# Alaska *Spartina* Prevention, Detection and Response Plan

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## Executive Summary

Four introduced, invasive species of *Spartina*, commonly called cordgrasses, have been present in estuarine areas of the U.S. west coast for over a century. Recently, a robust hybrid cordgrass (*S. foliosa* x *alterniflora*) formed in San Francisco Bay that is even more invasive than the introduced species. *Spartina* has not been documented in Alaska, but dispersal studies and northerly spread along the coast suggests that one or more *Spartina* species could spread from existing infestations and become established in highly valued Alaska estuaries. *Spartina* species are "ecological engineers" that are capable of causing severe alterations in hydrology and food webs that are detrimental to native wildlife, as well as commercial, subsistence and recreational uses of estuaries and the fisheries they support.

This Alaska *Spartina* Prevention and Response Plan reviews the known impacts, biology, and invasion history of *Spartina* on the west coast. It outlines strategies for prevention, early detection and efficient organization of rapid response efforts following the confirmation of an infestation. The goal of the plan is to prevent the establishment of any *Spartina* populations and to eradicate established infestations if detected within the State's estuaries or coastal wetlands. Five objectives and strategies are described and 31 specific tasks are outlined to achieve this goal. These include:

- Prevention of establishment through vector and source population control.
- Plan coordination by establishing clear procedures, authorities, and responsibilities for action, and a framework for implementation of the Plan.
- Monitoring to ensure early detection of small infestations that are most easily eradicated.
- Education and outreach to ensure that the public understands the threat of *Spartina* to Alaska's natural resources and to recruit citizen and agency personnel in surveillance.
- Research to increase understanding of vectors of introduction, susceptible habitat, and management to enhance efficacy of prevention, detection, and control.

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## Glossary of Terms

**Adjuvant –** An additive that enhances the effectiveness of the primary chemical (such as surfactants, extenders, penetrants, spreaders, stickers) or to modify the characteristics of the tank mix (e.g. acidifiers, defoaming agents, drift control agents).

**AKEPIC –** Alaska Exotic Plants Information Clearinghouse is a cooperative project between the United States Forest Service, the National Park Service, Bureau of Land Management, Alaska Natural Heritage Program and the United States Geologic Survey in support of the Alaska Committee for Noxious and Invasive Plants Management (CNIPM) and the Strategic Plan for Noxious and Invasive Plants Management in Alaska. The website and database of non-native plants is maintained by the Alaska Natural Heritage Program.

**Cespitose –** Growth form where culms and basal leaves of an individual plant arise from the same, relatively small root crown; plants are sometimes referred to as tufted or clumped.

**Clone –** All descendents of a single plant, produced by vegetative (sometimes called "clonal") growth and/or fragmentation.

**Cumacean –** Small, benthic marine crustaceans, common in muddy and sandy sediments with most inhabiting sediment surface layers and presumed to be deposit feeders, and others that are tube building filter feeders or micropredators.

**El Niño-Southern Oscillation (ENSO) –** Commonly called El Niño; a periodic change in the atmosphere and ocean of the tropical Pacific region; the warm phase is El Niño while the cool phase is La Niña.

**Gross acres –** area encompassed by lines connecting the outlying plants infested area

**Guerrilla growth strategy –** Pattern of vegetative growth where rhizomes and/or stolons are relatively long and often short-lived. Shoots of each clone are widely spaced and advance somewhat haphazardly into varying directions, like a guerilla army.

**Monospecific –** one species growing in large patches or areas with no or very little competition from other plant species

**Net acres –** area occupied if all plants in the infested area were a monoculture in one patch

**Pacific Coast Collaborative –** A cooperative group comprised of leaders from Alaska, British Columbia, Washington, Oregon, and California; this collaboration formed the Pacific Coast Collaborative Agreement which focuses on cooperative action, leadership, and information sharing. The Pacific Coast Collaborative has five priorities (clean energy, energy management, regional transportation, research, and innovation, and sustainable regional economies), but does not currently focus on invasive species such as *Spartina*. (www.pacificcoastcollaborative.org)

**Pacify Flyway –** A major north-south migratory route for birds between Alaska, British Columbia, West Coast states (west of the Continental Divide), and south as far as Patagonia in South America.

**Phalanx growth strategy –** Pattern of vegetative growth where rhizomes and/or stolons are relatively short and often long-lived. Shoots of each clone are closely spaced and advance along a densely packed front, like a Roman phalanx. Contrast with guerrilla growth strategy.

**Relative sea level rise (RSLR) –** The combination of eustatic sea-level (the absolute elevation of the earth's ocean) with regional variations due to subsidence, glacial rebound, tectonic uplift, and other factors. RSLR usually differs from the global average sea level rise.

**Rhizomatous –** Having rhizomes

**Rhizome –** A horizontal underground stem, often with roots at the nodes; a mode of vegetative reproduction

**Scutellum –** Structure within a seed; a band of tissue which acts as an absorbing organ; found between the embryonic shoot and the endosperm.

**Surfactant –** a type of adjuvant; a wetting agent which lowers surface tension of a liquid, allowing easier spreading

**Tiller** - A vegetative shoot, especially one that sprouts from the base of a grass

**West Coast Governors Agreement On Ocean Health –** A regional collaboration between Washington, Oregon, and California focused on protection and management of ocean and coastal resources along the entire West Coast; the finalized Action Plan calls for the eradication of *Spartina* from the entire West Coast by 2018. (http://westcoastoceans.gov/action)

## Introduction

The cordgrasses of the Poaceae family, so called because they were used to make cord (Greek sparte = cord or rope), are in the genus *Spartina* and include 17 species that are indigenous to North, Central, and South America, Europe, and North Africa (Mobberley 1956). Most species of *Spartina* are found growing in estuarine areas on saline substrates; however, a few are native to inland areas and tolerate alkaline substrates (e.g., *S. gracilis, S. pectinata*). Four species of *Spartina* have been introduced to, and are invasive species in estuaries on the west coast of North America. This management plan provides an outline of tasks needed to prevent introduction of *Spartina* to Alaska, detect new infestations and respond rapidly to all *Spartina* populations. It also includes tasks for outreach, education, coordination, and research.

### *Spartina* growth habit

*Spartina* species are robust, perennial grasses with stout, upright, densely spaced stems and thick mats of roots and rhizomes. Vegetative spread by rhizomes can rapidly expand the area covered by a clone. Clones of *Spartina alterniflora* and *S. patens* often form circular patches of vegetation, spreading radially by vegetative means; large clones of these species are readily seen from the air. In some locations, *S. alterniflora* has formed monospecific swards that have transformed open tidal mudflats into high, salt marsh meadows. These cordgrasses are highly effective at securing resources, often exhibiting both phalanx and guerilla growth strategies (Bortolus 2006, Nieva et al. 2005,

**_Spartina_ Profiles**

See Appendix A for drawings and detailed descriptions.

***S. alterniflora*** - Grows in dense, monospecific stands, though isolated small plants are clumpy and may appear cespitose. Inhabits intertidal mud flats and, in the Pacific NW, low and high salt marshes. Species introduced from eastern coast of North America.

***S. anglica*** - Forms dense monospecific stands; isolated small plants are clumpy and may appear cespitose . Tolerates a range of substrates, from tidal mud flats to sand and cobbled flats; inhabits flats and low salt marsh. Fertile offspring of a hybrid of the English *S. maritima* with *S. alterniflora*; introduced world-wide for shoreline stabilization and/or cattle forage.

***S. alterniflora x foliosa*** – Extremely difficult to distinguish from *S. alterniflora* in the field (may require DNA analysis); more variable in height, pollen and seed production and tolerance to tidal inundation than either parent species.

***S. densiflora*** - Distinguished by its cespitose growth habit. Inhabits mid-to- high salt marshes. Known to grow in mud or sand flats as well as rocky shores, and cobble beaches. Introduced from South America.

***S. densiflora x foliosa*** – Recently recognized diploid hybrid known only in limited area of San Francisco Bay. Unlikely to spread/persist due to low seed production and local eradication efforts.

***S. patens*** - Dense, matted perennial forming monospecific stands; restricted to upper salt marsh. Introduced from eastern coast of North America.

Proffitt et al. 2003). *S. densiflora* can grow in the same habitat as tufted hairgrass, (*Deschampsia cespitosa)* complicating detection from aircraft and boats. *Spartina patens* is particularly difficult to detect amongst native salt marsh vegetation and small clones are thought capable of setting viable seed in both Oregon and Washington (Milne 2007, V. Morgan pers. obs.).

*S. alterniflora* exhibits three distinct growth forms in its native east coast habitat: tall, medium, and short. The tall form (4-10 ft) typically grows on the banks of tidal channels, the medium form (2-4 ft) is found on levees, and the short form (≤ 1 ft) is found at higher elevations with high soil salinities (Adams 1963; Mooring, Cooper et al. 1971, Biber and Caldwell 2008). These growth forms are environmentally induced, with nitrogen availability, interstitial salinity and oxidation potential of the soil all as possible factors (Howes et al. 1996).

## *Spartina* anatomy and physiology

Anatomical and biochemical adaptations permit *Spartina* species to thrive in estuarine habitats on the west coast and to sometimes exclude native species. *Spartina* stems contain aerenchyma tissue that provides structural support with minimal metabolic load and allow oxygen transport to roots, which is critical to survival in anoxic sediments (Maricle and Lee 2002). *Spartina* species also possess salt glands on their leaves that excrete excess salt to maintain cellular ionic balance (Seneca 1972; Rozema et al. 1981). *Spartina* also uses the C-4 pathway of carbon fixation, which is more efficient at fixing $CO_2$ than the C-3 pathway in some environments (Thompson 1991).

*Spartina anglica* and *S. alterniflora*, often considered the most aggressive species of *Spartina* on the west coast, differ in their tolerance to flooding and anoxic substrates and, consequently, in their potential to invade different parts of the intertidal habitat. *S. anglica* is more efficient at transporting atmospheric oxygen to its roots than *S. alterniflora* (Mendelssohn, McKee et al. 1981; Maricle and Lee 2002). This could account for the greater success of *S. anglica* in colonizing the lower elevations of the intertidal zone. Accelerating rates of relative sea level rise (RSLR), combined with sediment supply, tidal ranges and primary productivity, may alter salt marsh habitat for *S. alterniflora* and other *Spartina* spp. as well (Morris et al. 2002, Chen et al. 2008). In areas with high sediment loads, *Spartina* may be able to accrete enough sediment to reach equilibrium with RSLR, but this will depend on site specific characteristics (Morris et al. 2002). Small differences in tidal heights – just a few centimeters – can determine if *Spartina* invaded mudflats in the San Francisco Bay will transition to high marshes, revert to open mud flats or be colonized by eelgrass (Williams and Grosholz 2008). Sea level rise has been proposed as an aid to control of invasive species like *Phragmites australis* and *Lythrum salicaria* on the east coast of the U.S. where these species have displaced *S. alterniflora*; because they are less tolerant of inundation and anoxic soil conditions compared to *Spartina*, they may lose their present competitive edge (Hellman et al. 2008).

### *Spartina* reproduction

*Spartina* reproduces sexually and vegetatively. Plants may flower, under optimal conditions, in just three to four months (Smart 1982, referenced in Biber and Caldwell 2008). The *Spartina* inflorescence is a congested spike bearing single-flowered spikelets. Each flower can produce a single seed (an achene). Individual flowers are protogynous (stigmas mature before stamens), although there is overlap in female and male function within an inflorescence since flowers at the bottom can have mature stamens while flowers at the top have only mature stigmas. Thus, self-fertilization is possible. Pollination experiments with *S. alterniflora* have shown that self-pollinated flowers have lower seed set than outcrossed flowers. In addition, seeds resulting from self pollination did not germinate (Daehler and Strong 1994). Factors influencing reproductive success in *Spartina* include location of the clone in the intertidal and inbreeding depression, especially in populations resulting from very small numbers of founder plants. The San Francisco Bay and Willapa Bay populations consist of mixtures of highly fertile clones and virtually sterile clones (Daehler and Strong 1994). An Allee effect - when populations grow more slowly at low densities - has been demonstrated in Willapa Bay and may explain the wide range in seed production as well as the lag phase in the invasions; isolated plants produced $<1/10^{th}$ the seed produced in coalesced meadows (Davis et al. 2004a). Pollen limitation in areas with small isolated plants is a major factor driving this Allee effect, which initially slowed the rate of spread of the invasion in Willapa Bay (Davis et al. 2004b).

