

By the 3rd year following primary treatment, the level of treatment intensity required to maintain the site free from *S. densiflora* is expected to decline substantially if follow-up treatments are carried out following the protocols described above during the 1st to 2nd years following primary treatment. Assuming substantial recovery by native marsh vegetation during the 1st 2 years, spot maintenance treatments conducted once or twice a year should be sufficient to address volunteer *S. densiflora* plants that reinvade the site. If native marsh vegetation recovers more slowly, the site will be more vulnerable to reinfestation and may require more effort.

Finding isolated occurrences of *S. densiflora* plants amidst established native vegetation can be difficult when conducting spot treatments. The plants will be most readily visible from late fall through early spring, when native marsh species are dormant. A 2nd survey conducted in mid-summer can be used to detect and remove any small flowering *S. densiflora* plants that may have been previously missed before they set seed.

Maintenance treatments will likely be needed until complete regional eradication is achieved. Disturbance from follow-up treatments may create open space that can be invaded by *S. densiflora,* thereby creating a feedback loop that can only be broken when the *S. densiflora* seed bank is depleted and propagule pressure is relieved (Pickart 2012).

4.6.5 Revegetation

In most cases, it is expected that the native salt marsh plant community will regenerate naturally; however, active revegetation measures may sometimes be warranted. The ability of native seedlings and vegetative propagules to populate a treated site can be substantial given an adequate source of propagules. In topographically or hydrologically isolated marshes, the propagule supply of native marsh plant species may be limited, resulting in a slower recovery. Revegetation measures may be warranted in these cases.

The native salt marsh plant community contains both perennial and annual plant species. Perennials can reproduce sexually through seed production and asexually through vegetative growth and expansion, while annuals reproduce solely by seed. The relative contribution of these reproductive mechanisms varies with species and can be influenced by environmental conditions. The removal of *S. densiflora* results in more available space, light, and nutrients for native salt marsh species, which can trigger the seed germination of those species. Alternatively, some native species spread vegetatively into bare areas. Larger bare areas are generally colonized primarily by seedlings.

At the LMM restoration site, natural recruitment contributed significantly to recovery by the native plant community. Vegetative expansion by remnant vegetation and colonization by seedlings contributed higher cover than that of experimental transplants. By the end of the 2nd growing season following initial treatment, cover by native plant species was approaching 100% in both revegetated and control plots. Perennial pickleweed was the dominant colonizer, while arrowgrass regrowth and expansion

Perennial Pickleweed Seedlings Recolonizing Site Following *S. densiflora* Removal

was dense in areas with freshwater input (Pickart 2012). During those 1st 2 years, bare areas were initially colonized by thick mats of green filamentous algae. Algal mats were subsequently displaced by vascular plants, while diatoms and cyanobacteria became more prevalent. Natural colonization occurred from a combination of seedlings and from the spread of rhizomes or stolons from adjacent areas of native plants.

At 5 years following *S. densiflora* treatment, native species diversity at the LMM was high, especially near freshwater springs that occur near the upper margin of the marsh. Native species that colonized the marsh through natural recruitment include perennial pickleweed, saltgrass, arrowgrass, salt marsh sand spurrey, sea lavender (*Limonium californicum* (Boiss.) A. Heller), low clubrush (*Isolepis cernua* (Vahl) Roem. & Schult.), western lilaeopsis (*Lilaeopsis occidentalis* J. M. Coult & Rose), and salt rush, and the rare plant species Humboldt Bay owl's clover and Point Reyes bird's beak (Pickart 2012).

At sites where limitations are suspected or when colonization is slow, planting either plugs or seeds of native marsh species may be warranted. Sites may contain localized areas that need greater attention to achieve revegetation. At LMM, small areas of apparently highly anoxic conditions remained as bare mud covered with a thick algal layer after 2 growing seasons, while the rest of the marsh had achieved high plant cover by native species; however, a closed canopy of native vegetation was present in these areas after an additional 2 years. Managers may also plant specific native species as a means of increasing species diversity at a restoration site. Plant source material should be collected from several locations within the Management Area. Plants may be collected or salvaged from development or restoration projects that require disturbance of native vegetation. At the LMM restoration site, experimental plantings of native species were successful (though surpassed by natural recruitment at this site). Native salt marsh plants, including pickleweed and saltgrass, were salvaged from HBNWR's Salmon Creek Restoration Project in South Humboldt Bay and planted as plugs. By the end of the 1st summer after treatment, pickleweed plugs and saltgrass had mean survival rates of 99% and 98%, respectively. Planting occurred from December 2007 through April 2008. While all plantings resulted in high survivorship, the earlier planted plugs had accelerated growth rates.

Humboldt Bay Owl's Clover in Restored LMM
(Photo by Andrea Pickart)

Spartina treatment at LMM restoration site has had a positive effect on rare plant populations. Humboldt Bay owl's clover has been censused and mapped at the site periodically since 1988. Pre-treatment population size fluctuated between 1000-3800 individuals, while post-treatment numbers reached 6213 the 1st year following restoration and have increased every year since, with an estimated 99,485 in 2011. A nearby control site peaked in 2008, but has declined every year since. Point Reyes bird's beak was observed to have a similar post-treatment positive effect, although the population was not quantitatively monitored due to its more cryptic nature (Pickart 2012).

4.6.6 Seed Suppression Treatment

Seed suppression treatments are designed to prevent or severely reduce seed production rather than to kill the plants. Seed suppression treatments can be an important component of *S. densiflora* treatment when strategically combined with other treatments. In general, seed suppression will be appropriate when reproductive plants are deemed a high threat to vulnerable sites and there are reasons why this threat cannot be addressed through primary treatment. Reasons might include impending seed set, limited time or funding (seed suppression is generally quicker than primary treatment), or limitations to perfoming ground disturbing activities at a particular site (since seed suppression can be achieved with a top mow or chemical application).

There are a number of factors to consider in evaluating the degree of threat posed to decide whether seed suppression measures are warranted. *S. densiflora* seedling recruitment in vegetated marsh is relatively low (Kittelson and Boyd 1997, Pickart 2012). In contrast, sites recently subjected to primary treatment using mechanical methods, resulting in the creation of large areas of bare ground, are highly susceptible to *S. densiflora* seedling invasion. Recent research demonstrates a persistent seed bank with seeds viable 2 or more years and suggests that seeds are primarily entering the bank at the site of seed production (Pickart 2012). Based on these findings, seed suppression would only be warranted in the immediate vicinity of treated areas or other areas of high vulnerability to invasion. Seed suppression treatments need to occur every summer until the plants can be killed by other means in order for treatment benefits to be maintained.

A wide scale seed suppression treatment has been proposed as a potential initial step in regional eradication of *S. densiflora*; however, this would not likely be a cost-effective use of resources given information now available on *S. densiflora* seed dynamics. In addition, top mowing used as a seed suppression measure may stimulate plant growth the following year. In HBNWR's experimental trials, late season seed suppression top mows applied to high density *S. densiflora* resulted in a significant increase in inflorescence density the following year (Pickart 2012). For more information on top mowing as a method of seed suppression, see Section 4.7.1. For the use of chemical methods to suppress seed set, see Section 4.8.1.

4.7 Mechanical Control Methods

Mechanical control of invasive species is broadly defined to include all physical manipulation or removal of plants or animals (Pickart 2011c). Equipment and materials for mechanical control include hand tools, portable mechanized tools (e.g., handheld brushcutters), or tools mounted on vehicles. Mechanical control is often labor-intensive and costly, but may be preferred in situations where the uses of chemical and/or biological controls are controversial, have associated unacceptable risk levels, have proven ineffective, or if evidence of biotic resistance to treatment is found (Pickart 2011c). The use of mechanical methods can be restricted in certain situations or have seasonal constraints to protect sensitive species.

A number of mechanical control techniques are presented here for use or potential use for treating *S. densiflora* in the Management Area, based on methods currently in use, with research in progress, or that offer potential for further development (Table 4-5). This 'toolbox' approach allows resource managers to select the best method or combination of methods and equipment best suited for site-specific conditions, *S. densiflora* extent and density, and treatment stage. For example, at any one site, *S. densiflora* may occur in dense stands at low to mid marsh elevations, with moderate to sparse distribution in the high marsh. The use of amphibious vehicular equipment may be determined as the most cost-effective primary treatment for the dense *S. densiflora* stands, involving first a top mow to remove aboveground material followed by tilling to destroy *S. densiflora's* shallow rhizomes. Field crews can be more selective and therefore are generally more suitable for use in the high marsh to avoid impacting native species, but essentially can achieve the same mowing/tilling action using handheld tools such as brushcutters and mini-tillers. The same site might contain small areas that are best treated by hand digging with shovels, such as areas with standing water or rocky substrates. If the site contains *S. densiflora* plants near levees, it may be possible to excavate these using a backhoe. For follow-up treatment of resprouts and seedlings, field crews using hand tools will generally be preferential. All of these methods and more are summarized in Table 4-5 and discussed in more detail in the following section.

Table 4-5. Summary of Mechanical Control Methods

Method	Description of Method	Setting/Uses	Timing	Tools and Equipment	Efficacy	Advantages	Disadvantages
Top Mow	Cutting aboveground stems, leaves, and flowering stalks; may include raking off wrack or fine chopping to create a mulch that can be left in place	Useful as a seed suppression measure; also used as a means of clearing aboveground material in preparation for other treatments; repeated top mows can be used to kill plants where ground disturbance is not acceptable	For seed suppression, work window is May-Aug; in preparation for other treatments, can be used as appropriate all year; to kill plants, repetition of top mow needs to be frequent enough to inhibit recovery of the plant and delplete belowground reserves	Corded weedeaters, handheld gas powered brushcutters; amphibious equipment (for dense infestations); rakes for clearing wrack in some cases (if equipment used for top mow is capable of finely chopping aboveground material, the resulting mulch can be left in place, eliminating the need to remove wrack)	For seed suppression, 90% seed reduction if applied in May-June, near 100% in July-Aug if flowering stems are mowed to the base; repeated top mows can reduce plant vigor and eventually lead to mortality	Top mowing does not cause ground disturbance and may be preferential where ground disturbance is a concern; when using handheld weedeaters or brushcutters, top mowing requires less equipment maintenance and repair than the grind treatment and also less training of labor crews	Labor-intensive when using handheld brushcutters; large initial investment for amphibious equipment; precautions need to be taken to prevent potential gasoline and oil spill into habitats; mowing can generate large amounts of wrack; used alone, top mowing requires frequent repeated applications to kill mature plants
Grind Method	Grinding rhizomes below soil surface 3-6 in (7-15 cm) using metal-bladed brushcutters held at an angle to strike the rhizome (method includes finely chopping aboveground material with brushcutter prior to belowground treatment)	Can be used as primary treatment (best for low to moderate infestations) and as follow-up treatment of resprouts, seedlings, and young plants that re-establish	Can be used all year, though summer is most conducive for primary treatment; resprouts any time of year; seedlings in spring through summer; selective grind treatment of young plants easiest to see in fall-winter	Handheld metal-bladed brushcutters have been used effectively in the Management Area; on larger scale, similar effect could be achieved by tilling with use of amphibious equipment for large, dense infestations	Can kill mature plants with follow-up of 0-2 treatment of resprouts; also effective for treating seedlings and selective removal of juveniles	Grind method is well-developed in the Management Area for use on *S. densiflora*; handheld brushcutters are easy to transport; suitable for a wide range of field conditions; can be selective, minimizing impacts to non-target plants; native plant recovery following treatment is good; helps reduce seedbank, especially deep grind	Labor-intensive; operators need training for proper technique; precautions need to be taken to prevent potential gasoline and oil spill into habitats; using brushcutters for belowground treatment requires frequent equipment maintenance and repair; soil disturbance can be potential source of temporary sediment increase in slough channels
Tilling	Macerating rhizomes below soil surface, similar action to grind method, but using handheld rototiller or amphibious equipment (best to first clear aboveground material using other methods)	Suitable for primary treatment in areas where ground disturbance is acceptable; need to prepare areas with other methods like top mow; need to do follow-up treamtents with other methods like grind	Can be used year round except in areas where mud is too saturated or where *Spartina* rhizomes aren't sufficiently dense to create traction	Trials in progress in Management Area using handheld rototillers, best in low-moderate infestations; trials in progress using amphibious equipment with rototiller attachment for large, dense infestations	Kills mature plants by macerating the rhizomes; trials show that this treatment is feasible with handheld rototillers and amphibious equipment for primary treatment, but extent of resprouting not yet determined	Tilling is less labor-intensive and potentially more cost-effective than grind method for primary treatment; handheld tillers are portable; research ongoing to assess application with large equipment	Disrupts the top layer of soil; need other methods to first remove aboveground biomass; need to take precautions to avoid potential transport of rhizome fragments on equipment; handheld rototiller results in more resprouts than grind treatment; application with large equipment still under investigation
Excavation	Complete removal of plant including rhizomes; excavated material either transported off-site for disposal, or can be stockpiled and covered on site for composting, or chopped on-site using brushcutters	Hand digging preferred over grind method in standing water conditions, on rocky substrates, and for community volunteer events; excavation with equipment suitable where accessible and for projects involving earthwork	Any time of year, best to avoid seed-bearing months (Sept - Oct) to minimize seed dispersal; selective digging of young plants in winter and spring when they are more readily visible	Shovels, digging bars, bags, wheelbarrows, handcarts, sleds, trucks to transport materials off-site; backhoes in areas with levees or roads near marsh, or amphibious excavating equipment	Successfully kills mature plants when rhizomes are thoroughly removed; useful for removing juvenile and small plants	Excavation results in fewer resprouts than grind treatment; hand shoveling is relatively safe and requires minimal training; excavation by heavy equipment often cost-effective where applicable	May leave deep holes or trenches in marsh; disposal of excavated material is problematic; hand digging is extremely labor intensive over large areas

Method	Description of Method	Setting/Uses	Timing	Tools and Equipment	Efficacy	Advantages	Disadvantages
Disking	Cutting/shredding the plant including the root system	At this time, no clear settings where disking would be advantageous for S. *densiflora*	Any time of year that the ground can be worked, with some areas possibly too saturated in winter	Amphibious equipment fitted with disk attachment	In 2012 experimental trials using amphibious equipment with disk attachment, did not substantially macerate rhizomes and did little to detach even the stems from the ground	At this time, no clear advantages of disking evident for treating S. *densiflora*	In 2012 experimental trials, disking appeared to have low potential as an effective method
Crushing	Crushing aboveground plant material, leaving a thatch that may smother plants and inhibit resprouts and seedlings	May be suitable for primary treatment of large dense stands if effective	Could be applied any time of year; optimal timing for efficacy undetermined	Tracked amphibious vehicles outfitted with various crushing devices, including rollers; standard heavy equipment where accessible	Undetermined for S. *densiflora*, but some indications that the method is worth investigation	Crushing is relatively inexpensive and rapid; no ground diturbance	If effective, would only be suitable for treating large dense stands to avoid impacts to native plants
Flaming	Heat/flame passed over the plant until it wilts, ruptures cell walls and kills the plant	May be used to kill seedlings	Apply soon after seedling emergence in the spring	Handheld propane torch; tractor-mounted flaming devices	Effective on seedlings, but not on mature plants	Flaming causes less soil disruption than brushcutters; can be used selectively	Not effective when plants are older than about 6 wks; can initially suppress native plant recovery
Covering	Covering aboveground material (plants may be cut first)smothers plants, restricts photosynthesis, and exhausts energy reserves; covering can also used for on-site stockpiles to kill plants following excavation	Best used on a small scale; may be used as primary treatment for small or remote infestations; behind diked areas with limited tidal action	Any time; cover should be in place until plants are dead (6 months for stockpiles, 2 growing seasons to kill standing plants)	Clear polyethylene plastic in areas of dry ground, black plastic, geotextiles fabric, landscaping fabric, spikes or stakes used as anchors	Stockpiled plants dead after 6 months; in SF Bay, 2 growing seasons recommended when used as primary treatment	Covering does not disrupt soil processes; allows for on-site stockpiling of excavated material; materials are relatively inexpensive over small areas	Logistically difficult to use over large areas; difficult to anchor over long-term; can be visually objectionable; sediment may accumulate on the covering
Flooding	Artificial inundation, manipulated via a tidegate or blocking a levee breach with an inflatable dam or other structure to impound water	Suitable only at limited sites where hydrology can be manipulated; potential uses for preventing seed recruitment, killing young and possibly mature plants	Depends on the method of hydrologic manipulation (eg, setup of dams in the fall would provide ponding of rainwater through winter-spring)	Tidegates, inflatable dams, geotextile tubes, or other structures to block levee breaches or other sources of inundation	Water depth of 3 in (8 cm) sufficient to inhibit seedling establishment; unknown efficacy on killing mature plants	Flooding does not cause ground disturbance; not labor-intensive under suitable conditions; could be worth further investigation	Hydrologic manipulation is not readily achieved at most infested sites; associated plant species would also be killed

4.7.1 Top Mowing

Top mowing involves cutting aboveground stems, leaves, and flowering stalks. Top mowing can be used as a seed suppression measure during the flowering season before seed set. Mowing can also be used in various combinations with other mechanical treatments (e.g., in preparation for tilling) or chemical treatments (e.g., as a follow-up to remove aboveground material). Repeated top mowing can cause *S. densiflora* mortality, however the mowing must be repeated with sufficient frequency to limit aboveground re-growth and eventually deplete the plants' belowground energy reserves. Monthly mowing over a 19-month period resulted in high mortality in HBNWR's 2004-2005 island experiments (Pickart 2005b).

If infrequent top mowing is the only treatment, *S. densifllora* can persist and re-grow for many years. In experimental plots, while top mowing in late summer was effective in suppressing seed set for that year, it also resulted in an increase in *S. densiflora* inflorescence density the following summer; the increase was slight in low to moderate stands, but nearly twofold in dense stands. Native species showed slight but significant increased cover in response to *S. densiflora* mowing as compared to control plots (Pickart 2012). Field applications suggest that over time, annual top mowing may afford some competitive advantage to native marsh plant species. Using repeated top mow treatments over a 2-year period, the City of Arcata has been able to reduce (but not eliminate) the cover and vigor of *S. densiflora,* with a corresponding increase in native plant species cover (Houghton, pers. comm., January 2011).

Seed Suppression Top Mow Using Brushcutters

Top mow treatments applied during the flowering season (May-August) before seed set (September-October) can effectively suppress *S. densiflora* seed production. It is important to mow low enough to cut flowering stems near their base to maximize the efficacy of the treatment. In experimental trials, seed production was reduced 90% by top mowing in May, and essentially eliminated by mowing in July. Following the late season mowing treatment, the mowed flower stems were examined and none of the seed continued to mature (after-ripening has been documented in some grasses) (Pickart 2012). Variation in the precise timing of seed set can be expected from year to year, among sites within a single year, and among individual plants occurring at the same site. This is especially true for sites in the process of undergoing treatment, in which the plants' typical phenology has been interrupted.


Top Mow Using Amphibious Equipment

For low to moderate infestations and sites with limited accessibility, mowing can be accomplished using handheld gas-powered equipment including corded weedwhackers and metal-bladed brushcutters. Operators are equipped with a safety harness and a face shield. For large dense stands, heavy equipment can be used for top mowing. Standard tracked equipment may be suitable in some locations where accessible and the substrate is firm enough. In most cases, an amphibious tracked vehicle will be required to access and maneuver marsh channels and soft substrates. A tractor with tracks with a front arm flailmower attachment was successfully used on high-elevation marsh at HBNWR's Jacoby Creek unit in June 2010 for a small experimental trial, but the operator did not venture into the lower marsh. A tracked skid steer with a front-mounted flailmower was tried at the same site at a lower elevation in September 2010, but became stuck in the mud and needed to be towed out of the marsh (Pickart 2011a). An amphibious tracked vehicle with a mower attachment was used successfully to top mow dense stands of *S. densiflora* at HBNWR in fall 2011 (Pickart, pers. comm., September 2012).

Mowing typically generates a large amount of wrack, which may damage nearby native vegetation or inhibit recovery of native species. In pilot project treatments in Mad River Slough, wrack was raked into piles and either burned or hauled off site for disposal (Pickart 2012). Raking and hauling are very labor intensive and burning is not always a feasible option. Alternatively, top mowing can be performed in a manner that finely chops aboveground material into a mulch that can be left in place to compost or be washed away by tides without generating large wrack mats. This mulching treatment was developed using brushcutters (Pickart 2012), and potentially other equipment can be used to achieve similar results.

4.7.2 Grind Method

HBNWR has developed a treatment referred to as the the grind method that effectively kills *S. densiflora* by targeting the shallow, belowground rhizomes using a brushcutter outfitted with a metal tri-blade. After cutting aboveground stems and leaves into a fine mulch (see discussion above, under "Top Mowing"), the blade on the brushcutter is rotated and applied such that the plane of the blade is tilted as it comes in contact with rhizomes, and the rhizomes are ground into small fragments. This method results in a large amount of debris (mud, plant fragments) that is flung into the air, so it is important that operators maintain a minimum distance of 50 ft (15.2 m) from one another for safety. The grind method requires frequent maintenance and repair of equipment due to wear and tear.

Follow-up treatments (much less intensive than the initial grind) are required to address resprouts that re-generate from rhizome fragments remaining in the soil. It is recommended that resprout treatments be conducted at 6-month intervals following primary treatment. Using this method, mature *S. densiflora* stands can be eliminated in 1-2 years (Pickart 2012). In dense *Spartina*, it can be advantageous to systematically treat short linear sections, first top-mulching the row, and then applying the grind such that the mud displaced is sidecast onto already treated areas. This technique increases rhizome visibility prior to grinding, and the sidecasting of mud over mulch can help minimize marsh elevation loss.


Grind Method

Experiments are currently underway at HBNWR's Jacoby Creek study site to determine optimal grinding depth to maximize efficacy and increase efficiency (fewer visits to treat resprouts) while minimizing impacts due to disturbance and elevation loss. The 'light grind' is applied to a depth of approximately 3 in (7.6 cm), and the 'deep grind' has a target depth of 5 in (12.7 cm), or up to a maximum of 6 in (15.2 cm) (Pickart 2011b). Preliminary results indicate that both light and deep grind treatments resulted in few resprouts. The deep grind test plots had fewer *Spartina* seedlings, presumably as a result of seed bank disruption. At 6 months post-treatment, a loss of up to 1.5 in (3.8 cm) in marsh elevation was evident in treated areas, but elevation fully recovered from these losses by 1.5 years post-treatment, at which time there were no significant differences in elevation between treated and control plots (Pickart, pers. comm., October 2012). These results are preliminary and are not necessarily representative of what will occur throughout the Management Area.

As a primary treatment, the grind method can be performed at any time of the year, though it is advisable to avoid the time when plants are bearing mature seed (Sept-October) to minimize seed dispersal. Experimental primary treatment using the grind method performed in the summer resulted in more resprouts but fewer seedlings as compared to winter treatment. Resprouts can be treated effectively at any time of the year, but are generally easier to see in late fall through spring when native plants are dormant. Seedlings are typically treated in the spring. Selective grind treatment of juvenile plants is best accomplished in late fall through early spring when they are most visible, but may be necessary in summer to catch young plants missed the previous year before they set seed.

4.7.3 Tilling

Tilling kills the plant by macerating the rhizome, similar to the grind method. To prepare the ground for tilling, aboveground material must first be cleared using other methods such as a top mow and the top plant material cleared away or chopped as mulch. In experimental trials, manually propelled rototillers were found to be too cumbersome to use in soft mud (Pickart 2011a). Recent work with handheld mini-tillers is promising. The mini-tillers are quicker than the grind method; however they do not penetrate as deep, resulting in a higher number of


Tilling Using Mini-Tiller
(Photo by Andrea Pickart)

resprouts and it is yet to be determined what the seedling response will be following this treatment. The time and labor resources required for follow-up treatments needs to be considered when determining whether this is the most appropriate method for primary treatment. It appears that the mini-tiller is most advantageous when *Spartina* cover is less than 50%. Preliminary results indicate that native plant species may recover more quickly using the mini-tiller instead of the grind method (Pickart, pers. comm., July 2012 and October 2012).

Tilling can be performed at any time of year that the ground can be worked (which might include some restrictions in areas where mud is too saturated or *Spartina* rhizomes aren't sufficiently dense to create traction). Amphibious vehicles equipped with rototiller attachments are currently under investigation for use in tilling dense *S. densiflora* stands (Pickart, pers. comm., October 2012).

4.7.4 Excavation

Excavation involves complete removal of the plant including all rhizomes. Excavation can be performed either by hand or using heavy equipment where accessible. Excavation by any means is not suitable for use in low marsh or with very soft substrates, since in both cases the method can result in excessive lowering of the marsh substrate (Pickart 2011a). The excavated material must be addressed in some manner after it is excavated. Plant material and mud clinging to the rootball needs to either be hauled off-site for disposal or stockpiled on-site or nearby. If stockpiled on-site, securely covering the plants with black plastic has been effective in killing the plants within 6 months. Alternatively, brushcutters may be used to grind the excavated material on-site, leaving it to compost or be flushed out by tides.

Community Volunteer Work Day

Hand digging is performed with shovels, hand trowels for small plants, or with digging bars in rocky areas. Hand digging requires minimal training of workers and can be used successfully for small areas and isolated plants, but is very labor intensive and not cost-effective over a large scale. Hand digging is advantageous in certain circumstances including gravelly or rocky substrates and areas of standing water, and it is a safe method for community volunteer events.

A backhoe has been successfully used to remove *S. densiflora* growing along the edges of levees and also at a restoration site where the soil had dried out sufficiently to allow access following draining of the marsh in the summer. An amphibious excavator has been used with some success in British Columbia in areas with muddy substrates (Dresen et al. 2010).

4.7.5 Disking

Disking is a treatment that involves cutting or shredding the plant, including the root system. In September 2012 HBNWR trials using an amphibious vehicle at Eureka Slough, an agricultural disk attachment had difficulty penetrating the standing *Spartina* and tended to bounce off the surface. It required 2-3 passes to expose much soil, and is unlikely to be an effective treatment as it did little to detach even the stems from the ground, and it did not macerate the rhizomes to any substantial degree (Pickart, pers. comm., October 2012).

4.7.6 Crushing

Crushing involves applying pressure by various devices such as rollers to crush aboveground material. The method has been used with some success on other invasive *Spartina* elsewhere, but hasn't been tried for *S. densiflora* in the Management Area, except inadvertently on a very small scale. In September 2010, HBNWR used a tracked skid steer with a flailmower attachment to apply an experimental top mow at HBNWR's Jacoby Creek Marsh. The equipment got stuck in the mud after treating only a small area; however, the top mow produced a thick thatch layer that remained on the marsh for at least 5 months, similar to the effect that might be produced by a crushing treatment. It was notable that within that small treated area, the thick thatch layer resulted in no resprouts. Based on these results, crushing may be worth investigation as a treatment, perhaps using an amphibious vehicle outfitted with a crushing attachment.

4.7.7 Flaming

Flaming Treatment of *S. densiflora* Seedlings

Flaming is a form of thermal weed control in which a flame is passed over a plant until it wilts, causing the fluid in the plant's cells to expand, rupturing cell walls and ultimately killing the plant. Grasses are generally considered resistant to flaming because their growing point can be below ground or protected by a leaf sheath. Flaming is not an effective method to kill *S. densiflora* mature plants; however, it can be used effectively to kill seedlings. A single flaming treatment at LMM restoration site resulted in 80% mortality of *S. densiflora* seedlings. While overall native plant recovery was somewhat suppressed by the flaming treatment in the 1st growing season, the effect was negligible by the end of the 2nd growing season (Pickart 2012). Flaming can be performed with the use of a handheld propane torch that delivers a small, controlled flame. Tractor-mounted flaming devices are also possible for larger scale infestations.

4.7.8 Covering

Covering can either be used as a means of heating the plants to lethal temperatures (solarization) or as a means of smothering the plants to restrict photosynthesis and growth, and exhaust the plant's energy reserves. Covering is not feasible as a primary treatment for *S. densiflora* due to the logistical problems of securing covers over large areas of estuarine marsh. However, covering may provide an option for treating small, remote *S. densiflora* populations in situations where other methods are not suitable. Covering is recommended for on-site stockpiles of excavated material when it is not possible to otherwise dispose of this material.

4.7.9 Flooding

Flooding has not been tested as a primary treatment, but the method could be worth investigation at locations where conditions are suitable. If hydrology can be easily manipulated, as via a tidegate or by blocking a levee breach with an inflatable dam, it may be possible to drown the plants by flooding the site. *S. densiflora* does not typically occur in marshes or portions of marshes with insufficient drainage or prolonged inundation. This measure would be best applied in high density stands of *S. densiflora* where few other plants occur, as other plant species could also be killed by the treatment.

Additionally, at suitable locations, flooding may be useful as a means of inhibiting *S. densiflora* seedling emergence. In controlled greenhouse experiments, Abbas et al. (2012) studied the effects of 5 water levels on *S. densiflora* germination and establishment, and concluded that artificial inundation of invaded marshes to a water depth of 3 in (8 cm) could potentially prevent re-establishment of *S. densiflora* from the seed bank. In 2010, at the Salmon Creek restoration site at HBNWR, young *S. densiflora* plants that emerged during summer months while the site was drained for restoration work were killed by flooding when inundation was re-introduced in the fall.

4.8 Chemical Control Methods

Chemical treatment involves the application of herbicides, typically sprayed on plant leaves during the active growing season. The chemicals are translocated by the plants to the root system and can kill or weaken the plant, or may be used for seed suppression. The 2 herbicides most widely used in estuaries on the West Coast for invasive *Spartina* control are glyphosate and imazapyr, and combinations of the two are also used. Imazapyr is the currently preferred herbicide. Use of imazapyr alone is the only chemical method proposed for use in the Management Area at this time.

4.8.1 General Considerations

When considering the use of chemical control methods and combinations of chemical with mechanical methods (Section 4.9), factors to consider include environmental setting, timing, tools and equipment, and efficacy (Table 4-6).

