Dense-flowered cordgrass (*Spartina densiflora*) in Humboldt Bay,
Summary and Literature Review

by Patti M. Clifford, January 2, 2002
Prepared for
Sheila Semans
California State Coastal Conservancy
1330 Broadway, 11th Floor
Oakland, CA 94612
Dense-flowered cordgrass (Spartina densiflora) is the dominant salt marsh plant in Humboldt Bay, California. This non-native species is able to outcompete native species and may threaten the remaining salt marsh community. The purpose of this report is to summarize available information related to this invasive exotic.

History

Spartina densiflora’s introduction to Humboldt Bay can only be speculated. It is believed that propagules of S. densiflora may have been introduced into the bay in the 1850s from ballast water dumped from ships returning from Chile (Spicher and Josselyn 1985). The 1840s-1850s were a time of economic growth in Chile, with an increased demand for timber to support infrastructure development. The 1850s were also a period of increased lumber production and exportation from Humboldt Bay. During this time, Chile imported much of its timber from Humboldt Bay (Cox 1974, Carranco 1982). Returning ships would have needed to weight their vessels for the voyage home. Seeds of S. densiflora could easily have been included in the beach stones that were carried for ballast (Barnhart et al. 1992).

The newly introduced Spartina adapted so well to its environment that until the 1980s most thought it was an ecotype of the native cordgrass Spartina foliosa (Barnhart et al. 1992). MacDonald and Barbour (1974) described the Humboldt Bay growth form (actually S. densiflora) as a compact, closely spaced tussock form that occupied irregular areas of the middle marsh. S. foliosa typically grew in a dense, meadow type of cover. Rogers (1981) noted the differences between elevational occurrences of S. foliosa (actually S. densiflora) in the Humboldt Bay salt marsh and S. foliosa in salt marshes elsewhere. This difference was attributed to environment. Other researchers also considered S. densiflora to be S. foliosa (Newby 1980, Claycomb 1983, Monroe 1973). Mobberly (1953) in his thesis on Spartina taxonomy and distribution stated that an earlier identification by Saint-Yves, which classified the species as Spartina densiflora forma acuta did not necessitate a separate classification from S. foliosa. Spartina densiflora’s identity as an exotic species was not verified until Spicher’s thesis in 1984. Faber (2001) collected S. densiflora from four locations in Chile and validated Spicher’s assumption that the species in Humboldt Bay identified as S. foliosa was actually S. densiflora. The mistaken identity of this species has led to further impacts due to early restoration efforts using S. densiflora and a lack of management/control.

Spread

Until recently, little effort has been put towards mapping the distribution of S. densiflora in Humboldt Bay. Quantitative evidence on its dispersal mainly comes from research on salt marsh ecology. Although most early research described S. densiflora as a mid-elevation species (Rogers 1981, Newby 1980), a study by Eicher (1987) on salt marsh vegetation showed that S. densiflora has spread into the higher elevation marshes. USFWS (1997) also quantified the increase of S. densiflora on high elevation salt marsh islands in the Mad River Slough over a period of 10 years. This may demonstrate a recent adaptation of the species to high marsh conditions. Spartina alterniflora (native to the east coast of the U.S.) was introduced into Willapa Bay, WA. in the late 1800s to early 1900s and began adapting to
its new environment. In the 1950s, there were approximately 400 acres in the bay. The estimated invaded acreage in 1999 was 15,000 – 25,000 acres.

The extent of the distribution of *S. densiflora* in Humboldt Bay was recently mapped by the USFWS (2001) (map below). According this study *S. densiflora* occurs in 94% of the salt marsh in Humboldt Bay. Of this area 38% of the marsh was categorized as having sparse to moderate infestation (5-69% cover). The cover of *S. densiflora* was least expansive in the Mad River Slough (76% coverage by all abundance classes sparse-dense, 9% covered by densities greater than 70% cover).