Vegetative rates of expansion have been estimated for *S. patens* ranging from 17.78 and 22.86 cm/year (Milne 2007. Growing in unvegetated mudflats, *S. alterniflora* may expand at nearly four times that rate (79.3 cm/year) (Feist and Simenstad 2000). *S. densiflora* in Humboldt Bay was measured to expand at rates of -6 to 26 cm/year when growing amongst other vegetation, and at 5 to 56 cm/year when growing in mudflats with no competition (Kittleson and Boyd

1997). Similar expansion rates (18-26 cm/year) have been noted in European infestations of *S. densiflora* (Nieva et al. 2005).

*Spartina* seeds require a 3-4 month period of cool, wet storage in order to germinate (Mooring et al. 1971; Broome et al. 1974; Seneca 1974) Stratification of seeds appears to require a minimum of 4-8 weeks at 4° C in wet storage; storage for greater than four months greatly reduces germination rates and seedling survival (Biber and Caldwell 2008). Plyler and Carrick (1993) showed that dormancy can be broken by surgically damaging the scutellum of the embryo and restored by treating altered seeds with abscisic acid. Thus, it is likely that autumn seed dispersal into the waters of the marsh, followed by their residence there throughout the winter, leaches a germination inhibitor out of the scutellum.

*Spartina* seeds can germinate in substrate salinities as high as 40 ppt (seawater is 35 ppt), although germination rates are highest at lower salinities (Seneca 1972; Shumway and Bertness 1992; Wijte and Gallagher 1996, Kittelson and Boyd 1997). Wijte and Gallagher (1996) also found that *Spartina* seeds would germinate at oxygen concentrations as low as 2.5 percent. Interestingly, seedling shoot emergence was faster at lower oxygen concentrations and root emergence was slower, possibly allowing the shoot to provide oxygen from the atmosphere to the root. High soil salinities may develop in salt marshes later in the growing season as evapotranspiration depletes interstitial soil water. Thus, seeds germinate in the spring after winter rains have replenished soil moisture and diluted soil salt concentrations. The biomass of germinated seedlings is also affected by soil salinity; 50 percent reduction in total biomass was observed at salinities of 19.2 ppt or higher (Lewis and Weber 2002).

Vegetative reproduction occurs by production of new tillers from underground rhizomes. Tillers may remain attached to the parent plant or can survive and thrive if detached. Rototilling as a means of control can result in dispersal by rhizome fragments. Rototilling produced an average of 310 fragments per $m^2$ within the top 10 cm of sediment and 87% of these still had vegetative shoots attached. Fragments as small as 2.5 cm in length had high survival rates when vegetative fragments were still attached and raised in 0-15 ppt water (Figure 1). Survival was considerably lessened across all treatments for those fragments exposed to ocean-strength (35 ppt) water. Fragments without attached vegetative stems showed 100% mortality across all treatment levels of size, salinity, and floating duration before planting (Greenfield 2005).

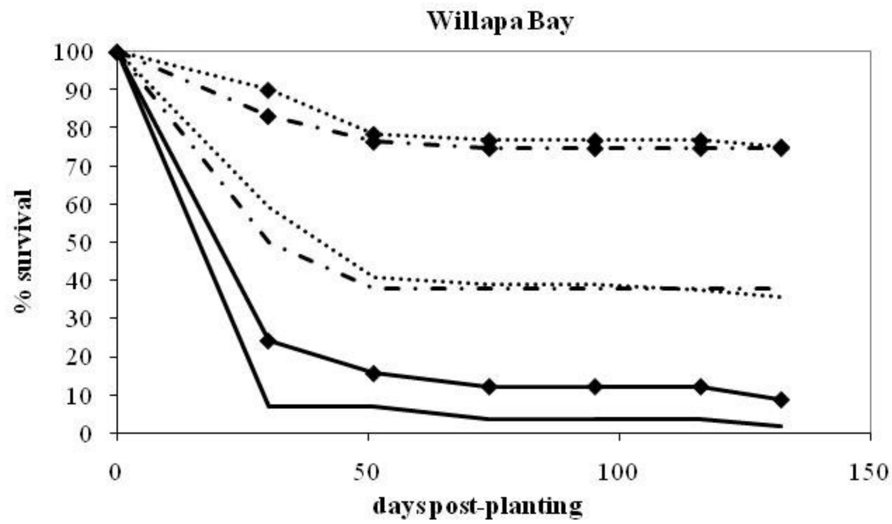


Figure 1. *S. alterniflora* rhizome fragment survival over time for Willapa Bay plants. Treatment groups are noted by salinity (•••••••• 0 ppt, — • — • — 15 ppt, and —— 35 ppt), and rhizome size (plain line = small, ◆= large) (Greenfield et al. 2005)

## *Spartina* dispersal

### *Natural dispersal*

Experiments have demonstrated that *Spartina* plants and plant pieces float in salt water for at least two months (Sayce et al. 1997). During fall and winter *Spartina* stems break off to form large, floating mats of wrack. The near-shore ocean currents flow predominately northward along the Oregon and Washington coasts in fall and winter (the wet season) when moisture laden storms with southerly winds move onshore. When high pressure moves in over these areas, northwesterly winds push the currents south along the coastline. Thus, northerly currents typically predominate in the wet season, but southerly currents regularly occur for some portion of each season (Hickey 1998). The early to mid-fall period is of particular concern because it is at this time that significant amounts of *Spartina* wrack bearing mature seeds leave Willapa Bay and move into the near-shore ocean. *Spartina* wrack has been found repeatedly on ocean beaches in Washington, Oregon, and California and large wrack rafts have been reported by commercial fisherman many miles off the Washington coastline (F. Grevstad and J. Graves, pers. comm. 2003; V. Howard pers. obs.).

Long-distance, nonhuman dispersal of *Spartina* spp. occurs via transport of seeds on currents and tides. Huiskes et al. (1995) collected seeds of *S. anglica* in floating and standing nets in a tidal salt marsh in the Netherlands. Eighty-eight percent of the seeds collected were captured in floating nets, indicating that tidal transport of seed was primarily on the water surface rather than along the sediment. In an earlier study in the same location, Koutsaal et al. (1987) released dyed sunflower seeds on outgoing and incoming tides to track tidal movement of seeds in the salt marsh. Seeds were found as much as 45 km away within one week of release. The final location of seeds was determined by the wind velocity and direction as well as by tidal currents.

Long distance ocean transport of *Spartina* is especially likely during El Niño years when increased current velocities often coincide with earlier onset of the northward, winter current flow. Numerous species normally found much further south, in California, were found in Washington waters in 1982-83 (Schoener and Fluharty 1984). During the 1997-1998 El Niño event, surface current speeds of 0.89 - 1.3 mi/hr were measured offshore of the west coast of the U.S. (Huyer et al. 1998; Kosro et al. 1998). At this speed, water borne *Spartina* seeds could travel the ~ 700 nautical miles from Willapa Bay, Washington north to Baranof Island, Alaska in one month. Strong El Niño Southern Oscillation (ENSO) events appear to have facilitated the colonization and persistence of the invasive green crab (*Carcinus maenas*) in Oregon, Washington, and British Columbia (Behrens Yamada and Hunt 2000, Behrens Yamada 2001, Behrens Yamada and Gillespie 2008) and may have transported *Spartina* seed as well.

The *Spartina* Dispersal Study used drift cards to assess the relative risk posed by existing major infestations to susceptible habitat along the west coast. Buoyant drift cards, coded for location and date of release, were dispersed monthly for one year (September 2004 – August 2005) from three locations: Willapa Bay, Washington and Humboldt and San Francisco Bays in California (Figure 2a). Rapid northward transport during the fall and winter releases was seen repeatedly from Humboldt Bay and Willapa Bay, with maximum estimated northward velocities reaching 24.5 and 36.8 km/day respectively (Figure 2b & 2c). Transport southward from Willapa coincided with spring releases and recoveries occurred frequently along the Oregon coast. Transport from San Francisco (Figure 2d) was notably less than from the other two release locations and maximum northward estimated velocities of 16 km/day (Morgan, unpublished data). These results, when paired with the timing of seed ripening, indicate Oregon, Washington, British Columbia, and possibly Alaska may be at increased risk for *S. densiflora* spreading from Humboldt Bay. Additionally, Alaska and British Columbia have almost certainly been receiving *S. alterniflora* seeds yearly for at least the last 20 years – when the infestation in Willapa Bay

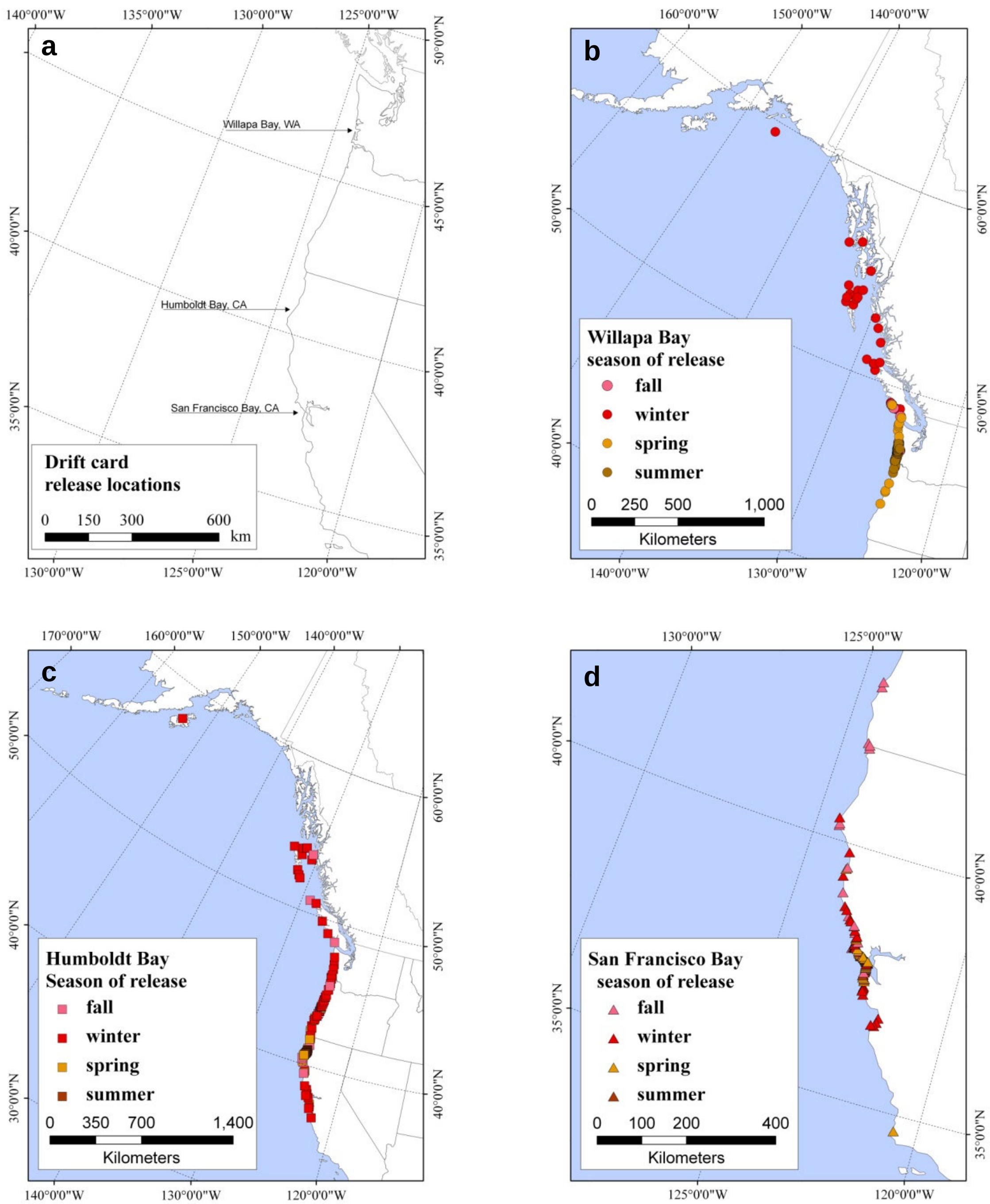


Figure 2. Locations of drift card release sites (a) and distribution ranges, grouped by season of release, for recovered drift cards from Willapa Bay, WA (b), Humboldt Bay, CA (c), and San Francisco Bay, CA (d). Fall releases performed Sept-Nov. 2004; winter releases performed in Dec. 2004 – Feb. 2005, spring releases performed March-May 2005 and summer releases performed June-Aug. 2005. (V. Morgan, unpublished data).

started to rapidly expand. Dispersal of *S. foliosa* x *alterniflora* from San Francisco appears less likely, but any satellite populations northward on the coast could allow a series of short-distance dispersal and establishment events to carry this aggressive hybrid further north. Detailed discussions of landings in British Columbia and Alaska are discussed in the section on Potential spread to Alaska.