Table 4-6. Summary of Chemical and Combined Chemical/Mechanical Control Methods

Method	Description of Method	Setting	Timing	Tools and Equipment	Efficacy	Advantages	Disadvantages
Chemical	Application of imazapyr, sprayed manually onto the leaves of targeted plants	May be appropriate for some areas where ground disturbance is unacceptable; could be used to treat large dense stands of *S. densiflora* with very few interspersed native plants; use should be minimized in areas with minimal tidal flushing	Efficacy directly relates to drying time: apply directly to plant during a low or receding tide for optimal dry time; imazapyr is best applied during active growing season (spring-summer) before seed set (Sept-Oct)	Backpack spray equipment, spray trucks, ATVs or tracked vehicles, amphibious equipment, airboats	Effective for seed suppression and in greatly reducing plant vigor of mature plants; low efficacy on top mowed plants and seedlings but stops development of young plants; unknown but not expected to affect seed viability in seed bank	Minimal ground disturbance; relatively rapid and less expensive than more labor intensive methods; successful for seed suppression	*S. densiflora* has exhibited herbicide resistance; methods not extensively tested on *S. densiflora* (use in the Management Area currently under investigation); local community may not support use of herbicides
Combined Chemical and Mechanical	Chemical and mechanical methods can be combined in numerous ways, such as top mowing after chemical application to remove aboveground material	Settings and timings of combination methods must consider the specific circumstances of each method and the *Spartina* conditions. See Table 4.5 and row above		Backpack spray equipment, spray trucks, ATVs or tracked vehicles, airboats, hand-held gas powered brushcutters; amphibious vehicles, rakes, shovels, digging bars, bags, wheelbarrows, handcarts, sleds, trucks to transport plant material	Top mowing can provide a uniform canopy for spraying; mowing following chemical application can help clear away aboveground material and may be sufficient to kill weakened plants	Chemical treatment followed by top mow may kill plants with minimal ground disturbance; relatively quick method of seed suppression for reproductive stands that threaten areas treated by mechanical methods	Combination methods may negate the cost savings of chemical methods; need further investigation; local community may not support use of herbicides

Chemical control has been used effectively in other West Coast estuaries to control multiple invasive *Spartina* species (Dethier and Hacker 2004, Hogle and OEI 2011, WSDA 2011). After considerable research and experimentation with various methods, the decision to use wide-scale chemical treatment resulted in rapid, relatively inexpensive, and dramatic decreases of populations of several invasive *Spartina* species in Willapa Bay, Washington and in the San Francisco Estuary, California. Both of these programs focused primarily on *S. alterniflora*.

S. densiflora is less responsive to chemical treatment than other *Spartina* species (Boe et al. 2010). *S. densiflora* has tightly inrolled leaves that limit good foliar contact by spray applications. Chemical treatments applied to *S. densiflora* in San Francisco Bay, California and in Grays Harbor, Washington have had varying levels of success (Kerr 2010, WSDA 2010). Chemical treatment alone is generally insufficient to kill mature plants, and is not effective at killing *S. densiflora* seedlings; however chemical treatments have arrested the development of small plants and effectively suppressed seed production of reproductive plants. For full *S. densiflora* eradication, the best results are achieved when chemical methods are combined with mechanical methods (Kerr, pers. comm., July 2012).

The observed herbicide resistance in *S. densiflora* was one of the reasons that the ACT Work Plan prioritized further research and development of methods for treating *S. densiflora,* especially with regard to the Management Area, which represents the largest *S. densiflora* population on the West Coast (Boe et al. 2010).

A study was initiated in Humboldt Bay by the Conservancy in 2011 to compare the efficacy of mechanical and chemical methods for *S. densiflora* control. In the chemical experimental plots, a single application of imazapyr was applied in summer 2011. Preliminary results indicate that the chemical treatment was effective at drastically reducing flowering and seed set (99% reduction in density of flowering *Spartina* stems) and in greatly reducing plant vigor (not evident until the following spring), but did not kill a significant percentage of *S. densiflora* plants (Gerwein, pers. comm., October 2012). Further research and method development could lead to improved efficacy, especially when chemical use is combined with mechanical methods such as top mowing (see Section 4.9 for more information).

Experimental Imazapyr Treatment of *S. densiflora*
(Photo by Joel Gerwein)

In the Management Area, chemical control may be appropriate for some areas where ground disturbance is unacceptable, such as at sites where erosion or disturbance to sensitive wildlife species is of concern. Herbicide use results in minimal damage to the marsh surface because it does not involve mechanical manipulation of the marsh surface, and also because the access to and over the marsh by large work crews is less than that required by mechanical methods. Chemical treatment may also be advantageous in areas where access is difficult, and where it would be difficult to perform repeated treatments using mechanical methods. Chemical use should be minimized in areas where regular tidal flushing does not occur.

Herbicide application must be performed by or under the supervision of a Certified Applicator. Herbicides may be applied using backpack sprayers or wick applicators while walking through the marsh or can be applied from spray equipment mounted on boats, trucks, or amphibious tracked vehicles. In other locations, aerial application of herbicides (broadcast using helicopters) has provided a cost-effective means of covering large infested areas; however aerial application is not currently proposed for the Management Area.

Chemical treatment is best applied during the active growing season before seed set, and is highly dependent on tide windows and daylight. It is best to maximize the time that plants will remain dry following chemical applications, such as during extended low tide periods. The concentration of herbicide solution required for control depends on how and where the herbicide is applied.

The use of non-selective chemicals such as imazapyr can affect non-target plant species growing in close association with *S. densiflora*. In the low marsh, there are often few associated species, and in the high marsh, trained operators using backpack sprayers can be selective during application to avoid non-target plants. Pickleweed appears to be somewhat resistant to imazapyr, presumably related to its succulent nature. In the Conservancy's experimental plots in the Management Area, some pickleweed survived the single imazapyr treatment applied in summer 2011 (Gerwein, pers. comm., October 2012). In the short term, chemical *Spartina* treatment can result in large areas of standing dead vegetation that may inhibit native plant recovery unless removed by mechanical means.

4.8.2 Imazapyr

Imazapyr is a broad-spectrum systemic herbicide formulated to have low toxicity to fish and wildlife in West Coast estuaries (Boe et al. 2010). Registered for use in California in 2005, imazapyr is sold under the trade names of Habitat® or Polaris AQ™. These 2 formulas consist of a solution of 28.7% isopropylamine salt of imazapyr in water; and contain a small amount of an acidifier. Habitat® is assumed to be the same formulation as Arsenal® and Arsenal® contains acetic acid, therefore the acidifier in Habitat® is likely also acetic acid (Pless 2005). No current information is available in the published literature on manufacturing impurities related to imazapyr. Although impurities may exist in technical grade imazapyr, concerns about these impurities are reduced because most existing toxicity studies on imazapyr were conducted with the technical grade products, therefore encompassing the toxic potential of the impurities (SERA 2004).

Imazapyr is in the herbicide family imidazolinone, which is a family of non-selective herbicides used to control weeds, broadleaved herbs, and woody species. It is a broad spectrum herbicide, affecting most vascular plant species. It is an amino acid synthesis inhibitor which inhibits the production of the 1st enzyme used when plants synthesize the 3 branched-chain aliphatic amino acids (valine, leucine, and isoleucine) required for DNA synthesis, plant growth, and maintenance (NCAP 2002). Animals do not synthesize their own 3 branched-chain aliphatic amino acids, but obtain them by eating plants and other animals, so direct disruption of this process in animals does not occur when imazapyr is encountered.

Imazapyr has been studied extensively to determine its effects on the environment and on non-target species. Imazapyr rapidly degrades in sunlight and dissipates in water within several days. Pless (2005) found no detectable residues of imazapyr in either water or sediment within 2 months. Imazapyr is rapidly diluted with incoming tides in estuarine systems. The toxicity of imazapyr to animals is low. It has a low potential for bioaccumulations and biomagnification, so adverse impacts to fish and wildlife are unlikely to occur through food web exposure (Kerr 2010). It is highly soluble in water, but because of its low solubility in lipids, it does not concentrate in animal fat or organ tissue (Pless 2005). The greatest risk for fish and wildlife is during and immediately following application when herbicides are present at relatively high concentrations. At those times, organisms that live in the water column, such as algae, non-target plants, fish and aquatic invertebrates may be affected. The period for acute exposure is fairly short because imazapyr degrades rapidly via photolysis.

Additional compounds are frequently added to the tank mix; they are adjuvants/surfactants and colorants. Adjuvants are additives that are combined with herbicides to improve their performance in aquatic environments. The long-term fate of many adjuvants is not well known. There are limited long-term monitoring data for these chemicals and the ingredients and the behavior or fates in the environment of many adjuvants are not disclosed by the manufacturers. Surfactants are mixed with herbicides to reduce water surface tension and help spread the herbicide in a thin layer over the leaf surface allowing it to stick to the plant and to penetrate into the plant tissues, thereby improving the spreading, dispersion, emulsifying, sticking, absorbing and penetrating properties of the spray mixture (Kerr 2010, Pless 2005). If a surfactant is not used, the herbicide mixture will remain on the waxy leaf surface or just roll off the leaves and will not efficiently uptake into the tough cuticle of *Spartina* plants (Pless 2005). The effectiveness and costs of surfactants vary. Dyes or colorants are added to the herbicide/surfactant solution to serve as markers so that spray crews can tell where they have sprayed after the initial spray application has evaporated; this helps ensure that spraying is adequate but not excessive. The surfactants that would likely be used include either lecithin [soy bean] based (Liberate™) or a methylated vegetable oil (Competitor®). No surfactants containing nonylphenol ethoxylate would be used because of the potential for endocrine disruption in fish (CSCC 2010). A water-soluble non-ionic polymeric colorant such as Blazon®, a blue dye, can be used to help detect treated plants.

Application of imazapyr is most effective when plants are actively growing (AMEC Geomatrix 2009). Imazapyr is applied to the leaves, after which it is absorbed into the plant tissue and circulatory system, and then translocated into the roots (CSCC 2010). *Spartina* readily propagates via rhizomes, so when the herbicides are transported to these tissues, the cell death that occurs is an effective mechanism to prevent the plant from spreading vegetatively. Imazapyr is slow acting and it takes several weeks or months for effects to show on the plants (NCAP 2002, Patten 2003).

4.9 Combination of Mechanical and Control Methods

An integrated management program incorporating a variety of methods used in combination offers flexibility and the ability to respond effectively to a variety of site conditions and logistical considerations. Mechanical and chemical control methods can be combined in various ways to optimize efficacy, minimize impacts, and achieve desired results. Settings and timings of combination methods must consider the specific circumstances of each site and the *Spartina* conditions.

Chemical and mechanical methods in combination have been successfully used in Washington, Oregon and San Francisco Bay, California as part of an integrated management strategy. The combined use of imazapyr with mechanical control has been particularly effective in San Francisco Bay. Chemical and mechanical methods were combined successfully at Creekside Park in San Francisco Bay. Imazapyr treatment was used for seed suppression, making it easier to contain the spread, dig up, and mow any additional plants or meadow areas (Kerr, pers. comm., March 2011).

A site can be transitioned to manual treatment methods after reducing the initial infestation with herbicide treatments. Established stands of chemically treated *S. densiflora* can appear to be half-dead. In this state, the plants are not healthy enough to translocate herbicides, and therefore are less susceptible to chemical treatment at this point. Mowing partially dead or dead plants after herbicide treatment removes aboveground biomass, and can be effective in killing the plants. At Redwood City in San Francisco, a small population of large, mature *S. densiflora* plants was treated with imazapyr (3% solution) in autumn 2010 when the plants were first discovered. When re-visited in spring 2011, the plants appeared to be severely weakened but not killed by the treatment. The plants were all mowed to the soil surface using a brushcutter. This combination yielded excellent results, 100% mortality of treated plants. In spring 2012, only 3 small plants (believed to be recruitment from the seed bank) were found at the site and easily removed (Kerr, pers. comm., July 2012). This combination treatment could be especially useful in the Management Area at sites or portions of sites where ground disturbance is unacceptable.

Mowing prior to chemical treatment was tried in San Francisco Bay as a way to promote new green growth that might better translocate herbicides than older leaves; however, the efficacy of treating regrowth of mowed *S. densiflora* is low (Kerr, pers. comm., July 2012). Chemical treatment could provide a relatively quick method of seed suppression for reproductive stands that threaten areas treated by mechanical methods.

4.10 Monitoring

The Regional Coordinator will establish and maintain a monitoring system for 1) assessing site conditions throughout the treatment period, including *Spartina* response to treatment and the level of recovery by native plants; 3) determining when performance criteria have been met, and 4) conducting long-term monitoring to ensure early detection of potential future *Spartina* invasions. Regional coordination of monitoring will help achieve consistent documentation throughout the Management Area and facilitate comparisons among treated sites.

Monitoring will rely primarily on rapid assessment methods performed by qualified biologists sufficient for the purposes listed above. This will allow a greater contribution of available funds to be directed towards implementation of treatment measures rather than extensive quantitative plot-based sampling, which is more labor intensive. Extensive quantitative data has been collected in association with research and method development by HBNWR and others, as referenced throughout this report.

Monitoring will be achieved by periodic site visits and will include recording specific data based on qualitative visual assessments and photo-documentation (Table 4-7). All monitoring data will be entered in the regional database. Monitoring forms could be developed to ensure consistent collection of monitoring data. These recommendations are intended as guidelines and can be adjusted as appropriate. For example, a particular site could be visited more frequently than the time intervals shown in Table 4-7, with data recorded and added to the database.

Table 4-7. Monitoring Guidelines

Timeline	Monitoring Activity
Prior to treatment	Document baseline conditions (this task already accomplished by site evaluation); establish photopoints
Soon after primary treatment	Describe early post-treatment conditions
6 months	Inspect site to determine the need for follow-up treatment (will vary depending on the method(s) selected for primary treatment)
1st spring	Monitor for *S. densiflora* seedlings and assess the need for treatment
Annually for 5 years	Inspect site to determine the need for follow-up treatments and to assess recovery by native salt marsh vegetation; photograph site at established points
5 year evaluation	Evaluate site to determine whether performance criteria have been met
Long-term monitoring	Surveys at sufficient intervals (to be determined) to detect reinfestation early and allow rapid response

4.10.1 Treatment Period Monitoring

The site evaluations prepared as part of site-specific plans (Section 4.5) will provide documentation of baseline conditions. If there is much delay between preparation of the site evaluation and initiation of treatment, the site evaluation may need to be updated. Prior to treatment, photopoints should be established. Photopoints should be distributed so that they capture the full range of diversity occurring at the site, and effectively document vegetation response to treatment. Some of the photopoints should provide panoramic views and include landmarks so as to capture the same view in subsequent photos. Geospatial data and aspect should be recorded so that the photopoints can be re-located in post-treatment monitoring. The site should be photographed at these established points at a minimum annually. General photos and photos capturing specific features at the site are encouraged at all monitoring visits.

Monitoring site conditions throughout the treatment period is a separate task from documenting implementation of the treatment itself (see Section 4.2), though the 2 are closely linked. The relevant information to record at each site visit depends on treatment stage, the type(s) of treatment used, and the season during which treatment was initiated.

Soon after primary treatment, the main purpose is to describe site conditions, including condition and status of any *Spartina* remaining on site, visual estimates of the amount and distribution of bare areas exposed, the condition of other plant species present, and condition of any sensitive resources on the site. At 6 months, the main focus will be to determine what follow-up treatments are needed, estimate the time that will be required, and make recommendations for scheduling the work. The 1st spring following primary treatment, the site should be evaluated to check for *Spartina* seedlings and determine whether seedling treatment is needed. Seedling emergence is generally highest in March-April, and seedlings are best treated when young.

Annually for the 1st 5 years, sites should be monitored to determine the need for follow-up *Spartina* treatments and to determine whether active revegetation measures are warranted based on the recovery by native salt marsh vegetation. It is expected that the need for follow-up treatments will decline by the 3rd year, though this may vary depending on specific site conditions and the methods implemented. Observations of any plant species colonizing the site, visual estimates of relative cover by species, and notes on site variability should be recorded. Since primary treatment might be initiated at any time of the year, the precise timing of annual visits can be adjusted as appropriate, and more than one visit per year may be desirable. For example, summer is generally the best time to assess native plant recovery, while a visit earlier in the spring would provide a better assessment of annual rare plant populations.

4.10.2 Performance Criteria

Performance criteria are proposed here to determine a threshold level at which native plant recovery has been achieved, *Spartina* cover has been reduced to negligible levels, and minimal effort will be required to detect and respond to *Spartina* plants that reinvade. Based on work to date, it is reasonable to expect that this threshold can be reached within 5 years or sooner, providing that sufficient resources are available to implement treatment measures as needed during this period.

Performance criteria to be evaluated at year 5:

- < 1% cover by *Spartina*
- > 70% total vegetation cover
- Vegetation dominated by native tidal marsh plant species

If performance criteria are not met by the 5th year, then the need for remedial measures will be assessed and implemented as warranted. Annual monitoring and treatment will continue until the performance criteria have been met.

Restored Lanphere-Ma-le'l Marsh
(Photo by Andrea Pickart)

4.10.3 Long-Term Monitoring

Long-term monitoring is important to detect new *Spartina* infestations early and allow a rapid response. All areas containing suitable *Spartina* habitat should be surveyed at time intervals deemed suitable for the purpose. Finding the last remaining plants is one of the largest challenges of a successful eradication program (Patten 2010, WSDA 2011).

Early detection is important so that plants can be removed before they have a chance to spread further. This includes *S. densiflora* that reinvades and potentially the arrival of other invasive *Spartina* species (see Section 3.1.1 for description and photos of all *Spartina* species that have invaded the West Coast to date). When plants are detected, geospatial data marking the location should be collected and notes recorded describing the occurrence, including abundance, phenology, associated species, and relevant site conditions. Survey intensity should be increased in the vicinity to search for any nearby plants. If invasive *Spartina* species other than *S. densiflora* are detected during monitoring, a specimen of the plant should be collected for positive identification. Treatment measures appropriate for the species should be implemented as soon as possible. Communication with managers at other locations who have experience with other species will be helpful. Some of the lessons learned from work to date are listed in Appendix C.

4.11 Communication and Outreach

The success of any management strategy requires the support and involvement of regional and local agencies, land managers, landowners, other stakeholders, and the public. The Regional Coordinator will lead communication and outreach activities, but could be assisted by a regional *Spartina* advisory committee that is comprised of key stakeholder representatives. The intent of the communication and outreach is to provide "pathways" for information between all interested parties. The purpose of this section is to describe processes and activities that will facilitate communication and outreach.

Communication and outreach activities include:

- Contacting all affected landowners, and requesting permission to access/treat infested lands
- Coordinating with landowners that take an active role in implementing *Spartina* treatments
- Working with local and regional resource agencies
- Interacting with the scientific community regarding ongoing research and method development
- Staying current on the status of coast-wide eradication efforts and sharing information on the work accomplished at our regional level
- Providing education that increases the community's awareness of, and appreciation for, the aesthetic and ecological values of salt marshes; and that increases the community's understanding of how invasive *Spartina* impacts salt marshes, and why its eradication is beneficial
- Tracking and communicating the progress of eradication efforts
- Creating and promoting opportunities for the community to become involved in *Spartina* eradication

4.11.1 Activities to Date

Communication and outreach activities have been an important component in the Management Area during the period of *Spartina* research and throughout the process of preparing the Regional Plan. These activities have included:

Conferences, workshops, and field tours:

- *Spartina* Summit, Eureka, CA, 13 February 13 2008, including field trips (http://www.fws.gov/humboldtbay/spartinasummit.html#Summit2008)

- *Spartina* Symposium, Eureka, CA, 29-30 June 2010, including field trips (http://www.fws.gov/humboldtbay/spartinasummit.html#Symposium2010)
- Humboldt Bay *Spartina* Symposium, Humboldt State University, 1 December 2011
- Friends of the Dunes school education programs- tours at Ma-le'l Dunes-2010-present
- Humboldt State University class field trips to HBNWR *Spartina* treatment sites 2010-2011
- Humboldt State University class guest lecture- 4 October 2012
- Training sessions by HBNWR staff for other local land managers on *Spartina* eradication methods 2010-2011
- Field tours to HBNWR restored site for labor crews working on *Spartina* treatments

Community Volunteer Work Days:

- Revegetation work days at HBNWR - 2007-2008
- "*Spartina* Shindig" and "People for Pickleweed" volunteer *Spartina densiflora* eradication work days at HBNWR - 2009-2011

Meetings initiated by Conservancy staff with:

- Californians for Alternatives to Toxics (CATs), 18 March 2008
- Humboldt Bay shellfish growers, 10 April 10 2008
- Humboldt County Weed Management Area, 25 July 25 2008
- Wiyot Tribe Environmental Staff, 21 August 21 2008
- Meeting with Humboldt Baykeeper staff, 18 March 2009
- *Spartina* Public Meeting, Arcata, CA, 15 October 2009
- *Spartina* Public Scoping Meeting, Arcata, CA, 19 January 2011

Presentations given by Conservancy or HBNWR staff, to:

- Humboldt County Farm Bureau, 19 November 2008
- Humboldt County Board of Supervisors, 27 January 2009
- Eureka City Council, 17 March 2009
- Arcata City Council, 18 March 2009
- CNPS North Coast Chapter, September 2010
- Print and electronic media outreach: *Restoring the Native Salt Marshes of Humboldt Bay National Wildlife Refuge,* educational brochure published by HBNWR
- Articles in the Summer, Fall, and Winter 2010 issues of *Dunesberry,* newsletter of the Friends of the Dunes (http://www.friendsofthedunes.org/news/dunesberry.shtml)
- Article in Winter 2010 issue of *Darlingtonia,* newsletter of CNPS North Coast Chapter (http://northcoastcnps.org/DT/Darlingtonia_11_1_Winter.pdf)

- HBNWR's website provides information on their *Spartina* project, as well as links to related projects and literature (http://www.fws.gov/humboldtbay/spartina.html)
- Radio interview: Andrea Pickart (HBNWR) and Joel Gerwein (Conservancy) interviewed by Ken Burton (Northcoast Environmental Center, Arcata), aired on KHSU 24 February 2011, 1:30 p.m. (http://khsu. org/audio_archives)
- Radio interview: Adam Wagschal (H. T. Harvey & Associates) interviewed by Jen Kalt (Northcoast Environmental Center, Arcata), aired on KHSU 26 April 2012, 1:30 p.m.

4.11.2 Key Stakeholders Identified to Date

In addition to the general public, a variety of stakeholders have either already participated in some way with *Spartina* eradication and outreach efforts, own land potentially impacted by the *Spartina* eradication, or have a particular interest in potential environmental impacts of proposed eradication strategies. Key stakeholders who are identified so far are:

- Elected officials and staff of the Humboldt County Board of Supervisors; the Harbor District; the cities of Ferndale, Eureka, and Arcata
- Resource agencies, such as USFWS, U.S. Army Corps of Engineers (USACE), National Marine Fisheries Service (NMFS), CDFG, State Historic Preservation Officer (SHPO), California Coastal Commission (CCC), North Coast Regional Water Quality Control Board (NCRWQCB), North Coast Unified Air Quality Management District (NCUAQMD), Humboldt County Agricultural Commissioner
- Public landowners and land managers such as HBNWR and CDFG; private landowners; and non-governmental organizations
- Aquaculture industry, such as shellfish growers, and others who may be affected directly or indirectly by *Spartina* treatment
- Conservation organizations, including CNPS, Friends of the Dunes, Humboldt Baykeeper, Friends of HBNWR, Redwood Region Audubon, Californians for Alternatives to Toxics, Northcoast Environmental Center, and Friends of the Eel River
- Scientific community, such as academic institutions (Humboldt State University), nonprofit corporations such as the Coastal Ecosystems Institute of Northern California
- Native American tribes, such as the Wiyot and Yurok tribes
- Recreational users, such as hunters, boaters, and hikers; members of the Humboldt Chapter of the California Waterfowl Association and Explore North Coast, a kayaking group
- School and youth groups, such as scouts, youth church groups, recreational groups
- News organizations, such as Eureka Times Standard, the Northcoast Journal, Northcoast Environmental Center's Eco-News, KHSU, Arcata Eye, McKinleyville Press, HSU Lumberjack

4.11.3 Future Activities

Future communication and public outreach activities can be based on past activities, using a variety of outreach tools. Examples of future activities include:

- Project brochures and newsletters, including print or web based publications, used to: keep those interested in the project informed, clarify issues, encourage dialogue, share success stories, and promote public events
- Project website, with relevant links, used as a readily accessible clearing house for information, and to post public events and news
- Outdoor interpretive exhibits or interpretive panels developed at key public access and viewing sites around the Management Area, used to heighten awareness about salt marshes and *Spartina* eradication efforts
- Presentations on television and radio, which provide excellent opportunities for publicizing public events and restoration updates
- Presentations to local groups, developed for ongoing use in speaking to service clubs, local conservation groups, recreational user meetings, educational groups, professional organizations, and other stakeholder groups
- Meetings and workshops, important for promoting dialogue, to be offered at a variety of locations throughout the Management Area and at various stages of project implementation
- Guided walks and field tours, which help build the connection between the public and marshes; engaging activities such as photography excursions and canoe and kayak tours will appeal to a variety of ages and interest levels
- Community work days, which build community connections and personal ownership in the success of the project; these activities are appropriate at accessible sites with sparse to moderate *Spartina* for activities requiring minimal training or supervision

A variety of communication and outreach tools will maximize dissemination of information to various audiences. The timing of activities can be scheduled to address specific project stages, and summaries of work accomplished will be provided annually.

Section 5.0 Environmental Compliance

The Regional Coordinator will be instrumental in acquisition and administration of permits, with assistance from the Conservancy. It is anticipated that the Regional Coordinator will be the applicant/holder of region-wide permits. The following permits/approvals will likely be required from the agencies indicated. Additional permits may be required on a site-specific basis.

Section 404 Nationwide Permit 27, USACE. Section 404 of the Clean Water Act (CWA) generally requires a USACE permit for discharge of dredged or fill material into waters of the United States, including adjacent wetlands. Under Section 404, USACE can issue general, or Nationwide, permits that cover classes of activities. A Nationwide Permit (NWP) could cover *Spartina* eradication activities, as described in NWP 27, which is a nationwide general permit for Aquatic Habitat Restoration, Establishment, and Enhancement Activities. Mechanical removal involves excavation and backfill of sediment in tidal areas, and placing markers and stakes in tidal areas; these actions would be regulated by USACE under CWA's Section 404 and the Rivers and Harbors Act (RHA), Section 10. Mowing or herbicide treatment would be considered by USACE in its evaluation of the project's overall cumulative impacts. The Regional Coordinator would apply to USACE for NWP 27, which would authorize and allow "mechanized land clearing to remove non-native invasive, exotic, or nuisance vegetation." This NWP applies to tidal waters and does not have an acreage limit. Through its authorization of an NWP, USACE is the federal agency that is required to consult with NMFS on potential adverse effects of *Spartina* eradication on Essential Fish Habitat (EFH). Eradication activities could likely be designed and modified to avoid all adverse effects on EFH.

Section 10 Rivers and Harbors Permit, USACE. Section 10 of the RHA of 1899, authorizes USACE to regulate virtually all structures or work within the navigable waters of the United States; the regulation occurs via a Section 10 permit. USACE can authorize the work by an individual permit, a letter of permission, an NWP, or a regional permit. The flooding method is the only *Spartina* eradication method that is likely to require a structure within navigable waters because to flood an infested area, a temporary flow obstruction would be needed. If this method could not be considered under NWP 27's restoration and enhancement, and if this method would require an individual Section 404 and/or Section 10 permit, then a National Environmental Policy Act (NEPA) analysis would likely be required. Due to the relatively small and defined areas where flooding may be a feasible eradication method, an Environmental Assessment, rather than an Environmental Impact Statement, would likely suffice.

Section 401 Water Quality Certification, North Coast RWQCB. The CWA's Section 401 requires that discharges from dredge or fill actions be certified to comply with state water quality standards; the document that supports compliance is called a Water Quality Certification or a "401 Certification." (The Section 401 Certification is must be issued before USACE's Section 404 permit, discussed above.) Eradication methods will not require dredging or filling to an extent or severity that occurs during, for example, waterfront development. However, eradication activities could disturb surface and near subsurface soils during grinding, disking, digging, and excavation. These methods could cause sedimentation and a decrease in water quality by increasing turbidity and suspended sediment. Therefore a Section 401 Certification would likely be required, and would be issued by NCRWQCB. It could be obtained by incorporating best management practices into eradication activities that would reduce and minimize any loss of water quality.

NPDES Permit, General Permit No. CAG990005, North Coast RWQCB. Section 402 of the CWA requires that projects comply with National Pollutant Discharge Elimination System (NPDES) requirements, as evidenced by issuance of a NPDES permit. Chemical eradication is a method that would likely require a NPDES permit. Despite regulatory changes in permitting for pesticides and weed control, it appears that for any of the Regional Plan's eradication activities that require herbicide use, an NPDES permit is required. The State Water Resource Control Board's (SWRCB) Water Quality Order No. 2004-0009-DWQ established the Statewide General NPDES Permit for the Discharge of Aquatic Pesticides for Aquatic Weed Control in Waters of the United States (General Permit No. CAG990005). To qualify for this general permit, the entity who will be applying herbicide must submit 1) a Notice of Intent to comply with the Terms of the General Permit, 2) a vicinity map, and 3) an application fee to the appropriate Regional Water Quality Control Board. Glyphosate and imazapyr are covered under this Aquatic Pesticides General Permit. The entity applying the herbicide would annually prepare and submit an Aquatic Pesticide Application Plan to the RWQCB, conduct water quality monitoring at the required treatment sites, and prepare and submit water quality monitoring reports. The North Coast RWQCB may adopt this General Permit for chemical eradication treatments under a CEQA categorical exemption, but entities that wish to receive this NPDES General Permit must prepare and submit certain CEQA-related information, such as documentation of public notification, a detailed project description, a time schedule, water monitoring plan, and contingency plans.

CEQA Notice of Determination, Conservancy. Although the NPDES General Permit would likely not require an Environmental Impact Report, a PEIR is being prepared to evaluate potential environmental effects from *Spartina* eradication. For eradication activities in the Humboldt Bay region, the Conservancy has been identified as the CEQA lead agency. Other involved and responsible agencies include the Harbor District, CCC, CDFG, the North Coast RWQCB, and the California Department of Pesticide Regulation (CDPR). A PEIR is being prepared because numerous eradication methods could be applied, and because the infested areas within the Humboldt Bay region are ecologically similar. Based on comments received from the Initial Study and the Notice of Preparation, resources that will be analyzed in detail are aesthetics, air quality, biological resources, geology/soils, hazardous materials, hydrology/water quality, land use, noise, and cultural resources.