There is very little historical information on the extent of *S. densiflora* in Humboldt Bay. Rogers (1981) described the Eureka slough, a mid-elevation salt marsh, as a uniform stand of *S. densiflora* with patches of *Salicornia* and isolated other salt marsh plants. Newby (1980) mapped the distribution of *S. densiflora* on Indian Island, Humboldt Bay. She found it to occur at lower elevations with frequent tidal inundation. Low elevation, oblique air photos from the 1970s (Humboldt County Public Works Collection) confirm that large areas of the island were still without *S. densiflora* at that time. Similarly, photographs dating from the 1980s show that *S. densiflora* had not yet reached dominance in the Jacoby Creek marsh, a high elevation salt marsh. The current mapping of *S. densiflora* is too generalized to make true comparisons with these photos, and the historic spread of *S. densiflora* in Humboldt Bay is in need of focused research so that future projections can be made. *S. densiflora*’s recent expansion in high marshes of Humboldt Bay may be similar to the change in *S. alterniflora*’s distributional expansion in Willapa Bay. Alternatively, the rate of spread may have been poorly documented, and may have been continuous with the species just now reaching the more remote and higher elevation Mad River Slough. Further research on historic spread using satellite imagery would assist in understanding past spread and modeling future invasion.

*S. densiflora* visible along tidal creeks and at western edge of Jacoby Creek marsh in 1981.
Impacts

The *Spartina densiflora* infestation impacts the Humboldt Bay estuary through the reduction of biodiversity and the physical alteration of the estuary. The impacts of this invasive exotic are far-reaching, as propagules (thought to have been the native *Spartina foliosa*) have been collected for a restoration project in San Francisco Bay, thus introducing the exotic into another estuarine system.

Humboldt Bay 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 1992, MacDonald and Barbour 1974). The salt marsh community at Humboldt Bay contains two rare species: Humboldt Bay owl’s clover (*Castilleja ambigua ssp. humboldtiensis*) and Point Reyes bird’s beak (*Cordylanthus maritimus ssp. palustris*). The Humboldt County salt marshes are the northern limit for sea lavender (*Limonium californicum*); and do not contain *Frankenia grandiflora* and sea blite (*Suaeda californica*) typical of other California salt marshes (Eicher 1987, MacDonald and Barbour 1974).
Distribution of Spartina densiflora in Humboldt Bay, 2000 (after USFWS 2001).

Cover Spartina densiflora
5-69%: Sparse--Moderate
70%+: Dense

Coastline
Eicher (1987) found the salt marsh community at Humboldt Bay to be divided into three marsh types: *Salicornia* marsh at low elevations, *Spartina* marsh at mid-elevations and Mixed marsh at high elevations. The *Salicornia* marsh type contains five species with 70% of the cover contributed by *Salicornia*. The *Spartina* marsh type contains 10 species with 87% of the cover from *Spartina*. The Mixed marsh type is the most diverse, containing 22 species, with none having more than 25% cover. This marsh community also contains the rare salt marsh plants Humboldt Bay owl’s clover and Point Reyes bird’s beak. Currently the mixed marsh has the least severe infestation of *S. densiflora* (USFWS 2001).

*Spartina densiflora* has a competitive advantage over the native salt marsh species, as it does not have a dormancy period (Kittleson 1993). *Spartina densiflora* can outcompete the two dominant native species at Humboldt Bay, *Salicornia virginica* and *Distichlis spicata* (Josselyn and Buchholz 1984, Daehler and Strong 1996). *S. densiflora* quickly colonizes bare areas and through its production of large quantities of wrack is able to smother other species (Kittelson and Boyd 1996).

The physical and biological characteristics of an estuary change as it accrues sediment. The sedimentation rate in the Humboldt Bay estuary has increased through development activities such as reclamation, pollution, and watershed alteration (Monroe 1973). *Spartina* species accrete and retain sediment in the tidal areas they invade. As Daehler and Strong (1996) state, “Plants that alter their physical environment can have great ecological effects on native communities.”