Birds may also be an important natural dispersal mechanism for *Spartina*. Vivian-Smith and Stiles (1994) collected, identified, and counted seeds from the feathers and feet of waterfowl from a New Jersey salt marsh. While seeds of 11 plant taxa were identified, 30 percent of the total number of seeds were *S. alterniflora*. The study did not determine the origin of the seeds, i.e., whether from within the same marsh or a distant one, but it did demonstrate that birds can be a vector for *Spartina* dispersal. The large number of migrating waterfowl that move between the heavily infested south end of Willapa Bay to feeding grounds in the Columbia River estuary are one possible pathway for the clone of *S. alterniflora* that has been found in that system. Birds cannot be ruled out as possible vectors of transport of viable *Spartina* seeds between infested and uninfested estuaries.

### *Human-mediated dispersal*

Humans were responsible for the initial intentional or accidental introduction of non-native *Spartina* species to the estuaries of the west coast, as well as worldwide. The likelihood of intentional introductions has waned in recent decades with the recognition of negative impacts and costs associated with bioinvasions, but accidental transport of *Spartina* is still possible. Ship ballast and fouling of ship hulls have been the vectors of invasion for numerous marine organisms (Cohen 1997; Carlton 2001). The floating seeds of *Spartina* - dispersed by the tides and carried to the open ocean - are likely to come into physical contact with ship hulls and rigging, or entrained in solid ballast used by dredges for stability when moving from estuary to estuary. *Spartina* seeds require a 3-4 month period of cool, wet storage in order to germinate (Mooring et al. 1971; Broome et al. 1974; Seneca 1974), so it is likely that some of the seeds present on or in ships, barges, and dredges could remain viable and germinate successfully at estuarine sites of discharge. While modern anti-fouling paints and fouling release coatings reduce the accumulation of fouling, fouling organisms are still capable of settling on protected hulls especially as the treatments age and degrade. Thus, while this vector may not be as strong (relative to current vectors) as it was in the 19th century, it is still a possible pathway for *Spartina* seeds and other invasive species like *Carcinus*. Transport in ballast water is not a likely pathway for *Spartina* since, in over five years of ballast water sampling on the west coast, no seeds of *Spartina*, nor other vascular plants, have been found (J. Cordell, pers. comm. 2006).

U.S. Department of Defense vessels, such as those belonging to U.S. Army Corps of Engineers (USACE), operate regularly between water bodies on the west coast of the United States. Only one, the Yaquina, uses solid ballast. The other dredge, the Essayon, as well as dredge vessels under contract to USACE, use water as ballast. (S. Carrubba, USACE, pers. comm.) Current practice is to unload dredge spoils at Environmental Protection Agency (EPA) designated ocean disposal sites before entering another bay. Continuous jetting (pumping ocean water through the dredge hopper to rinse off sediment during the unloading process), can be easily done and could provide an additional measure of protection from accidental transport of *Spartina* seeds.

Accidental introduction of *Spartina* seeds is possible via transport of live shellfish between estuaries. Because oysters cannot spawn in the cold waters of Alaska, spat must be imported to supply local growers. Permits for transporting marine shellfish are issued by the mariculture coordinator of ADF&G's Division of Commercial Fisheries and spat must be from certified seed sources. The current list of seed sources includes many in-state hatcheries, but also two in Washington and one in Oregon. Imports from out-of-state will probably remain important to this industry until the financial stability of in-state hatcheries is more certain. Restrictions and prohibitions of transport permits have been focused primarily on preventing spread of pathogens like Vibrio bacteria (*Vibrio tubiashii*) as well as green crabs and oyster drills. Precautions taken for these species, and the fact that oyster seed is almost never transported in the fall when seeds are shed (Sue Cudd, pers. comm. 2003), may mitigate the risk of *Spartina* introduction via this pathway.

### Species distribution over marsh elevation gradient

The mixed semi-diurnal tidal patterns of the west coast of North America result in the presence of *Spartina* at lower and higher intertidal positions than are typical of infestations in other parts of the world. *S. alterniflora* has the broadest ecological amplitude and can inhabit the entire elevation gradient (Figure 3). *S. anglica* colonizes the lower intertidal while *S. densiflora* and *S. patens* are found in the mid to high salt marsh.

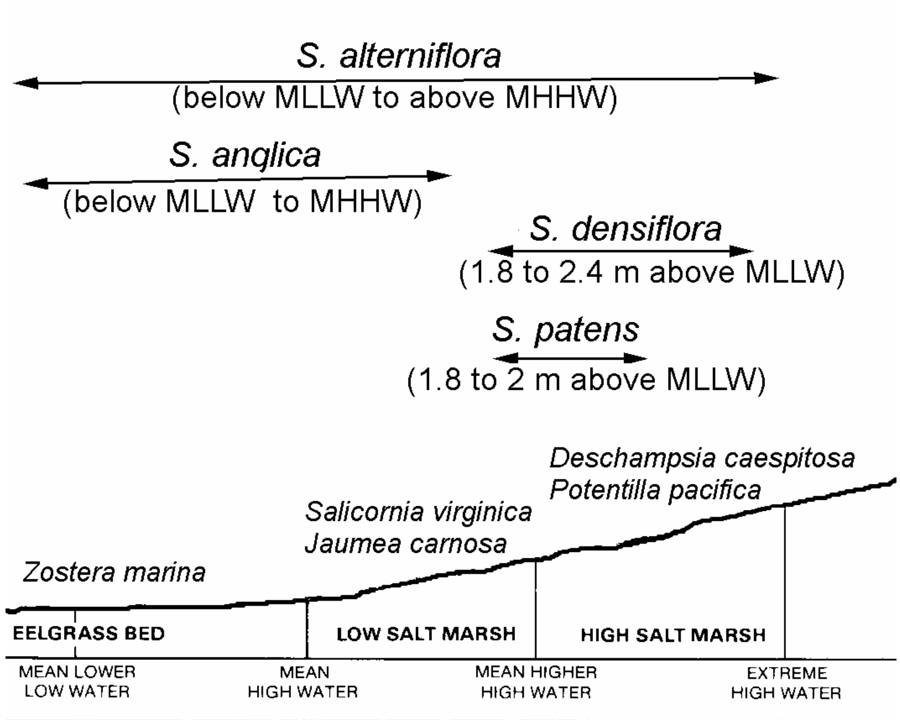


Figure 3. Distribution of exotic *Spartina* species in west coast estuaries. Dominant, native plant species are listed above each zone.

## ***Spartina* impacts**

*Spartina* infestations in Alaska could have ecological, economic, recreational, cultural, and social impacts. Sizable infestations could negatively impact numerous native species, some of which are vital to thriving commercial and recreational fisheries and aquaculture.

### Ecological impacts

Several species and one hybrid of cordgrass (*Spartina alterniflora*, *Spartina anglica*, *Spartina densiflora*, *Spartina patens*, *Spartina foliosa* x *alterniflora*) are exotic estuarine invasive plants in Europe, Asia, Australia, New Zealand, and along the west coast of North America. *Spartina* species are ecological engineers – they spread rapidly by both seeds and rhizomes and form dense monocultures that can disrupt the hydrology and ecology of infested estuaries (Baye 2004, Levin et al. 2006, Lambrinos and Bando 2008)

*Spartina alterniflora* and *S. anglica* were intentionally introduced into coastal wetlands for erosion control because their dense stems and thick mat of roots and rhizomes are very effective at filtering and trapping sediment particles brought in by river and tidal currents. Sediment trapping results in increased elevation of intertidal lands (Figure 4). One year of sediment accumulation data at Willapa Bay, Washington showed an average elevation increase of 1 cm /yr (Sayce 1988). In England, marsh elevations rose at rates ranging from 2 to 6 cm per year over 50 years due to *Spartina* infestations (Ranwell 1964). Thompson et al. (1991) showed *Spartina*-related sediment accumulation ranged from 0.2 to 10 cm per year in infested European areas (in Lacambra et al. 2004). Increased elevation of intertidal lands alters the hydrology and tidal flow within estuaries and alters the oxygen balance within the sediments (Howes and Teal 1994). In addition to marked, intertidal elevation changes, the densely spaced stems of *Spartina* reduce the amount of light reaching the underlying sediments (Neira et al. 2005). In San Francisco, the hybrid cordgrass (*S. foliosa* x *alterniflora*) has invaded thousands of acres and caused a major trophic shift from an algae-based food web to a detrital one (Levin et al. 2006).

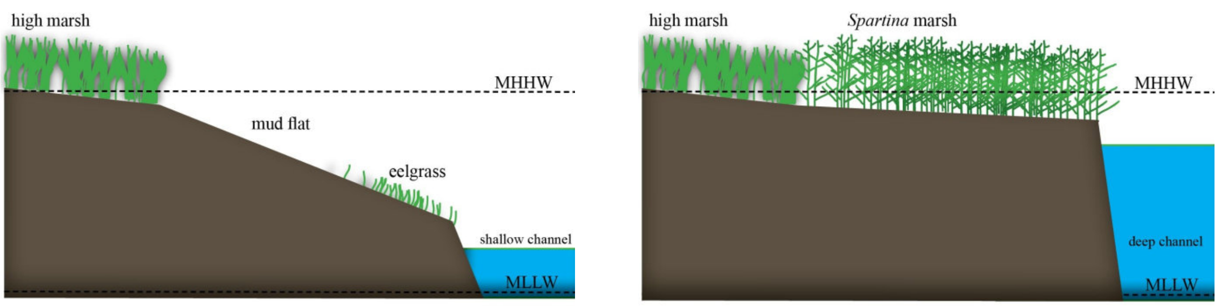


Figure 4. *Spartina* invasion of mudflats results in sediment accretion, an increase in elevation, and alteration of estuarine hydrology.

Resident and migratory shore birds forage on the unvegetated, intertidal mudflats typical of west coast estuaries. Foraging habitat for these birds is lost when *Spartina* invades and alters the ecosystem. For example, dunlin are common shorebirds of North America and Europe that feed on organisms living in the sediments of intertidal mudflats. A drastic decline in dunlin abundance in south Willapa Bay, Washington between 1995 and 2001 (Table 1) coincided with a precipitous increase in *Spartina* coverage (Figure 5). Goss-Custard and Moser (1988) showed similar trends in Britain, with the greatest decline in shore bird numbers in estuaries with the greatest increase in *Spartina* coverage. In the San Francisco Bay, spread models suggest that as much as 54% of the productive south bay area could become infested with *Spartina*, resulting in habitat loss scenarios, based on inundation tolerance and mudflat habitat values, ranging from 9 to 80% (Stralberg et al. 2004). Impacts of *Spartina* on trophic relationships are likely to alter diversity and/or abundance of benthic organisms that serve as food to threatened or endangered species such as Steller's eider (*Polysticta steller*i; threatened) or other species of cultural importance.

Recent work from Willapa Bay compares bird use in *Spartina* meadows, herbicide treated plots, tilled plots, and bare mudflats, and suggests dramatic increases of shorebird use within a few years of treatment in areas cleared of *Spartina* (Patten and O'Casey 2007). Kachemak Bay and the Copper River delta are critically important for shorebird habitat; over 1.1 million birds, including Western Sandpipers and Dunlin, are estimated to use the Copper River delta at peak spring migration (WHSRN 2009). Food found in these vital mudflats sustains birds during their annual migration and could be diminished by monotype growths of *Spartina*.

Table 1: Numbers of dunlin at south Willapa Bay, Washington (C. Stenvall, U.S. Fish and Wildlife Service, unpublished data).

| | **1995** | **2000** | **2001** |
|---|---|---|---|
| Spring peak | 54,500 | 29,000 | |
| Non - peak | 27,300 | | 8,500 |

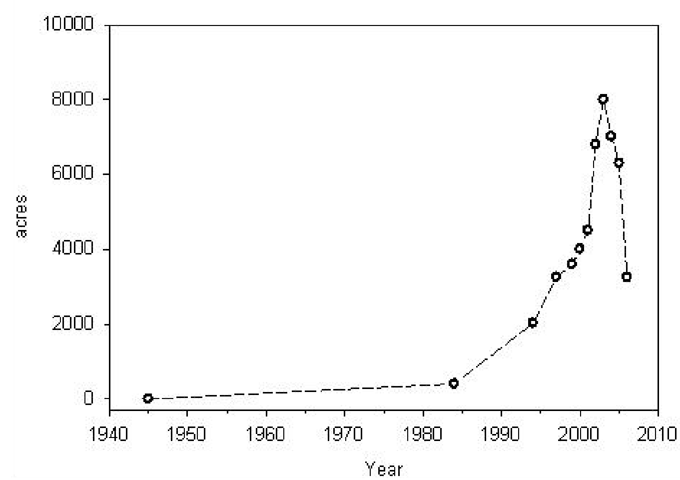


Figure 5. Estimated solid acres of *S. alterniflora* in Willapa Bay, Washington between 1945-2009.