Cultural resources are additionally regulated by the National Historic Preservation Act (NHPA), which protects historical and prehistoric resources from impacts by federal projects. It requires consultation (under the NHPA's Section 106) with the SHPO. Compliance is particularly important to eradication activities in the Humboldt Bay region because significant tribal and cultural resources are known to exist in or in the vicinity of infested areas. To comply with the NHPA and the cultural resources assessment of CEQA, prehistoric and historical information is collected through archival research and consultation with the Native American Heritage Commission and coordination and consultation with the State Office of Historical

Preservation's North Coastal Information Center. Additionally, assistance could be provided by the USFWS Regional Cultural Resources Office. The Wiyot Tribe, Table Bluff Reservation, owns and manages approximately 61.5 ac of land within the Humboldt Bay watershed, including the Table Bluff area and a portion of Indian Island. The Wiyot Tribe is recognized by the federal government as a tribal organization under the general protection of the federal government, with sovereign rights of self-determination. The Regional Coordinator will work with the Tribe to ensure that cultural resources are protected throughout the *Spartina* eradication process.

Input on PEIR and Non-Standard Permit for burning, NCUAQMD and Cal-Fire. NCUAQMD will review the PEIR and will determine whether eradication activities will require a permit. Burn permits will likely be required from the NCUAQMD if burning is proposed to dispose of wrack generated by mowing *Spartina*; this activity would likely qualify as a Non-Standard Permit. If wrack burning is to occur during fire season, additional permits will be required by Cal-Fire. If heavy equipment is used to mow, excavate, or otherwise eradicate *Spartina*, diesel exhaust will be emitted but the California Air Resource Board's off-road diesel vehicle regulations will limit the exhaust's effects (CARB 2011). These regulations apply to owners and renters of off-road diesel vehicles that are self-propelled and over 25 horsepower.

Coastal Development Permit, CCC. The Federal Coastal Zone Management Act (CZMA) directs the states to develop and implement coastal management programs; California has complied with its California Coastal Management Program (CCMP). CCC administers the CCMP under the enforceable policies of Chapter 3 of the California Coastal Act of 1976. Under the CZMA, federal agencies are required to carry out their activities and programs in a manner consistent with the CCMP. Federal agencies make consistency determinations on proposed federal activities that may affect coastal resources; applicants for federal permits, licenses, or federal financial assistance make consistency certifications. Then, CCC reviews these determinations and certifications; the Commission concurs or objects based on a proposal's consistency with laws and policies. If USACE authorizes the eradication activities under NWP 27, CCC will nevertheless treat the NWP as any other CWA Section 404 permit, and a consistency certification will be required (CCC 2011). CCC has objected to USACE's NWP program, and the Commission can still review for consistency. However, CCC can either waive or require a consistency certification.

Development Permit, Harbor District. The statutory purpose of the Harbor District is to manage Humboldt Bay for the promotion of commerce, navigation, fisheries, recreation, and the protection of natural resources, and to acquire, construct, maintain, operate, develop, and regulate harbor works. The Harbor District Board of Commissioners is authorized to grant permits to entities proposing development within the jurisdiction of the Harbor District. The Harbor District's regulatory jurisdiction includes all of Humboldt Bay up to the mean higher high water level except for Indian, Woodley, and Daby islands where the Harbor District jurisdiction is up to the mean high water level. In most cases, the Harbor District permit will be issued before the CCC Coastal Development Permit and USACE's Section 10 and 404 Permits.

Restricted Materials Permit, Humboldt County Agricultural Commissioner. The California Code of Regulations Title 3, and Division 6, Chapters 1-4 (Pesticide Regulatory Program, Pesticides, Pest Control

Operations and Environmental Protection), define the specific requirements of pesticide application within the State of California. These regulations are at least commensurate with, and generally more stringent than, federal regulations. The State Water Quality Management Agency Agreement is an agreement between SWRCB and CDPR to coordinate the 2 agencies in their efforts to monitor and control herbicide use. In Humboldt County, the County Agricultural Commissioner is the person responsible for issuing Restricted Materials Permits (RMPs); he is assisted by one other Agricultural Inspector. New RMP applicants are interviewed in person, and permits are valid for 1 year. Pesticide use reporting requirements are reviewed with the applicant. If a specific infested site within the Humboldt Bay region is to be eradicated using restricted materials (herbicides), then an RMP application would need to be filed.

Incidental Take Permit, USFWS and NMFS. The Federal ESA of 1973, as amended (Federal ESA), establishes a national program for the conservation of threatened and endangered species and the preservation of the ecosystems on which they depend. The Federal ESA protects listed fish and wildlife species from harm or "take" which is broadly defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, collect, or attempt to engage in any such conduct. Take can also include habitat modification or degradation that directly results in death or injury to a listed wildlife species. Listed plant species are provided less protection than listed wildlife species; they are legally protected from take under the Federal ESA if they occur on federal lands. An activity can be defined as causing "take" even if project effects were unintentional or accidental. If USACE issues a Section 404 or Section 10 permit, the issuance could be an action under the Federal ESA's Section 7, which would require that USACE consult with, and obtain an opinions statement from, USFWS and NMFS.

The 1972 Marine Mammal Protection Act prohibits taking or harassment of any marine mammals except incidental take during commercial fishing, capture under scientific research and public display permits, harvest by Native Americans for subsistence purposes, and any other take authorized on a case-by-case basis as set forth in the Act. USFWS is responsible for the polar bear, sea otter, marine otter, walrus, manatee, and dugong (none of which are likely to be present in eradication areas). NMFS is responsible for all other marine mammals, which are also unlikely to be present in eradication areas.

The Federal Migratory Bird Treaty Act (MBTA) governs the taking, killing, possessing, transporting, or trading in migratory birds, their eggs, parts, and nests except in accordance with regulations prescribed by the Secretary of the Interior. The take of all migratory birds is governed by the MBTA's regulation of taking migratory birds for educational, scientific, and recreational purposes and requiring harvest to be limited to levels that prevent overutilization. The MBTA prohibits the take, possession, import, export, transport, selling, purchase, barter, or offering for sale, purchase or barter, any migratory bird, their eggs, parts, and nests, except as authorized under a valid permit (50 CFR 21.11). While few nests of any kind are expected in the *Spartina*, best management practices will be followed to avoid take of nesting birds or nests while accessing the eradication sites. None of the eradication activities are likely to have measurable negative effects on migratory bird populations.

Streambed Alteration Agreement, CDFG. CDFG is responsible for conserving, protecting, and managing California's fish, wildlife, and native plant resources. To meet this responsibility, the Fish and Game Code (Section 1602) requires an entity to notify CDFG if any proposed activity may substantially modify a river, stream, or lake, by diverting or obstructing flow, changing or using material from river bed, banks or channel. Notification of streambed alteration is required by an entity that proposes an activity that will either: 1) substantially divert or obstruct the natural flow of any river, stream or lake; 2) substantially change or use any material from the bed, channel, or bank of, any river, stream, or lake; or 3) deposit or dispose of debris, waste, or other material containing crumbled, flaked, or ground pavement where it may pass into any river, stream, or lake. *Spartina* eradication methods have the potential to require notification, if the eradication occurs in or near a stream. If CDFG determines that the activity may substantially adversely affect fish and wildlife resources, a Lake or Streambed Alteration Agreement will be prepared, and the Agreement must comply with CEQA.

Access permits that may be required:

- Visitation Permit, City of Eureka
- Nature Area Entrance Permit, City of Arcata
- Special Use Permit, USFWS (HBNWR)
- Letter of Permission, Wiyot Tribe
- Permission to Enter, Manila Community Services District
- Master Land Use Agreement, California Redwood Company
- Caltrans Encroachment Permit
- Railroad Right-of-Way Agreement
- CSLC Lease

Section 6.0 Cost Characterization

The purpose of this section is to compile *Spartina* eradication costs that occurred at various project sites and under varying conditions, so that we can broadly characterize costs for eradication techniques that could be employed within the Management Area. These Management Area eradication cost characterizations are intended to be relative, so we can discuss treatment costs by technique. Cost estimate "rules of thumb" in dollars per acre, multiplied by total treatment area in acres can be helpful, but are too variable to be used for budgeting on a programmatic or Management Area wide level. Each site poses specific challenges related to access, treatment method, density of infestation, adjacent land uses, geomorphic setting, soil types, and work windows.

6.1 Treatment Costs from Other West Coast Estuaries

Costs were compiled from various reports, management plans, e-mails, and phone conversations (Table 6-1). These data document the cost variation found among control program locations, types of *Spartina* infestations, and treatment methods. The costs shown include treatments applied to various invasive *Spartina* species. Note that these costs might be higher or lower if applied in Humboldt Bay to *S. densiflora* due to differences in the effectiveness of the methods on different *Spartina* species and other factors. Not all methods listed are proposed for use on *S. densiflora* in the Management Area, but are included here for comparison purposes.

Table 6-1. Summary of Treatment Costs from Other West Coast Estuaries

Method	Description of Method	Cost Per Acre Per Year	Source
Mowing	Seed clipping only (hand)	$16,850-33,700	Dresen et al. 2010
	Seed clipping only (brushcutter)	$2,700	
Excavation	Hand digging with shovels	$85,000-130,000 ($2-$3/ft^2)	Pfauth et al. 2003
	Hand digging with shovels	$100,000	Dresen et al. 2010
	Hand digging with shovels	≥$87,000	Morgan and Sytsma 2010
	Large scale mechanical excavation	$390-$2,000	Pfauth et al. 2003
	Excavator digging, standard upland equipment	$3,000	Dresen et al. 2010
	Excavator digging, amphibious equipment	$9,000	
Tilling, disking, and crushing	Amphibious equipment	$290 - $2,000	Morgan and Sytsma 2010
Covering	Covering with plastic or other materials	$8,500-1,300,000	Pfauth et al. 2003
		$20,000-60,000	Dresen et al. 2010
Chemical (application of herbicides imazapyr and/or glyphosate)	Various application methods	$300-$780	Pfauth et al. 2003
	Aerial application	$100-200	Dresen et al. 2010
	Hand application (backpack sprayer)	$300 – 400	Dresen et al. 2010
	Hand application (*S. densiflora* treated on 3.4 ac in Corte Madera Cr, San Francisco Estuary, CA)	$4000	Guldman, pers. comm., August 2011
	Unknown method of application	$300 - $780	Morgan and Sytsma 2010

6.2 Cost Characterization for *Spartina* Control in the Management Area

Cost information for various control methods proposed for treating *S. densiflora* in the Management Area is summarized below, based on work conducted in the Management Area and in the San Francisco Estuary. Limitations and assumptions affecting these costs are:

- Labor costs are highly variable. Labor sources include conservation corps crews, inmate crews, trained laborers, natural resource management staff, and community volunteers.
- Vehicle costs for transporting staff and field equipment (e.g., vehicle depreciation, gas, maintenance) were not included because these costs are not readily available on a per acre basis.

- Sites may be treated by more than one method. Site-specific evaluation will be required to determine the appropriate treatment for any given site. Each site will likely require several treatments, possibly using multiple methods, to adequately control *Spartina*.
- The level of effort for follow-up treatment will decline over time, thus decreasing costs for these treatments.
- Long-term monitoring will be required to detect and respond to potential future *Spartina* invasions; the costs associated with these efforts are not addressed here.

To present cost information, we have grouped the eradication methods into mechanical and chemical treatment methods, recognizing that some methods will likely be used in various combinations and different methods may be more appropriate for different treatment stages, including primary, follow-up, or maintenance treatments.

6.2.1 Mechanical Control Costs

Within the Management Area, HBNWR has primarily used the grind method to treat *S. densiflora* on HBNWR lands, with trials in progress using amphibious equipment (such as the Marsh Master II). In 2010, HBNWR received $1 million in funding from the USFWS to complete removal of *Spartina* within HBNWR boundaries. Equipment costs shown in Table 6-2 are based on information provided by HBNWR for the first year of this effort. The total cost to purchase and operate 54 brushcutters (units plus maintenance) was approximately $38,000-$65,000. Maintenance costs are an average overall and do not reflect variations associated with individual site characteristics, such as *Spartina* density and substrate type, which affects the level of maintenance and blade replacement required.

Table 6-2. Mechanical Control Equipment Costs Using the Grind Method on *S. densiflora*

Equipment or Material	Estimated Cost
Brushcutter cost per unit	$500 – $1,000 per brushcutter
Brushcutter maintenance and repair (monthly cost per unit)	$50 unit/month (includes maintenance and blades)
Safety gear (helmet, face shield, harness, rubber boots)	$200/person

To estimate labor costs associated with hypothetical application of the grind treatment region-wide, the following numbers were based on the original acreage of infestation as mapped by Grazul and Rowland (2011) minus acreage that has been restored or nearly restored by current efforts (Table 6-3). Cost estimates for applying primary treatment using the grind method to treat remaining infested acres in the Management Area are shown in Table 6-3. The time required to apply the grind treatment varies with the density of the infestation as shown. An overall estimate, not broken down by *Spartina* density, is approximately $1,970 to $5,400 per acre for primary treatment using the grind method. Labor costs vary widely depending on the labor source; low and high end costs are provided to illustrate this difference.

Table 6-3. Cost Estimate for Primary Treatment Using the Grind Method on *S. densiflora*

Spartina Density	Number of Acres to Treat[1]	Person Hours to Complete 1 Acre[2]	Untrained Workers (Cost Per Acre at $8/Hour)	Trained Workers (Cost Per Acre at $21/Hour)	Total Untrained Worker Cost ($)	Total Trained Worker Cost ($)
Low	589	85	680	1785	400,520	1,051,365
Medium	333	171	1368	3591	455,544	1,195,803
High	592	186	1488	3906	880,896	2,312,352
Total	1514				1,736,960	5,559,520

[1] Estimated untreated acreage remaining in 2011
[2] Preliminary time estimates based on HBNWR work in 2010-2011

The need for follow-up treatments is expected to vary by site and is hard to predict on a region-wide basis. Preliminary information provided by HBNWR in 2011was used to estimate follow-up treatment costs (Tables 6-4 and 6-5).

Table 6-4. Cost Estimate for Seedling Treatment Using the Grind Method on *S. densiflora*

Spartina Density	Number of Acres to Treat	Person Hours to Complete 1 Acre	Untrained Workers (Cost Per Acre at $8/Hour)	Trained Workers (Cost Per Acre at $21/Hour)	Total Untrained Worker Cost ($)	Total Trained Worker Cost ($)
Low	589	30	240	630	141,360	371,070
Medium	333	35	280	735	93,240	244,755
High	592	40	320	840	189,440	497,280
Total	1514				424,040	1,113,105

Table 6-5. Cost Estimate for Resprout Treatment Using the Grind Method on *S. densiflora*

Spartina Density	Number of Acres to Treat	Person Hours to Complete 1 Acre	Untrained Workers (Cost Per Acre at $8/Hour)	Trained Workers (Cost Per Acre at $21/Hour)	Total Untrained Worker Cost ($)	Total Trained Worker Cost ($)
Low	589	27	216	567	127,224	333,963
Medium	333	55	448	1176	149,184	391,608
High	592	60	480	1260	284,160	745,920
Total	1514				560,568	1,471,491

Seed suppression prevents or reduces seed production. Seed suppression treatments are most likely to be used to suppress seeds in a particular region of the Management Area until funding becomes available for primary treatment. Top mowing has been effectively used in Humboldt Bay to suppress seed production of *S. densiflora* (Pickart 2012). Approximately 92 person hours per acre are required to perform a seed suppression top mow using a brushcutter.

Maintenance treatment costs are relatively minimal. Following treatment using the methods described above, the time and cost to maintain treated sites in general drops dramatically after the first 2 years and thereafter. At HBNWR's pilot restoration project, the time required for spot treatments conducted 1-2 times per year is approximately 10 person-hrs/ac, at five years following initial treatment (Pickart 2012). As more of the Management Area progresses into maintenance status, the total number of acres requiring this level of treatment will rise and subsequently the overall cost associated with maintenance region-wide will increase.

HBNWR is currently conducting experiments with an amphibious tracked vehicle (the Marsh Master II). It is likely that the use of this type of equipment will be preferred over the grind method for dense stands of *Spartina;* however, this conclusion is still preliminary and has not yet been incorporated into the cost estimate. The Marsh Master II can be outfitted with various attachments to perform mowing, tilling, disking, or crushing, and these are all currently under investigation. In September 2011, the Marsh Master II was used in a top mowing experiment to determine its ability to maneuver in the marsh and the viability of using it for HBNWR treatment activities. It was determined that the equipment is suitable for working in the local marsh environment. The 2011 trials were used to roughly determine the level of effort and cost required for such activities. The labor cost was $120/hr (for 2 operators) and the equipment rental cost was $1,200 per day. It took approximately 6 hrs/ac to achieve a top mow (2 passes required to cut aboveground material low to the ground). This application rate is expected to vary with a number of factors including weather, tides, and site-specific conditions. Transportation and setup time will depend on location and site-specific limiting factors. Over the time period of the project, it likely would be most cost-efficient to purchase amphibious equipment (estimated cost $150-250,000) rather than rent, although a more thorough analysis is needed to determine the costs for labor and operating costs (fuel, maintenance, transportation) of a purchased vehicle if this option is chosen.

6.2.2 Chemical Control Costs

Chemical control costs include labor, herbicide materials (herbicide, surfactant, and dye), and equipment used to apply the herbicide. Chemicals can be applied using backpack sprayers, hoses or tanks mounted on trucks, or amphibious vehicles. Cost information available from previous work did not always include breakdowns between materials and labor costs. The following are chemical treatment costs found in the literature and gathered during personal communications:

- Average materials cost per acre were estimated for large scale herbicide treatments by the San Mateo Mosquito and Vector Control District in San Francisco Bay over a 7-year period. For imazapyr, surfactant, and colored dye, the cost ranged from $150 to $300 per acre per year (Counts, pers. comm., November 2011).
- To perform chemical treatment using backpack applicators, costs are approximately $1,000/acre ($800/acre for labor and $200/acre for herbicide) (Dresen et al. 2010).
- Based on a small trial in Humboldt Bay, the estimate for primary treatment of *S. densiflora* using imazapyr applied with a backpack sprayer for that site was $900 per acre (Nelson, pers. comm., September 2011).

6.2.3 Environmental Compliance and Permitting Costs

Total CEQA compliance costs are estimated to be approximately $100,000, but could be higher. As of November 2012, a Draft PEIR is nearing completion. Future CEQA compliance activities include presentations to the Humboldt County Planning Commission and possibly the Board of Supervisors, compiling and addressing public comments, and producing and circulating a Final PEIR. Costs to complete the CEQA process will depend on the degree of agency and public comments and the revisions needed to the PEIR.

The PEIR is expected to provide the analysis of environmental impacts necessary for NEPA compliance, but a federal agency will have to review that analysis and determine that it concurs that the project will not have a significant environmental impact. Federal agency review and subsequent NEPA compliance is expected to be completed either through the Section 404 permitting process with USACE or through USFWS, which is a potential funder of the project.

The cost for permitting can vary widely, depending on the permits that will be required, resource agency staff availability, and stakeholders' ability to work collaboratively. Permitting costs over the lifetime of the project could range from $250,000 to $400,000, depending on the suite of permits that will be required. This cost estimate range assumes that no multi-year species studies will be required, and that available information will be sufficient to address all agencies' permitting requirements. This estimate range also does not include any legal fees, which could be required if a party exhausts all other administrative processes.

6.2.4 Communication and Outreach

A successful eradication program in the Management Area will require substantial public outreach to develop support and understanding of the project's goals; such an outreach program will be most successful if conducted over time. An initial 1-year cost estimate for outreach and communication is $30,000 (Vander Meer, pers. comm., November 2011). Activities within the first year would include preparing a project brochure, maintaining a website, leading public meetings, organizing an initial *Spartina* summit, developing presentation materials, leading public tours, and developing interpretive signs. Assuming a 5-year program, additional outreach activities would be approximately $10,000 per year, to sustain stakeholder coordination and interest, and project management to adapt outreach strategies. Based on these assumptions, an estimated cost for a 5-year program is approximately $60,000 to $75,000.

6.2.5 Summary

Based on the cost characterization as presented in the sections above, broadscale estimates are presented for treating *S. densiflora* in the Management Area, using: 1) Mechanical control methods; and 2) Combined mechanical and chemical control methods (Table 6-6). Insufficient information is currently available to estimate the costs associated with regional coordination of these efforts or the development of site-specific plans.

Table 6-6. Comparison of Costs for Mechanical Control Methods and a Combination of Mechanical and Chemical Control Methods

	Mechanical Control, Humboldt Bay and Mad River Estuaries		Mechanical Control, Eel River Estuary		Combined Mechanical/Chemical Control for Humboldt Bay and Mad River Estuary		Combined Mechanical/Chemical Control for the Eel River Estuary	
	Low Estimate ($)	High Estimate ($)	Low Estimate ($)	High Estimate ($)	Low Estimate ($)	High Estimate ($)	Low Estimate ($)	High Estimate ($)
Permitting	140,000	224,000	110,000	176,000	140,000	224,000	110,000	176,000
Outreach	33,600	42,000	26,400	33,000	33,600	42,000	26,400	33,000
Primary Treatment	972,700	2,930,700	764,200	2,302,700	593,400	1,093,500	466,200	859,200
Seedling Treatment	237,500	623,300	186,600	489,800	237,500	623,300	186,600	489,800
Resprout Treatment (2 years)	627,800	824,000	493,300	647,500	627,800	824,000	493,300	647,500
Monitoring (2 years)	51,000	73,800	40,000	58,000	51,000	73,800	40,000	58,000
Total	2,062,500	4,717,800	1,620,600	3,706,800	1,683,200	2,880,700	1,322,500	2,263,400

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Appendix A. Existing Conditions in the Management Area

A.1 Regional Setting

Estuaries are dynamic systems that provide a transition zone between freshwater and marine habitats. Estuarine habitats exhibit a mixture of marine and riverine physical and chemical characteristics. The dominant mixing forces in an estuary are river flow, tides, waves, and wind. Physical features such as water depth, current velocity, salinity, and temperature are highly variable and constantly changing (Bottom et al. 1979, 2005, Johnson et al. 2003). The dynamic nature of estuaries can make invasive species management challenging, as new opportunities for colonization arise frequently. The *Humboldt Bay Regional Spartina Eradication Plan* Management Area (Management Area) comprises three estuarine systems located in the Humboldt Bay region: Humboldt Bay, the Eel River Estuary, and the Mad River Estuary (Figure 2-1).

The climate of the Humboldt Bay region is temperate maritime, with generally mild, wet winters and cool, foggy summers. The average annual air temperature is 52° F (11.1°C), ranging from the mid-30s °F to mid-70s °F, (2-21°C) with summer days averaging only about 10°F (-12°C) warmer than winter days. Average annual rainfall is about 40 inches (1016 mm), with 90% of the rainfall occurring between October and April. Summers are characterized by low clouds and fog, resulting in high humidity throughout the year. Prevailing winds are from the northwest, while strong southerly winds are associated with winter storm events (NWS 2009).

The coastline of the Management Area experiences intense wave activity during winter storms and littoral currents that shift seasonally. The nearshore waters support notably high productivity related to seasonal upwelling. The Humboldt Bay coastal region has mixed semi-diurnal tides: 2 high tides of unequal magnitude and 2 low tides of unequal magnitude every day.

Geologic evidence indicates that Humboldt Bay historically represented three estuarine systems linked together by the formation of a barrier spit (Ogle 1953, Thompson 1971). During the mid-Pleistocene, the Mad, Elk, and Eel Rivers presumably drained into Humboldt Bay. The Mad River later eroded a new channel and it now empties into the ocean north of the bay. Currently, the Mad River Slough transports overflow floodwaters from the Mad River to Humboldt Bay; however, there is no evidence in slough sediments that indicate that the slough represents a former river channel. The Mad River likely entered the Pleistocene-era bay east of what is now Mad River Slough (Vick 1988). The Elk River still drains into Humboldt Bay.

To the south, the Eel River floodplain became separated from Humboldt Bay by coastal uplifting; creating a coastal bluff known as Table Bluff. Historically, the Eel River was a narrow, deep channel with expansive estuarine marshes near the mouth and a well-developed riparian corridor of Sitka spruce (*Picea sitchensis* (Bong.) Carriere), black cottonwood (*Populus trichocarpa* Hook.), willow (*Salix* spp.) and red alder (*Alnus rubra* Bong.) (Westdahl 1888, as cited in Roberts 1992). The main channel has remained in a similar configuration since a flood event in 1964 when the majority of flow was forced around the north side of Cock Robin Island. The flood delivered large volumes of sediment that accumulated in the main estuary channel, filling deep pools and increasing channel bed elevations. Tidal marsh dominated by *Spartina* has colonized many of these sediment deposits from the 1964 flood. Flooding also eroded large lengths of shoreline and widened the estuary main channel (Van Kirk 1996). The Salt River (a tributary of the Eel River) occupies a former channel that may have been "left behind" as the dominant channel of the Eel River migrated north across the delta over centuries of change (Downie and Lucey 2005).

The predominant rock formations occurring in the watersheds of these estuaries are the highly erodible Franciscan and Wildcat formations, which contribute large volumes of sediment downstream. In Humboldt Bay, Jacoby Creek is a source of considerable sediment, and deposition has resulted in net accretion near the mouth of Jacoby Creek. As a result, salt marsh expansion has occurred in this area since the 1970s, comprising primarily *Spartina*-dominated stands. In the Eel River Estuary, the clearing of riparian vegetation in the upper watershed has contributed to erosion and subsequent increases in sediment load to the river over the last 50 to 100 years. Today, the Eel River has one of the highest sediment loads of any river in the world (HCPWD 1992).

The 3 estuaries in the Management Area (Humboldt Bay, Eel River and Mad River Estuaries) have been the subject of numerous studies. Descriptions of these estuaries have been compiled for Humboldt Bay by Monroe (1973), Shapiro and Associates (1980), Barnhart et al. (1992), and Schlosser and Eicher 2012); for the Eel River Estuary by Monroe et al. (1974), Roberts (1992), CDFG (CDFG 2010), and Schlosser and Eicher (2012); and for the Mad River Estuary by Stillwater Sciences et al. (2010). More detailed discussions of these three estuaries follow in the sections below.

A.1.1 Humboldt Bay

Humboldt Bay (40° 44' 59", -124° 12' 34") is situated on a low-gradient alluvial plain at the base of the Coast Ranges. The mouth of Humboldt Bay has been stabilized by jetties since the late 1800s. Two barrier beaches on either side of the entrance, the North and South Spits, shelter the estuary. The three regions of Humboldt Bay are defined as: 1) North Bay: the basin north of the Highway 255 Samoa Bridge, 2) Entrance Bay: the channel from the Highway 255 bridge south to the South Jetty, and 3) South Bay: the basin south of the South Jetty. Major tidal sloughs associated with the North Bay include Mad River, McDaniel, Gannon, Freshwater and Eureka Sloughs. White and Hookton Sloughs are associated with the South Bay. Two islands, Indian Island and Woodley Island, are located at the north end of Entrance Bay.

Humboldt Bay is a tidally-driven coastal lagoon with limited freshwater input (Costa 1982, Emmett et al. 2000). It is California's second largest estuarine system after San Francisco Bay, which is located 231 miles (mi) (371.8 km) to the south. The closest major estuary is Coos Bay, Oregon, 185 mi (297.7 km) to the north. The Humboldt Bay watershed is 223 mi^2 (577.6 km^2) (HBWAC and RCAA 2005), which is relatively small for a bay its size. Discharge from Elk River is Humboldt Bay's largest freshwater source. Other major tributaries include Jacoby Creek and Freshwater Creek (via Eureka Slough) both of which empty into North Bay, and Salmon Creek, which empties into South Bay. The freshwater input to the bay varies with season and is largely governed by storm events. While its overall flow contribution is relatively small, the freshwater input has important localized effects on sedimentation rates and patterns, nutrient flux, and productivity (Barnhart et al. 1992).

Humboldt Bay is about 14 mi (22.5 km) long and its width varies from 0.5 mi (0.8 km) in Entrance Bay to 4.3 mi (6.9 km) across the widest part at North Bay. At high tide, the bay occupies an area of 24.1 mi^2 (62.4 km^2), which is reduced to 10.8 mi^2 (27.97 km^2) at low tide (Proctor et al. 1980). At low tide, extensive intertidal mudflats are exposed, comprising about two thirds of the bay area (Gast and Skeesick 1964, Proctor et al. 1980). The bay entrance and shipping channel depths are maintained at 38 to 48 feet (ft) (11.6 to 14.6 m) by periodic dredging (HBHRCD 2007).

Tidal flushing is the dominant biophysical process affecting Humboldt Bay. The tidal influx of nutrient-rich waters associated with seasonal upwelling in nearshore coastal waters supplies nutrients to the bay. Other nutrient sources include seasonal freshwater input from several small rivers and creeks, salt marsh runoff, and regenerated nutrients from mudflats and eelgrass beds. In all regions of the bay, especially the North Bay, the bay waters have developed chemical and biological characteristics distinct from those of nearshore ocean waters. In general, Humboldt Bay water temperature is more affected by atmospheric conditions, nutrient levels are lower, and biological productivity is lower than in nearshore waters (Pequegnat and Butler 1982).

Humboldt Bay water column salinities are similar to nearshore oceanic conditions, reflecting the important marine influence in the estuary, ranging from 25 to 34 parts per thousand (ppt). Lower values are associated with periods of runoff during the rainy season. Higher values are associated with periods of offshore upwelling and with high evaporation rates, both of which occur during clear, calm weather, typically during summer months (Barnhart et al. 1992, HSU 2008). Varying degrees of salinity are found in Humboldt Bay. The salinity range is wider in the North Bay than in the South Bay, with hypersaline levels reached in late summer (Tennant 2006). The seasonal development of hypersalinity is especially pronounced in the eastern part of North Bay.