In 1976 *S. densiflora* was introduced into Creekside Park in San Francisco Bay as part of a restoration project. The restorationist liked the vegetative appearance of the *Spartina* at Humboldt Bay, which was thought

![Wrack composed of dead *S. densiflora*.](image)
to be a growth form of *S. foliosa*. The propagules at Creekside Park became established and eventually spread to other areas of the Bay. Currently *S. densiflora* has invaded sites in Corte Madera, Muzzi Marsh, and Greenwood Cove in Marin County (Josselyn and Buccholz 1982). There has also been a recent infestation in Tomales Bay, Marin County (Smith 2002). This demonstrates *S. densiflora*’s ability to move to uninfested estuarine systems.

**Biology**

The genus *Spartina* is in the Poaceae family. The genus occurs over a wide gradient of wetlands from freshwater to salt marsh. Halophytes (salt tolerant species) have strong ecotopic adaptations. This enables a species to have a distribution over a range of edaphic conditions (MacDonald and Barbour 1974). *Spartina* species are dispersal-limited. They are considered the most problematic invasive species in coastal wetlands as they are able to invade undisturbed natural habitats as well as restoration sites. Eradication is difficult and requires frequent monitoring (Callaway and Sullivan 2001). *Spartina foliosa* is the only *Spartina* species native to the Pacific coast of North America its range is from Baja, CA to Bodega, CA (Daehler and Strong 1996).

*S. densiflora* Brongn. is a perennial species which has a caespitose growth form, but may form meadow-like stands when spreading by short tillers. The leaves are basal and cauline, generally inrolled when fresh, with ridges on the upper surface. The blade is 12 – 43 cm long and 4 – 8 mm wide at the base. The inflorescence is panicle-like; each spike with 2 – 20 overlapping appressed branches. The spikelet is 8-14 mm; glume and lemma keels have short, sharp bristles at least near the tip. The lower glume is 4-7 mm, the upper glume 8-14 mm, and the lemma 7-9 mm. The species is native to South America (Jepson 1996).

Spicher (1984) studied the phenology of *S. densiflora* at San Francisco Bay. The species undergoes a partial dieback from September to February. However, it never enters a complete dormant stage and maintains a larger percentage of living culms in the winter. The flowering period is from late April to August with seed set from August to September.
S. densiflora’s native distribution is the Pacific and Atlantic sides of southern South America. Mobberly (1953) found a geographic trend within the population, with plants in the north-eastern portion of the range having fewer and longer spikes. A decrease in spike length and increase in number occurs as one moves south and west. The decrease in spike length is often accompanied by an increase in width.

Distribution of *Spartina densiflora* in South America (Mobberly 1953)

In Humboldt Bay, Kittelson and Boyd (1997) found there to be approximately 1,977 viable seeds per plant (approximately 78% of total seeds per plant). The highest germination success was in salinities less than 11%. Seedling survival and growth was greatest in fresh water and 4% salinity with moderate survival in salinities of 11% - 26%. The research indicates that if a seedling becomes established the mature plant can withstand and grow in higher salinities.

*S. densiflora* has also invaded mid- and high elevation salt marshes in southwestern Spain Castillo et al. (2000). The cordgrass has invaded a range of habitats including dunes, high marsh and levees, salt pan, and intertidal flats.

Newby (1980) found that phosphorus correlates with *S. densiflora* and *Salicornia virginica* cover, and is the most important nutrient affecting *S. densiflora*’s distribution and abundance at Indian Island. Her study examines the mineral nutrient and elemental content of the tissues of *S. densiflora* and *Salicornia virginica* as related to their distribution on Indian
Island marsh. *S. densiflora* was found to be tallest, most vigorous, and most abundant in areas of Indian Island subject to frequent tidal inundations and high phosphorus values.