*Spartina* growth is also detrimental to eelgrass *(Zostera marina*), a key species in the food chain of intertidal ecosystems. Eelgrass beds are an integral component of primary production, while also functioning as nurseries, feeding grounds, and refuges from predation for large numbers of small and juvenile invertebrates, such as juvenile Dungeness crab (Stevens and

Armstrong 1984, McMillan et al. 1995, Dean et al. 1998). Eelgrass beds provide forage for American wigeon, northern pintail and brant (Moore and Short 2006). Brant, in particular, are heavily dependent on eelgrass, which is their preferred forage (Wyllie-Echeverria and Ackerman 2003). As *Spartina* clones spread vegetatively, increasing stem density reduces the amount of light reaching the sediment surface. Eelgrass is able to persist under open canopy conditions (widely spaced seedlings and within *Spartina* clones having very low shoot densities i.e., <10 stems/$m^2$), but is shaded out as clones mature into dense meadows (K. Sayce, pers. comm.). The sediment filtered and retained by *Spartina* ultimately has a channelization effect on the intertidal area (Lambrinos and Bando 2008). In developing *Spartina* infestations, the velocity of water running through channels within openings between patches increases. Current velocity has profound influence on the structure of eelgrass beds as well as the distribution of organisms inhabiting the beds. Eelgrass beds tolerate maximum currents of 2.7 to 3.3 m/hr; at higher current velocities sediments are subject to erosion and scouring (Fonseca et al. 1983). Ultimately, the increased elevation of the intertidal lands caused by *Spartina* will destroy eelgrass habitat and lead to subsequent decline in species that depend upon eelgrass, such as migratory waterfowl and invertebrates.

In China's Yangtze River estuary, *S. alterniflora* has displaced native plants in areas of early salt marsh succession; has had significant impact on numerous bird species; and altered trophic structure of nematode communities and macrobenthic invertebrates (Li et al. 2009). Zhous et al. (2009) found significantly lower diversity in *S. alterniflora* patches compared to mud flats in the Jiangsu coastland and evidence that native macrobenthic organisms were being displaced into lower reaches of the intertidal. Certain effects, such as shoreline stabilization, wave attenuation, nutrient and pollutant absorption, and potential as a biofuel are still considered by some in China as positive effects (Wan et al. 2009).

Because *Spartina* alters the habitat so drastically, it may facilitate invasion by other invasive species. The non-native green crab (*Carcinus maenas*), a more recent invader of west coast estuaries, is an aggressive predator of oysters, clams, and other shellfish as well as native crab species. Studies suggest that green crabs are more abundant in areas where *Spartina* is present (Carr & Dumbauld 2000). Green crabs have been collected on the edges of native salt marshes and in *Spartina* meadows in Washington estuaries, including Willapa Bay and Grays Harbor

(Behrens Yamada 2005). Carbon from *Spartina* has been found in tissue of an introduced cumacean (*Nippoleucon hinumnensis*) in Washington State (Wonham and Carlton 2005).

## Economic impacts

Certain direct economic impacts can be estimated, but others that are indirect, such as the effect of the loss of eelgrass habitat on Dungeness crab production and survival of juvenile salmonids, are difficult to assess. Coastal biomes in Alaska generate an estimated $322 million[1] each year in ecosystem services such as regulating disturbances, cycling nutrients, providing biological control, and habitat (Colt 2001).

Aquatic farms are also important to the state economy. In 2007, the production value of aquatic farms (including oysters, clams, mussels, geoducks, and scallops) in Alaska was over $600,000 (ADFG 2008). Oysters grown in Alaska use suspended culture techniques, in which oysters are grown in nets or perforated trays hung in deep waters, rather than beach-grown cultures used elsewhere in the Pacific Northwest. Increased elevation caused by *Spartina* eliminates beach-grown operations. Therefore, Alaska oyster production would not be directly impacted by *Spartina* infestations but cultivation of littleneck clams (*Protothaca staminea*), Pacific and Arctic razor clams (*Siliqua patul* and *S. alta*), and butter clams (*Saximdomus giganteus*) could suffer adverse impacts if patterns of sediment accretion or nutrient cycling were severely altered by *Spartina*. In 1994, recreational clamming efforts totaled over 30,000 days of effort (Nelson 1994) and between 2000-2004, commercial harvest of razor clams averaged 377,670 pounds, valued at $218,620 (ADF&G 2006) (Table 3). Recreational opportunities such as sport fishing (including shellfish), boating, and beach access would also be reduced by the infilling of estuaries by *Spartina*. Over 188,000 residential sport fishing licenses, which are required for harvest of clams, were sold in 2008 at a total value of $3,908,673. It is difficult to approximate what share of these licenses were used exclusively for shellfish harvests, but clam digging remains a popular activity along certified beaches in the Cook Inlet and Kachemak Bay area. Loss of foraging, refuge or nursery habitat as well as alterations to benthic invertebrate communities may impact survival or growth of Dungeness crab (*Cancer magister*) and salmonids.

[1] Calculated in 1998 dollars.

In addition to direct and indirect losses for commercial, sport, and subsistence harvests of shellfish, coastal communities could also lose jobs associated with shellfish production and could threaten nature-based tourism. Commercial fisheries are vital to the economy of Alaska; in Southeast Alaska alone, the seafood industry accounted for 40.2% of the income of the private sector in 1994 (Hartman 2002). Tourism is a sustainable economic use of natural resources, presenting economic opportunities for residents in both urban and rural areas. Nature-based tourism, while difficult to define precisely, generates over $250 million per year of direct business revenues in Southeast Alaska alone (Dugan et al. 2007).

Invasions by exotic weed species typically include a lag phase characterized by slow population growth, followed by a period of exponential increase in coverage. *S. alterniflora* in Willapa Bay, Washington displayed such a growth curve (Figure 5) as did *S. patens* on Cox Island, Oregon (Figure 6). It is in the early stage of infestation, when population sizes are relatively small, that control efforts can be most cost effective. This is clearly shown by analysis of data obtained from 28 years of exotic weed eradication efforts in California by Rejmanek and Pitcairn (2002) (Figure 7).

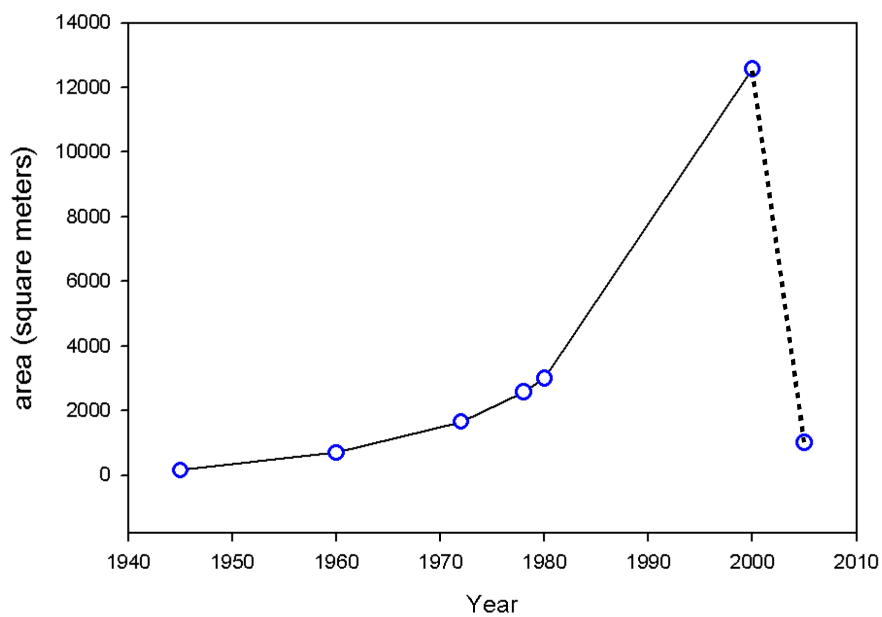


Figure 6. Expansion of cover of *S. patens* on Cox Island, Oregon. The last data point is an estimate based on 2009 surveys (data from Frenkel and Boss 1988, Pickering, pers. comm. 2007, Morgan and Sytsma 2009)

Given the remote and rugged coast of Alaska, the difficulty of working in estuarine environments; and the high cost of all available management methods; early detection and rapid response are critical to successfully protecting Alaskan estuaries from widespread infestation by *Spartina*. There are many stakeholders who could be potentially impacted by *Spartina* and who optimally will play a role in preventing or minimizing infestations within Alaska's treasured coastal landscape (Table 2)

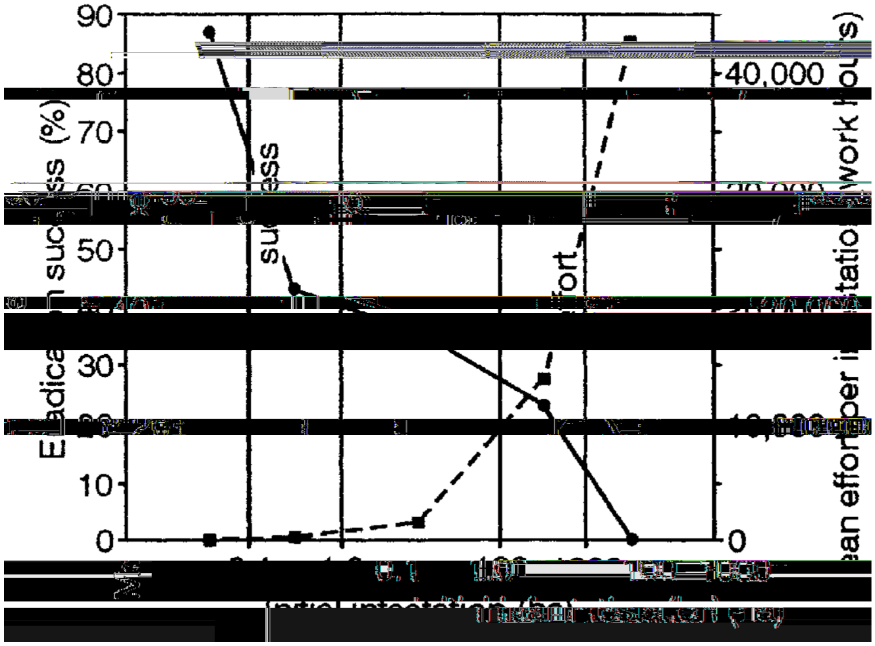


Figure 7. Dependence of eradication success and mean effort on initial infestation size (from Rejmanek and Pitcairn, 2002)

Table 2. Non-governmental stakeholders that may be impacted by invasions of *Spartina*.

| Stakeholder | Interests | Potential Impacts by *Spartina* |
|---|---|---|
| Recreational anglers | Clamming, fishing | Reduce catch of recreational species, indirect impacts to prey base |
| Commercial fishers | Fishing | Reduce catch of commercial species, indirect impacts to prey base |
| Ecotourism & nature enthusiasts | Natural habitats | Degrade and alter pristine habitats and communities |
| Birdwatchers & boaters | Preservation of habitat & access to shore | Degrade and alter pristine habitats and communities, hamper access to tide lands |
| Aquaculture industry | Cultivation of marine species | Displace cultured species, alter nutrient cycling and reduce harvests |
| Native peoples | Preserving indigenous culture & traditions of hunting, trapping & fishing | Degrade and alter pristine habitats and communities, hamper access to tide lands, and reduce harvests |
| Subsistence users | Clamming, fishing | Degrade and alter pristine habitats and communities, hamper access to tide lands, and reduce harvests |
| Habitat restoration professionals | Restoring marine habitats | Potentially displaces eelgrass transplants |

Table 3. Commercial (C), Recreational (R), and Subsistence (S) fisheries, and mariculture species (M) that may be affected by invasion of *Spartina* spp. in Alaska .

| Common name | Scientific name | Fishery type | Landings (metric tons) | Estimated value (USD)[1] |
|---|---|---|---|---|
| Geoduck clam | *Panopea abrupt* | C, R, S, M | 162.6 | $753,037[5] |
| Razor clam | *Siliqua patula* | C, R, S, M | 171.3 | $218,620[5] |
| Pacific oyster | *Crassostrea gigas* | M | 479.8 | $470,955[3] |
| Littleneck clam | *Protothaca staminea* | C, R, S, M | 28.0 (cultured) | $148,924[3] |
| Littleneck clam | *Protothaca staminea* | C, R, S, M | 11.4 (commercial) | $36,965[4] |
| Butter clam | *Saxidomus giganteus* | C, R, S, M | 11.4 (commercial) | $36,965[4] |
| Bay mussel | *Mytilus trossulus* | M, S | 0.8 | $4,484[3] |
| Dungeness crab | *Cancer magister* | C, R, S | 2,045.7 | $6,740,000[2] |

[1] Values do not include landings or value of recreational and subsistence fisheries
[2] Mean landings and value of the commercial fishery between 1998 and 2002, Woodby et al. 2005
[3] Production and value of the cultured populations from 2003, Timothy and Petree 2004
[4] Mean landings and values are for the commercial fisheries for Littleneck clams, Butter clams, and Basket cockles together between 1998 and 2002; individual values were not available
[5] updated figures from ADF&G, Division of Commercial Fisheries 2006.