Sediment grain size can be related to position in the tidal frame and distance from the bay mouth. Smaller grain sizes occur with higher tidal elevation and farther distance from the bay mouth; intertidal marshes consistently have the most fine-grained sediments of any bay environment (Borgeld and Stevens 2004, Thompson 1971). Thompson (1971) characterized the substrate of Humboldt Bay's intertidal marshes as highly organic silty clay or clayey peat, olive gray to black streaked with yellow-brown iron concretions forming around plant remains.

A.1.2 Eel River Estuary

The Eel River Estuary is the 4^{th} largest estuary in California. The mouth of the Eel River (40° 38' 29", -124° 18' 44") is approximately 9 mi (14.5 km) south of the Humboldt Bay mouth; however, wetlands associated with the 2 estuarine systems are narrowly separated by Table Bluff, which is less than 1 mi (1.6 km) wide. The area of the Eel River Delta is about 50 mi^2 (130 km^2), of which 4 mi^2 (10 km^2) are open sloughs, side channels, and mudflats (CDFG 2010). Tidal influence extends upstream approximately 7 mi (11.3 km) inland. The Eel River Estuary experiences a much larger freshwater influence than Humboldt Bay, has a smaller tidal prism, and has greater seasonal variability.

The mouth of the Eel River remains open to tidal exchange year round but migrates north and south, likely due to variations in longshore transport of sands from ocean currents, but also related to debris accumulations, tides, and flood flows. The location of the mouth directs ocean waves that enter the estuary and strike the shoreline. Wave energy can cause significant erosion of loosely consolidated or sandy shorelines that are not protected by woody debris or vegetation. Over recent years, the north and south migration of the mouth along the sand spit has also affected sediment deposition (CDFG 2010).

The western edge of the mouth of the Eel River is bordered by sandy beaches that form a spit composed of marine shoreline deposits and sand dunes. At high water, the estuarine area of the river is estimated at 9.3 mi^2 (24.1 km^2). The estuary is divided into 5 zones based on channel characteristics and mixing regimes of tidal marine water and river freshwater: 1) North Sloughs: channels north of the river mouth, 2) North Bay: embayment extending from the river mouth upstream to near Cock Robin Island bridge, 3) Middle Estuary: main channels from Cock Robin Island bridge to Fulmor Rd, 4) Upper Estuary: main channel from Fulmor Rd to Fernbridge, and 5) South Sloughs: channels south of the river mouth, including the Salt River. Tidal sloughs north of the Eel River mouth include McNulty, Hawk, Quill, Hogpen, Sevenmile, Mosley and Ropers Sloughs. Sloughs south of the river mouth include Morgan and Cutoff Sloughs and the Salt River.

The Eel River Estuary receives runoff from over 800 tributary streams, collectively 3500 mi (5632.7 km) long, draining 3700 mi^2 (9582.9 km^2) of the mountainous Eel River watershed. Mean annual discharge from the Eel River Basin is approximately 5.4 million acre-feet (CDFG 2010). In the Eel River Estuary, salinity is strongly related to seasonal discharge and daily high and low tides. Salinity ranges from fresh (< 0.5 ppt) to hypersaline (>35 ppt) (Cannata and Hassler 1995). Flood flows due to large winter rainstorms can temporarily inundate the estuary with freshwater. After peak flows subside, high tides move a mass or wedge of seawater back into the lower estuary. During the spring-summer period, the lower estuary has vertical density variation and is partially or moderately stratified. There is daily variation in the degree of stratification in the lower estuary during the summer and rapid shifts in stratification with the tides in both temperature and salinity (H. T. Harvey & Associates 2009). Mixing occurs both vertically in the water column and horizontally along the channel. In general, salinity decreases in the main channel along a longitudinal gradient from the mouth extending up to Fernbridge, but during summer/fall, brackish conditions can extend farther upstream (CDFG 2010). In the 1800s, tidewater was noted to extend to the confluence of the Eel and Van Duzen Rivers (Van Kirk 1996). River flow decreases during the summer/fall season allow greater influence by marine tides, which shifts the conditions in the upper estuary channel from predominantly fresh to include tidally driven brackish water (1-15 ppt.) (Cannata and Hassler 1995). During the warm summer season, when evaporation rates are high, the water can become hypersaline in slough channels because less water is exchanged between tides (CDFG 2010).

A.1.3 Mad River Estuary

The Mad River (40° 56' 31", -124° 8' 6") is located north of Humboldt Bay. The mouth of the river is continually migrating, and is currently located approximately 14 mi (22 km) north of the mouth of Humboldt Bay. The Mad River is a freshwater-dominated system, with tidal influence extending approximately 5 mi (8 km) upstream to the Highway 101 Bridge. The estuary sub-basin drains 17 mi^2 (44 km^2), while the watershed drains 497 mi^2 (1287 km^2). Major tributaries that flow into the estuarine portion of the river are Widow White Creek and Mill Creek (Stillwater Sciences et al. 2010).

The historical channel configuration has substantially changed in response to tectonics and sea level changes. More recently, channel dynamics in the lower river and estuary have been controlled by stream discharge and sediment load during large storms, wave erosion, tidal currents, and anthropogenic changes. In 1854, a canal was built to convey logs from the Mad River to Humboldt Bay. 1870 survey maps show the mouth of the river located at what is now known as Mad River County Park (south of the current mouth location). The canal was decommissioned in 1888 due to public opposition and economic constraints. Natural slough channels in the lower Mad River were blocked in the 1900s and the mainstem channel was straightened and channelized to minimize flooding of agricultural lands (Stillwater Sciences et al. 2010).

Borgeld et al. (1993) described migration of the Mad River mouth in three time periods. During the *oscillation period* (1870–1969), the influences of tides and river flows were in relative balance. At times of low flow, the mouth was episodically closed. During this time, the mouth migrated only within a 1-mi (1.5 km) length of coastline. During the *transition period* (1969–1971), the mouth migrated farther north than it had during the preceding century. The change was apparently initiated in 1969 by erosion due to waves and tidal currents. During the *progressive migration period* (1971–1992), the northward migration continued, driven by tidal currents that increased in magnitude as the outlet migrated. In 1992, the California Department of Transportation installed rock slope protection to protect Highway 101 in the vicinity of the vista point overlooking Clam Beach.

The Mad River mouth remained in the vicinity of the vista point until 1998, when storm discharge resulted in a breaching of the bar approximately 1.5 mi (2.4 km) to the south, placing the location of the new mouth in the vicinity of its 1969 location (Stillwater Sciences et al. 2010). Since 1998, the river mouth has gradually migrated northward and is currently near the location of Murray Road (Stillwater Sciences et al. 2010). The abandoned channel became a lagoon estuary with a mixture of fresh and brackish marshes. As the river outlet moved northward and the channel lengthened, a sequence of alternating bars characteristic of low-gradient meandering rivers developed. The shifting channel caused significant erosion of the coastal bluffs bordering the river. Several bank stabilization projects have been completed to prevent further erosion (Stillwater Sciences et al. 2010).

A.2 Tidal Marsh Resources in the Management Area

In Humboldt Bay, tidal marsh area is currently about 905 ac (366 ha), less than 10% of its estimated historical extent (Borgeld et al. 1993, Laird et al. 2007, Schlosser and Eicher 2012). Most of the historical tidal marshes of Humboldt Bay were diked for agriculture in the late nineteenth and early twentieth centuries (USFWS 2009b). In North Bay, tidal marsh occurs on interior islands; the islands and banks of Mad River Slough; bordering the channels of McDaniel, Butcher, Gannon, Eureka, Freshwater, and Fay Sloughs as well as smaller secondary sloughs; near the mouth of Jacoby Creek and Rocky Gulch; and as an interrupted fringe around the bay perimeter. At the north end of Entrance Bay, Indian Island supports one of the largest contiguous areas of tidal marsh remaining. The shoreline of Entrance Bay is extensively developed with only a narrow and intermittent remnant fringe of marsh remaining. In the South Bay, small amounts of tidal marsh occur in association with White Slough and Hookton Slough, and tidal connectivity has recently been restored to portions of Salmon Creek (Laird et al. 2007, Pickart 2001, Shapiro and Associates 1980, USFWS 2009c).

In the Eel River Estuary, tidal marsh extent is currently about 639 ac (259 ha), less than 10% of the estimated historical extent (Laird et al. 2007, Schlosser and Eicher 2012). The majority of existing estuarine marsh is found in the Centerville Slough area of the Salt River drainage (south of the Eel River mouth) and the recently breached area adjacent to McNulty Slough (north of the Eel River mouth). Tidal marshes also occur on the banks of tidal sloughs and sporadically on the banks of the main channel and Cock Robin Island (Laird et al. 2007, Roberts 1992).

The extent of tidal marsh in the Mad River Estuary has not been mapped, but is relatively small compared to the other 2 estuaries in the Management Area. Channel dynamics, bank stabilization, and the predominance of freshwater influence in the system are all factors that contribute to the relative scarcity of estuarine marsh in the Mad River system. Estimating historical extent is difficult, but early descriptions indicate that the floodplains were dominated by coniferous forests.

A.2.1 Habitat Condition

The Management Area was included in a statewide assessment of the health of perennial, saline estuarine wetlands of California (Sutula et al. 2008a). For purposes of comparison, the state's coastline was divided into 4 regions based on eco-regional boundaries developed by Hickman (1993): the North Coast, San Francisco Estuary, Central Coast, and South Coast. Field data were collected for 30 randomly selected sites within each region. Most of the estuarine wetlands that represent the North Coast region were located within the Management Area. Sutula et al. (2008a) described ambient conditions at representative assessment sites and discussed how conditions vary by region within the state. Major stressors were identified for each region, and the ambient conditions assessments utilized CRAM (Version 5.0.2) (Collins et al. 2008).

CRAM uses field indicators to assess wetland attributes within 4 categories: Landscape Context, Hydrology, Physical Structure, and Biotic Structure. A series of metrics was developed to provide scores that measure wetland health. The Landscape Context attributes measure the degree of aquatic connectivity and the size and condition of natural buffers that border the wetland. Hydrology attributes include freshwater source, hydrologic connectivity, and hydroperiod. Physical Structure attributes include structural patch richness and topographic complexity. Biotic Structure attributes include plant community composition, vertical vegetation structure, and horizontal zonation and interspersion of plant species or assemblages. Scores are reported as a percentage of the maximum possible CRAM points that can be assigned for each attribute category. Higher scores represent better condition and higher potential to provide wetland functions. Scores are ranked as follows: greater than 82 = Category 1; scores between 63 and 82 = Category 2; scores between 44 and 63 = Category 3; and scores less than 44 = Category 4 (Sutula et al. 2008a, b).

In terms of overall CRAM index scores, North Coast perennial, saline estuarine wetlands scored the highest of all California regions (averaging 4-15 points higher than other regions), especially with regards to Physical Structure (25-27 points higher). Mean ambient scores for North Coast wetlands fell within Category 1 for all attribute categories except Biotic Structure, which fell within Category 2. The reason for the relatively low score in Biotic Structure is attributed to the predominance of *S. densiflora* in North Coast marshes. Lack of treatment of invasive plant species was identified as the most frequent stressor, occurring at 88% of North Coast sites, and it was also considered to be the most severe stressor present at 70% of the sites. North Coast CRAM index scores were significantly lower for individual sites where the invasive plant stressor was severe.

Following invasive species, other top stressors identified for North Coast wetlands were: excessive sediment from local watersheds (occurring at 20% of sites), dikes and levees (20%), non-point source pollution (13%), and mosquito ditching (13%). Sutula et al. (2008a) recommended that S. densiflora in North Coast estuarine wetlands be controlled to improve overall species richness and biotic structure.

A.2.2 Plant Communities

Little historical botanical information is available for the region and preinvasion floristic descriptions of Management Area tidal marshes are lacking (Clifford 2002). Today, tidal marshes in the Management Area share a number of floristic features with other West Coast marshes. Plant species that range from British Columbia to Baja California include perennial pickleweed (*Salicornia pacifica* Standl.), (synonyms: *Sarcocornia pacifica* [Standl.] A. J. Scott: *Salicornia virginica* L., [misapplied]) (Baldwin et al. 2012), saltgrass (*Distichlis spicata* [L.] E. Greene), marsh jaumea (*Jaumea carnosa* [Less.] A. Gray), arrowgrass (*Triglochin* spp.), and saltmarsh dodder (*Cuscuta salina* Engelm.). Approximately 200 miles and further south, the native species *Spartina foliosa* is an important component of the low elevation salt marshes. Tidal marshes to the north generally occur in association with larger rivers and therefore have a greater freshwater influence. Lyngbye's sedge (*Carex lyngbyei* Hornem), a species typically associated with brackish conditions, is locally abundant in the Management Area, but it is a dominant species in tidal marshes further north (FNAEC 1993+, Grewell et al. 2007, Leppig and Pickart 2009, Macdonald 1977, Macdonald and Barbour 1974). On the West Coast of North America, the predominance of *S. densiflora* is unique to Management Area tidal marshes, although it has also been introduced to San Francisco Bay and has spread to a few locations in Washington and British Columbia.

The tidal elevation range of salt marsh in Humboldt Bay is from about 5.4 ft (1.7 m) MLLW (slightly below the level of MLHW) to about 8.8 ft (2.7 m) MLLW, or potentially higher where not truncated at its upper limit by levees. The transition from low/mid-elevation salt marshes to high salt marshes occurs at about 7.3 ft (2.2 m) MLLW (Claycomb 1983, Eicher 1987, Falenski 2007). Slight variations in marsh elevation influence length and duration of tidal inundation, which in turn influence the distribution of marsh plants

(Figure A-1). Low tidal elevations tend to have higher soil and water salinity and higher soil organic matter but lower soil aeration (Clarke and Hannon 1969, Zedler 1977).

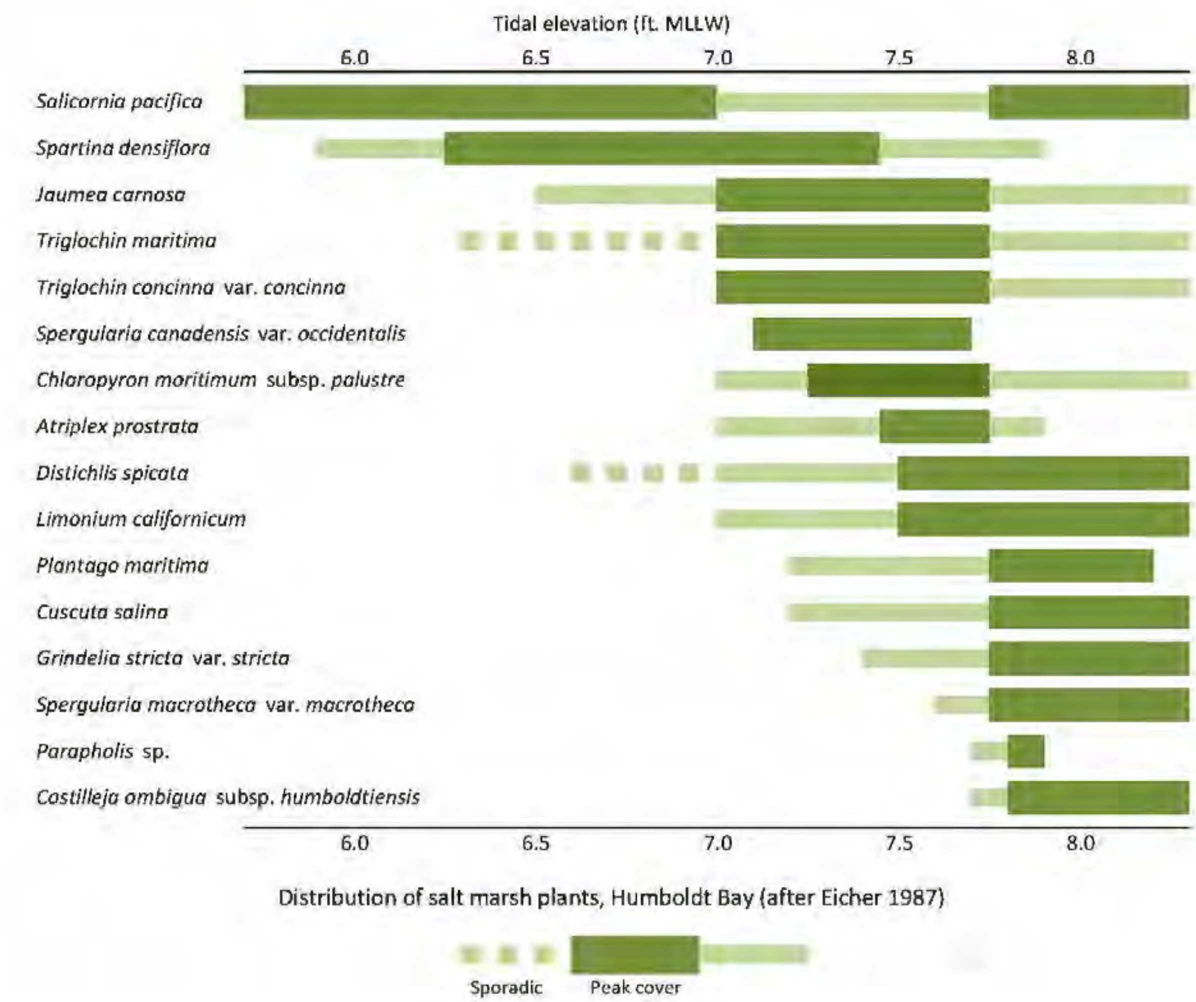


Figure A-1. Salt Marsh Plant Species Distribution in the Management Area

Vegetation types within Management Area estuarine marshes are classified and described here following *A Manual of California Vegetation* (MCV) (Sawyer et al. 2009) (Table A-1). The MCV generally follows NVCS (FGDC 2008, NatureServe 2009), emphasizing the lower units of alliance and association, which are based on floristic components, over higher NVCS levels, which are based on a combination of physiognomy and floristics. In MCV, vegetation types dominated by non-native plant species are referred to as semi-natural stands rather than alliances. Most of the vegetation types presented in this report were previously described by Pickart (2006) for diked wetlands of HBNWR. Pickart (2006) collected elevation, salinity, and soil moisture data to characterize the alliances. It should be noted that no regional classification for intertidal marsh vegetation occurring outside diked areas has been completed for the North Coast, so the classification used here is likely incomplete and subject to change.

Table A-1. Estuarine Marsh Vegetation Types in the Management Area

Marsh Nomenclature Based on Salinity[1]	Manual of California Vegetation Type[2]	Alliance Common Name[2]
Slightly brackish marsh	*Juncus lescurii* Herbaceous Alliance	Salt Rush Herbaceous Alliance
Brackish marsh	*Deschampsia caespitosa* Herbaceous Alliance	Tufted hairgrass Herbaceous Alliance
	Potentilla anserina subsp. *pacifica* (Baldwin 2012) Herbaceous Alliance	Pacific silverweed Herbaceous Alliance
	Carex lyngbyei Herbaceous Alliance[3]	Lyngbye's sedge Herbaceous Alliance
	Distichlis spicata Herbaceous Alliance	Saltgrass Herbaceous Alliance
	Bolboschoenus maritimus Herbaceous Alliance	Alkali bulrush Herbaceous Alliance
	Atriplex prostrata-Cotula coronopifolia Semi-natural Herbaceous Stands	Triangle orache-brass buttons Semi-natural Stands
Salt marsh	*Salicornia pacifica* (Baldwin 2012) Herbaceous Alliance	Pickleweed Herbaceous Alliance
	Spartina densiflora Semi-natural Herbaceous Stands	Dense-flowered cordgrass Semi-natural Herbaceous Stands

[1] Vegetation types listed in order of increasing salinity (adapted from Pickart 2006)
[2] Sawyer et al. (2009) classification, modified with Baldwin et al. (2012) scientific nomenclature as noted
[3] Alliance not represented in MCV, but recognized locally and by NVCS (NatureServe 2009)

A.2.2.1 Description of Vegetation Alliances

Atriplex prostrata-Cotula coronopifolia **Semi-natural Herbaceous Stands:** characterized by an intermittent to continuous canopy of herbs < 3.0 ft (1.0 m) tall, with orache and/or brass buttons as dominant or co-dominant species (Sawyer et al. 2009). Pickart (2006) recognized both an *Atriplex triangularis* (synonym of *A. prostrata*) Alliance and a *Cotula coronopifolia* Alliance.

Cotula coronopifolia **Herbaceous Alliance**

This vegetation type represents an ephemeral, seasonally flooded marsh with relatively high salinities. Both orache and brass buttons are early successional species indicative of disturbed conditions in saline wetlands, while brass buttons typically emerges earlier and is more persistent. The stands fluctuate annually and may not persist with changes to flooding regimes or colonization by other species (Pickart 2006, Sawyer et al. 2009). While both orache and brass buttons are non-native species, they are recognized as sources of winter feed for ducks and other waterfowl and are sometimes planted or otherwise encouraged in managed wetlands (Burns 2003, Sawyer et al. 2009).

In diked wetlands of the HBNWR, Pickart (2006) found brass buttons to be the dominant and characteristic species in seasonally to semi-permanently flooded brackish marshes of moderate salinity and intermediate elevation. Orache was dominant at relatively high salinities, representing an ephemeral, seasonally flooded brackish marsh at intermediate elevations.

In California, *Atriplex prostrata-Cotula coronopifolia* Semi-natural Herbaceous Stands also occur in other coastal marshes on the Northern and Central California Coasts and in alkaline flats in the Great Valley (Sawyer et al. 2009).

***Bolboschoenus maritimus* Herbaceous Alliance**

***Bolboschoenus maritimus* Herbaceous Alliance:** characterized by an intermittent to continuous canopy of herbs < 4.5 ft (1.5 m) tall, with saltmarsh bulrush (*Bolboschoenus maritimus* (L.) Palla subsp. *paludosus* (A. Nelson) T. Koyama) as a dominant or co-dominant species. Synonyms for saltmarsh bulrush include *Scirpus maritimus* (used in the First Edition of the *Jepson Manual: Higher Plants of California* [Hickman 1993]) and *Schoenoplectus maritimus* (NRCS 2007). Saltmarsh bulrush is an emergent wetland plant that is widespread in North America and worldwide. California plants are *B. m.* subsp. *paludosus.* The *Bolboschoenus maritimus* Herbaceous Alliance occurs in tidal brackish marshes and seasonally flooded mudflats (Sawyer et al. 2009). Saltmarsh bulrush corms and seeds are highly favored food items for wintering waterfowl, and this native species is commonly encouraged and maintained on refuge lands (Kantrud 1996).

In diked wetlands of the HBNWR, Pickart (2006) described the *Bolboschoenus maritimus* Herbaceous Alliance occurring at intermediate elevations that are seasonally flooded and typically have high salinity, including the banks of former tidal channels with leaking tide gates or other areas with saltwater input. Saltmarsh bulrush is the dominant and diagnostic species, with longstem spikerush and creeping bentgrass as frequent associated species with low to moderate cover. Saltmarsh bulrush is often the first species to colonize newly excavated areas that receive saline inputs. Total plant cover is low in newly colonized areas and up to 100% in established stands.

In California, the *Bolboschoenus maritimus* Herbaceous Alliance also occurs in other marshes on the Northern, Central, and Southern California Coasts and in the Great Valley (Sawyer et al. 2009).

***Carex lyngbyei* Herbaceous Alliance:** characterized by a continuous canopy of herbs < 6.0 ft (2.0 m) tall, with Lyngbye's sedge as a dominant or co-dominant species in the herbaceous layer. The *Carex lyngbyei* Herbaceous Alliance occurs in brackish marshes in the Management Area, commonly bordering the banks of sloughs and tidal creeks or at the upper margin of salt marshes. This vegetation type is not represented in Sawyer et al. (2009), but it is recognized locally and by NVCS (NatureServe 2009). The *Carex lyngbyei* Herbaceous Alliance is common in estuarine marshes along the west coast north of the Management Area.

***Carex lyngbyei* Herbaceous Alliance**

***Deschampsia cespitosa* Herbaceous Alliance**

***Deschampsia cespitosa* Herbaceous Alliance:** characterized by an intermittent to continuous canopy of herbs < 3.0 ft (1.0 m) tall, with tufted hairgrass (*Deschampsia cespitosa* (L.) P. Beauv.) as a dominant or co-dominant species in the herbaceous layer. Tufted hairgrass is a native perennial bunchgrass with a widespread distribution ranging from sea level to alpine locations. Grazing or other disturbances can lead to successional shifts from the *Deschampsia cespitosa* Herbaceous Alliance to woody alliances. Coastal stands are restricted to the immediate coast, as on steep coastal bluffs and edges of estuaries, where conditions inhibit the growth of woody plants (Sawyer et al. 2009).

In diked wetlands of the HBNWR, Pickart (2006) reported the *Deschampsia cespitosa* Herbaceous Alliance occurring at the upper margins of intertidal marshes and in seasonally flooded areas of moderate salinity, often near saline ditches or former tidal channels. Tufted hairgrass has > 60%, with saltgrass frequently present with low to moderate cover.

In California, the *Deschampsia cespitosa* Herbaceous Alliance also occurs in other marshes on the Northern and Central California Coasts, in the Great Valley, on the Modoc Plateau, and in the Klamath, Mono, Sierra Nevada, and Southern Cascade Ranges (Sawyer et al. 2009).

***Distichlis spicata* Herbaceous Alliance:** characterized by an open to continuous canopy of herbs < 3.0 ft (1.0 m) tall, with saltgrass as a dominant or co-dominant species in the herbaceous layer. Saltgrass has > 30% relative cover, and if perennial pickleweed is present, it has < 30% relative cover. The *Distichlis spicata* Herbaceous Alliance occurs in coastal salt and brackish marshes that are intermittently flooded (Sawyer et al. 2009). Saltgrass is a native species, and it is one of the most common species occurring in estuarine marshes throughout the Management Area.

***Distichlis spicata* Herbaceous Alliance**

A brackish marsh vegetation type dominated by saltgrass has been described for Humboldt Bay tidal marshes study sites by Newby (1980) and Pickart (2005b). In diked wetlands of the HBNWR, Pickart (2006) reported the *Distichlis spicata* Alliance occurring in seasonally flooded brackish marshes with intermediate salinity and elevation. Pickart (2006) described two associations. In the *Distichlis spicata-Parapholis strigosa* association, the non-native species sickle grass (*Parapholis strigosa* (Dumort.) C.E. Hubb.) occurs as a co-dominant. The *Distichlis spicata* association has more homogenous cover by saltgrass and lacks sickle grass.

Extrusion of salt through salt glands allows saltgrass to tolerate highly saline or alkaline environments, ranging from the coast to inland mountains and deserts of California. In addition to the Management Area, the *Distichlis spicata* Herbaceous Alliance also occurs in other marshes on the Northern, Central, and Southern California Coasts; in the Great Valley; on the Modoc Plateau; in the Colorado, Mohave, and Sonoran Deserts; in the Northwestern Basin and Range; in the Southeastern Great Basin; in the Northern California Coast Ranges, in the Central California Coast Ranges; in the Klamath, Mono, Sierra Nevada, and Southern Cascade Ranges; and in the Southern California Mountains and Valleys (Sawyer et al. 2009).

***Juncus lescurii* Herbaceous Alliance**

***Juncus lescurii* Herbaceous Alliance:** characterized by an intermittent to continuous canopy of herbs < 4.2 ft (1.4 m) tall, with salt rush (*Juncus lescurii* Bol.) as a dominant or co-dominant species in the herbaceous layer. *J. lesueurii* is an alternate spelling of the scientific name. Salt rush is native from Central California to British Columbia. The *Juncus lescurii* Herbaceous Alliance occurs in seasonally wet brackish marshes at the upper edges of salt marshes or behind dikes in former salt marsh (Sawyer et al. 2009).

In diked wetlands of the HBNWR, Pickart (2006) reported the *Juncus lescurii* Alliance occurring in saturated to seasonally flooded, slightly brackish marshes at intermediate elevations. Salt rush is the dominant and diagnostic species, with cover > 60%, often forming pure stands in circular clones. Associated species, when present, include Pacific silverweed and velvet grass (*Holcus lanatus* L.), which is an invasive wetland grass common in pastureland throughout the Management Area.

***Potentilla anserina* subsp. *pacifica* (Baldwin et al. 2012) Herbaceous Alliance:** characterized by a continuous canopy of herbs < 3.0 ft (1.0 m) tall, with Pacific silverweed (*Potentilla anserina* subsp. *Pacifica* (Howell) Rousi) as a dominant or co-dominant. Pacific silverweed is a perennial wetland plant that is native to salt and brackish marshes of intermediate salinity and intermediate tidal elevation along the Pacific Coast (Pickart 2006, Sawyer et al. 2009). The closely related species *Potentilla anserina* subsp. *anserina* grows in uplands on sandy or gravelly soils (Sawyer et al. 2009). The alliance is widespread throughout the Management Area.

***Potentilla anserina* subsp. *pacifica* Herbaceaous Alliance**

In diked wetlands of the HBNWR, Pickart (2006) described this vegetation type as the *Potentilla anserina* Alliance, occurring in seasonally flooded fresh to brackish marsh behind dikes and leaky tidegates. Pickart (2006) recognized four associations based on the presence of various co-dominant plant species:

- *Potentilla anserina* association has over 50% cover (and typically over 90% cover) by Pacific silverweed and either lacks or has < 5% cover by the diagnostic species that characterize the other associations within this alliance type,
- *Potentilla anserina-Alopecurus aequalis* association, which is relatively rare, is dominated by the native aquatic grass water foxtail (*Alopecurus aequalis* Sobol.),
- *Potentilla anserina-Eleocharis macrostachya* association, with the native species longstem spikerush (*Eleocharis macrostachya* Britton) as a co-dominant with Pacific silverweed, often occurs in localized low areas in agricultural wetlands, and
- *Potentilla anserina-Lotus uliginosus* association has over 25% cover by the diagnostic invasive species greater bird's foot trefoil (*Lotus uliginosus* Schkuhr).
- Invasive species creeping bentgrass (*Agrostis stolonifera* L.) frequently occurs in all of the Pacific silverweed associations (Pickart 2006).

In California, the *Potentilla anserina* subsp. *pacifica* Herbaceous Alliance also occurs in other marshes and seeps on the Northern, Central, and Southern California Coasts and in the Great Valley (Sawyer et al. 2009).