*S. densiflora*’s distribution may be limited by several factors mentioned in Spicher’s (1984) thesis. *S. densiflora* was found to grow at sites in San Francisco Bay where the pH was between 6 – 8. It was not found at any site where the pH was below 5. Submergence may limit the lower zone of distribution. *S. densiflora* has a less developed aerenchyma tissue than *S. foliosa* and has few lacnae in the leaves (Spicher1984).

A study by Figueroa and Castellanos (1988) in Spain, at the Gulf of Cadiz, showed that *S. densiflora* has a continuous growing season from February to November. It forms dense stands and does not shed dead leaves. *S. densiflora*’s net primary production and high standing crop allow it to replace *Spartina maritima* (the native cordgrass). *S. densiflora* colonizes open areas, competitively excludes other plants, and impedes succession.

Salt marshes are one of the most productive ecosystems in the world. Spartina species are one of the most productive plants. A study by Rogers (1981) examined the net primary productivity of three major salt marsh species in Humboldt Bay; *Spartina, Salicornia,* and *Distichlis,* and found that the high productivity and the amount of area covered at low and mid elevations make *S. densiflora* the primary producer. These productivity estimates are among the highest for terrestrial or marine plants. *S. densiflora* showed the greatest decline in productivity in 1977, a year of low rainfall. Live standing crop of *S. densiflora* decreased to minimum levels from December to April and increased to a seasonal maximum in August. Productivity estimates were approximately 2,500g dry wt/m$^2$/yr from 1976 and 1978, and 774g dry wt/m$^2$/yr for 1977.
### Comparison of Morphological Characteristics (Spicher 1984)

<table>
<thead>
<tr>
<th>Feature</th>
<th>S. foliosa (Creekside Park)</th>
<th>S. densiflora (Creekside Park)</th>
<th>S. densiflora (Mobberly description 1956)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Culms</td>
<td>To 1.5 m tall (to 2m)</td>
<td>To 1.4 m tall Indurate</td>
<td>To 1.5 m tall Indurate</td>
</tr>
<tr>
<td></td>
<td>Fleshy</td>
<td>Caespitose from knotty bases</td>
<td>Caespitose from knotty bases</td>
</tr>
<tr>
<td></td>
<td>Evenly spaced from</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>rhizomes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blades (fresh)</td>
<td>Flat to loosely involute</td>
<td>Involute</td>
<td>Involute</td>
</tr>
<tr>
<td></td>
<td>8-12 mm wide</td>
<td>6-7 mm wide</td>
<td>3-8 mm wide</td>
</tr>
<tr>
<td></td>
<td>adaxial surface</td>
<td>adaxial surface</td>
<td>adaxial surface</td>
</tr>
<tr>
<td></td>
<td>glabrous</td>
<td>glabrous</td>
<td>glabrous</td>
</tr>
<tr>
<td></td>
<td>abaxial surface</td>
<td>abaxial surface</td>
<td>abaxial surface</td>
</tr>
<tr>
<td></td>
<td>glabrous</td>
<td>glabrous</td>
<td>glabrous</td>
</tr>
<tr>
<td></td>
<td>30-50 blade ridges</td>
<td>9-10 blade ridges</td>
<td>----</td>
</tr>
<tr>
<td>Inflorescence</td>
<td>12-25 cm long</td>
<td>8-23 cm long</td>
<td>10-30 cm long</td>
</tr>
<tr>
<td></td>
<td>5-10 mm wide</td>
<td>4-8 mm wide</td>
<td></td>
</tr>
<tr>
<td>Spikes</td>
<td>4-10 in number</td>
<td>6-20 in number</td>
<td>2-15 in number</td>
</tr>
<tr>
<td></td>
<td>2-8 cm long</td>
<td>1-5.5 cm long</td>
<td>1-11 cm long</td>
</tr>
<tr>
<td>Spikelets</td>
<td>8-30 in number</td>
<td>5-27 in number</td>
<td>10-30 in number</td>
</tr>
<tr>
<td></td>
<td>8-25 mm long</td>
<td>9-12 mm long</td>
<td>8-14 mm long</td>
</tr>
</tbody>
</table>