## Invasion history

### Global distribution

*Spartina alterniflora* is native to the east and gulf coast regions of the United States where it is an important component of salt marshes. This species was intentionally planted for shoreline stabilization and marsh reclamation efforts in estuaries and coastal wetlands across many continents starting in the early 1900's. Established populations have been documented in Australia, New Zealand, France, the Netherlands, the United Kingdom, China, India, and North America (GISD 2005). In China's tidelands, it is a dominant invader and has either been planted or successfully established between Beihai (21° 36' N) and Tianjin (38°56' N) (An 2007). Introductions along the Pacific coast of North America, including California, Oregon, and Washington are discussed in detail in the next section.

*Spartina anglica* is the fertile offspring arising from a hybrid between *S. maritima* and *S. alterniflora*, thought to have arisen in southern Britain around 1890 and spread to France around 1906 (Baumel et al. 2002). Infestations of *S. anglica* are currently known in Ireland, Britain, New Zealand, China, and the west coast of North America (GISD 2005, An 2007). In China, populations of *S. anglica* reached 36,000 hectares in the mid-1980's, but following the termination of planting this species for reclamation and dike protection in 1985, this species declined to less than 50 hectares (An 2007). Introductions to North America, including California, Washington, and British Columbia, are discussed in detail in the next section.

*Spartina densiflora* is native to South America; along the east coast is found between Sao Paulo State, Brazil (23° 20' S) to Rio Gallegos city, Argentina (51°33' S) and along the Chilean coast it is known between Las Cruces (33° 30' S) and Isla Talcan (42° 46' S) (Bortolus 2006). In Europe, this species colonizes low to high tidal elevations and is presumed to have been introduced via lumber trade between Spain and South America (Nieva 2005). *S. densiflora* has spread extensively along Spain's coast including marshes near Gibraltar (36° 9' N), within the Odiel and Tinto rivers in the Gulf of Cadiz (ca. 37° 11' N) and north to Galica (43° 10' N) (Bortolus 2006, Nieva 2005). *S. densiflora* has also been found in one lagoon in Morocco, and is thought to have been introduced either by way of accidental introduction to a botanical garden or via solid ballast (Bortolus 2006). Introductions to North America, including California, Washington, and British Columbia, are discussed in detail in the next section.

*Spartina patens* is native to the east and gulf coast states of the U.S. and from eastern Canada, including New Brunswick, Newfoundland, Nova Scotia, Prince Edward Island and Quebec. *S. patens* has been known for many years in the western Mediterranean where seed is speculated to have escaped when the dry plant material was used for packing material; this species was most recently discovered in 1997 to be expanding in numerous marshes of the Iberian Peninsula (SanLeon et al. 1999). Introductions along the Pacific coast of North America, including California, Oregon, Washington, and British Columbia, are discussed in detail in the next section.

## Pacific Coast of North America

The four non-native species of *Spartina* on the west coast, *S. alterniflora*, *S. anglica*, *S. densiflora*, and *S. patens*, arrived in the estuaries of California, Washington, Oregon, and British Columbia through deliberate introduction, followed by natural dispersal and unintended transport. Additionally, multiple hybrids have resulted from these introduced species crossing with *Spartina foliosa* (native from Bodega, California to Baja, Mexico), but of these only *Spartina foliosa* x *alterniflora* has thus far become highly invasive (Ayres et al. 2008a, Ayres et al. 2008b) (Figure 8).

### *California*

<u>Humboldt Bay</u>

*S. densiflora* was likely introduced into Humboldt Bay, California, with solid ballast used on ships transporting lumber to Chile in the mid-1800's (Spicher and Josselyn 1985). *S. densiflora* now occupies 94 percent of Humboldt Bay's remaining salt marsh – approximately 812 acres according to surveys completed in 1999 - (Clifford 2002, Pickart 2001) and is particularly problematic in marsh restoration sites and other disturbed areas (Kittelson and Boyd 1997; Pickart 2005). Ocean currents and solid ballast carried in dredges are potential pathways of introduction of this species into Alaska. Documented populations of *S. densiflora* are known in the tidal marshes of the Mad and the Eel rivers, which are immediately north and south of Humboldt Bay (A. Pickart and H. Falenski pers. comm. 2006). A recent two-year study of repeated mechanical treatments using metal-bladed weed-eaters to cut below the root-crown of *S. densiflora* suggest this may be a viable (but slow and expensive) control option, especially where re-seeding from neighboring populations is limited (Pickart 2008). There is currently no bay-wide control plan in place for this large population, though discussions have been spurred by the goal of coast-wide eradication of *Spartina* by 2018 in the West Coast Governors' Agreement on Ocean Health.

<u>San Francisco Bay</u>

*S. alterniflora* was introduced into San Francisco Bay, California, by a combination of circumstances. Seeds were originally planted in a U.S. Army Corps of Engineers test site in the early 1970's and, when the dikes at the test site were subsequently breached, *S. alterniflora* began to spread aggressively into San Francisco Bay (Faber 2000). Prior to the treatment season in 2006, approximately 1000 acres (net) of invasive *Spartina* were estimated in San Francisco Bay (P. Olofsen, ISP, pers. comm. 2007). Nearly 98.9% of this infestation is comprised of the hybrid *S. alterniflora* x *S. foliosa* and the native *S. foliosa* is increasingly threatened with extirpation (Daehler and Strong 1997).

*S. densiflora* was introduced into San Francisco Bay in the 1970s when it was mistaken for a growth form of the native cordgrass and planted as part of a landscaping plan (Faber 2000). It currently infests 13 net acres of the Bay. *S. anglica* and *S. patens* are also present although at much lower levels (≤0.7 net acres) (San Francisco Estuary Invasive *Spartina* Project 2001). *S. anglica* was a deliberate introduction from Puget Sound, Washington, in the 1970's. There is no known explanation for the introduction of *S. patens* into California (Spicher and Josselyn 1985).

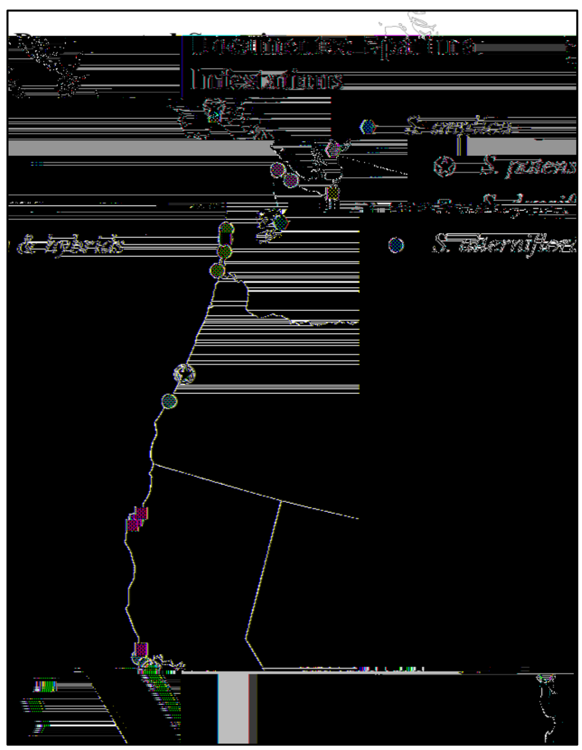


Figure 8. Known infestations of cordgrass (*Spartina* spp.) along the Pacific Coast of North America as of fall 2008. Symbols reflect the general locale of infested regions, rather than discrete infestations.

Small infestations of *S. alterniflora* and *S. alterniflora* x *foliosa* have been found in Bolinas Lagoon, Drakes Estero, and Limantour Estero and *S. densiflora* has been sighted in Tomales Bay. Each of these satellite populations lies just outside the San Francisco Bay mouth and suggest transport of propagules from the main infestations within the bay (Ayres et al. 2004). In 2004, large-scale control measures aimed at eradication were begun in the San Francisco Bay area despite the difficulties of scheduling control measures around endangered species habitat, and the complications of working in a highly populated environment.

### *Washington*

Puget Sound

*S. anglica* was deliberately introduced into Puget Sound, Washington, in 1961 by an agronomist who used it to stabilize dikes and as cattle forage (Hacker et al. 2001). When the Washington State Department of Wildlife first began monitoring this species prior to 1979, it comprised nine clumps distributed in Port Susan and Skagit Bays (Aberle 1993). By 1997, *S. anglica* had infested approximately 988 net acres (8,182 gross acres) at 73 sites within the Puget Sound area (Hacker et al. 2001). Progress on eradication has been made in the last few years, with the start-of-season 2006 estimate standing at 350 net acres (Murphy et al. 2007).

*S. densiflora* was found in Puget Sound in 2001 by *Spartina* survey crews. The pathway of introduction is unknown although solid ballast in dredges has been suggested as a possible mechanism of movement.

Grays Harbor

The discovery of *S. densiflora* in Grays Harbor, Washington, in 2001 by *Spartina* survey crews was the first sighting of this species on the west coast outside of Humboldt Bay and San Francisco Bay (Murphy 2005). The pathway of introduction is unknown although ocean currents from Humboldt Bay or solid ballast in dredges have been suggested as possible mechanisms of movement. Extensive aerial survey in 2005 revealed ten solid acres of *S. densiflora* within Grays Harbor, with concentrations around the Elk River, North Bay, and Grass Creek areas. *S. alterniflora* has also established here, presumably from propagules originating in Willapa Bay. Between 2005-2007, 12.5 net acres of *S. densiflora* and *S. alterniflora* were chemically treated; in 2008, 0.45 net acres were treated (chemical and manual removal) across 3,900 gross acres. An estimated 0.25 net acres remain (WSDA 2009).

Willapa Bay

Transplantation of oysters from the east coast of North America at the turn of the $19^{th}$ century was the likely pathway of introduction of *S. alterniflora* to Willapa Bay, Washington. *Spartina* plant parts or seeds probably contaminated barrels used to pack oyster spat and young adults for shipment to Willapa Bay in the 1800's and early 1900's. The seeds may have been introduced into the barrels either on oyster shells or by being blown into open barrels during packing and were subsequently dispersed into Willapa Bay upon arrival and unpacking (Civille et al. 2005). The Willapa Bay infestation was thought to have originated from a single or very few introduced clones (Stiller and Denton 1995), but more recent analysis supports repeated introductions, likely resulting from sustained import of oysters from the east coast, and multiple established clones throughout Willapa Bay by 1945 (Civille et al. 2005). The initial infestation spread to a maximum of 8,500 net acres in 2003 in just over 100 years; recent control efforts have notably reduced this population in the past two years (Figure 5).

The need for *Spartina* control in Willapa Bay was recognized in the 1980s and *S. alterniflora* was placed on Washington State's noxious weed list in 1989. Experimental studies for control of this weed by State of Washington and federal agencies began in the late 1980s – about the same time that the *S. alterniflora* population began its explosive expansion. The cost of management has been substantial; the Washington State Department of Agriculture and the Department of Natural Resources allocated $1-2 million per year for the last 10 years in control costs (WSDA 1998-2007). Eradication of *Spartina* from Willapa Bay was complicated by a number of factors, including: the size of the estuary; rapid spread of the plant following a long latent period; sensitivity of the estuarine habitat; difficult logistics; lack of understanding of the biology of the plant and how to manage it; the controversial nature of herbicide application; and the challenges inherent in coordinating a response among the large number of stakeholders in Willapa Bay, including government agencies, the public, and commercial interests. However, substantial improvements have come with use of the herbicide Imazapyr and improved GIS maps with tidal elevations which allow herbicide application with optimal drying times, and the State of Washington claims 95% control of the population (Allen Pleus, pers. comm. 2009).