***Salicornia pacifica* Herbaceous Alliance**

***Salicornia pacifica* Herbaceous Alliance:** characterized by an intermittent to continuous canopy of herbs < 3.0 ft (1.0 m) tall, with perennial pickleweed as a dominant or co-dominant species in the herbaceous layer (Sawyer et al. 2009). Perennial pickleweed has succulent stems that increase in water content to dilute salts, and the plant sheds tissues to remove salts (Adam 1990). The native pickleweed is one of the most common species occurring in salt and brackish marshes throughout the Management Area.

Sawyer et al. (2009) describe four associations within the *Salicornia pacifica* Herbaceous Alliance that occur in Northern California coastal marshes, based on the presence of co-dominant plant species:

- *Salicornia pacifica* association,
- *Salicornia pacifica-Cuscuta salina-Spartina densiflora* association,
- *Salicornia pacifica-Distichlis spicata* association, and
- *Salicornia pacifica-Jaumea carnosa-Distichlis spicata* association.

At study sites within the Management Area, these vegetation types have been described by a variety of investigators, though not classified as such. The first association, which occurs at low marsh elevations, consists of fairly homogenous mats of perennial pickleweed with few associated species, as described for Humboldt Bay tidal marshes (Claycomb 1983, Eicher 1987, Newby 1980, Rogers 1981) and for diked, managed, highly saline marshes at HBNWR (Pickart 2006). This vegetation type is now relatively rare in the Management Area, presumably due to past and continuing encroachment by *S. densiflora* (Pickart 2001, 2006). In the second association, cordgrass occurs as a co-dominant with pickleweed (Eicher 1987, MRB and PWA 2004, Newton 1989). The third association, a pickleweed/saltgrass vegetation type, appears to be more prevalent in areas with muted tidal action (Newton 1989). The fourth association, in which fleshy jaumea is often a co-dominant with either pickleweed and/or saltgrass, has the highest species diversity and tends to occur at the highest tidal marsh elevations (Claycomb 1983, Eicher 1987, Newton 1989, Rogers 1981). The high marsh, which supports several rare plant species, is also threatened by encroaching *S. densiflora* (Pickart 2001, 2006).

In California, the *Salicornia pacifica* Herbaceous Alliance also occurs in Central and Southern California tidal marshes and other managed saline or alkaline wetlands (Sawyer et al. 2009).

Spartina densiflora **Semi-natural Herbaceous Stands:** characterized by a continuous canopy of herbs < 4.5 ft (1.5 m) tall, with dense-flowered cordgrass (*S. densiflora*) as a dominant or co-dominant species (> 50% cover) in the herbaceous layer. *S. densiflora* has narrow, in-rolled leaf blades and dense, narrow inflorescences (Sawyer et al. 2009). Native to Argentina and southern Brazil (Bortolus 2006), *S. densiflora* invaded Humboldt Bay in the mid-to-late 1800s (Spicher and Josselyn 1985) and is now a dominant species in estuarine salt marshes throughout the Management Area (Eicher 1987, Eicher and Bivin 1991, Kittelson and Boyd 1997). In addition, *S. densiflora* has invaded palustrine wetlands and is encroaching onto mudflats in some locations (Grazul & Rowland 2010, Pickart 2006).

Spartina densiflora **Semi-natural Herbaceous Stands**

Spartina densiflora Semi-natural Herbaceous Stands are characterized by low species diversity. Dense growth by *S. densiflora* crowds out native species and is often found growing in dense, homogenous stands. Numerous investigators have noted this vegetation type at study sites in Humboldt Bay (Eicher 1987, Eicher and Sawyer 1989, MRB and PWA 2004, Newby 1980, Newton 1989, Pickart 2005b, 2006, Rogers 1981), in the Eel River Estuary (Eicher and Bivin 1991, H. T. Harvey & Associates 2008). In the diked marshes of HBNWR, the occurrence of *S. densiflora* is low (< 10% frequency in study plots) in all alliances except the *Spartina densiflora* alliance and the *Salicornia virginica* (synonymous with *S. pacifica*) alliance, probably because dispersal through tide gates is limiting (Pickart 2006). However, with recently installed tide gates that increase tidal influence, the species is expected to increase behind dikes unless control measures are continued.

A.2.2.2 Sensitive Plant Species

Sensitive plant species that occur in intertidal coastal marshes in the Humboldt Bay/Eel River region include Humboldt Bay owl's clover (*Castilleja ambigua* Hook & Arn. subsp. *humboldtiensis* (Keck) Chuang & Heckard), Point Reyes bird's beak (*Chloropyron maritimum* (Benth.) A. Heller subsp. *palustre* (Behr) Tank & J.M. Egger, formerly *Cordylanthus maritimus* subsp. *palustris*) (Behr) T.I. Chuang & Heckard), western sand spurrey (*Spergularia canadensis* (Pers.) G. Don var. *occidentalis* R. Rossbach), Lyngbye's sedge, seacoast angelica (*Angelica lucida* L.), and dwarf alkali grass (*Puccinellia pumila* (Vasey) A. Hitch.) (CNPS 2012, Grewell et al. 2007, Leppig and Pickart 2009).

Humboldt Bay Owl's Clover

Humboldt Bay owl's clover and Point Reyes bird's beak are discussed together here because they are related taxa that co-occur in similar habitat and have similar growth characteristics. Both are ranked by CNPS with a California Rare Plant Rank of 1B.2, fairly endangered in California (CNPS 2012). Neither have state or federal listings. Humboldt Bay owl's clover has a limited distribution, occurring only from Humboldt Bay south to Tomales Bay, California (Grewell et al. 2007). Point Reyes bird's beak's range extends northward into Oregon, where it is endangered. In California, the subspecies has been reported as far south as Santa Clara County (CNPS 2012).

Both Humboldt Bay owl's clover and Point Reyes bird's beak are small annuals and they are both facultative hemiparasites; they parasitize other plant species by root connections called haustoria, but also derive some of their energy through photosynthesis. Both Humboldt Bay owl's clover and Point Reyes bird's beak occur in high-elevation salt marshes (Eicher 1987). The life histories of these two rare annuals have been studied in high elevation salt marsh on islands of the intertidal coastal marsh at Mad River Slough and on the mainland of Mad River Slough in north Humboldt Bay (Bivin et al. 1991).

Pickart (2001) mapped Humboldt Bay owl's clover in May-June 1998 and Point Reyes bird's beak in June 1999 in salt marshes throughout Humboldt Bay. USFWS maintains an ongoing monitoring program for these species on refuge lands. Both species have exhibited high annual fluctuations in population numbers in over a decade of monitoring in Mad River Slough (Pickart 2001, 2008, Pickart and Miller 1988). Both species are locally abundant, but are rare across their range because of a drastic habitat decline. At the Lanphere and Ma-le'l Dunes Units, removal of *S. densiflora* from these species' habitat resulted in an explosive population increase of both Humboldt Bay owl's clover and Point Reyes bird's beak (Pickart 2011a).

Point Reyes Bird's Beak

Western sand spurrey has a CNPS rank of 2.1, seriously endangered in California, but more common elsewhere (CNPS 2012). The plant grows in Oregon and Washington intertidal coastal marshes, but in California it is known only in Humboldt Bay/Eel River estuarine marshes. Western sand spurrey is a tiny annual plant that occurs in high elevation salt marshes. Eicher (1987) found *S. canadensis* var. *occidentalis* ranging from 7.1 to 7.7 ft (2.2 to 2.3 m) MLLW in North Humboldt Bay, typically associated with arrowgrass, common pickleweed, and marsh jaumea, whereas the more stout perennial sticky sand spurrey (*S. macrotheca* (Hornem.) Heynh. var. *macrotheca*) tended to grow at higher elevations (7.6 to 8.4 ft (2.3 to 2.6 m) MLLW), often in association with saltgrass.

Lyngbye's Sedge

Lyngbye's sedge has as CNPS Rank of 2.2, fairly endangered in California, but more common elsewhere (CNPS 2012). Lyngbye's sedge is locally abundant in intertidal coastal marshes along the coasts of Alaska, Washington, and Oregon. In California, the species extends as far south as Bolinas Lagoon, just north of San Francisco Bay, California (CNPS 2012). In Management Area tidal marshes, Lyngbye's sedge is typically found bordering sloughs near river mouths and where there are other freshwater inputs.

Seacoast angelica has a CNPS rank of 4.2, limited distribution (Watch List); the species appears to be fairly endangered in California but more common elsewhere (CNPS 2012). Seacoast angelica occurs in Oregon, Washington, Alaska, and on the east coast of North America. In California, seacoast angelica extends from Del Norte County south to Mendocino County. In Humboldt Bay and the Eel River Estuary, seacoast angelica occurs in brackish marshes, usually at the upper margin of the marsh or growing on adjacent levees.

Dwarf alkali grass has a CNPS rank of 2.2 as fairly endangered in California, but more common elsewhere (CNPS 2012). Dwarf alkali grass is currently known from only 2 occurrences in California, one in the Eel River Estuary and the other in Fort Bragg, Mendocino County (CNPS 2012). This species occurs in Washington and in Oregon, where it is on a watch list. It has also been introduced to the Northeastern United States, and is found in Maine.

A.2.3 Animal Communities

Animal communities in the Management Area have been described in numerous reports (Barnhart et al. 1992, CDFG 2010, Monroe 1973, Monroe et al. 1974, Roberts 1992, Schlosser and Eicher 2012, Stillwater Sciences et al. 2010, USFWS 2009c). Brief descriptions are provided here, grouping animal communities into the broad categories of invertebrates, fish, birds, mammals, amphibians, and sensitive wildlife species.

A.2.3.1 Invertebrates

Invertebrates occupy several major habitat niches in estuarine marshes. Benthic fauna comprise both infauna, invertebrates that live under the soil surface, and epifauna, that live on the surface of the mud or on other organisms or plants. In addition to these aquatic invertebrates, terrestrial invertebrates, including flying insects, spiders, and mites, utilize the marsh at low tides or seek refuge on unflooded portions of the plants. Tidal creeks and salt pannes also have their own distinct fauna.

In Humboldt Bay Management Area marshes, the dominant benthic invertebrates are gastropods, crustaceans, and polychaetes, which graze on microalgae growing on the soil surface. They also feed on algal mats deposited in the marsh at high tide. Common gastropods include the native species *Assiminea californica* and the non-native *Ovatella myosotis*. On the fringes of the estuarine marshes, the non-native gastropod *Alderia modesta* feeds on mats of the macroalgae *Vaucheria longicaulis*. Polychaete species include the native species *Eteone californica* and *Capitella capitata,* and the non-natives *Polydora cornuta* and *Streblospio benedicti*. The most common crustacean is the native amphipod *Orchestia traskiana*, typically found in low-elevation marshes, under driftwood and at the base of *Spartina* stems. The yellow shore crab, a native species, frequently burrows in salt marsh banks and feeds in tidal sloughs that dissect the marsh. In high-elevation salt marshes the native isopods *Armadilloniscus coronocapitalis, Littorophiloscia richardsonae,* and *Porcellio* spp. are common (Barnhart et al. 1992, Boyd 1982, Boyd et al. 2002, Read 2003). Thompson (1971) noted that activity by benthic infauna in Humboldt Bay intertidal coastal marshes results in thorough mixing or turning of sediments, a process known as bioturbation.

Several studies are in progress to characterize the macrofauna of invaded and native salt marshes in Humboldt Bay. Mitchell (2010) completed a pilot study on relatively small areas of invaded and restored low to mid-elevation salt marshes in Mad River Slough to characterize terrestrial and epifaunal invertebrates. *Spartina*-dominated marsh was dominated by invertebrates from the orders Mollusca (molluscs), Amphipoda (amphipods), and Isopoda (isopods), and also included a significant number of mosquitoes (Order Diptera). The dominant functional group in *Spartina*-dominated marsh was detritus feeders. Restored, saltgrass- and pickleweed-dominated marsh was dominated by invertebrates from the orders Acari (mites), Araneae (spiders), Mollusca, and Hemiptera (true bugs). The dominant functional groups in saltgrass- and pickleweed-dominated marsh were predators and herbivores. Additional studies are in progress to examine benthic infauna in *Spartina*-dominated marsh, and to directly measure change in invertebrate assemblages after the removal of *S. densiflora*.

A.2.3.2 Fish

Approximately 110 marine and estuarine fish species are known to occur in Humboldt Bay (Shapiro and Associates 1980) and although Humboldt Bay has been invaded by many non-native invertebrate species, the fish fauna remains primarily native. Indeed, a recent study to document non-native aquatic species in Humboldt Bay identified 52 non-native invertebrate species but only one non-native fish species (mosquito fish [*Gambusia affinis*]) (Boyd et al. 2002). However, since that study in 2002, pikeminnow have been found in Martin Slough.

Humboldt Bay, the Eel River Estuary and the Mad River Estuary are utilized by three salmonid species that are listed as threatened under the Federal ESA: Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and steelhead trout (*Oncorhynchus mykiss*). Estuaries are known to be important rearing areas for juvenile salmonids before they enter the ocean (Healey 1980). Small Chinook salmon often occupy salt marshes, tidal creeks, intertidal flats, and other shallow nearshore habitats. Marsh habitats may be of particular importance to subyearling salmonids because of the high insect and invetebrate prey resources and potential refuge from predators (Bottom et al. 2005). Wallace (2006) found significant use of the tidal portions of Freshwater Creek, Elk River, and Salmon Creek (Humboldt Bay tributaries) by juvenile Chinook salmon, coho salmon and steelhead trout. Pinnix et al. (2008) found that in Humboldt Bay, juvenile coho salmon also utilize deep channels, channel margins and floating eelgrass mats.

Tidewater goby (*Eucyclogobius newberryi*), a species listed as endangered under the Federal ESA, has been found in Humboldt Bay's off-channel habitats that are only reached by very high tides, including areas behind tide gates, and tidewater gobies also occur in the Eel River Estuary (Chamberlain 2006, 2011). In both Humboldt Bay and the Eel River Estuary, substantial potential habitat for tidewater goby is likely on privately owned land that has not been surveyed. Longfin smelt (*Spirinchus thaleichthys*), which are listed as endangered under the State of California ESA has been identified in the Eel River Estuary (Puckett 1977) and Humboldt Bay (CDFG 2009). Green sturgeon (*Acipenser medirostris*), which is listed as threatened under the Federal ESA, also occur in Humboldt Bay (Fritzsche and Cavannagh 2007).

Humboldt Bay is a nursery for other species that are important to recreational and commercial fisheries including rockfish (*Sebastes* spp.), kelp greenling (*Hexagrammos decagrammus*), cabezon (*Scorpaenichthys marmoratus*) (Schlosser and Bloeser 2006) and Dungeness crab (*Metacarcinus magister*). Dungeness crab use salt marshes as habitat to escape predators during molting. Dungeness crab also use salt marshes as nursery habitat for larva which has been deposited into the estuary and transported shoreward by tidal currents (Lellis-Dibble et al. 2008). Furthermore, there is a recreational fishery within Humboldt Bay that focuses on rockfish, lingcod (*Ophiodon elongates*), cabezon and kelp greenling at the jetties near Humboldt Bay's entrance; California halibut (*Paralichthys californicus)* and leopard sharks (*Triakis semifasciata*) in bay channels; and surfperches (Embiotocidae) throughout the bay. Clamming is also popular, particularly in south Humboldt Bay mudflats. Commercial fisheries focus on Pacific herring (*Clupea pallasii)* roe as well as northern anchovy (*Engraulis mordax*), which are captured to support live bait fisheries in the Pacific Ocean.

A.2.3.3 Birds

Numerous species of birds use the Management Area marshes as a location to roost at high tide and/or as a place to forage. The table below provides a representative list of some of the bird species known to forage or roost in the marshes in the Management Area (Table A-2). The Management Area is located on the Pacific Flyway, a major north-south travel route for migratory birds extending from Alaska to Patagonia. The Humboldt Bay, Eel River, and Mad River estuaries are major foraging and resting grounds for numerous species of migratory birds, particularly shorebirds and waterfowl that use the Pacific Flyway (Monroe 1973, Monroe et al. 1974, Springer 1982) (Table A-2).

Table A-2. Representative List of Bird Species that Commonly Use the Management Area Marshes[1]

Common Name	Scientific Name
Shorebirds:	
Dunlin	*Calidris alpina*
Least sandpiper	*Calidris minutilla*
Western sandpiper	*Calidris mauri*
Baird's sandpipers	*Calidris bairdii*
Marbled godwit	*Limosa fedoa*
Willet	*Catoptrophorus semipalmatus*
Black-bellied plover	*Pluvialis squatarola*
Semipalmated plover	*Charadrius semipalmatus*
American avocet	*Recurvirostra americana*
Long-billed curlew	*Numenius americanus*
Sanderling	*Calidris alba*
Short- and Long-billed dowitchers	*Limnodromus griseus* and *L. scolopaceus*
Greater and Lesser yellowlegs	*Tringa melanoleuca* and *T. flavipes*
Black turnstone	*Arenaria melanocephala*
Ruddy turnstone	*Arenaria interpres*
Whimbrel	*Numenius phaeopus*
Killdeer	*Charadrius vociferus*
Herons:	
Great blue heron	*Ardea herodias*
Black-crowned night heron	*Nycticorax nycticorax*
Great egret	*Casmerodius albus*
Snowy egret	*Egretta thula*
Gulls:	
Western gull	*Larus occidentalis*
Glaucous-winged gull	*Larus glaucescens*
Mew gull	*Larus canus*
Rails:	
Virginia rail	*Rallus limicola*
Sora rail	*Porzana carolina*
American coot	*Fulica americana*
Waterfowl:	
Mallard	*Anas platyrhynchos*
American green-winged teal	*Anas crecca carolinensis*
Gadwall	*Anas strepera*
Raptors:	
Red-tailed hawk	*Buteo jamaicensis*
Red-shouldered hawk	*Buteo lineatus*
White-tailed kite	*Elanus leucurus*
Northern harrier	*Circus cyaneus*
Barn owl	*Tyto alba*
Short-eared owl	*Asio flammeus*
Songbirds:	
Savannah sparrow	*Passerculus sandwichensis*
Song sparrow	*Melospiza melodia*
Lincoln's sparrow	*Melospiza lincolnii*
White-crowned sparrow	*Zonotrichia leucophrys*
Golden-crowned sparrow	*Zonotrichia atricapilla*
Marsh wren	*Cistothorus palustris*
Yellow warbler	*Dendroica petechia*
Yellow-rumped warbler	*Dendroica coronate*

[1] This list included species that commonly occur or may occur in the Management Area (Danuvsky and Colwell 2003, Harris 2006, Monroe 1973, Springer 1982); it is not intended to represent an exhaustive list.

Bird species that commonly occur and forage in the open waters of Humboldt Bay include osprey (*Pandion haliaetus*), Brandt's cormorant (*Phalacrocorax penicillatus*), double-crested cormorant (*P. auritus*), pelagic cormorant (*P. pelagicus*), brown pelican (*Pelecanus occidentalis*), western grebe (*Aechmophorus occidentalis*), pigeon guillemot (*Cepphus columba*), and common murre (*Uria aalge*) (Harris 2006).

The marshes (including agricultural wetlands) and upland pastures around Humboldt Bay are important foraging and roosting habitat for many shorebird species. Large numbers of shorebirds arrive in summer after migrating from northern breeding grounds. Shorebird species richness and abundance is greatest in summer, presumably coinciding with prey availability (Colwell 1993). The shorebird community composition changes dramatically in fall, when some species depart and others, such as dunlin, arrive for the winter (Colwell 1993). In winter, shorebirds appear to use the Mad River Estuary for roosting and less so for foraging, presumably due to reduced prey availability in the estuary as a consequence of higher river volume and flooding of foraging habitat (Colwell 1993). They tend to move from the mudflats to roost in the salt marshes at high tide in winter, and at extremely high tides, they move to the surrounding agricultural wetlands (Gerstenberg 1972, 1979).

Few shorebird species currently forage in salt marshes around Humboldt Bay; however, it is possible that shorebird usage of the marshes might increase following restoration of native salt marsh plant communities. Willets were found to use salt marshes in the Mad River Estuary for foraging when mudflats are flooded, particularly during higher tides in the spring (Long and Ralph 2001). Dunlin, least sandpipers, long-billed curlews, marbled godwits, black-bellied plovers, and greater yellowlegs were found to prefer either mudflats at low or intermediate tides, and adjacent agricultural pastures when the mudflats were flooded (Long and Ralph 2001). Mudflats around Humboldt Bay were also preferred feeding grounds for common egrets during daylight hours (Yull 1972). Wading birds, gulls, and waterfowl use the agricultural pastures around the Mad River Estuary (Colwell and Dodd 1995). The importance of intertidal agricultural pastures for winter foraging by curlews at Humboldt Bay has been noted by Leeman (2000), Mathis (2000) and Colwell and Mathis (2001).

Shorebird species differ in their use of substrates and habitats around Humboldt Bay. In the Mad River Estuary, least sandpipers, western sandpipers, and Baird's sandpipers were found to aggregate in sandy areas within 1 m of the tide edge, where they foraged by probing for a burrow-dwelling amphipod, *Corophium* spp., while semipalmated plovers and ruddy turnstones foraged by pecking in drier, coarse-grained substrates greater than 1 m from the tide edge (Colwell and Landrum 1993). Around Humboldt Bay, sanderling incidence was higher with greater substrate particle size, and at sites at which tides ebbed earliest, while American avocets preferred smaller substrate particle sizes (Danufsky and Colwell 2003). Whimbrel incidence was correlated with standing water, narrow tidal flats, and sites at which tides ebbed earliest, while short-billed and long-billed dowitchers preferred less standing water (Danufsky and Colwell 2003).

Preliminary data show no significant differences in shorebird use of marshes dominated by *Spartina densiflora* vs. restored salt marsh in Humboldt Bay (Johnson 2011). However, some passerine birds appear to be more abundant in *Spartina*-dominated marsh than in restored marsh, perhaps because of the greater amount of physical structure and the abundant seed resources that are available (ibid.). Large differences in bird abundance in salt marshes were only noted in common species, such as marsh wrens, savannah, song, and white crowned sparrows (ibid). Preliminary invertebrate research supports the possibility that *Spartina* invasion alters invertebrate functional group composition, with potential trophic cascades affecting shorebird use.

A.2.3.4 Mammals

Small rodents such as the California vole (*Microtus californicus*), white-footed mouse (*Peromyscus maniculatus*), vagrant shrew (*Sorex vagrans*), and house mouse (*Mus musculus*) are known to forage and breed in high-elevation intertidal coastal marshes. Other mammals that use the Management Area marshes include raccoons (*Procyon lotor*), black-tailed deer (*Odocoileus columbianus*), river otters (*Lutra canadensis*), striped skunk (*Mephitis mephitis*), and mink (*Neovison vison*). Bats forage over the marshes for insects (Springer 1982) and yuma myotis (*Myotis yumanensis*) is a regular forager in these habitats. Mammals that use agricultural wetlands include shrews, moles, Botta's pocket gophers (*Thomomys bottae*), mice, raccoons, long-tailed weasel (*Mustela frenata*), striped skunk (*Mephitis mephitis*), opossum (*Didelphis virginiana*), porcupine (*Erethizon dorsatum*), gray fox (*Urocyon cinereoargenteus*), black-tailed deer, bats, and feral cats (*Felis catus*) (Springer 1982).

A.2.3.5 Amphibians

Amphibians such as Pacific tree frogs (*Pseudacris regilla*) and northern red-legged frogs (*Rana aurora*) occur in vegetated tidal marshes in the Management Area. However, while these species occur in Management Area marshes, they probably do not use these areas for breeding, because both these species of frogs have a low tolerance for salinity. Jennings and Hayes (1989) reported that exposure of pre-hatchling red-legged frog embryos to salinity greater than 4.5 parts per thousand caused 100% mortality and larvae will only tolerate salinities up to 7 ppt. However, these species may breed adjacent to the salt marshes in areas with fresh water inflows.

A.2.3.6 Sensitive Wildlife Species

Several sensitive wildlife species forage in or use the Management Area marshes and immediately adjacent areas. California Species of Special Concern that are known to use the area include northern harrier, short-eared owl (*Asio flammeus*) and northern red-legged frog. The western red bat (*Lasiurus blossevillii*) may also use the marshes (Johnston and Whitford 2009). The federally threatened western snowy plover (*Charadrius alexandrinus nivosus*) is known to occur on the beaches adjacent to Humboldt Bay.

A.3 Land Use in the Management Area

Management of tidal waters in the Eel River and Mad River estuaries is the primary responsibility of CSLC, but in Humboldt Bay this responsibility has been transferred to the Harbor District. The incorporated cities of Eureka and Arcata, which are adjacent to Humboldt Bay, also have tideland jurisdiction over areas of

Humboldt Bay. Land use management in unincorporated areas remains the responsibility of the County of Humboldt.

Land use in the Management Area includes agriculture, marine dependent industrial uses, conservation management, urban, and residential. In Humboldt Bay, HBHRCD (2007) identified geographic areas where different kinds of activities are expected to occur. These geographic distinctions provide a broad policy framework for HBHRCD's management decisions. The central part of the bay is associated with commercial and coastal-dependent industrial uses while the northern and southern parts are considered to have greater importance as habitat or natural areas. However, there are some portions of Central Bay, such as the beaches and marshes along the south end of the North Spit that are of high biological sensitivity.

Humboldt County's economy has historically depended on fishing, logging, agriculture and associated milling and shipping. However, according to statistics available from the U.S. Census Bureau (USCB 2009), employment in the farming, fishing and forestry sector has declined by half since 1990. Mariculture, primarily the cultivation of oysters (producing about 70% of the oysters grown in California), remains a major industry in the North Bay, with some limited shore-side facilities. In coastal Humboldt County, the largest employers are currently in the education, health and social services sectors (EDD 2010).

Appendix B. *Spartina* Ecology and Ecological Impacts

B.1 *Spartina* Ecology and Ecological Impacts

Non-native invasive species introductions are among the most important changes occurring in estuaries around the world, and have become increasingly common in marine environments such as bays, estuaries, and open coasts (Carlton and Geller 1993, Grosholz 2002, Ruiz et al. 1997, Silliman et al. 2009). Non-native species invasions result in altered habitat composition, quality, structure, and function and modification of broad scale ecosystem properties such as biodiversity, geomorphology, hydrology, biogeochemistry, and disturbance regimes (Carlton 2009, Gordon 1998, Silliman et al. 2009). Coastal estuarine and marine systems around the world have been heavily invaded with anthropogenic dispersal of non-native species via ship ballast, aquaculture, fisheries enhancement, waterway connections with canals, and non-native invasive species releases into waterways (Carlton 2010, Grosholz 2002, Ruiz et al. 1997). Non-native invasive species threaten recreation, fisheries, and aquaculture (Daehler and Strong 1996).

While invasions can initially contribute to increased species richness by adding species that were not in the original environment, dominance by non-native invasive species can also reduce species richness, if the invasive species excludes other species to a great extent. Other potential impacts to native communities include decreased variation in species composition, greater habitat homogeneity, genetic modifications and altered genetic diversity, local native species extinctions, food web changes, and displacement of unique or endemic species (Levin et al. 2006, Ruiz et al. 1997, Simenstad and Thom 1995). Invasion by a single species can result in community-level and ecosystem-level impacts by significantly modifying existing habitat, altering substrates, and altering patterns of herbivory (Grosholz 2002). Successful invasive species are able to effectively reproduce and disperse, often out-competing local native species, and occupying vacant niches. They alter the habitat at invasion sites, and if the colonization site lacks herbivores or pathogens specific to the invader, successful establishment is further assisted (Gordon 1998).

Coastal marine habitats are among the most heavily invaded ecosystems in the world (Grosholz, 2002). In a study of just four estuaries, the number of non-indigenous species ranged from 60 to 212 species per estuary and included a broad range of taxonomic and trophic groups occupying diverse habitats (Ruiz et al. 1997). Non-indigenous marine species include a diverse array of species such as mollusks, crabs, bryozoans, ctenophores, and vascular plants. These invasions affect multiple species, trophic structure, and ecosystem and community level dynamics.

Within marine systems, non-native species invasions of tidal salt marshes are particularly important because salt marshes are among the most productive ecosystems in the world. Tidal salt marshes perform the essential function of maintaining estuary health and ecology, and export organic fuel to nearshore waters (Mitsch and Gosselink 2000, Neves et al. 2010). Tidal salt marshes are critical transition zones; plants, animals, and microbes survive within the salt marsh based on their ability to tolerate salinity fluctuations, varying levels of drying and submergence, and daily and seasonal temperature variations.

Public officials recognize that aquatic invasive species pose one of the greatest threats to native species and habitats along the West Coast, threatening the ecological, social, public health, and economic integrity of marine resources (OGWOC 2008). Examples of aquatic invasive species found on the West Coast include cordgrasses (*Spartina* spp.), European green crab (*Carcinus maenas*), Chinese mitten crab (*Eriocheir sinensis*), quagga and zebra mussels (*Dreissena* spp.), and an invasive green alga (*Caulerpa taxifolia*).

The *Draft Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California* lists invasion by non-native species as one of the most pressing threats to the tidal marshes of California, and in San Francisco Bay in particular (USFWS 2009a). Several species of invasive *Spartina* have invaded San Francisco Bay, threatening one of the most ecologically important expanses of tidal mudflats and salt marshes in the western United States. The San Francisco Estuary Invasive *Spartina* Project has identified numerous ways that invasions by non-native *Spartina* can affect the ecology of native marshes. These effects are tied primarily to the invasion of San Francisco Bay involving *S. alterniflora* and the *S. alterniflora* x *S. foliosa* hybrid. These species reduce or eliminate sensitive species habitat, tidal sloughs, tidal flats, and channels; alter natural sedimentation processes; eliminate foraging habitat for migratory shorebirds; cause genetic assimilation and potential extinction of native *S. foliosa*; produce large areas of standing biomass (wrack); and increase potential for spread to other West Coast estuaries (SFEISP 2003). The invasion by *S. alterniflora* and the resultant hybrid into San Francisco Bay has been the focus of an aggressive eradication program by the San Francisco Estuary Invasive *Spartina* Project.

The Management Area's marine and marsh environs also support invasive non-native species. Approximately 95 non-indigenous marine species can be found in Humboldt Bay. These species include most of the major organismal groups, including fish, vascular plants, and invertebrates such as polychaetes, amphipods, and bryozoans. Of these 95 species, 31 have been reported in both San Francisco Bay to the south and in Coos Bay to the north (Boyd et al. 2002), reflecting the ease by which marine species can be transported between estuaries. No comprehensive indigenous species surveys have been conducted for the Eel or Mad River estuaries.