### Control

Control methods for *Spartina* infestations need to be tailored to each site. Although there has been little effort to control *S. densiflora*, there are ongoing efforts to remove other exotic *Spartina* species on the Pacific West Coast. Valuable insights can be learned from these efforts and applied at Humboldt Bay. There are several levels of control that should be considered when deciding upon a control method (IPM Access 2001):

1. Prevention: reduce or eliminate the conditions that allow Spartina to establish.
2. Containment: Keep established population from spreading. Good for large infestations.
3. Reduction: Reduce area covered or dominance of Spartina.
4. Eradication: complete removal of Spartina from an area.

Control methods will ideally be combined in an Integrated Pest Management strategy to reach the management goals. An effective program will time the method with the natural history of the *Spartina* species, and will utilize an adaptive management approach combining monitoring with management decisions. The invasive *Spartina* species at Willapa Bay, Washington and San Francisco Bay, California, have been managed using mechanical, chemical, and biological controls. Biological control attempts to reduce the infestation and keep it at manageable levels. The *Spartina alterniflora* at Willapa Bay has been separated from its natural herbivores for about 100 years. An insect control using *Prokelisia marginata*, a plant hopper, is being researched. Physical control methods include hand removal,

**Restoration**

Tidally influenced areas in Humboldt Bay are estimated to have been 27,000 acres before habitat alteration, and now comprise 17,000 acres. In 1850, the salt marsh community was estimated to cover 7,000 acres (Humboldt Bay Working Group 1984). After completion of the railroad around the margin of the Bay ca.1920, salt marsh was reduced by approximately 90%. Currently it is estimated that only 900 acres of salt marsh remain (USFWS 2001).

Restoration is seen as a way to mitigate the loss of marshlands that are converted due to some type of development. Josselyn and Buchholz (1984) caution planners, regulators and scientists that restoration is still in the experimental phase as there is much about ecosystems that we still do not understand. With this in mind, it has been suggested that native plants used in restoration efforts should be confined to local species, as genetic difference may influence distribution patterns (Josselyn et al. 1982). Restoration goals should include maximizing diversity and the restoration of historic habitat loss (Humboldt Bay Working Group 1984). Mitigated restored salt marsh should be similar to the destroyed salt marsh to prevent loss of this type of habitat (Claycomb 1983).

Restoration projects at Humboldt Bay should consider the invasiveness of *S. densiflora*. Kittelson and Boyd (1997) found that *S. densiflora* expands both vegetatively and through sexual reproduction. Bare and disturbed areas are quickly colonized by vegetative tillers from surrounding *S. densiflora*. Seedling recruitment is possible in periods of high rainfall as the soil salinity is reduced. The rate of this process was slowed if the site contained other species. Revegetation of the site as part of the restoration process can help in reaching the restoration goals. Revegetation of experimental *S. densiflora* removal plots at Humboldt Bay National Wildlife Refuge reduced the rate of reinvasion significantly (USFWS 2001). For restoration projects in Humboldt Bay the establishment of high marsh community should be the goal when possible. This type of community contains the greatest diversity and seems to be the most resistant to Spartina invasion (USFWS 2001).

Several salt marsh restoration projects have occurred around Humboldt Bay, although the most recent was in 1986 when *S. densiflora* was barely recognized as an exotic species. Restoration projects at Park Street (Eureka Slough), Bracut (Highway 101), and Elk River mouth all consisted of the breaching of dikes to restore tidal influence. The Elk River restoration project was far enough up the estuary that brackish marsh resulted. The other two projects are summarized below.
Humboldt Bay Restoration Projects (Josselyn et al. 1982 and Barnhart et al. 1992)