### *Oregon*

#### Siuslaw River, Cox Island

Four infestations of *Spartina* have now been recorded in Oregon. The largest and most persistent is on Cox Island Preserve, Siuslaw River estuary. A population of *S. patens* has been present on the island since at least the late 1930s. It was probably introduced sometime before then in imported oyster spat (Frenkel and Boss 1988). The Nature Conservancy (TNC) acquired the site and began efforts to eradicate it in 1996 when there was an estimated 2.5 acres; as of 2009, TNC has treated 8.4 acres by covering patches with geotextile fabric anchored in place for two years (Pickering 2009). Recent detailed monitoring surveys covered 60-70% of the susceptible habitat on the island, finding 126 clones with net coverage of less than 90 $m^2$ (Morgan and Sytsma 2009). Four individual clones have been found since 2000 in marshes neighboring Cox Island; these individual plants have been treated and active surveys will continue. Eradication, while still the goal, may take longer than first estimated due to the difficulties in detecting small, potentially flowering patches of this species co-mingled with other native vegetation.

<u>Siuslaw River, Port of Siuslaw</u>

*S. alterniflora* has also been recorded in the Siuslaw River, near the Cox Island Preserve. Planted intentionally in the late 1970's on land owned by the Port of Florence (Frenkel 1990), it had expanded to approximately one acre by 1990 when the Oregon Department of Agriculture began control efforts. After chemical applications and digging, the infestation was deemed eradicated in 1997, following three years of monitoring with no signs of re-growth (Noxious Weed Control Section ODA 2000). Subsequent monitoring detected no regrowth until 2005, when a solitary clone surrounded by dense high-marsh vegetation was found and removed (Howard et al. 2006). Yearly monitoring has shown no regrowth since 2005.

<u>Coos Bay</u>

During a 2005 early detection survey, *S. alterniflora* was found in Coos Bay, east of the Charleston Marina. This site was a former dredge material disposal site, graded to tidal elevation in 1993 as part of a remediation project. Vegetative characteristics and genetic analysis from UC Davis & Bodega Marine Labs (D. Ayres, pers. comm.) confirmed the population as *S. alterniflora*. At that time, the population covered 26 $m^2$, spread across a shallow pond infrequently inundated with saline water during winter storm surges. Unintentional transplantation is the most likely cause of this infestation; contractors harvested native plant plugs from the Siuslaw River, Port of Siuslaw property in 1994 and transplanted them to this site. In 1995, monitoring revealed an aggressive growth of an unidentified grass that was tentatively identified as an invasive subspecies of common reed (*Phragmites australis* ssp. *australis*); it was manually removed in 1998, 2003, and 2004 before positive identification as *S. alterniflora*. Both the Coos Bay and Siuslaw River sites were in areas of low wave-energy and neither population was ever observed flowering[2]. It is therefore unlikely that they spread to other areas via natural seed or rhizome dispersal. Bay-wide surveys of surrounding areas revealed no additional clones and no regrowth has been observed since 2007 (Craig Cornu, pers. comm. 2009)

Columbia River Estuary

A single clone of *S. alterniflora* was found on the Oregon side of the Columbia River during *Spartina*-targeted, helicopter-based early detection surveys in 2008. The clone, measuring approximately 75 $m^2$, was clipped of all seed heads and treated with a combination of glyphosate and imazapyr in early October; monitoring one year later revealed approximately 99% control efficacy (Tim Butler, pers. comm. 2009). Transport, either by waterfowl or ocean currents, from the nearby Willapa Bay infestation is the most like source for this infestation.

### *British Columbia*

Frazer River Delta Region

In 2003, *S. anglica* was found in Boundary Bay and Roberts Bank areas near the Frazer River Delta, near Vancouver, British Columbia. A rapid response effort was mounted to remove seed heads, map the extent of the infestation and, in 2004 and 2005, control the infestation with manual digging and deep burial for larger clones (Buffett 2005, G. Williams, pers. comm. 2006). Although over 400 individual clones have been treated, more clones and seedlings are being found each year, suggesting recurring seed transport from the heavily infested Puget Sound region. Detailed ArcGIS maps of 2009 survey results, available through the Community Mapping Network (http://www.*Spartina*.ca/), include hundreds of plants ranging from individual seedlings to clones up to 5 m in diameter. Canadian parties have consulted extensively with *Spartina* managers in Washington, and have opted to focus on non-chemical control methods after considering the relatively small size of the infestation as well as limitations on herbicide use set forth by Fisheries and Oceans Canada.

Burrard Inlet

*S. patens* has been documented near the Maplewood Conservation area and has reportedly spread to areas near Port Moody on the east side of the City of Vancouver (Brekke 2006). No active management is underway for this infestation currently, but potential collaboration between the property owners and the British Columbia *Spartina* Working Group might lead to covering treatments, perhaps as soon as 2010 (D. Buffett, pers. comm. 2009).

[2] The plants originally transplanted to the Siuslaw River area were collected from a Georgia salt pan and were speculated to be a sterile biotype (W. Ternyik, pers. comm. 2005)

Vancouver Island

*S. patens* has also been observed near Comox harbor on the north east side of Vancouver Island since as early as 1974 and may occupy up to 5 acres of high fringe marsh habitat in that area (BEN, 1991, G. Williams pers comm., pers. obs. by V. Morgan). This species has recently begun to spread into the nearby Baynes Sound (BC *Spartina* Working Group, undated).

In late 2005, *S. densiflora* was confirmed in Baynes Sound near Ships Point. As of June 2006, there were a few large clones and hundreds more small plants with maximum densities of approximately 4.25 plants/$m^2$ (pers. obs. by V. Morgan). Surveys conducted in 2006 and 2007 for intertidal invasive organisms, including *Spartina* spp., revealed additional clones spread throughout the Baynes Sound region including the south eastern edge of Comox Bay, Denman Island, and Hornby Island (T. Therriault, pers. comm.). Local volunteers hand removed all *S. densiflora* from the Ships Point region in 2008 and 2009 (D. Buffett, pers. comm.).

## Potential spread to Alaska

### *Potential for introduction*

*Spartina* seed, wrack, and rhizome fragments float and are spread by tides and ocean currents. The *Spartina* Dispersal Study described in the above revealed repeated and often rapid transport northward from both Willapa Bay, Washington, and Humboldt Bay, California. Many fall and winter-released cards were recovered along Vancouver Island and the Queen Charlotte Islands in British Columbia and within the Alexander Archipelago of Southeast Alaska (Figure 9 a-b). While this year-long study cannot account for inter-annual variability, it does suggest propagules may be transported on the ocean surface within their period of optimal viability (1-4 months). The many cards recovered from beaches and embayments along Vancouver Island and the Queen Charlotte Islands suggest the possibility of *Spartina* establishment in these regions, which could subsequently add to the propagule load for dispersal into Alaskan waters (V. Morgan, unpublished data).

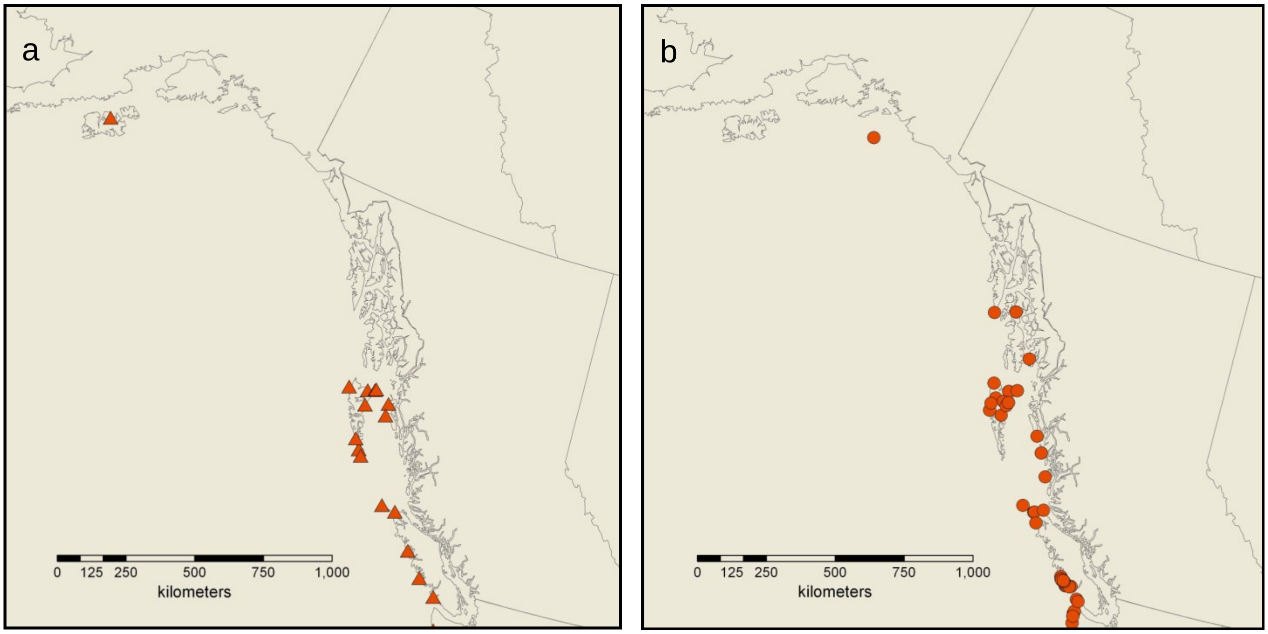


Figure 9. Northern most recoveries of drift cards from the *Spartina* Dispersal Study, including: a) recovery locations from releases at Humboldt Bay, California, and from b) Willapa Bay, Washington. The northern-most recovery point from Willapa Bay was found on Middleton Island, south of Cordova, Alaska. (V. Howard Morgan, unpublished data).

Human mediated transport of *Spartina* seeds could result from the transfer of shellfish spat or equipment from areas with established infestations. The current growth practices of shellfish hatcheries as well as regulations imposed by the ADF&G permitting process serve to minimize potential invasive animal species such as green crab and oyster drills; these likely will reduce any chance of *Spartina* seed accidentally hitchhiking with spat shipments. It is unknown what, if any, regulations apply to the transport of equipment involved in mariculture operations (crab nets, buoy lines, oyster pens, rafts, etc.) from areas with known infestations of *Spartina* or other estuarine species including tunicates and seaweeds (*Sargassum muticum*). Currently, ADF&G certified shellfish hatcheries include two from the Puget Sound region (Bellingham and Quilcene). Historically, spat sources may have included hatcheries from Baynes Sound on Vancouver Island, where *Spartina patens* and *S. densiflora* infestations are known. Records of spat transport or equipment movement from any areas with documented *Spartina* infestations into Alaska could yield additional high priority areas to survey beyond those recommended herein.

Movement with solid ballast is also possible. In 1999, the U.S. Army Corps of Engineers (USACE) dredge, the Essayon, sailed from its last assignment in Richmond Harbor within the San Francisco Bay of California to Anchorage Harbor to remove a large shoal blocking the Port of Anchorage (Hilton 2000). This vessel, as well as dredge vessels under contract to USACE, use water as ballast (S. Carrubba, USACE, pers. comm. 2002) which is less likely than a solid ballast dredge to transport plant seeds (Jeff Cordell, pers. comm. 2006). Of the USACE vessels in use on the west coast, only one, the Yaquina, uses solid ballast.

### *Potential for establishment*

Formal risk assessments and habitat suitability models elucidate the threat of *Spartina* in Alaska. The Alaska Invasiveness Ranking system was developed based on four other invasive ranking systems, but accounted for Alaska's climate (CLIMEX climate matching program) and relatively few plant invasions to date compared to other regions. All four *Spartina* spp. were ranked together as "extremely invasive" with a ranking of 86 of 100 total possible (Carlson et al. 2008; see Appendix B for the analysis that generated this score).

Habitat suitability models developed by Harney (2008) predict wave-protected or partially protected areas with at least one additional habitat characteristic (wide sediment-dominated flats or estuarine habitat) are suitable areas for *Spartina* establishment in Alaska. Sites that exhibit all three *Spartina* habitat characteristics may be particularly prone to invasion. In southeast Alaska, 340 km (3% of the total shoreline analyzed) of shoreline exhibit all three habitat attributes and are predicted to be especially prone to invasion (Figure 10); 2,432 km (18% of the total shoreline analyzed) of shoreline had two or more habitat attributes (Figure 11). It is important to note that not all of Alaska's shoreline was included in this analysis; the same queries could be performed once additional regions are mapped by the ShoreZone project. Furthermore, the maps likely underestimate the susceptible area because rocky intertidal areas, which have been colonized by *S. densiflora* in British Columbia and in Argentina (Bortolus 2006), were not included in the assessment.