B.1.1 Ecology of Genus *Spartina*

B.1.1.1 Background

The genus *Spartina* consists of 17 species of perennial cordgrass in the Poaceae family, with native ranges in North, Central, and South America; Europe; and North Africa (Mobberley 1956). Most of the species grow in coastal areas or on riparian stream banks. *Spartina* species possess specific adaptations to tolerate seasonally freezing temperatures, frequent inundation, and varying salinities (Daehler and Strong 1996). These adaptations help *Spartina* to be highly competitive with other salt marsh plants, thus allowing many species within the genus to competitively exclude native species throughout the tidal range.

A number of *Spartina* species have expanded outside their native ranges into other marine systems. Non-native *Spartina* species have invaded salt marshes around the world including the west coast of North America from California to British Columbia, China, North Africa, Australia, New Zealand, and Europe (United Kingdom, France, Denmark, Germany, Spain, and the Netherlands) (Morgan and Sytsma 2010). The only species of *Spartina* that is native to the Pacific Coast of North America is *S. foliosa* (Daehler and Strong 1996, Mobberley 1956). *S. foliosa* historically ranged from Point Reyes, California to Baja California with some gaps in between, and is notably absent in Monterey Bay and Morro Bay. The largest populations are found in San Francisco and San Pablo Bays, California (SFEISP 2003). However, four non-native invasive *Spartina* species have been documented on the Pacific Coast: 1) *S. densiflora*; 2) *S. alterniflora*; 3) *S. patens*; and 4) *S. anglica*.

Spartina densiflora
(Photo by Andrea Pickart)

S. densiflora (dense-flowered cordgrass) is distinctive from other *Spartina* on the West Coast by its bunchgrass growth form; its short, shallow, creeping rhizomes; narrow, firm, in-rolled leaves that are grayish green; and its compact inflorescences. The bunchgrass habit is most apparent when the grass is interspersed with other species, and not as evident when the plants grow close together in dense stands.

S. alterniflora (Atlantic smooth cordgrass) is a tall, wide leaved grass with stems solitary or forming small clumps. Initially, the invasion appears as a round clone, eventually developing into dense stands or meadows. *S. alterniflora* has a relatively wide elevation range and can invade both tidal marsh and mudflat habitats. *S. alterniflora* spreads vigorously by rhizomes that are longer and grow deeper than *S. densiflora*. The leaf sheaths are often a reddish color. Inflorescences are open.

***Spartina alterniflora* clone**
(Photo courtesy of San Francisco Estuary Invasive Spartina Project)

Spartina anglica **(Photo courtesy of San Francisco Estuary Invasive Spartina Project)**

S. anglica (English cordgrass) is a hybrid between *S. alterniflora* and England's native *S. maritime*. *S. anglica* exhibits high morphological variability. It has solitary stems that can grow in small clumps or form monospecific stands. Like its parent *S. alterniflora, S. anglica* can spread vigorously by creeping rhizomes into marsh and mudflat habitats. It has wide leaves that often protrude at a right angle to the stem. Inflorescences are erect and dense.

S. patens (salt meadow cordgrass) grows as a dense turf or sod, with fine, matted, decumbent stems. *S. patens* is intolerant of waterlogged mud, but invades high salt marsh with sufficient drainage. It has fine stems and the narrow, green leaves are soft and strongly inrolled. The inflorescence is open with spreading, narrow spikes.

Spartina patens **(Photo courtesy of San Francisco Estuary Invasive Spartina Project)**

B.1.1.2 Reproduction and Expansion

Most of the *Spartina* species spread both vegetatively (i.e., lateral rhizomes and tillers) and by seed. Some species disperse more successfully by one or both of these methods than others. Expansion rates have been calculated for several species of *Spartina* and are variable between species (Table B-1).

Table B-1. Expansion Rates for Invasive *Spartina* Species

Species	Expansion rate (in/year)	Expansion rate (cm/year)	Source
S. patens	7.0 to 9.0	17.8 to 22.9	Feist and Simenstad 2000
S. alterniflora	31.2	79.3	
S. densiflora (Europe)	7.1 to 10.2	18 to 26	Kittelson and Boyd 1997
S. densiflora (Humboldt) in bare areas	1.9 to 22.0	5 to 56	

B.1.1.3 Sedimentation

Because of their sediment trapping abilities, *Spartina* species have been introduced in estuaries around the world in order to minimize erosion, protect and stabilize coasts, and reclaim land (e.g., Australia and New Zealand: Adam 1990, UK: Gray et al. 1991, USA: Faber 2000, China: Wang et al. 2008, Germany and The Netherlands: Nehring and Hesse 2008). Many of these projects have contributed to the colonization and extensive spread of non-native *Spartina* in estuaries of the Pacific, Australia, Europe, China, and the United States with long-term consequences.

Colonization by *Spartina* along river banks and tidal channels can restrict flow and alter a site's hydrology. In the intertidal areas where *Spartina* invades, the rigid and densely packed stems contribute to local accretion with the dense root mats also contributing to sediment accumulation as the plant filters and traps sediment particles brought in by the river and tidal currents. *Spartina*'s ability to increase the potential for sediment accumulation is part of a positive feedback mechanism. As *Spartina* colonizes and expands, the densely packed stems and roots of the colonizing plants decrease the tidal current velocity, creating drag around individual plants and clones resulting in sediment dropping out of the water column. As roots and stems grow up through the deposited sediments, the process is repeated and the elevation of the marsh eventually increases (Ball 2004, Grozholz et al. 2009). Sediment accretion and stabilization may eventually alter local topography and habitats relative to tidal elevation; create changes in mudflat habitats, tidal channels and drainage networks; and change topography from gentle slopes to steep slopes in tidal channels. In addition to ecological impacts, sediment accretion in drainage channels can lead to increased maintenance costs and flooding problems.

Sediment accretion rates in *Spartina*-dominated marshes are typically higher than for areas dominated by other salt marsh species and vary between species of *Spartina*. Accretion rates for *S. anglica* may range from 0.08-0.8 in (0.2-2.0 cm) per year, but can be higher than this depending on localized conditions (Ranwell 1972). For example, an area in the Netherlands recorded sediment accumulation in areas of *S. anglica* of 5.9 ft (1.8 m) over 22 years (Ranwell 1967). In *S. alterniflora* colonized marshes in Willapa Bay, WA, annual sediment accumulation averaged 0.4 in (1 cm) per year (Sayce 1988). Ball (2004) recorded sediment accumulations rates on *Spartina* mounds in Willapa Bay from 0.14 to 0.33 inches (3.6 - 8.4 mm) per year in sandy substrates.

In Willapa Bay, Washington, Ball (2004) documentented that sedimentation may continue to occur even after *S. alterniflora* has been eradicated from a site, and may result in loss of sediment on nearby mudflats or marshes. *S. alterniflora* mounds that had been treated with herbicides continued to gain elevation at a rate of 0.29 inches (7.4 mm) per year. In that study, nearby mudflat sites lost elevation at 0.70 inches (17.9 mm) per year, suggesting that the *S. alterniflora* sites could be contributing to sediment loss from adjacent mudflat areas.

B.1.1.4 Productivity

Spartina species are highly productive and the export of *Spartina* detritus to adjacent estuarine systems accounts for a large contribution of organic matter to the food chain (Trilla et al. 2010). Productivity is typically higher nearer tidal creek channels because of the availability of tidal and freshwater flow. Higher reported primary productivity can also be related to latitude which contributes to the length of the growing season and to nutrient availability either from natural or anthropogenic sources. Other factors that influence primary productivity include competition, salinity, degree of inundation and grazing by invertebrates (Silliman and Bortolus 2003).

B.1.1.5 C3 vs. C4 Photosynthetic Pathway

Spartina species employ a photosynthetic strategy that makes them highly competitive with other salt marsh plants and is an important factor in their ability to colonize in an invasive manner. There are 3 types of photosynthesis, which include CAM, C_3, and C_4 photosynthesis. CAM photosynthesis is an adaptation to water availability and is typical of plants in arid environments, particularly in desert conditions. When conditions are extreme, CAM plants can leave their stomata closed both night and day and "idle" by using oxygen given off in photosynthesis for respiration and CO_2 given off in respiration for photosynthesis.

Most plants typically use C_3 photosynthesis which is so named because the CO_2 is first incorporated into a 3-carbon compound (phosphoglyceric acid) versus a 4-carbon compound (oxaloacetic acid) for C_4 plants (Ebasco 1992, Mitsch and Gosselink 2000). Photosynthesis in C_3 plants takes place throughout the leaf, while photosynthesis in C_4 plants takes place in the inner cells. C_4 plants have better water use efficiency because of the use of PEP Carboxylase as the enzyme involved in the uptake of CO_2. This enzyme allows CO_2 to be taken into the plant very quickly for photosynthesis and also means that the plant does not need to keep the stomata open as long (thus minimizing water loss by transpiration) (Ebasco 1992).

Plants in the *Spartina* genus photosynthesize through the C_4 pathway. The C_4 pathway has an advantage over the C_3 pathway under conditions of low water availability, high temperatures, and nitrogen or CO_2 limitation. High water use efficiency is useful in high salinity salt marsh conditions and can help the plant to reduce transpiration and thus salt uptake. C_4 plants use an extra biochemical pathway and special anatomy to reduce photorespiration. Photorespiration slows the production of sugars from photosynthesis when the enzyme that grabs CO_2 grabs oxygen instead. Photosynthesis typically occurs faster in C_4 plants under high light intensity and high temperatures (Mitsch and Gosselink 2000). C_4 plants have been shown to exhibit higher photosynthetic rates than C_3 plants at higher temperatures. However, C_4 plants can maintain rates of photosynthesis at temperatures comparable to C_3 plants (Thompson 1991). While a C_3 plant must have its stomata open to take up CO_2 for photosynthesis (resulting in water loss), a C_4 plant may fix CO_2 in the dark, giving *Spartina* species the ability to photosynthesize in low light conditions that may be less favorable for its competitors. Lower light conditions in northern latitudes in the early spring may favor *Spartina* over C_3 marsh species.

The C_4 photosynthetic pathway confers a competitive advantage that translates into higher growth rates and organic matter production than many salt marsh plants. Mitsch and Gosselink (2000) report that C_4 plants have a maximum growth rate of 130.3 $gm^{-2}d^{-1}$ and dry matter production of 3,860 $gm^{-2}yr^{-1}$, compared to a maximum growth rate of 19.5 $gm^{-2}d^{-1}$ and dry matter production of 2,200 $gm^{-2}yr^{-1}$ for C_3 plants.

B.1.1.6 Structural Adaptations

Spartina species have developed a number of structural adaptations that enable them to be effective competitors when they invade native salt marshes. These include:

- Salt-secreting glands on plant leaves, which allow the plant to excrete excess salt to maintain cellular ionic balance in high salinity environments (Rozema et al. 1981)
- Stomata protected by papilla which help prevent moisture from entering the stomata during inundation
- Numerous rhizomes and roots with high surface areas, which help scavenge oxygen from the surface water in waterlogged zones, while also helping to generate energy to acquire nutrients
- The formation of large interconnected air spaces called aerenchyma in leaves, rhizomes, and roots that provide some structural support and serve as conduits for the transport of oxygen from the shoots to the roots (especially beneficial during long periods of inundation)
- High lignification, which strengthens cell walls and increases the plant's structural stability, helping with the transport of water and resisting penetration by microorganisms and fungi
- Individual plants within clones exhibit varying architecture, and different age class plants contribute to varying shoot density and tussock size, thereby ensuring that individual clones persist over time (Castillo et al. 2003)

B.1.2 Ecology of S. densiflora

B.1.2.1 Background

S. densiflora is a long-lived perennial species with a bunchgrass growth form, forming tight clumps or tussocks; short creeping rhizomes; and narrow, firm, in-rolled leaves (Boe et al. 2010, Bortolus 2006, Spicher 1984). Based on biogeographical (Bortolus 2006) and molecular evidence (Fortune et al. 2008), *S. densiflora* is believed to be native to the southeastern coastal marshes of South America, where it ranges from Sao Paulo, Brazil to Rio Gallegos, Argentina. From South America, *S. densiflora* spread by various means to Chile, the USA, Spain and Morocco. It is now found on both the Atlantic and Pacific coasts of South America with larger distributions in the southern end of the continent (Bortolus 2006). On the Pacific Coast is has only been found in small isolated lagoons in contrast with the extensive temperate marshes observed in Brazil, Argentina, Chile, and Uruguay on the Atlantic coast (Bortolus 2006). *S. densiflora* can inhabit a broad range of habitats. In Chile, it is only found in estuarine systems, but in Argentina, it also occurs as large mono-specific grasslands in areas characterized as terrestrial systems (Bortolus 2006) and it also colonizes different types of rocky shores (Bortolus et al. 2009) where it is one of the three more important ecosystem engineer species inhabiting the intertidal zone (Sueiro et al. 2011).

S. densiflora invaded Europe, with the first locations apparently occurring in Spain in the Odiel and Tinto Rivers and the southwest Iberian Peninsula. Subsequently, it was transported from Spain to the Merja Zerga lagoon in Morocco (Bortolus 2006, Trilla et al. 2010). *S. densiflora* is mentioned in historical records on the Atlantic coast of North America, but the absence of any other posterior mention or record suggest that it is not currently found there (Bortolus 2006).

Along the West Coast of North America, populations of *S. densiflora* are currently found in Baynes Slough on Vancouver Island; along the coast of Vancouver Island in British Columbia, Canada; in Grays Harbor and on Whidbey Island, WA; and in Humboldt Bay and San Francisco Bay, California (Boe et al. 2010, Bortolus 2006, CIPC 2010). While populations of *S. alterniflora* and *S. patens* have been identified in Oregon, no populations of *S. densiflora* have yet been identified. In San Francisco Bay, plant material believed to be *S. foliosa* was transplanted from Humboldt Bay to the Creekside Park Marsh in a restoration planting in 1977. It was later determined to be *S. densiflora* and was subsequently found in Corte Madera Creek, Muzzi Marsh, Greenwood Cove, Richardson Bay, and Brickyard Cove in San Rafael; and at Point Pinole on the east side of San Francisco Bay (Spicher and Josselyn 1985). Smaller populations have also been found in Burlingame Lagoon at Sanchez Marsh in Burlingame, California. Populations have also been found in Tomales Bay just north of San Francisco Bay.

B.1.2.2 Habitat Characteristics

In its native habitat, *S. densiflora* dominates coastal tidal marshes, but it is also found in a few riverine marshes without marine influence. In these instances, its occurrence appears to be related to soil salinity (Vicari et al. 2002). Some of the large populations in Argentina are found in terrestrial systems with little influence from the tides, while a few populations are found in strictly terrestrial systems. (Bortolus 2006, Trilla et al. 2010).

S. densiflora is tolerant of a broad spectrum of environmental and edaphic conditions and survives throughout a wide vertical range within the tidal frame. It can easily colonize intertidal to terrestrial habitats that include mudflats, sand, muddy and rocky shores, and cobble beaches (Bortolus 2006, Clifford 2002). Some of the more extreme substrates on which *S. densiflora* can be found include hard or soft substrates including volcanic stones, sand, clay and limestone, and rocky shore. *S. densiflora* currently occupies all of these habitats only in

Argentina (Bortolus 2006). No other native species can colonize within such a wide range of ecological conditions (Nieva et al. 2005). *S. densiflora* can grow in well-drained to very anoxic soils and in a wide range of conductivities from brackish to saline and even temporarily hypersaline (Bortolus 2006, Kittelson and Boyd 1997, Nieva et al. 2001, Vicari et al. 2002). *S. densiflora* typically does not grow at tidal elevations as low as the other *Spartina* species that have invaded the west coast, such as *S. alterniflora*. The combined effect of interspecific competition, tidal flooding, and air/water temperature on zonation is unclear (Bortolus 2006). *S. densiflora* appears to be somewhat constrained by the combined effects of flooding, high salinity, anoxic conditions, and mechanical wave action, which limit establishment in these conditions (Castillo et al. 2000, Kittelson and Boyd 1997, Trilla et al. 2010).

Different growing strategies enable *S. densiflora* to adapt to local environmental variables and microhabitat conditions (Kittelson and Boyd 1997, Nieva et al. 2005). The tiller density, biomass production, flowering period, and phenotype of *S. densiflora* are highly variable among the regions where it occurs (Bortolus 2006). Differences in plant vigor between locations where the plant is native and where it is introduced are the subject of current studies (Bortolus 2010).

At the upper edges of marshes, *S. densiflora* can grow in association with tufted hairgrass, and also occasionally with European beachgrass (*Ammophila arenaria*), both of which are also dense, clumped grasses, thus complicating detection when its occurrence overlaps with these species (Morgan and Sytsma 2010, SFEISP 2003).

The frequency and duration of tidal inundation may be a factor limiting the lower zone of *S. densiflora* distribution. Populations in the lower intertidal zone are likely to have lower net photosynthetic rate because frequent tidal inundation limits the photosynthetic period (Bortolus 2006, Nieva et al. 2003).

Structural characteristics of *S. densiflora*, common to other members of the genus as described above, allow it to grow in anaerobic and saline soils (Nieva et al. 2001). Such structures include salt-secreting glands on leaves that allow the plant to excrete excess salt to maintain cellular ionic balance (Rozema et al. 1981), and other structures such as lysigenous aerenchyma which is found on leaves, rhizomes and roots and provides structural support and allows transport of oxygen. *S. densiflora* has less developed aerenchyma tissue than *S. foliosa* (Spicher 1984), which may in part explain why *S. densiflora* occurs at higher tidal elevations where inundation is less frequent. Additional plant structures include papilla-protected stomata and foliar rolling of the leaf surface, both of which may serve to protect against flooding during inundation; high lignification, which provides additional structural support; and specialized root cells (suberized cells) that limit the water that moves through the root structures, thus protecting the roots. Its relatively tall height and dense growth form also give *S. densiflora* an advantage in competing with other shorter stature plants for available light to use for photosynthesis.

In the Management Area, *S. densiflora* is found in intertidal salt marsh and adjacent, irregularly flooded brackish marsh. It can also be found, generally with low frequency and abundance, in areas of brackish marsh lying behind leaking or overtopped tide gates. Additionally, *S. densiflora* has been noted on mudflats and on sand spits, and it may have the potential to spread in these environments. Substrates are typically mud or sand, however, *S. densiflora* sometimes occurs on gravel substrates such as riverbars on the lower Mad River. It is also found growing on artificial substrates such as rip-rap levees.

In the Management Area, *S. densiflora* exhibits different growth forms and density levels, apparently in response to a combination of environmental factors and interspecific competition. It is most robust at mid to low tidal elevations with ample tidal flushing, or in areas of high freshwater input. Those plants occurring at lower tidal elevations in the Mad River Estuary have wider and less-rolled leaves. Pure stands of the dense clumped grass can cover large areas of low or mid-elevation marsh or occur as a fringe bordering tidal channels in higher marsh. On mature, well-drained marsh plains with relatively high salinities, *S. densiflora* grows at lower densities interspersed with other marsh species, or as linear stands bordering tidal creeks and salt pannes. In brackish marshes, *S. densiflora* is sometimes mixed with other tall graminoids and can be hard to discern.

B.1.2.3 Reproduction and Expansion

S. densiflora is a perennial grass that can reproduce both sexually and by vegetative expansion making it very competitive in invading marine ecosystems. The processes of vegetative reproduction and seed production and dispersal are described below.

Vegetative Reproduction. *S. densiflora* can spread vegetatively by the formation of belowground rhizomes and tillers which spread laterally and can result in the growth of plants distant from the original plant (Nieva et al. 2001). The production of annual tillers from short rhizomes each year results in expansion and competition with existing salt marsh plants and gives the plant the characteristic 'tussock' look (Kittelson 1993). *S. densiflora* appears to use a combination of "phalanx-growing" and "guerrilla-growing" expansion strategies by creating overlapping guerrilla clones that grow in different directions while generating multi-clone phalanx-growing modules (Bortolus 2006). *S. densiflora* ramets may be densely packed within the clones, creating a configuration that defines a phalanx growth strategy. This strategy is characterized by slow surface spreading of the tussocks and occupation of the invasion site for long periods of time. This strategy enables the plant to capitalize on any locally abundant resources and allows it to outcompete other species. In contrast, the guerrilla growth form is characterized by connections between ramets that have many and/or long internodes, resulting in widely spaced ramets. This strategy allows clonal plants such as *S. densiflora* to spread quickly in horizontal space (Humphrey and Pyke 1998).

S. densiflora can exhibit different strategies of clonal growth in contrasting habitats. Nieva et al. (2005) showed that *S. densiflora* can develop very different strategies of clonal growth between the low and high marshes in southwest Spain. *S. densiflora* in the low marsh had greater intra-tiller density and tiller emergence and mortality than in the high marsh (Nieva et al. 2005). Lateral production of tillers was greater in the low marsh populations and may promote faster colonization of bare sediments. Low marsh populations had faster ramet turnover, with a shorter tiller life span (Nieva et al. 2005). The clonal growth traits of *S. densiflora*, combined with its ability to survive a variety of environmental conditions, have allowed this species to effectively colonize a wide range of tidal habitats throughout the world. Additional information on tiller population dynamics may lead to a better understanding of how the species performs. Information on number of tillers in relation to plant biomass may help us understand total annual productivity (Vicari et al. 2002**)**.

In sites populated by *S. densiflora* in the United States, vegetative growth typically occurs year round with tussocks expanding during the winter months (November to February in the Northern Hemisphere), giving the plants a competitive advantage over salt marsh species native to Humboldt Bay, during months when other plants are in winter dormancy (Kittelson 1993, Kittelson and Boyd 1997). Once *S. densiflora* is established, particularly in bare areas, it can form dense monocultures that occupy both above- and belowground space. Newly accreted tidal sediments often contain concentrations of essential macronutrients which further aid in colonization (Ranwell 1964). *S. densiflora*'s concentrated use of above- and belowground space, and of other resources such as light and nutrients, inhibits establishment or colonization by other plants (Nieva et al. 2001).

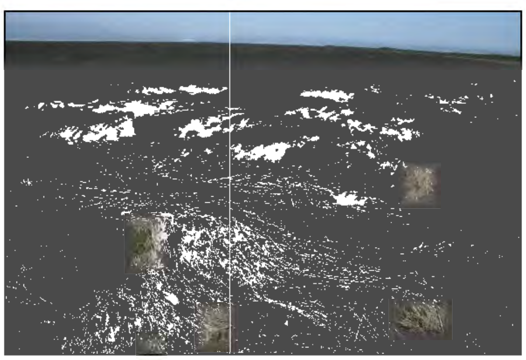
S. densiflora establishment and spread is typically lower in undisturbed marshes (Kittelson and Boyd 1997) than in disturbed marshes. Estuarine marshes are by nature dynamic systems. Patches of open space are commonly created by storm damage, wrack accumulation, or human disturbance. In the field, Kittelson and Boyd (1997) found the vegetative growth of *S. densiflora* to be greater in plants surrounded by bare space than in those with neighboring vegetation. Plants growing in association with competitors produced tightly packed tillers, but plants growing in the absence of competitors produced tillers that expanded farther away from the plant, resulting in vegetative expansion over a greater area.

Seed Production, Viability, Dispersal, and Establishment. *S. densiflora* is capable of sexual reproduction and flowers in Humboldt Bay from June through August, with seed maturation and dispersal occurring in September through October (Kittelson 1993). *S. densiflora* has extremely high fecundity, producing 35-47 million seeds/ac (88-118 million seeds/ha) in a recent study in the Management Area (Pickart 2012). The study also confirmed that S. *densiflora* has a persistent seed bank lasting at least two years. Seed viability in the seed bank declined at most study sites after two years (seed replenishment was prevented to derive this assessment), but remained the same in the site characterized by the densest seed bank. HBNWR plans to continue these seed bank studies to determine longevity. Seed bank density, ranging from 0.4-15 million seeds/acre (1-38 million seeds/ha) of surface area in the first year, was strongly correlated to aboveground abundance of *Spartina*, suggesting that seeds are primarily entering the bank at the site of seed production (Pickart 2012). An additional study to measure the relative contributions of seed rain and dispersal from seeds produced off-site is scheduled to start in fall 2012 (Pickart, pers. comm., September).

Spicher and Josselyn (1985) found that the seeds of *S. densiflora* are tolerant of long storage periods in dry or moist conditions. However, HBNWR staff has found that seed kept dry was dead after 6 months. Seed germination and seedling survival occur at salinities less than 11% as determined in experimental trials (Kittelson and Boyd 1997). In salinities of 4%, seedling survival and growth was higher than in salinities of 11% to 26% (Clifford 2002). *S. densiflora* can germinate in fresh or brackish conditions, which allows it to colonize salt marsh areas with freshwater inputs (Kittelson and Boyd 1997). While germination rates are highest at lower salinities, *Spartina* seeds can germinate in high substrate salinities (40%) (Kittelson and Boyd 1997, Shumway and Bertness 1992).

Seedlings are not as competitive in established marshes as in bare areas (Falenski 2007, Kittelson 1993, Kittelson and Boyd 1997, Rogers 1981). Mateos-Naranjo (2008b) found limited germination of *S. densiflora* seedlings occurring under vegetation canopies survived the initial 3-month recruitment period, confirming that competition may play a substantial role in seedling establishment. Seedling recruitment is higher in bare areas, especially during periods of high rainfall (periods of lower salinity). Periods of heavy rainfall, lower soil salinities, and disturbed, bare, or sparsely vegetated soil may particularly favor seedling establishment. Seedling recruitment and establishment is lower during years of lower rainfall and in soils with higher salinities (Kittelson and Boyd 1997). Once plants are established, growth and expansion easily occur at higher salinities. High seedling flushes have been observed occurring in areas where *Spartina* has been removed from HBNWR treatment sites, suggesting that disturbance may facilitate a seedbank release and contribute to seed rain onto bare areas.

Various ecological interactions in the presence of competitors and herbivores may affect habitat characteristics that enhance the sexual reproductive success of *S. densiflora*. Bortolus et al. (2004) found that plants in undisturbed marshes have a lower reproductive effort than plants in highly disturbed marshes, and that increased disturbance resulted in increased seed production in *S. densiflora*. Herbivory by crabs has been found to induce increases in reproductive stem size, seed production, and proportion of viable seeds.



***Spartina densiflora* Wrack**

Colonization of Bare Space. Estuarine marshes are by nature dynamic systems. Patches of open space are often created by storm damage, wrack accumulation, or other forms of disturbance. These bare areas create opportunities for new plant colonization. As noted above, seedling recruitment was also observed to be higher in bare areas, especially during periods of high rainfall (resulting in lower salinity), and Kittelson and Boyd (1997) found vegetative growth of *S. densiflora* is greater by plants that were surrounded by bare space than by those with neighboring vegetation. The wrack generated by *S. densiflora* is not as abundant as that produced by *S. alterniflora* (Bortolus 2006). However, *S. densiflora* can create suitable establishment conditions by generating wrack that either creates bare ground for further colonization by *S. densiflora,* or decreasing physical space and light, thereby preventing other species from establishing (Kittelson and Boyd 1997, Trilla et al. 2010).

Rate of Spread. Grozholz (1996) found that marine plant species demonstrate more variability in the rate of spread from year to year than terrestrial plant species. This may be related to the variability of physical forces such as currents and oceanographic conditions over time (Grosholz 1996). Characteristics of estuaries vulnerable to invasion by the genus *Spartina* include areas protected from wave action but exposed to year-round tidal action (Daehler and Strong 1996), and areas where other *Spartina* species are present. Low levels of tidal action likely limit establishment areas for *Spartina* because of increased salinity, anoxic waters, and increased sulfide in the substrate. The fact that estuaries in the Management Area are protected from wave action may contribute to the successful establishment of *S. densiflora* in Management Area marshes.

Vectors for Spread. Seeds of *S. densiflora* are moved around Humboldt Bay primarily by the tides, but these seeds can also be spread out of the estuary and into the nearby ocean current where they may be carried to other estuaries along the West Coast where no invasion currently exists, or where other *Spartina* species are currently being eradicated. In addition to these tides and currents, vectors for dispersal of viable seeds between estuaries include migrating waterfowl, dredging and shipping, intentional and unintentional introductions (Pfauth et al. 2003). Seeds dispersed by tides into the open ocean can potentially be entrained into ship ballast or come into physical contact with ship hulls and rigging and could successfully germinate even after 3-4 months. Transport of live marine shellfish between estuaries provides an additional transport mechanism for *Spartina* seeds. Along the West Coast measures have been developed to minimize the potential for commercial transport of *Spartina* seeds related to shellfish operations and to ensure that proper cleaning of gear occurs when moving between infested and non-infested sites (Boe et al. 2010). *Spartina* produces large amounts of wrack which breaks off in the fall and moves with the tides and currents around the estuary and into the open ocean. These floating wrack mats also contain mature seeds which may transported between estuaries. Seeds attached to the feather and feet of waterfowl have also been identified as a potential dispersal mechanism between Pacific flyway estuaries (Morgan and Sytsma 2010).

The Role of *S. densiflora* as an Ecosystem Engineer. *Spartina* species generally operate as efficient ecosystem engineers. *Spartina* modifies community structure and can alter nutierent cycling, marsh productivity, hydrology, and habitat availability. The densely packed roots and stems decrease tidal flow around the plant which contributes to sediment trapping, resulting in increased marsh elevations. Changes in marsh elevations contribute to changes in species composition of plants and animals.

B.1.2.4 Productivity of S. densiflora

In Humboldt Bay, Rogers (1981) found that S. *densiflora* displayed higher aboveground primary productivity than pickleweed or saltgrass, but did not measure belowground primary productivity or the primary productivity of non-vascular autotrophs. Lagarde (2012) used above and belowground biomass measurements coupled with paired closed-chamber carbon dioxide flux measurements to compare primary productivity of *S. densiflora* dominated marsh to that of marsh dominated by native vegetation. While NPP of *S. densiflora* marsh was higher for aboveground biomass, it was lower for belowground biomass and total NPP was lower overall (Table B-2). *S. densiflora* marsh also exhibited lower net ecosystem exchange measurements (gross primary productivity minus ecosystem respiration rate), presumably as a result of shading and subsequently lower production by benthic macroalgae. Benthic macroalgal cover was a good predictor of net ecosystem exchange (Lagarde 2012).