<table>
<thead>
<tr>
<th>Location</th>
<th>Park Street</th>
<th>Elk River</th>
<th>Bracut</th>
<th>Second Slough</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>1979</td>
<td>1980</td>
<td>1981</td>
<td>1986</td>
</tr>
<tr>
<td>Restoration Method</td>
<td>Dike breach</td>
<td>Dike breach</td>
<td>Dike breach, revegetation, regrading</td>
<td>------</td>
</tr>
<tr>
<td>Acreage</td>
<td>9.5</td>
<td>20</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>Objectives</td>
<td>Wildlife habitat, mitigation, research, open space</td>
<td>Mitigation, research, open space</td>
<td>Mitigation, public access, wildlife habitat, research</td>
<td>------</td>
</tr>
<tr>
<td>Habitat created</td>
<td>Salt marsh</td>
<td>Mudflat, brackish marsh</td>
<td>Brackish and salt marsh</td>
<td>Salt marsh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bracut Mitigation Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Bracut mitigation “bank” was created in 1981 to offset wetland loss in the city of Eureka. A former fill site was excavated and tidal action was re-introduced through dike breaching. <em>S. densiflora</em>, thought to be the native <em>Spartina foliosa</em>, was planted in 1982. In 1987, concerns over the success of the mitigation prompted a study by Josselyn (1988), which found that limited revegetation had occurred (despite the planting) because of compacted soils. There were occurrences of the two rare salt marsh annuals, which are known to thrive in compacted soils (Newton 1986). Josselyn recommended excavation in the northern part of the marsh to improve habitat for salt marsh plants. In 1992-3 the site was excavated to remove compacted surface layers and an additional levee breech was added. In 1999, Eicher (1999) found that these modifications had resulted in increased salt marsh cover in the northern portion of the site. Currently, the site supports predominantly the <em>Spartina</em> marsh type, with lesser areas of upland or transitional brackish wetland vegetated by <em>Deschampsia caespitosa</em>, and small areas of unvegetated gravel substrate or cryptogamic mat. The marsh continues to support populations of the rare salt marsh plants (Mad River Biologists, unpublished data).</td>
</tr>
</tbody>
</table>

Southwest portion of Bracut in 1984.  
Same site vegetated with *S. densiflora* (foreground) in 2001.
**Park Street Mitigation Site**

The Park Street site was chosen as a mitigation site for the Woodley Island Marina development near Eureka. A dike was breached along the Eureka Slough, allowing tidal influence to return to what had become freshwater, agricultural wetland. The site was studied by Claycomb (1983), who documented an increase in salt marsh plant cover from 8% to 15% between 1979-1982. It was vegetated mainly by *Distichlis spicata*, *S. densiflora* and *Salicornia virginica*. *S. densiflora*’s occurrence in the study quadrats showed a frequency change from 4% to 20% over a 3-year period from 1979 to 1982. Claycomb (1983) speculated that the middle tidal marsh community (*Spartina* marsh) would eventually cover much of the mitigation area. The map illustrating his predictions (below) is similar to the actual vegetation on the site in 2002.

**Diagrams of Park Street Mitigation Site** (Claycomb 1983)

![Diagrams of Park Street Mitigation Site](image)


In 1981 and 1982 after the dike breach, *S. densiflora* occurred between 1.65- 2.26 m above MLLW, with its highest cover at mid-elevations (Claycomb 1983). Eicher (1987) found *S. densiflora* to occur in elevations between 1.8 – 2.41 m above MLLW in North Bay study sites (below).
Park Street mitigation site in 1984, shortly after the dike breach.

Same view in 2002, vegetated primarily by S. densiflora.
Conclusions

*Spartina densiflora* is currently the dominant species of Humboldt Bay’s salt marshes. Introduced in the 1800s, its pattern of spread has never been determined. Historic photographs and other data since the 1970s indicate that *Spartina* has continued to spread over the past 30 years, predominantly in high elevation salt marshes. During the past decade *S. densiflora* has become much more abundant on high elevation marshes in the Mad River Slough. Whether this represents a new period of increase or the most recent portion of a continuous rate of spread needs further study. Modeling of *S. densiflora* populations (spatial and demographic) in areas where expansion is still occurring would enable predictions of future increase. This information is vital as the marshes that are currently undergoing new invasions are the most diverse (high elevation Mixed marsh) and contain the two rare salt marsh plants.