Table 4. Summary of Shorezone *Spartina* habitat suitability queries (data from Harney 2008).

| Shorezone *Spartina* Habitat Rating | Shoreline distance (km) | Percent of shoreline analyzed | Notable concentrations of rated habitat |
|---|---|---|---|
| 1 | 5,875 | 43% | Baranof Island<br>Prince of Wales Island<br>Ketchikan area<br>Lynn Cannel<br>Juneau area<br>Yakutat Bay<br>Icy Bay |
| 2 | 2,432 | 18% | Baranof Island<br>Prince of Wales Island<br>Ketchikan area<br>Lynn Cannel<br>Juneau area<br>Yakutat Bay<br>Icy Bay |
| 3 | 340 | 3% | Limited areas around Baranof Island<br>Prince of Wales Island<br>Ketchikan area<br>Lynn Cannel<br>Juneau area |

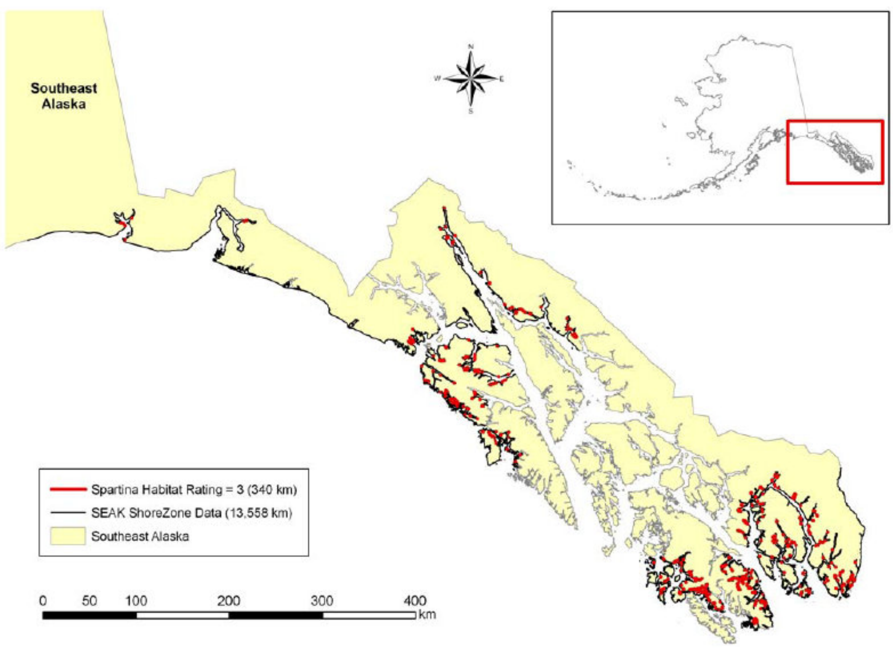


Figure 10. Areas rated as highly suitable for *Spartina* in Southeast Alaska. All areas in black were analyzed; those in red exhibit three critical habitat characteristics (protection from wave exposure, wide sediment dominated flats, estuarine) determined by a habitat suitability model to be conducive to *Spartina* colonization. Figure provided by Jodi Harney (Coastal and Ocean Resources Inc.).

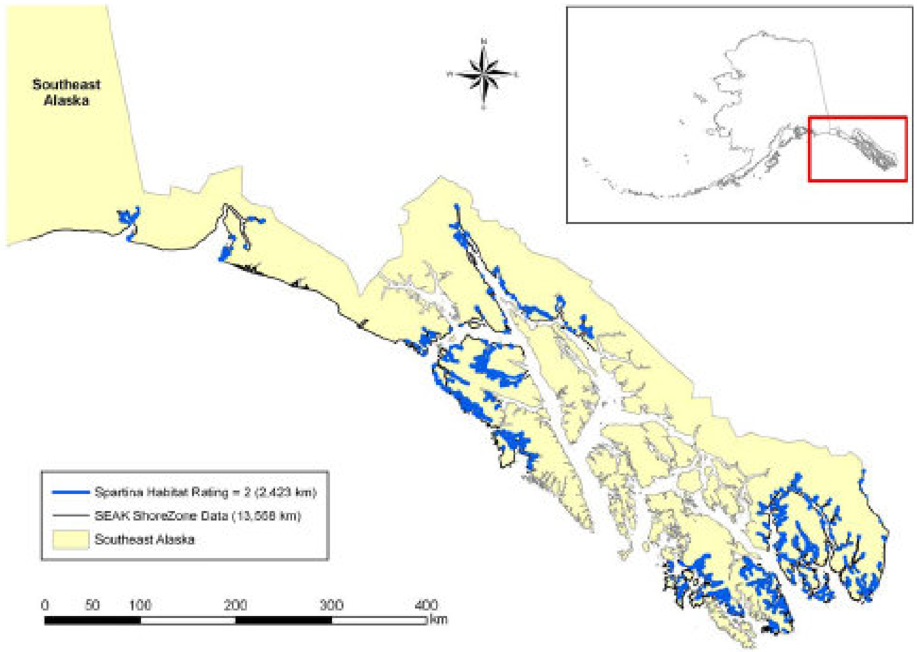


Figure 11. Areas rated as moderately suitable for *Spartina* in Southeast Alaska. All areas in black were analyzed; those in blue exhibit two of three critical habitat characteristics (protection from wave exposure, wide sediment dominated flats, estuarine) determined by a habitat suitability model to be conducive to *Spartina* colonization. Figure provided by Jodi Harney (Coastal and Ocean Resources Inc.)

A recent report to the US Fish & Wildlife Service produced current and predicted ranges for *Spartina* spp. and a number of other invasive plants, under two climate change models, two emission scenarios and for three time steps (2020, 2050, 2080) (HDR 2009). All *Spartina* species were aggregated for the analysis. Figures 12 shows the current predicted range, with 12% suitable habitat, as well as the 2020 and 2080 projected ranges (18% and 25% suitable habitat, respectively) using the most accurate parameters. Since *Spartina* currently has a small, but still substantial, predicted range and no known current occurrence within Alaska, the authors propose this region as a strong candidate for eradication for any found populations.

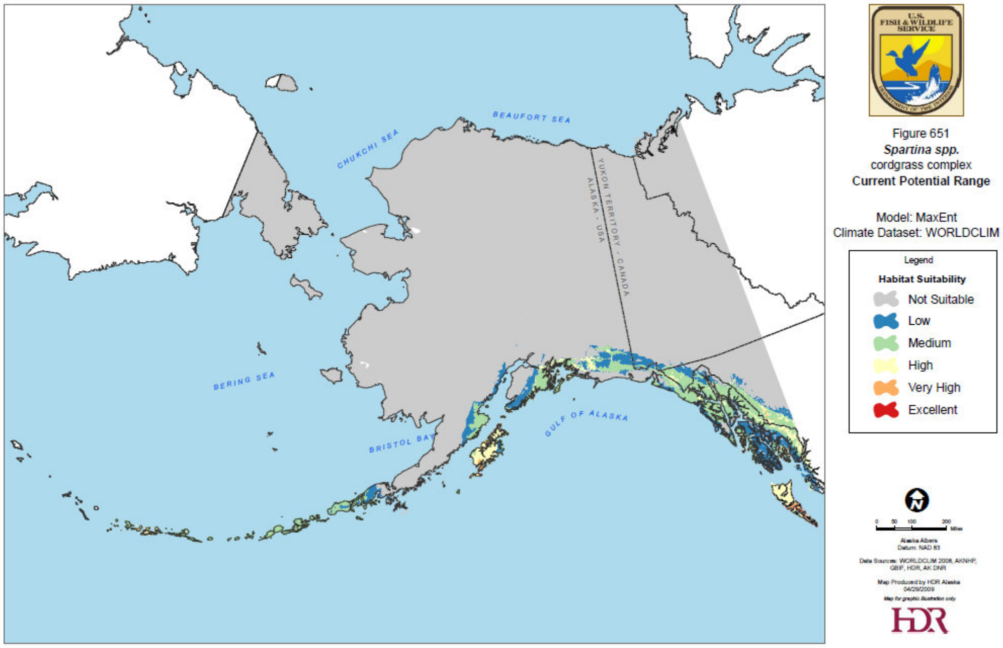


Figure 12. Current predicted bioclimatic range model for the cordgrass complex (*Spartina* spp.). Figure provided by Elizabeth Bella (HDR Alaska, Inc.).

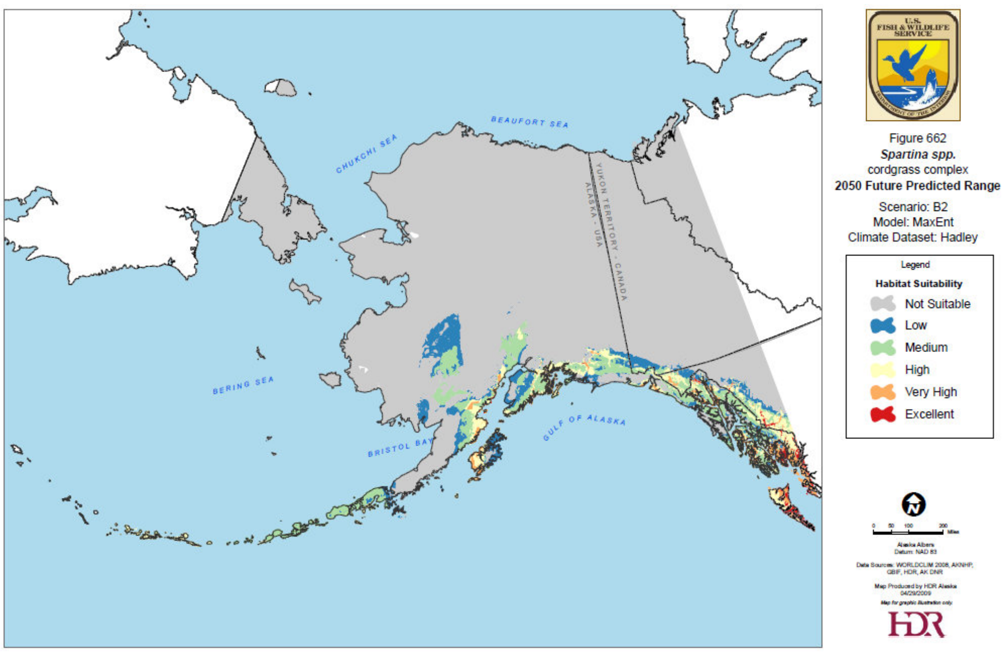


Figure 13.Projected bioclimatic range model for the cordgrass complex (*Spartina* spp.) in 2050. Figure provided by Elizabeth Bella (HDR Alaska, Inc.).

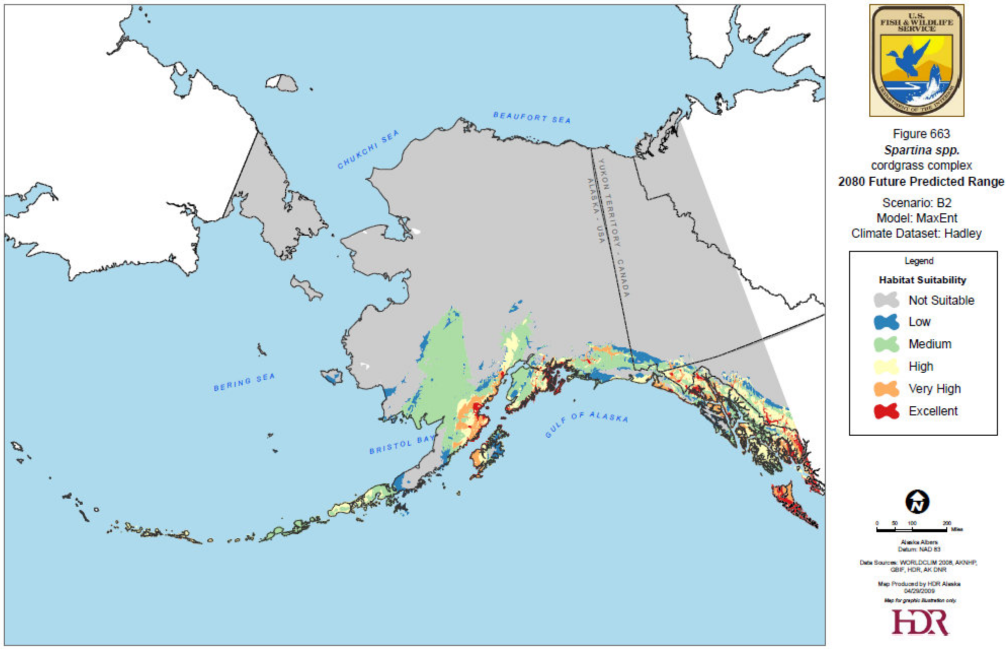


Figure 14. Projected bioclimatic range model for the cordgrass complex (*Spartina* spp.) in 2080. Figure provided by Elizabeth Bella (HDR Alaska, Inc.).