Table B-2. NPP in Native and Invaded Marsh in the Management Area

Marsh Type	Aboveground NPP[1] (g C/m²/year)	Belowground NPP[1] (g C/m²/year)	Overall NPP[1] (g C/m²/year)
Native Marsh	194/459	5169/4168	5363/4491
S. densiflora Marsh	628/680	1749/1732	2377/1917

[1] The 1st number shown was derived using the Maximum Minus Minimum Method and the 2nd number using Smalley's Method (Lagarde 2012)

B.1.2.5 Edaphic Characteristics

Nutrients. Nutrient availability can also affect the distribution and abundance of *Spartina*. Phosphorus was determined to be the most important nutrient correlating with distribution and abundance of *S. densiflora* and perennial pickleweed on Indian Island in North Humboldt Bay (Newby 1980). *S. densiflora* abundance was correlated to high levels of phosphorus in plant tissues, and the tallest, most vigorous, and most abundant plants were found in areas subject to frequent tidal inundation and with high phosphorus values. It is unclear whether *Spartina* colonizes areas of high phosphorus concentrations or high phosphorus is a result of the release of phosphorus through the roots of *Spartina*. Phosphorus is deposited on the marsh with the clay particles found in tidal waters, and is most abundant at low elevations in the marsh. Newby (1980) suggested that low phosphorus levels may be limiting to *Spartina* at higher tidal elevations. A correlation between *S. densiflora* abundance and phosphorous levels was also noted by Falenski (2007) working in Humboldt Bay salt marshes. In a salt marsh in Portugal, *S. densiflora* had a more efficient use of nitrogen and potassium, and a higher ability to absorb phosphorus, than the native succulent *Arthrocnemum macrostachyum* (Neves et al. 2010). Falenski (2007) found that sites susceptible to invasion had very reduced soil conditions and high available soil phosphorus, with some invaded marshes showing high available soil phosphorus concentrations greater than 5 parts per million. Other environmental factors correlated with *S. densiflora* abundance were negative reduction-oxidation (redox) values that are associated with high soil saturation, low elevation, and low elevation gradient.

pH. In general, *S. densiflora* can tolerate a fairly small range of soil pH within the netural range. In San Francisco Bay, Spicher (1984) found *S. densiflora* growing at sites with soil pH ranging from 6 to 8, but not at sites with pH less than 5. However, *S. densiflora* was found to germinate in sites polluted with heavy metals and pH values as low as 2 in the Tinto River on the Southwest Iberian Peninsula of Spain (Curado et al. 2010). Curado et al. (2010) also found that seedlings were able to establish with high survivorship and growth rates in an acidic environment with a pH of 4.

Salinity. Salinity is one of the main chemical factors in salt marshes and combined with elevation can drive the vegetation distribution for individual species. Many halophytes, such as *Spartina,* have salt glands that help regulate ion concentrations by secreting salt from tissues such as leaves and stems. The presence of large water storage parenchyma cells on both sides of the leaf also helps with salt storage and protects the plant against salt toxicity and dehydration. In short-term greenhouse studies, Castillo et al. (2005) found that *S. densiflora* has a high short-term salinity tolerance with high growth and photosynthesis exhibited at salinities from 0.5 to 20 parts per thousand. At the highest salinity level (40 parts per thousand), decreases in growth and net photosynthesis were observed. These results suggest that fresh water inputs and brackish environments also offer favorable environments for establishment and survival of *S. densiflora*.

B.1.2.6 Tolerance of Pollutants

Many native plants are intolerant of anthropogenic disturbance, particularly pollution, which is often associated with excess metals. *Spartina* appears to be more tolerant of chemical pollutants, and the ability to sequester metals into tissue or cellular compartments makes these species good competitors. Their ability to compartmentalize metals, particularly into root structures, minimizes translocating excess metals into leaves where photosynthesis occurs. *S. alterniflora* can excrete metals in salt crystals, which can then be released through salt glands. Whether *S. densiflora* employs the same mechanism is unknown, but if so, high levels of metals may be excreted when the plant is exposed to high salinities. *S. densiflora* has been found to tolerate high and continued exposure to zinc, and has been found growing in sediments with concentrations of zinc between 100 and 4800 parts per million (Mateos-Naranjo et al. 2008a). In addition to this, *S. densiflora* is important in determining the distribution of persistent contaminants, since a significant portion of hydrophobic toxic compounds such as the heptachlor epoxide (the most abundant organochlorine pesticide in many estuarine environments worldwide) may be deposited in the cordgrass biomass (Menone et al. 2000).

B.1.2.7 Summary

S. densiflora's characteristics give it numerous competitive advantages over native marsh plants. These advantages are summarized:

Physical Characteristics. *S. densiflora* successfully colonizes and establishes because its physical characteristics allow it to compete well with other native plant species. These characteristics include a tall canopy and production of abundant aboveground biomass, which can reduce light availability and limit photosynthesis for shorter stature species; the reduced light and shading from the tall canopy can also alter sediment temperature (Bortolus et al. 2002). Dense tussocks and dense root systems preclude colonization by other species. Abundant seed production and germination allows the species to be reproductively competitive. Physical structures such as aerenchyma allow *S. densiflora* to gather available oxygen in oxygen-limited environments. Physical processes such as C_4 metabolism give *S. densiflora* a competitive advantage over C_3 salt marsh plants, such as pickleweed, in conditions of low water availability, and allow it to photosynthesize more readily. This translates into higher growth rates and organic matter production.

Plant Dormancy. Many salt marsh plants such as pickleweed, jaumea, and saltgrass experience dormant periods (Kittelson and Boyd 1997). *S. densiflora* does not go completely dormant, allowing it to be an effective competitor year round (Trilla et al. 2010, Vicari et al. 2002).

Spatial Dominance. The ability of *S. densiflora* to densely occupy below ground space is a key ecological factor that limits colonization by other species (Nieva et al. 2001). However, although it is densely distributed belowground, it is relatively shallow compared to other *Spartina* species. In studies of *S. densiflora* in a variety of marsh types in Spain, Nieva et al. (2001) found that most of the below ground biomass was concentrated in the upper 20 cm of soil. In addition to exploiting space, the below ground root structures mechanically alter sediments and can influence soil geochemical conditions (Silliman et al. 2009). Bare areas resulting from wrack deposition favor dominance by *Spartina* over other salt marsh species by restricting native species establishment and smothering established species (Kittelson and Boyd 1997). This creates a negative feedback look that promotes further colonization by *Spartina*.

Sedimentation Feedback Loop. Rejmanek et al. (1988) demonstrated a positive correlation between the plant biomass and sediment deposition. The structure of *S. densiflora* and its high stem densities provide an environment that is more resistant to the mechanical stresses of wave impacts than other salt marsh species, so *S. densiflora* can more easily colonize exposed areas, such as mudflats, than other species. The cespitose nature of *S. densiflora*, high stem densities, and stout leaves effectively trap nutrient-laden sediment particles suspended in the water column. The resulting increase in sediment deposition favors further establishment of *S. densiflora*.

Edaphic Characteristics and Tolerance to Pollutants. *S. densiflora* exhibits a tolerance for environments that may be challenging for other salt marsh plants, such as a tolerance for some chemical pollutants, and the ability to colonize areas with high levels of phosphorus, a wide range of soil pH, a wide range of soil salinities, and with high soil saturation. It can also accumulate high concentrations of organochlorine pesticides in its tissues (Menone et al. 2000).

B.1.3 Invasion and Rate of Spread in the Management Area

B.1.3.1 History of Discovery and Invasion

Little historical botanical information is available for the region and preinvasion floristic descriptions of Management Area estuarine marshes are lacking (Clifford 2002). It is believed that *S. densiflora* was inadvertently introduced to Humboldt Bay in the latter part of the 19th century (Spicher and Josselyn 1985). To support reconstruction efforts in the aftermath of a major earthquake in Chile in 1868 (Billings 1915), Chileans imported lumber from Humboldt Bay (Carranco 1982, NCAP 2002). Presumably, *Spartina* seeds were transported inadvertently on empty lumber ships returning to Humboldt Bay weighted with ballast gathered from Chilean shorelines (Spicher and Josselyn 1985).

From Humboldt Bay, *S. densiflora* presumably spread to the Eel and Mad River estuaries. Relatively recent sedimentation and accretion in the Eel River Estuary may have contributed to *S. densiflora* expansion and dominance in the newly accreted areas. *S. densiflor*a is a notable component of Mad River marshes, but the total acreage of tidal marsh associated with the Mad River is much less than either of the other two estuaries.

Until the 1980s, the *Spartina* in the Management Area was thought to be a northern ecotype of *S. foliosa*, which is native to intertidal coastal marshes from Bodega Bay, California to Baja California (Daehler and Strong 1996). Under that erroneous assumption, plant material from Humboldt Bay was transplanted to a marsh restoration site in San Francisco Bay in 1976, where it naturalized (Faber 2000). *S. densiflora* grows in compact tussocks and it grows higher in the intertidal zone than *S. foliosa*. These differences were originally thought to be intraspecific phenotypic variation due to environmental conditions (Clifford 2002). Noting these differences in morphology and habitat preferences in the intertidal zone between the transplanted plants and the native plants when the two plants were growing side by side, Spicher (1984) determined the Humboldt Bay *Spartina* to actually be *S. densiflora*. Faber (2000) verified the work of Spicher (1984) after traveling to Chile and collecting *S. densiflora* from four locations there.

In a 1985 investigation at Humboldt Bay, Eicher (1987) recorded salt marsh vegetation occurring from 5.7 to 8.4 ft (1.7 to 2.6 m) MLLW. *S. densiflora* was distributed at almost the full range of elevations examined, occurring from 5.9 to 7.9 ft (1.8 to 2.4 m) MLLW. *S. densiflora*-dominated marsh was most prevalent from 6.9 to 7.3 ft (2.1 to 2.2 m) MLLW. Evidence suggests that since that time, *S. densiflora* distribution and abundance has expanded into the lowest marsh elevations, with clumps of *S. densiflora* observed encroaching onto intertidal mudflats below the elevation of existing salt marsh vegetation, and into the highest marsh elevations, including high diversity marshes that support rare plant species (Pickart 2001).

The first extensive mapping of *S. densiflora* in Humboldt Bay was in 1999 by Pickart (2001). Pickart (2001) mapped *S. densiflora* in conjunction with mapping of two rare plant species in Humboldt Bay salt marshes. For assessment purposes, Humboldt Bay was divided into four subareas. The total acres of salt marsh (and percentage of salt marsh occupied by *S. densiflora*) were as follows: 149 ac (76%) for the Mad River Slough area, 609 ac (99%) for North Bay, 37 ac (100%) for Central Bay, and 73 ac (85%) for South Bay. In general, the two rare plants were more abundant in locations with lower frequency and density of *S. densiflora*. The Mad River Slough area was distinguished by having the largest amount of salt marsh as a proportion of total bay acreage, the least severe invasion by *S. densiflora,* and the highest densities of rare salt marsh plants per acre. Altogether, nearly 94% of the 868 ac of salt marsh surveyed was infested to some degree by *S. densiflora*, with 38% of marshes characterized as sparse to moderate *S. densiflora* (5%-69% cover) and 55% of marshes characterized as dense *S. densiflora* (≥70% cover) (Pickart 2001).

Pickart's (2001) study was significant in describing how pervasive *S. densiflora* is in Humboldt Bay and in documenting the leading edge of an increasing infestation with increasing range and density. The frequency of *S. densiflora* measured in high salt marshes at the Mad River Slough showed a 50-fold increase between 1989 and 1997 (Pickart 1997). Colonization of bare and disturbed areas was observed and incremental expansion was observed in established marshes through vegetative growth as documented by Kittelson and Boyd (1997). Seedling recruitment by *S. densiflora* in established marshes was also observed (Pickart 2001). Only 6% of the salt marshes surveyed in 1999 were uninfested and 38% were sparsely to moderately infested. These marshes have the highest native plant species diversity and the most abundant populations of rare plants in the region and are vulnerable to invasion by *S. densiflora*, which has invaded 94% of salt marshes in Humboldt Bay (Pickart 2001).

B.1.3.2 Current Distribution

S. densiflora can now be found in salt marshes, brackish marshes, along brackish river channels, on sandy substrates in dune wetland areas, and on bare mudflats throughout the Management Area. By the 1960s, when Macdonald (1967) described the flora, *S. densiflora* was a dominant species. Photographs from the 1970s show that large areas of Indian Island and Jacoby Creek marsh were free of *S. densiflora*. Since that time, numerous investigators have noted the predominance of *S. densiflora* in tidal marshes at specific study sites and/or in general descriptions of the region (Barnhart et al. 1992, Boyd et al. 2002, Claycomb 1983, Clifford 2002, Eicher 1987, Eicher and Bivin 1991, Falenski 2007, H. T. Harvey & Associates 2008, Kittelson 1993, Kittelson and Boyd 1997, Macdonald 1977, Macdonald and Barbour 1974, Monroe 1973, Monroe et al. 1974, Newby 1980, Newton 1989, Pickart 2001, 2005b, Roberts 1992, Rogers 1981, Schlosser and Eicher 2012, Shapiro and Associates 1980).

Detailed *S. densiflora* maps were completed in 2011 for the Management Area (Grazul and Rowland 2011) (Figures 3-2, 3-3, & 3-4). The regional mapping was conducted by HBNWR staff through an agreement with the Harbor District and was funded by the Conservancy and BOEMRE. The regional *S. densiflora* maps created from this mapping will be useful throughout the planning and permitting process to help determine land ownership and jurisdiction of infested lands, opportunities for collaboration, project phasing, and estimating the cost of labor and other resources based on acreage and density of infestations.

Aerial imagery used for the mapping was acquired by the National Oceanic and Atmospheric Administration (NOAA) on 27 June 2009 at a low tide around 0.0 ft. MLLW. The true color and color infrared imagery provides 1.6 ft (0.5 m) spatial resolution, ± 9.8 ft (2.99 m) horizontal spatial accuracy. Most of the Mad River Estuary is not covered by this imagery data set and was mapped using 2006 Quickbird satellite digital imagery, panchromatic (0.6 m resolution) or pan-sharpened (2.4 m resolution). In addition to mapping, several field surveys were conducted to determine whether *S. densiflora* has spread outside of its known range. Potential coastal habitats to the north and south of the Management Area that were surveyed include Redwood Creek estuary to the north, the Mattole River estuary to the south, and smaller coastal streams throughout the region (Pickart and Goodman 2008). Mapping results found that approximately 1,700 ac of *Spartina* occur throughout the Management Area.

The density of *S. densiflora* was categorized according to three cover classes: 1-25%, 26-60%, and 61-100% cover. The mapping conducted by HBNWR combined photo interpretation and field mapping that functions as a continuous interpretive feedback loop. Potential occurrences were first identified using photo interpretation, visited in the field, and then refined using heads-up digitizing. Photo interpretation was carried out using several sets of imagery, including National Agricultural Imagery Program 2005 and 2009 true-color imagery, and Humboldt Bay 2009 true-color imagery captured at a resolution of 0.5 m. The 2009 Humboldt Bay imagery has proved to be most useful in detecting *S. densiflora* remotely. Some locations required 100% field mapping due to variable color signatures on the imagery, and low abundance or sparse distribution of *S. densiflora* among native species.

A total of 1,671 ac of salt marsh in the Management Area were mapped as infested with *Spartina*. The total infested area for the Mad River Estuary is 7.4 ac, for the Eel river Estuary 656 ac, and for Humboldt Bay 947 ac. Of the total 1,671 ac, 622 ac have between 61-100% cover, 460 ac have 26-60% cover and 588 ac have 1-25% cover. Of this total, approximately 20% are currently undergoing treatment for *Spartina*.

B.1.3.3 Potential for Future Spread

The Humboldt Bay region contains the only substantial area of salt marsh between San Francisco Bay and Coos Bay, Oregon. The salt marsh of Humboldt Bay is considered a floristic link between northern and southern salt marshes (Barnhart et al. 1992, Macdonald and Barbour 1974). Humboldt Bay could potentially provide a link between the invasions in the souther marshes of California with northern salt marshes. *S. densiflora* has the potential to invade other estuarine environments along the West Coast, given that 1) it is widely distributed within South America, Western Europe and North Africa, 2) it is present in Grays Harbor, Humboldt Bay, and San Francisco Bay, and 3) it can colonize a variety of substrates with varying salinity regimes (Bortolus 2006). *Spartina* seed is capable of floating on the tide, which may enable it to expand its range outside of currently invaded sites. In California, isolated plants have been found on the outer coast of California north of San Francisco Bay suggesting that populations from San Francisco Bay can provide seed source to other estuaries along the California and the Pacific Coasts (Strong and Ayres 2005). Strong vigorous plants with large inflorescences have been spotted growing among rocks and boulders inside the Woodley Island Marina, from where the seeds could potentially be transported on equipment such as nets, cords, etc. via boats to other harbors and ports of the West Coast.

During a one-year period in 2004 and 2005, drift cards were released monthly from Willapa Bay, Washington, and Humboldt and San Francisco Bays in California, to determine the relative risk of major infestations colonizing other locations along the west coast. Drift cards released from Humboldt Bay were found within a month of their release at locations along the Oregon Coast and in southwest Washington. Observed seasonal trends were related to nearshore ocean currents that flow predominately northward along the Oregon and Washington coasts in the fall and winter. During the fall and winter, drift card releases traveled northward 15.2 mi/day (24.5 kilometers (km) /day) and 22.9 mi/day (36.8 km/day) from Humboldt Bay and Willapa Bay, respectively. During the spring drift card release, drift cards from Willapa Bay were recovered in Oregon. Drift cards released from San Francisco Bay traveled northward at approximately 9.9 mi/day (16 km/day) (Morgan and Sytsma 2010). The drift card study supports the notion that established invasive *Spartina* colonies can easily disperse seeds between West Coast estuaries.

B.1.3.4 Implications for Restoration Projects

The ability of *S. densiflora* to colonize newly disturbed or bare areas poses potential threats to the objectives of new restoration projects. Newly restored marshes provide available substrate for *Spartina* colonization, particularly if located near existing invasive *Spartina* marshes. Areas newly opened to tidal influence and without established vegetation are prime colonization areas for *Spartina*. This is particularly relevant to tidal marsh creation, restoration, and/or enhancement projects, which typically create large amounts of open, bare ground in the early stages. This may result directly from earthwork/contouring of the site. Invasion pathways may also be indirect, such as when a levee is breached and the new tidal influx results in die-off of the existing vegetation. Either way, the open space created is often conducive to *Spartina* establishment, and can result in *Spartina*-dominated marshes. In a study of tidal marsh restoration projects in San Francisco Bay, 56 of 96 completed projects totaling 9,000 ac (3,642 hectares (ha)) were invaded by 4,300 ac (1,740 ha) of non-native *Spartina*. While some of these projects only supported a few plants, most sites had greater than 30% cover by non-native *Spartina* (Olofson 2007).

In Humboldt County, examples of *Spartina* colonizing restoration project sites have been documented in the following areas/projects: in the Management Area for the Park Street Restoration Project (Claycomb 1983, Clifford 2002, Springer et al. 1984); the King Salmon Slough Restoration Project (Eicher 1993); the Palco Marsh enhancement project (Eicher et al. 1995); and the Butcher's Slough Restoration Project.

In a recent marsh restoration project at the Lanphere and Ma-le'l Dunes Units of HBNWR, *S. densiflora* was successfully controlled on about 35 ac (14.2 ha) of tidal marsh. Following manual removal of mature plants using brushcutters in 2006-2007, abundant seedling recruitment by *S. densiflora* was observed colonizing the open areas. The seedlings were destroyed using a combination of flaming and brushcutters. Native plant seedling recruitment was also high after *Spartina* was destroyed. Follow-up control measures included selective removal of *S. densiflora*, and the restored marshes are now vegetated by a diversity of native salt marsh plant species (Pickart 2012).

B.1.3.5 Invasion by Other Spartina Species

Aside from *S. densiflora*, the only other invasive *Spartina* species that has been documented in the Management Area is smooth cordgrass (*S. alterniflora* Loisel). Native to the eastern and Gulf coasts of North America, *S. alterniflora* was first detected in Humboldt Bay in 1985 at an intertidal coastal marsh in Samoa, on the eastern shoreline of Humboldt's North Bay. *S. alterniflora* initially colonized unvegetated mudflat that occurred at lower intertidal elevations than *S. densiflora* marsh (Eicher and Sawyer 1989). Over 3 years, the *S. alterniflora* stand increased from 10 ft^2 to 5,000 ft^2 and spread upward into vegetated salt marsh. CDFG effectively eradicated the species by diking the area, cutting the grass to grade, removing all cuttings from the site, applying salt, covering it with black semi-permeable geotextile fabric, and weighing down the fabric and seams with sand bags. Around the same time, *S. alterniflora* was detected in the Eel River Estuary, within vegetated salt marsh but along an eroding edge of the marsh. This population was washed away by winter floods, covered by a subsequent layer of deposited (alluvial) sand, and did not re-establish (Kovacs, pers. comm., February 2010). *S. alterniflora* and/or other species of *Spartina* could invade restored areas, and land managers should stay alert for early detection and rapid response should invasion occur. This species can colonize low in the tidal range, as discussed above, so without the control efforts by CDFG, it is likely that it would have spread widely onto the mudflats of the Bay.

B.1.4 Ecological Impacts of *Spartina* Invasions in Other Estuaries

B.1.4.1 Landscape Impacts

The ability of *Spartina* to thrive within a wide vertical range in the tidal frame and to tolerate a broad spectrum of environmental and edaphic conditions makes it a serious competitor in estuarine environments. If left uncontrolled, non-native *Spartina* can alter the hydrology of estuaries by modifying tidal creeks and navigational channels, dominating newly restored tidal marshes, displacing thousands of acres of shorebird habitat, and drastically reducing biodiversity.

Invasions by non-native *Spartina* can have a significant impact on the flora and fauna of salt marsh communities and can affect physical structure and biological composition of salt marshes, mudflats, and creeks. These invasions can also alter ecological processes such as biogeochemical cycling and sediment dynamics (Callaway and Josselyn 1992). *Spartina* species can outcompete other native plants in the intertidal zone (Callaway and Josselyn 1992, Frenkel 1991). *Spartina* can rapidly expand and spread to new areas, and can act as ecosystem engineers by increasing sedimentation which alters the topography of the marsh. This altered marsh topography can transform mudflat areas to low marsh, and low marsh to high marsh, leading to colonization by different species adapted to the altered inundation regimes. Even when invasive *Spartina* can be removed from an area, it may not be feasible to restore the natural marsh topography. Furthermore, *Spartina* species possess numerous physiological adaptations such as the use of the C_4 photosynthetic pathway and structural adaptations such as aerenchymous tissue and salt-secreting glands. Their ability to rapidly colonize bare ground allows them to take advantage of large-scale disturbance events when other species may be displaced. The most drastic examples of these invasions on the West Coast include invasions by non-native *Spartina* in Willapa Bay and San Francisco Bay, and by *S. densiflora* in Humboldt Bay. Both Willapa Bay and San Francisco Bay managers have implemented aggressive eradication programs to control the invasion and spread of non-native *Spartina* species.

In Willapa Bay, Washington, *S. alterniflora* converted vast areas of estuarine mudflats into uniform expanses of dense cordgrass, and converted shellfish beds to grassy meadows, choked tidal creeks, and displaced shorebird habitat. Before coordinated regional control efforts were implemented, *S. alterniflora* converted more than 9,000 ac (3,642 ha) of mudflat into *Spartina* meadows. In 2008, after 5 years of coordinated treatment, the live infestation was reduced to less than 2,000 solid ac (809 ha), but most of the treated area remains as masses of dead root mass and vegetative stubble, with little return of the habitat to its former ecological structure (Boe et al. 2010).

Invasive *Spartina* alters mudflat and salt marsh habitats for native plant and animal species, threatens habitat for migrating birds and feeding areas for Brant geese and widgeon, alters use of the mudflat and salt marsh by invertebrate populations, and threatens commercial interests such as commercial oyster culture (Sayce 1990, Thom et al. 1997). In addition, *Spartina* species are known to disrupt habitat structure for oysters, clams, crab, salmon, migratory waterfowl, and a variety of marine mammals (Mumford et al. 1990).

B.1.4.2 Estuarine Foodweb Alterations

Food web impacts related to invasions by *S. densiflora* have not been studied extensively. Grosholz et al. (2009) found that *S. alterniflora* invasion of mudflats in Willapa Bay, Washington and in San Francisco Bay, California negatively affects microalgal productivity, suggesting that invasive *Spartina* has an important role in altering the overall estuarine food web. Large amounts of available nitrogen are contributed to the surface of the salt marsh via algal production. Shading from *Spartina* may lower marsh productivity by shading algal species that are typically fast nutrient cyclers.

Spartina invasion of tidal wetlands can alter the trophic structure of marsh ecosystems (Guntenspergen and Nordby 2006). Large quantities of detritus produced by *Spartina* alter trophic structure. Levin et al. (2006) documented a shift from an algae-based to a detritus-based food web in mudflat areas of San Francisco Bay invaded by a *Spartina* hybrid (*Spartina alterniflora* x *S. foliosa*). Increased detrital loads supplied to the estuary, and decreased benthic microalgae productivity, favored subsurface deposit feeders and detritivores over grazers, suspension feeders, and surface deposit feeders. This resulted in a shift from a mudflat system based on primary production to a detrital based system within those areas that were colonized. A loss of trophic support in mudflats for consumers such as fish, birds, crabs, and benthic species not typically consumed by species at a higher trophic level may be the result of these shifts (Silliman et al. 2009). More research is needed to compare the food web benefits of native species versus those of invasive species. For example, it is unclear whether or not the dead tissue from pickleweed (which may decompose faster than *Spartina* detritus) provides an important food web energy source to the estuarine food web and how it compares to the contribution provided by *Spartina* detritus.

Biochemical shifts may also occur from *Spartina* invasions. In estuaries with substantial mudflat habitat invaded by non-native and hybrid *Spartina*, Grosholz et al. (2009) found that increases in below ground biomass, combined with changes in sediment dynamics, resulted in increased levels of sulfide and decreased ammonium levels, which are detrimental to other organisms.

B.1.4.3 Threats to Biological Diversity and Ecosystem Function

Invasion by *Spartina* threatens biological diversity and ecosystem function and physically alters estuarine habitat. Habitat alteration affects many marsh species, including vertebrates such as birds and rodents, and also invertebrates such as crustaceans and gastropods. Habitats can be altered when stem and root density, plant height, and shading increase compared to shorter native plants such as pickleweed and saltgrass. Structural changes within the marsh may also affect colonization of vascular plants by algal species.

B.1.4.4 Facilitation

Increased elevation of *Spartina*-invaded marshes may enable establishment of other salt marsh species that otherwise would not establish; such changes may even facilitate a transition or succession to other vegetation types. Non-native *Spartina* colonization may also facilitate invasions by other invasive species. In San Francisco Bay, Silliman et al. (2009) suggest that the invasive hybrid has facilitated invasion by non-indigenous invertebrate species in recently colonized *Spartina* areas, particularly at the leading edge of the hybrid meadows. In San Francisco Bay, non-native clam densities can be 2 to 10 times higher at the growing edge of hybrid *Spartina* meadows, compared to adjacent mudflats (Silliman et al. 2009), but this may be simply related to additional structures for attachment. In Willapa Bay, Washington, habitat created as a result of *Spartina* colonization may benefit the invasive European green crab, which has been collected at the edges of native salt marshes, and in *S. alterniflora* meadows in Willapa Bay and Grays Harbor, Washington. European green crabs have also been documented in San Francisco Bay as occurring more abundantly in hybrid *Spartina* marshes than in adjacent mudflats (Grosholz et al. 2009).

B.1.4.5 Impacts to Native Plant Habitats

Spartina species directly displace native marsh plant species by outcompeting for available space, light, and nutrients. The development of a *Spartina* dominated plant community results in an overall reduction in plant diversity within the community, and greater habitat homogeneity. A structurally complex native marsh, including a variety of interspersed plant associations with associated variance in plant height and other attributes, provides a wide range of habitat niches, thus supporting greater wildlife diversity. *Spartina* dominance also diminishes the topographic and structural complexity that is typically found in a healthy, native dominated marsh (Sutula et al. 2008a).

An even greater threat potentially posed by *Spartina* invasions is the threat to genetic integrity of the native *Spartina foliosa*. *S. alterniflora* can hybridize with the native *S. foliosa*, resulting in a *S. alterniflora* x *S. foliosa* hybrid, which is a serious threat to the genetic integrity of native *S. foliosa* populations in San Francisco Bay. The hybrid is difficult to distinguish in the field from *S. foliosa*. It can be variable in height and in pollen and seed production, and can tolerate greater variance in inundation than the native species. It has colonized large areas of San Francisco Bay. The eradication effort led by the Invasive *Spartina* Project (ISP) is focused on eradication of both the hybrid and the non-native *S. alterniflora*. The second most prevalent invasive *Spartina* in San Francisco Bay is *S. densiflora,* which tends to dominate in the middle and high marsh elevations. A *S. densiflora* x *S. foliosa* hybrid has also been found in San Francisco Bay, but low seed production and eradication efforts limited its potential for spread, and all known individuals have recently been eradicated (Ayres et al. 2008, Morgan and Sytsma 2010).

B.1.4.6 Impacts to Invertebrate Communities

Non-native plant invasions can alter invertebrate communities and can alter the taxonomic composition within those communities, which may affect the trophic cascade of a particular ecosystem (Mitchell 2010). Effects of *Spartina* invasion on tidal mudflat invertebrates and cascading effects on shorebirds are particularly well-known. *Spartina* invasions may change the invertebrate community composition in intertidal zones by reducing benthic invertebrate densities (Capehart and Hackney 1989).

In areas where *Spartina* invasion results in mudflat converting to marsh, the shift in invertebrate community composition is distinct. O'Connell (2002) found that in mudflats converting to *S. alterniflora* marshes, invertebrate abundance decreased, and several species of burrowing polychaetes, crustaceans, and bivalves were excluded in favor of terrestrial species such as dipteran larvae and pupae. This change became more pronounced as distance into the *Spartina* meadow increased. The transformation of the invertebrate community from mudflat to terrestrial species limits the food source for larger benthic predators.