Past salt marsh restoration projects in Humboldt Bay have mostly consisted of dike-breaching, although the Bracut restoration project included excavation of fill. The outcome of these projects, almost 20 years later, has been the establishment of primarily mid-elevation *Spartina* marsh. Future restoration projects will need to determine whether elevations are conducive to the establishment of this type of marsh. If so, issues to be considered are whether *Spartina* marsh is desirable, and if not, what prevention and control measures will be enacted.

Control efforts directed towards *S. densiflora* have been minimal in Humboldt Bay. A pilot project conducted by the U.S. Fish and Wildlife Service showed that revegetation with native plants was a crucial step following removal of *S. densiflora*. Control of other *Spartina* species has been carried out in San Francisco Bay and Washington state. Methods have
included mechanical and chemical, and a bio-control strategy is under development. Because
*S. densiflora* has even recently been spreading to new estuaries on the Pacific coast, its control
is a regional issue of great importance. Resources will need to be directed to this problem,
research conducted, and cooperation between agencies, jurisdictions, and landowners will be
 crucial.

**Annotated Bibliography and References Cited**

Aberle, B. 1990. Chronology of *Spartina* control methods in Washington, California, and
Record. University of Washington: Washington Sea Grant Program.

An Estuarine Profile. Washington, D.C.:USFWS

An ecological review of Humboldt Bay. Has chapters on biological habitats,
ecological relationships and management considerations. Contains Appendices with
plant and wildlife species lists from Humboldt Bay.

Base, L. Composition, Status, and Changes of Birds and other Wildlife on a Tidal Marsh
Restoration Site at Humboldt Bay. M.S. thesis. Humboldt State University. Arcata,
California USA. 64 pp.

Has appendices of plant species and wildlife monitored during the study. Year long
study that monitored the changes in plant species and wildlife at the restoration site
during the first year following dike breaching.


Cain, D.J. and H. T. Harvey. 1983. Evidence of salinity-induced ecophenic variation in

Callaway and Sullivan. 2001. Sustaining restored wetlands: identifying and solving

Contains drawings of tidal wetland plants invertebrates and fish common to southern
California. Discusses developing a restoration framework and applying it to physical
and biological conditions at the site. Uses examples throughout the discussions.

This chapter discusses the exportation of lumber from Humboldt Bay to other parts of the world. The focus is from the 1850’s to the 1880’s. The author mentions the lumber trade with Chile.


A transplant experiment to determine physical and chemical factors that determine lower vegetation limits in a tidal environment. Spartina densiflora showed increased photosynthetic stress with lower elevations.


Thesis quantifies vegetational changes at the Park St. wetland restoration site in Eureka. Species presence and frequency changed in the mitigation area from 1979-1981. Spartina densiflora exhibited a positive frequency change of 575%.


Discusses the expansion of the lumber industry in pacific markets. Hawaii, China, Australia and the Pacific coast of Latin America. Mentions period of exportation of lumber to Chile.


Article examines the distribution of non-native Spartina ssp. in Pacific estuaries. Authors discuss the impact of Spartina spp. on native vegetation, invertebrates, and shorebirds. Using aerial surveys and tidal range information the authors predict estuaries that are vulnerable to invasions and suggest possible protective management.


Faber, P.M. 2001. Good Intentions Gone Awry. California Coast & Ocean 16 (2).

Discusses the introduction of Spartina alterniflora and Spartina densiflora into San Francisco Bay. Both species were used in restoration projects and have since spread from original revegetation sites.


Article describes the vertical structure, above and below ground biomass of Spartina maritima and Spartina densiflora in Spain. The author found that S. densiflora has a competitive edge over S. maritima because of net primary production and vertical structure.