B.1.4.7 Impacts to Fish Communities

The most significant impacts to fish communities from *Spartina* invasions are likely to occur where the distribution of fish communities overlaps with non-native *Spartina*, primarily within mudflats and tidal channels. *Spartina* species that establish in mudflats and tidal channels, such as *S. alterniflora*, can substantially alter the hydrology and geomorphology of those habitats. For instance, invasive *Spartina* species have the potential to restrict flow and change the topography (e.g., increase slope steepness) in tidal channels, potentially restricting the movement of fishes through tidal channel habitats. *Spartina* invasions on mudflats have the potential to reduce foraging opportunities for fish species that use mudflats for foraging. Although the impacts of *Spartina* invasions on fish communities have not been specifically investigated, the physical and evolutionary changes (Mooney and Cleland 2001) resulting from *Spartina* invasions may have a significant effect on fish communities.

B.1.4.8 Impacts to Avian Species Communities

Spartina also reduces the areas of open intertidal mudflats that provide important foraging habitat for shorebirds (Evans 1986). This has been demonstrated on the Yangtze River estuary in China, where the invasion of *Spartina alterniflora* on mudflats resulted in a reduction in the occurrence of plovers (*Charadriidae*) and sandpipers (*Scolopacidae*), possibly due to a decrease in food resources and the physical alteration of mudflat habitat (Li et al. 2009). Shorebirds tend to avoid dense *Spartina* because they have difficulty landing or using the areas as roosting habitat, and also because they are unable to obtain benthic and epibenthic invertebrate prey in those areas (Evans 1986). In Willapa Bay, Washington, where the area covered by *Spartina* tripled between 1994 and 2002 (Buchanan 2003), shorebird numbers decreased by approximately 60% (Jaques 2002).

In addition to direct removal of suitable habitat, *Spartina* invasions may have more subtle impacts on wildlife. The spread of invasive *Spartina* in San Francisco Bay may alter foraging habitat for the endangered California clapper rail (*Rallus longirostris obsoletus*) by altering the topography and hydrology of tidal channels (Zaremba and McGowan 2004). However, invasive *Spartina* may also provide breeding and refugia habitat for clapper rails (Grijalva and Kerr 2006), thus the overall benefits and/or impacts of invasive *Spartina* on clapper rails are currently unknown. Additionally, Alameda song sparrows (*Melospiza melodia pusillula*) nests constructed in invasive *Spartina* had a lower rate of survival and tended to experience a higher rate of flooding than nests that were located in native vegetation (Nordby et al. 2009). Song sparrow nests located in *Spartina* are also more easily invaded by marsh wrens (*Cistothorus palustris*) because invasive *Spartina* provides attractive habitat for aggressive wrens, which in turn may destroy song sparrow eggs (Nordby et al. 2004). Also, song sparrows nesting in *Spartina*-infested tidal marshes of San Francisco Bay may experience a reduction in breeding success due to reduced food availability in those areas (Guntenspergen and Nordby 2006). Therefore, invasive *Spartina* in San Francisco Bay may function as an ecological trap for song sparrows (Nordby et al. 2009) and potentially other species as well.

When native plants are replaced by *Spartina*, food and carrying capacity may be reduced for a number of waterbird species, including geese, ducks, and cranes (Li et al. 2009). A study in eastern China found lower avian species richness and relative abundance in non-native *Spartina* than in the native salt marsh vegetation

(Gan et al. 2010); an earlier study found lower species diversity and population densities of songbirds (Gan et al. 2009), presumably due to changes in habitat structure and decreases in availability of seeds and arthropod food resources (Gan et al. 2010). Arthropod species diversity and abundance has been found to be significantly lower in *Spartina* than in the native *Phragmites* (Wu et al. 2009).

B.1.4.9 Impacts to Mammal Communities

Spartina species that invade higher elevation zones in the coastal marshes may reduce habitat for small mammals such as the California vole (*Microtus californicus*), vagrant shrew (*Sorex vagrans*), and house mouse (*Mus musculus*) that are known to forage and breed in these zones. *Spartina* provides dense cover but little horizontal structure; Shellhammer et al. (1982) speculated that dense cover and horizontal branching are important habitat features preferred by the salt marsh harvest mouse (*Reithrodontomys raviventris*), a salt marsh-obligate species in San Francisco Bay.

B.1.4.10 Implications of Sea Level Rise

Sea level rise will increase the stresses on all marsh species. The ability of invasive species to occupy new niches may make competition more acute as species are forced to migrate inland under projected sea level rise scenarios. Donnelly and Bertness (2001) determined that increased flooding associated with accelerating sea level rise rates will stress high marsh communities in New England salt marshes and promote landward migration and dominance of *S. alterniflora*.

Climate change impacts may provide *Spartina* with additional competitive opportunities to invade new marsh areas. Sea level rise and global warming predictions suggest that new stresses and large-scale disturbances will result in species losses in native marshes, opening up opportunities for invasions by non-native species. Because of the competitive abilities of *Spartina*, the predicted inland migration of marshes and mudflats from rising sea level will increase the opportunity for invasive *Spartina* to colonize new areas, replace native marshes, and occupy new habitats. The resulting *Spartina* monocultures will likely provide different habitat functions and values than currently exist in native marshes.

B.1.5 Ecological Impacts of *S. densiflora* within Humboldt Bay Region

B.1.5.1 Threats to Biological Diversity and Ecosystem Function

Salt and brackish marshes in the Management Area are valuable components of local estuarine ecosystems, and are intricately linked to other estuarine habitats such as mudflats, subtidal channels, and native eelgrass (*Zostera marina*) beds. Therefore, impacts of *Spartina* invasion are not only detrimental to marsh communities but the entire ecosystem.

In Humboldt Bay, *S. densiflora* produces large amounts of wrack which may help create the disturbance and resulting bare space necessary to facilitate opportunities for its own continued invasion and spread (Kittelson and Boyd 1997). In mudflat systems in San Francisco Bay, abundant wrack production can result in a large detrital input and could cause a shift in the microalgal/benthic infauna community from an autotrophic system to a heterotrophic system (Grosholz et al. 2009).

B.1.5.2 Threats to Native Plant Communities

In low and mid-elevation marshes, *S. densiflora* commonly forms dense monocultures that have displaced native plant species such as pickleweed, fleshy jaumea, and seaside arrow grass. Continuing encroachment by *S. densiflora* in already scarce high-elevation salt marshes within the region threatens a diverse plant community that includes the rare plant species Humboldt Bay owl's clover and Point Reyes bird's beak. In addition, high elevation marshes have experienced a drastic decline in habitat from approximately 9,000 ac to less than 900 ac due to the diking and conversion of marshes for agriculture. The invasion by *S. densiflora* further threatens the remaining habitat for these two species. The areas that are particularly vulnerable to invasion have the highest native plant diversity and the most abundant populations of rare plants (Pickart 2001).

In addition to colonizing salt marshes, *S. densiflora* is also invading brackish marshes in the Management Area, particularly areas near open or leaking tide gates (Pickart 2001). These brackish communities can include plant species such as Lyngbye's sedge, hardstem tule (*Scirpus acutus*), seacoast bulrush (*Schoenoplectus maritimus*), tufted hairgrass, salt rush, sea watch angelica (*Angelica lucida*), saltgrass and narrow-leaved bur-reed (*Sparganium angustifolium*). Lyngbye's sedge status is listed as CNPS 2.3. CNPS List Status 2.3 refers to plants that are rare to endangered in California but are common elsewhere with a low degree or immediacy of threat or threat not currently known (CNPS 2010). The proximity of *S. densiflora* to leaking tidal gates suggests that the detrimental effect of salt water on fresh marsh plants may enhance their susceptibility to *S. densiflora* invasion.

S. densiflora has colonized some mudflats in the Management Area. Within the boundaries of HBNWR, 4.9 ac (2.0 ha) of *S. densiflora* was documented growing directly on mudflat with no other salt marsh vegetation nearby (Grazul and Rowland 2010). It has been observed growing on mudflats in other areas of the world where it has invaded (Bortolus 2006, Clifford 2002). Mudflat communities include several species of algae, invertebrates such as polychaete worms, ghost shrimp, and clams, and native eelgrass (*Zostera marina*). Eelgrass is a large contributor to estuarine primary productivity and eelgrass habitat also functions as nursery, feeding, and refuge areas for juvenile invertebrates, Dungeness crab, and many bird species (Dean et al. 1998, Pfauth et al. 2003).

B.1.5.3 Threats to Fish and Wildlife Communities

Fish may be impacted by changes to ecosystems, geomorphology and hydrology that are a result of *S. densiflora* invasion. Native fishery species in the Management Area that may be affected by these changes include Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss*), Dungeness crab (*Metacarcinus magister*) and tidewater goby (*Eucyclogobius newberryi*). Potential impacts to these species from a *Spartina* invasion in lower elevations may include barriers to movements in tidal waters as the edges of the channels are vegetated, and potentially reducing some foraging habitat on mudflats or along the edges of channels. These species have both ecological and economic value and depend on habitats within the Management Area to complete critical portions of their life cycle. If *S.*

densiflora becomes more prominent at lower elevations (i.e., in mudflats and tidal channels), more significant effects to fish communities could occur in the Humboldt Bay region.

Relative to bird species, the primary potential impact of a *Spartina* invasion on habitat quality in the Humboldt Bay region would be from loss of mudflat habitat, should *Spartina* expand into unvegetated mudflat areas. Whereas *Spartina* species have invaded mudflats and tidal channels in other regions, *S. densiflora* has not yet extensively invaded intertidal mudlfats in the Bay. In terms of potential wildlife impacts, a *Spartina* invasion in mudflats of the Humboldt Bay region may be most significant for shorebirds such as dunlin, western sanpiper, least sandpiper, and others that congregate and feed on intertidal mudflats throughout the winter each year (Danufsky and Colwell 2003, Harris 2006).

The impact of *Spartina* invasion in the Humboldt Bay region on wading birds such as great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), black-crowned night heron (*Nycticorax nycticorax*), and great blue heron (*Ardea herodias*) is unknown. However, in a study conducted in North Carolina, great egrets and black-crowned night herons were reported using *Spartina* habitat (Custer and Osborn 1978). *S. densiflora* may provide species such as egrets with safe areas in which to forage. While snowy egrets were reported using *Spartina* in an estuary in New York City, the dense stands may impede foraging and offer hiding places for small fishes and other prey (MacCarone and Parsons 1994). Although common birds such as the song sparrow may use *Spartina*, songbird diversity and abundance is likely reduced due to *Spartina* invasion in the Humboldt Bay region.

Reduced diversity and abundance of terrestrial invertebrates and changes in representation of functional groups were observed in a *S. densiflora* invaded marsh in the Mad River Slough in Humboldt Bay. Recent research suggests that this reduced invertebrate diversity in *Spartina*-invaded marshes may be increased once restoration occurs. In the Mad River Slough, Mitchell (2010) found that a restored site had twice the invertebrate diversity and abundance than the nearby invaded site, at a similar tidal elevation.

Community composition of invaded sites includes an abundance of mollusks, isopods, and amphipods. *Spartina*-invaded sites provide an extra habitat niche for species such as a long jawed orb weaver (Tetragnathidae) which is abundant in *Spartina* marshes, but not in restored areas. *Spartina* also appears to facilitate establishment of the invasive marsh snail (*Myosotella myosotis*) which is also very abundant in *Spartina* marshes. In fact, competition may be occurring between the invasive marsh snail and the native snail (*Littorina subrotundata*) (Mitchell 2011). Once *Spartina* is removed, restored areas appear to support increased abundance of the native snail.

Species composition of restored areas includes low abundance of mollusks, more hemipterans, particularly Delphacidae (which might be a specialist in saltgrass), talitrids (fish and bird food source), soil mites including predators (Tromblidae) and detritivores (Oribatidae). The native threatened snail *Littorina subrotundata* is also found in abundance in restored areas.

Appendix C. Lessons Learned from Previous *Spartina* Eradication Work

C.1 Lessons Learned from Previous *Spartina* Eradication Work

Management plans similar to this one have been implemented in the states of Washington, Oregon, and Alaska, in Canada, and in San Francisco Bay, California. Differences in geography and individual *Spartina* species occur, but many of the strategies implemented by West Coast managers for other *Spartina* invasions (Boe et al 2010, Brown 2006, Morgan and Sytsma 2010, WSDA 2011) can be applied to the Management Area regional strategy. The strategies provided below are not comprehensive, but provide general guidance gained from these programs for implementing a successful eradication program.

General Operational Guidelines:

- It is important to establish regional coordination and management
- Citizen and agency support are paramount for success
- A strong mechanism for long-term funding needs to be secured
- It is important to develop a coordinated response with clear procedures, authorities, defined responsibilities for control and monitoring, and a framework for implementation
- The use of integrated management techniques can improve effectiveness and offer flexibility
- Maintaining a database is important for housing regional and site-specific data and mapping results
- Annual reports are important for describing the progress of eradication efforts
- An adaptive management approach should be adopted, including periodic re-evaluation of treatment strategy based on monitoring results and on new research findings

Planning:

- Phased approach allowing temporal and spatial partitioning of available resources
- Management Units to be based primarily on hydrologic connectivity (relating to tidal seed dispersal mechanisms of *S. densiflora*)
- Prioritization of treatment efforts among defined Management Units, in conjunction with a proposed timeline for treatment phases
- Site-specific planning in advance of treatment implementation
- Planning for at least two years of intensive treatment to kill established *S. densiflora* stands
- Allocation of adequate resources to continue lower intensity maintenance treatments at all sites until regional eradication is achieved

Controlling Spread:

- Strategic use of seed suppression treatments as an interim measure to help prevent reinfestation until implementation of all treatment phases have been completed
- Monitoring program designed to assess reinfestation of previously treated sites and to detect new infestations

- Implementation program to ensure prompt treatment of all infestations detected by monitoring

Mechanical Control:

- Continued research to refine mechanical treatment techniques currently in use by HBNWR
- Research to determine other methods that can be used in conjunction with mechanical control to provide cost-effective treatment
- Further experimental trials using amphibious vehicular equipment to apply mechanical control
- Labor/cost analysis of mechanical treatments (in progress by HBNWR)

Chemical Control:

- Complete experimental trials to investigate the efficacy and non-target impacts of using imazapyr to control *S. densiflora*, and to compare efficiency with mechanical methods (study in progress by the Conservancy)
- Research the use and costs associated with the use of herbicide treatments in conjunction with mechanical methods to enhance success
- Monitoring program to determine the most effective concentrations and application rates at particular sites
- Labor/cost analysis of chemical treatments

Eradication Success:

- Defined treatment goals and success criteria, with interim targets corresponding to project timeline
- Commitment of long-term resources for treatment of all *Spartina* and for prevention of reinvasion

Long-term Monitoring:

- Monitoring Plan designed to ensure complete eradication of existing *Spartina* populations
- Early detection, rapid response program to find and eliminate new infestations, with surveys of all suitable *Spartina* habitat conducted at a frequency deemed adequate for the purpose

Continued Research:

- *S. densiflora* seed ecology: longevity of the seed bank; relative contributions of seed rain and seed bank (study in progress by HBNWR)
- *S. densiflora* seed dispersal model based on available data for tides, wind patterns, and circulation dynamics in the Management Area; peak timing of seed dispersal; seed buoyancy; range (distance) of dispersal; and dispersal modes
- Use of *S. densiflora* habitat by avifauna (study in progress by HSU); impacts of eradication treatments on avifauna

- Impacts of *S. densiflora* and impacts of mechanical treatments on benthic invertebrates (study in progress by HBNWR); can be expanded to other locations within the Management Area
- Impacts of mechanical treatments on tidal channel bank stability (study in progress by HBNWR)
- Impacts of mechanical and chemical treatments on tidewater goby
- Identification of cultural resources in areas infested by *S. densiflora* and development of measures to avoid or mitigate impacts associated with implementation of *S. densiflora* eradication measures

Community Support:

- Program to develop and maintain the support of community leaders to ensure continued support for the eradication efforts and help in identifying outside funding opportunities
- Outreach program to educate the public, allow for public participation in the planning process, and provide volunteer opportunities
- Communication to develop interagency support, ongoing planning and treatment activities

C.2 Lessons Learned from Willapa Bay, Washington

Willapa Bay is a close analog to Humboldt Bay with respect to invasion by *Spartina* because both bays originally had no native *Spartina*, and the infestations are dominated by only one *Spartina* species. However, unlike the Humboldt Bay region, the major *Spartina* species found in Willapa Bay is *S. alterniflora,* which differs from *S. densiflora* in its life history, ecology, and response to treatments. The Willapa Bay management program, implemented in the 1980s, has the advantage of a relatively long treatment and outcome history. In contrast, the Humboldt regional project benefits from the fact that eradication is being planned in a concentrated and coordinated way. The pilot efforts and experiments carried out in Humboldt Bay allow for cost efficiency in that new techniques have been tried over a relatively small area.

Over time, the Willapa Bay eradication effort has combined control/treatment methods using physical, mechanical, biological, and chemical methods. Most of the physical, mechanical and biological methods were only slightly successful, despite extensive effort and expense. The *S. alterniflora* population in Willapa Bay was not significantly reduced until sufficient funding was appropriated and use of the chemical imazapyr was approved. Success in Willapa Bay depended on systematically organizing an array of people, agencies, institutions, and funding in a concerted and effective manner, and has required strong financial support by public agencies and private individuals. Wecker (2010) provides guidance based on management lessons learned from the Willapa Bay eradication effort:

- Develop a systematic and thorough mapping program to provide an understanding of the scale of the invasion and to use as a monitoring and planning tool
- Inform the public in order to provide an understanding of the problem and to generate broad-based support for eradication efforts

- Acknowledge the scale of the invasion and initiate a prompt response to solve the problem with the least costs and the least ecological impacts. A delayed response allows the invasion to accelerate
- Designate a single entity to provide coordination of the eradication efforts (The Washington State Legislature designated the Washington State Department of Agriculture to fill this role)
- Design a monitoring and research program to provide objective quantitative information and prevent debate between various agencies and entities on the success of various eradication methods. A strong scientific program also informs politicians and the public
- Develop a long-term planning strategy and adequately convey that strategy to the key stakeholders
- Design a systematic program to eliminate large blocks of *Spartina* rather than trying to eradicate piecemeal blocks. This strategy requires various management entities to consolidate their efforts and cooperate on a large scale
- Natural resource managers need to develop a 'thick skin' and be willing to accept criticism and listen to the concerns of the public and stakeholders. Open dialogue provides a means for evaluation and program improvement, and helps elicit public support and confidence

A summary of lessons learned in Willapa Bay is shown in Table C-1. Any application of these lessons to the Management Area must consider the differences in biology between *S. alterniflora* and *S. densiflora*. *S. alterniflora* has longer rhizomes, larger leaf area, and a faster growth rate. *S. densiflora* is more resistant to herbicides, is slower to spread vegetatively, and has a more persistent seedbank. Considering these differences, the phasing and treatment strategies proposed differ from those in Willapa Bay.

Table C-1. Summary of *S. alterniflora* Eradication Methods in Willapa Bay, WA

Location	Lessons Learned (Source)
Willapa Bay, Washington	• Herbicide treatments using imazapyr provided the most effective control. Other treatment methods, including covering with black plastic, mechanical removal, biological, and glyphosate, either were not viable or only provided light to moderate control (Hedge et al. 2003, Murphy et al. 2010, Wecker 2010) • On the ground eradication data can be highly variable between site and treatment years, and are less effective than what might be found in ideal conditions. Efficacy can vary by at least 20% from the expected level (Patten 2010) • In a comparative study by Patten (2010), the methods which provided the best expected efficacy over a reasonable time frame (6-8 years) were tilling (mechanical) and imazapyr (herbicide). • Tilling was found to be a successful method of mechanical control, but is costly and slow and can only be done in a narrow window in the summer. It also results in massive seedling density • Crushing is less expensive and faster than tilling, but requires multiple treatments per year. This method is limited to sites with specific sediment characteristics • Disking is relatively inexpensive and comparable to crushing, but large uprooted mats of *Spartina alterniflora* can easily re-establish in deeper tidal zones • Hand-spraying using glyphosate provides consistent control, but rates and costs are difficult to assess as tank mixes and volumes can vary • Use of imazapyr resulted in the reduction of *Spartina* infestation from over 8,500 solid ac in 2003 to approximately 18 solid ac in 2010 (WSDA 2011) • Eradication cannot be achieved as long as there is significant seedling recruitment

C.3 Lessons Learned from Other West Coast Estuaries Specific to *S. densiflora* Eradication

Although a large, regional eradication effort continues in San Francisco Bay, California on *S. alterniflora* and its hybrids, *S. densiflora* is also an important eradication target. Additional West Coast estuaries trying to eradicate *S. densiflora* include Grays Harbor, Washington and Vancouver Island, British Columbia. Lessons learned specific to treatment of *S. densiflora* from these other estuaries are included in Table C-2.

Table C-2. Summary of S. densiflora Eradication at Other West Coast Estuaries

Location	Lessons Learned (Source)
San Francisco Bay, California	• Mowing can be used to promote new green growth that can better translocate herbicides than plants that are not undergoing vigorous growth. Repeated mowing can also weaken the plants by interrupting nutrient transfer from aboveground plant material to the perennial root system and eventually depleting their reserves (Kerr 2010) • Mowing of partially dead or dead plants after herbicide treatment can allow managers to assess plant status and further treatment strategy • *S. densiflora* doesn't spread as vigorously by rhizomes as *S. alterniflora* hybrids, so individual plants can be dug with minimal concern for spread • Post-mowing herbicide application reduces the amount of aboveground biomass, thereby reducing the amount of herbicide. • When using imazapyr herbicide treatment in Creekside Park over a 2-year period, 93% of the treated sites required only light manual maintenance treatments thereafter • Established stands of chemically treated *S. densiflora* can appear to be half-dead. In this state, these plants are not healthy enough to translocate herbicides. Less vigorous plants are less susceptible to herbicide treatments than healthy plants
Grays Harbor, Washington	• Managers use mechanical and herbicide treatments separately and combined • In small areas of infestation (just a few small plants per acre), mechanical (digging) treatments were more cost effective than herbicide treatments • Managers have determined that *S. densiflora* seedbanks regenerate annually, and the small seedlings are difficult to find • Effective reduction of the seedbank requires aggressive mowing with large equipment (i.e., Marsh Masters equipped with hydraulically driven mowers) from April to November before the plants set seed • *Spartina* in Grays Harbor is intermixed with tufted hairgrass. It can be difficult to locate *Spartina* individuals in tufted hairgrass stands, so achieving a high percentage of eradication success is also difficult between June and November, before native plants begin to senesce. Treatments initiated later in the year (late October) were more successful because much of the native vegetation had senesced (WSDA 2011)
Vancouver Island, British Columbia	• No recolonization from subsurface growth occurred after burial of *S. densiflora* clones

C.4 Lessons Learned from the Humboldt Bay Region

HBNWR has undertaken numerous studies to 1) develop and refine mechanical eradication methods, 2) provide a greater understanding of *S. densiflora* biology and ecology, and 3) understand the impacts of *S. densiflora* infestation and the impacts of control measures on biotic communities. Research is occurring at all treatment sites, concurrent with follow-up treatments and monitoring to help inform future efforts.

Following is an excerpt from *Spartina densiflora Invasion Ecology and the Restoration of Native Salt Marshes at Humboldt Bay National Wildlife Refuge* (Pickart 2012) summarizing the results of *S. densiflora* work conducted by HBNWR beween 2006-2011.

- 31 previously untreated acres of salt marsh on the Mad River Slough were restored through the removal of invasive *Spartina densiflora*.
- Mature plants were killed in 1-2 years through the application of a subsurface "grind" technique using a tri-blade brushcutter applied directly on the shallow rhizomes. Resprouts were treated at approximately 6-month intervals.
- Above-ground parts of plants were mowed, raked and burned or removed, however a new method of "mulching" the above-ground material with the brushcutter now eliminates this step.
- Dense *Spartina* seedling flushes emerged after the first treatment (mean 240/m^2), and were flamed or removed with brushcutters. Subsequent seedling emergence was much lower. Seedling density in the first year was positively correlated with cover of *Spartina* prior to treatment. This initial flush of seedlings may be emerging from the seed bank, and a "deep" grind (4-6 in) has subsequently been shown to minimize seedling emergence and eliminate much of the seed bank.
- A successional trend during restoration was documented, in which bare areas resulting from treatment became colonized first by filamentous algae (first winter following treatment). Native vascular plants, especially pickleweed, began colonizing the first summer after treatment and significantly increased in cover during the second summer. Canopy closure was achieved between 2 and 4 years after initial treatment.
- *Spartin*a seedling emergence following treatment was positively correlated with algal mats, which may have reduced desiccation in the spring.
- Application of a first treatment in summer (vs. winter) resulted in fewer *Spartina* resprouts but more *Spartina* seedlings. Pragmatically, timing of treatment is more likely to be a function of crew availability and site accessibility. Sites are far more accessible in summer due to tides, and weather is more suitable.
- Revegetation can be accomplished using "plugs" of native salt marsh dominants (pickleweed or salt grass) planted at any time between December and April. Both pickleweed and salt grass exhibited extremely high survivorship. Earlier transplants resulted in more rapid canopy closure, and canopy composition shifted to predominance by pickleweed by the end of the first summer after planting.
- Canopy closure occurred in all areas, included those not planted, by year 4, suggesting that revegetation is not a required step in marsh recovery.
- Arrowgrass, a brackish and high marsh plant, appeared resistant to the mechanical treatment, resprouting from rhizomes vigorously in treated areas in the first spring after treatment, and accelerating vegetation recovery. However, this species was largely confined to areas with freshwater input.
- In areas without freshwater input, pickleweed was the dominant colonizer, emerging from seed in the first or second summer after treatment. Salt grass was observed to recruit only vegetatively from established stands bordering controlled areas, but even in these areas pickleweed was often the first colonizer.

- The rare salt marsh annual Humboldt Bay owl's clover responded dramatically and positively to restoration, with the population in the restored area increasing from approximately 3,000 individuals pre-restoration to over 99,000 five years post-restoration.
- Continued maintenance to remove newly established plants will be required until regional eradication is completed.
- *Spartina densiflora* has extremely high fecundity (35-47 million seeds/ac), and a persistent seed bank lasting at least two years. Viable seed in the seed bank was reduced at most sites after two years (when replenishment was prevented) but remained the same in the site characterized by the densest seed bank. Seed bank studies will continue in order to determine longevity.
- Seed bank density, ranging from an average of 100 to 3,805 seeds/m^2 of surface area in the first year, was strongly correlated to above ground abundance of *Spartina*, suggesting that seeds may primarily enter the bank at the site of seed production.
- Top mowing of dense *Spartina* can be used to suppress seed production when complete control isn't feasible. Mowing in July completely suppressed seed production, mowing in April reduced it by 90%. Top mowing resulted in increased native cover, but also increased seed production in the second year. These results suggest that annual mowing would be needed for this method to be effective.
- *Spartina* continued to increase in density in the control plots at one experimental restoration site over a two year period, indicating that the invasion was still in progress, even in moderate to dense areas. There are many areas around Humboldt Bay where *Spartina* can be observed spreading to new areas, but this study suggests that it is continuing to increase in density even in areas where it appears to be fully established.

C.4.1 Ongoing Method Development and Research

One area of research is focused on determining the optimal depth for subsurface mowing treatments. This depth is currently estimated at somewhere between 3-6 inches (8-15 cm). Deeper initial treatment requires fewer follow-up treatments; however, the deeper treatment may result in unacceptable non-target impacts. Removal of dense stands of *S. densiflora* results in large areas of bare ground which could potentially result in excessive erosion.

Mowing typically generates a large amount of wrack, which may damage nearby native vegetation or inhibit recovery of native species. In pilot project treatments in Mad River Slough, wrack was raked into piles and either burned or hauled off site for disposal. Raking and hauling are very labor intensive and burning is not always a feasible option. From 2010 to the present, brushcutters have been used by HBNWR to finely chop stems and leaves. The resulting fine material is left in place on the marsh to either compost on site or wash away without creating damage to the marsh.

HBNWR prepared a qualitative assessment of experimental mechanical treatments for eradication conducted at HBNWR during 2010-2011 (Pickart 2011a). This work served as a basis for selecting certain treatments for more rigorous quantitative experimental trials that were initiated at HBNWR's Jacoby Creek Unit in March 2011. Follow-up monitoring is in progress to measure both *S. densiflora* resprout and seedling response and native plant recovery for all treatments. Data collection includes measuring vegetation cover, elevation, redox potential, and impacts to invertebrate species. Results will be used to evaluate effectiveness, efficiency, and non-target impacts of subsurface mowing treatments (Pickart 2011b).

HBNWR is currently experimenting with using mini-tillers as an alternative to brushcutters for sub-surface treatments to a depth of 2-3 inches. The area to be tilled first must be top-mowed in some fashion and the top plant material cleared away or chopped as mulch. Initially, the method is significantly less time consuming than the grind method, although there are more resprouts, so the need for a greater number of follow-up treatments is expected. Preliminary trials indicate that the mini-tiller will be most advantageous when *Spartina* cover is less than 50%. It appears that native plant species may recover more quickly using the mini-tiller instead of bruschcutters (Pickart, pers. comm., July 2012).

Ongoing research projects include:

- *S. densiflora* seed ecology: longevity of the seed bank; relative contributions of seed rain and seed bank (study in progress by HBNWR)
- *S. densiflora* seed dispersal model based on available data for tides, wind patterns, and circulation dynamics in the Management Area; peak timing of seed dispersal; seed buoyancy; range (distance) of dispersal; and dispersal modes
- Use of *S. densiflora* habitat by avifauna (study in progress by HSU); impacts of eradication treatments on avifauna
- Impacts of *S. densiflora* and impacts of mechanical treatments on benthic invertebrates (study in progress by HBNWR); can be expanded to other locations within the Management Area
- Impacts of mechanical treatments on tidal channel bank stability (study in progress by HBNWR)
- Impacts of mechanical and chemical treatments on tidewater goby
- Identification of cultural resources in areas infested by *S. densiflora* and development of measures to avoid or mitigate impacts associated with implementation of *S. densiflora* eradication measures