Applied research on use of infrared aerial photography for the differentiation of marsh vegetation types. Discusses seasonal and imagery alternatives for mapping marsh species in several areas of the United States. Suggests remote sensing can be used to answer physiological questions related to halophyte ecology.


A report summarizing the identification of mitigation needs and restoration goals for Humboldt Bay. Put together by a consortium of regulatory and resource agencies. Discusses current and historic wetlands around Humboldt Bay.


The goal of the paper is to provide a list of completed wetland restoration projects in California and provide bibliographic data. Only considered projects that involved the complete or partial establishment of tidal waters to establish native vegetation and wildlife habitat. Includes projects at Humboldt Bay.


Discusses the introduction of *Spartina densiflora* into San Francisco Bay. Includes a study of its ecology. Examines three restoration projects in Marin County. Includes erosion/sedimentation, revegetation, and wildlife restoration issues.


Report on a study to access the physical and biological characteristics of the Bracut wetland mitigation bank. Examines the use of the restored area by invertebrate and bird species.


Study examines the rate of expansion of Spartina densiflora in areas with competitors compared to areas without. Quantifies salinity tolerances of seeds, seedlings, and vegetative tillers in a greenhouse experiment.


This book examines the ecology of Halophytes. One of the chapters lists and discusses the Beach and salt marsh vegetation of the North American Pacific coast. Several chapters focus on ecological and research aspects related to Spartina ssp. mainly on the east coast of the United States.

Dissertation that examines the variability within the genus *Spartina*. The author’s purpose was to develop keys to the taxa, determine geographic variability and gather information that supports the hybrid origin for several species. Mobberly discusses *S. densiflora*’s distribution and concludes that the Spartina species in Humboldt Bay is foliosa.


This report discusses Humboldt Bay’s importance as a coastal estuary for wildlife. It inventories coastal wetlands. One of its objectives is to guide citizens, administrators, and planners in coastal development.


Has an extensive *Spartina* bibliography.


Thesis that examines the tissues of *Spartina densiflora* and *Salicornia virginica* to determine the role of nutrients and elements in their distribution on Indian Island marsh, Humboldt Bay, California. Study demonstrates the influence phosphorus has on *Spartina* distribution and abundance. Author states that nutrient levels should be considered in restoration design.


Examines ecological adaptations of *Spartina densiflora* in the various habitats it has invaded in the Odiel marsh, Spain. Results indicate *S. densiflora* has a high tolerance to a variety of environmental conditions, intense occupation of above and below ground space, and the ability to sexually reproduce.

Article relates the history of *Spartina alterniflora* introduction into San Francisco Bay. Discusses the advent of The Invasive Spartina Project and its purpose of educating the public and controlling Spartina in San Francisco Bay. Mentions control methods used at Cogswell marsh, hand pulling, black plastic, burning, and rodeo.


Abstracts from discussions on Spartina. Includes international aspects, *Spartina* ecology, impacts on native habitat, public activism, and control techniques. The discussion on priorities for research, monitoring, and management include; monitoring the spread and impact of *Spartina* and its control and mapping of current and future Spartina populations


A senior project in the Department of Environmental Resources Engineering at Humboldt State University. Contains a literature review on wetlands including tidal wetland development. Discusses tidal marsh restoration goals with local examples.


In this 3-year study, Rogers finds *Spartina densiflora* to have the highest primary productivity in the salt marsh community. One year had low rainfall and *Spartina* was found to be the most impacted.


Discusses the 5 species of *Spartina* in northern California. Contains tables of morphological characteristics. *Spartina densiflora*’s introduction to San Francisco Bay is reviewed.


Presentation from a symposium examining resource issues in Humboldt Bay. The author discusses the number and type of animal species that occur at the bay. Separated into habitat types and variety of uses by species. Includes salt marsh habitat.


Discusses monitoring done at the Park Street mitigation site, Humboldt Bay, 1 ½ years after introducing tidal flows. Report analyzes the restoration effects on plant and wildlife in the site. Contains appendices with monitored species names.