## *Spartina* Management

### Physical removal

Cost-effectiveness of physical methods, such as digging, mowing, covering, and tilling vary with the size of the infestation to be controlled, location of the infestation in the estuary, and possibly species. Hand digging is only feasible in areas with seedlings or isolated small clones no larger than 50 cm diameter according to Hammond and Cooper (2002); any rhizomes left behind could regrow in place or disperse to a new area.

Rototilling of *Spartina* has been somewhat effective in Willapa Bay, when done in winter months, but regrowth from rhizomes typically necessitates costly repeat treatments. Digging and rototilling inevitably result in the escape of small pieces of stems, roots, and rhizomes into sediments and tidal currents that could spread the infestation. Dispersal by fragments is clearly a concern, since even small fragments remain viable in fresh or brackish conditions and could re-establish into mature plants (Greenfield et al. 2005). Continued monitoring of treated sites and prompt removal of resprouting material is critical to the success of containment and/or eradication efforts.

Covering with specialized landscaping cloth has been effective on small patches of *S. patens* on Cox Island in the Siuslaw River estuary. Use of the landscaping material, rather than black plastic typically found at hardware stores, is crucial for success in the winds and tides of an estuarine environment. Recent experience indicates that the fabric should extend at least two feet beyond the edge of the patch. Covers typically require two years to kill *S. patens* and can be reused 2-3 times (four to six year lifespan) (Pickering 2000). Native vegetation rapidly reestablishes once the fabric is removed. The Nature Conservancy has used covering to target larger patches as well by focusing on the edges and working toward the center of the patch. Thus, covering can be used to contain and gradually eradicate large patches. Covering should be part of an integrated strategy. For example, The Nature Conservancy also mows large patches that have yet to be covered to prevent seeding (Pickering 2000).

### Biological control

Biological control of *Spartina alterniflora* using the plant hopper, *Prokelisia marginata*, was not effective in substantially reducing the *Spartina* population in Willapa Bay. Use of biocontrol agents is not considered an eradication technique. It may be most effectively used as part of an integrated management strategy for management of large infestations that also incorporates physical and chemical methods. In short, there is no known effective biocontrol for *Spartina*.

### Chemical control

Herbicides can provide effective control of *Spartina*, but their use can be controversial and can thereby generate additional cost and delays in response time. With any weed management program, resource managers must allocate resources after weighing the economic and environmental implications of no-action as well as issues of treatment efficacy and protecting native plants and animals from non-target effects. Herbicide application for *Spartina* control is complicated by the physical and hydrological characteristics of estuaries. Soft sediments limit access to infested areas, tides limit application periods, and sediment deposition on leaves limits penetration of the chemical into the leaf tissue. Experience from herbicide applications elsewhere will inform use of herbicides for *Spartina* management in Alaska. Herbicides are likely the only cost-effective option for large infestations, which often require substantial specialized equipment and may entail significant permitting costs; however, they may also be used efficiently and effectively on small infestations using backpack sprayers.

Imazapyr and glyphosate are currently being used for control of *Spartina* in Washington and California. Prior to 2004, glyphosate, the active ingredient in Rodeo ® (Dow Chemical) and Aquamaster ® (Monsanto), was the only herbicide labeled for use in estuaries. Imazapyr, the active ingredient in Habitat ® (BASF), was registered for use in estuaries in 2004 and is now the preferred choice for chemical treatment (Murphy 2004). The EPA recently evaluated imazapyr for re-registration, revising the label requirements to distinguish between uses in exclusively aquatic or non-aquatic sites and those with potential application to both (US EPA 2008). While the cost of imazapyr is more than twice that of glyphosate ($180 vs. $81 per acre treated) it is more consistently effective against *Spartina* and is considered of low toxicity to fish and invertebrates (Tu et al. 2001 (revised 2004)). Imazapyr can be used at much lower concentrations, requires much lower carrier volume of water, and has shorter persistence in water than glyphosate (Patten and Stenvall 2002; Patten 2002). The amount of fresh water required for mixing incurs significant cost and logistical challenges, thus the much lower water requirements of imazapyr (one tenth that of glyphosate) contribute to its greater cost effectiveness.

Research into the efficacy of chemical treatments on *S. densiflora* infestations in Spain suggests that imazamox and glyphosate may not be effective on this species (Mateos-Naranjo et al. 2009). Imazamox and imazapyr are in the same family of herbicides, which inhibit production of acetohydroxyacidsynthase. Glyphosate had greater negative impacts on photosynthesis and growth compared to imazamox, but neither was successful in killing this species (Mateos-Naranjo et al. 2009). A combination of glyphosate and imazapyr evaluated on *S. densiflora* in Grays Harbor, Washington, found 41% mortality 3-months post treatment with another 33% of plants showing some signs of stress (WSDA 2009).

Applications of herbicides approved for use in aquatic/estuarine settings often are supplemented by the use of adjuvants such as surfactants and dyes. Concern for potentially toxic effects on aquatic organisms has led Washington State to develop a list of approved adjuvants for use in aquatic settings (http://www.ecy.wa.gov/programs/wq/pesticides/regpesticides.html) with associated toxicity data for both rainbow trout and daphnids. Alaska currently has no regulations regarding surfactant use, however the Alaska Department of Environmental Conservation favors the use of Washington approved surfactants (G. Graziano, pers. comm. 2009).

Chemical applications are applied with backpack sprayers by workers on foot or in boats and, for very large infestations like Willapa Bay, with boom sprayers powered by an amphibious tractor or attached to helicopters. Aerial (broadcast) spraying is generally the most cost-effective method of treating large infestations.

### Integrated management

Relatively small, pioneering populations of *Spartina* are susceptible to a variety of control techniques applied in a manner that is most appropriate for the site and the size and stage of growth of the infestation. A small infestation of *S. alterniflora* in the Siuslaw estuary in Oregon was eradicated using a combination of herbicides and digging. A combination of mowing and covering is being used effectively on some relatively large *S. patens* patches on Cox Island, Oregon. There is clearly no single *Spartina* control technique that can be applied successfully under all circumstances, however, large infestations cannot be economically managed without some use of herbicide.

### Permitting and costs

Control of *Spartina* using chemical methods would require an Alaska Department of Environmental Conservation (DEC) Pesticide Use Permit from the Division of Environmental Health's Pesticide Control Program; exemptions to this requirement are available under emergency circumstances as determined by the Commissioner of the DEC. Additionally, federal permits may be required to treat in reserves, sanctuaries, and parks; these permits are available through NOAA, the National Park Service, the U.S. Fish and Wildlife Service, ADF&G and/or DNR. Manual methods of control (digging and covering) are appropriate for small infestations, but become prohibitively expensive for use on large sites due to their high cost per acre (Table 5). Notably, logistical costs in Alaska could substantially boost the listed treatment costs per acre. Mechanical and chemical methods, with their lower per acre costs, are more appropriate on large sites. Intermediate sized sites could be treated using a combination of methods.

Table 5. Estimated cost per unit area of *Spartina* control methods.

| Digging[1] | Covering[2] | Mechanical[3] | Chemical[4] |
|---|---|---|---|
| ≥$87,000/acre<br>($2-$3/ft$^2$) | ≥$9,600/acre<br>($0.22 - $30/ft$^2$) | $390-$2000/acre<br>($0.01 - $0.05/ft$^2$) | $300-$780/acre<br>($0.01 - $0.02/ft$^2$) |

1. Estimate from D. Isaacson.
2. Low range estimate based upon costs of *S. patens* control on Cox Island (D. Pickering, pers comm.). High range estimated from cost of fabric + 3 hours transportation and labor @$10/hr.
3. Low range estimate from (Ecology 2002). High range estimate from M. Wecker, Olympic Natural Resources Center.
4. Low range estimate from M. Wecker, Olympic Natural Resources Center. High range estimate from (Ecology 2002).

Note: Actual costs could be quite different; estimates shown to illustrate that expense of differing techniques vary greatly.

## Considerations in determining a management strategy

Potential management options may be considered according to the size, location, and species of *Spartina*. Deciding whether control or eradication is the management goal is key to subsequent management decisions. Infestation size is the primary determinant of the efficacy of various methods of controlling *Spartina* (Table 6). Small infestations, near the size suggested for a detection threshold of about one-half acre, should be amenable to eradication using physical methods. The size that can be controlled using physical methods is likely to be species specific. *S. patens* and *S. densiflora*, for example, which grow at higher elevations among native salt marsh plants, probably pose fewer logistical problems in accessing a site and may be more amendable to physical control methods. Work demonstrated by The Nature Conservancy and the Humboldt Bay National Wildlife Refuge suggests infestations as large as 10 acres of these two species may be controlled using physical methods, although repeated treatments over successive years may add considerably to costs. Chemical methods are likely to be required for eradication of larger (>1 acre) infestations, but the size threshold is likely to be species specific. Operationally, eradication refers to completely eliminating *Spartina* from a site with no evidence of regrowth for six years following cessation of management activities (Howard et al. 2006).

Table 6. Control strategy/method based on size of initial infestation of each method. All treatment options are summarized in Appendix C.

| Category | Infestation Size (net/gross acres)[1] | Goal | Treatment Methods |
|---|---|---|---|
| 1 | ≤ 0.1/<5 | Eradication | Digging, Covering |
| 2 | 0.1-0.5/~5.0 | Eradication | Digging, Covering, Herbicide |
| 3 | 1.0-10.0/40.0 | Containment, Eradication | Digging, Covering, Herbicide, Mowing |
| 4 | ≥10.0/80.0 | Containment, Eradication | Mowing, Herbicide |

1. Net infestation size is the area occupied if all plants in the infested area were grouped into a single monoculture or patch. Gross infestation size is the area encompassed by lines connecting the outlying plants.

The stage of growth of *Spartina* when it is discovered will also influence treatment response. For example, if *Spartina* was flowering, mowing might be employed to prevent development and release of seeds (note that mowing should not be done on plants which have set seed). Size of an infestation may also require adjustment of the program goal. Eradication of large sites may be impractical and containment – controlling an established *Spartina* infestation so that it does not increase in area or spread propagules to other areas – may be a more appropriate short-term goal. A modeled strategy for Willapa Bay that focused on targeting outlier, satellite populations prior to targeting the core, meadow infestations resulted in up to 44% less time and effort to eradicate the infestation in the Bay (Grevstad 2005).

It is unlikely that Alaska's resource and weed managers can prevent all possible accidental or unintentional human-mediated introductions. It is even more unlikely, if not impossible, to prevent introduction via currents, birds, or other natural vectors. Consequently, it is advisable for the State of Alaska to operate on the premise that *Spartina* infestations are inevitable. The question becomes not IF *Spartina* will invade but WHEN and WHERE.

## Early detection of *Spartina*

### Methods

Because the size of any weed infestation is inversely correlated with the probability that it can be successfully eradicated and directly correlated with the resources required for eradication, early detection of small, pioneer *Spartina* infestations in Alaska is critical to an effective control and eradication strategy. Active surveyors have found multiple patches of *S. alterniflora* in Washington and Oregon in recent years (Chad Phillips, pers. comm. 2009, V. Morgan, pers.

obs.). Determination of an acceptable detection limit will aid survey teams with their search images. In Oregon, the stated detection limit has varied from 0.5 to 1.0 acres, but smaller populations have been found repeatedly. In addition to size, the likelihood of detection is related to the number, training, experience and motivation of the observers; the distance of observers from an infestation; and to the frequency and thoroughness of search efforts.

Alaska can increase the probability of successful detection by utilizing active search methods combined with passive surveys by informed field crews. "Active", in this sense refers to searchers whose assigned duty is the detection of *Spartina* to the exclusion of any collateral assignments. “Passive” detection involves searchers who have duties and interests other than searching for *Spartina*, but who might be in areas where *Spartina* could become established and could detect a new infestation if they are educated with appropriate identification information. Commercial oyster growers, who have a significant economic interest in preventing *Spartina* establishment, exemplify those who could be recruited for passive detection of *Spartina*. Passive detection approaches can also be effective and efficient, especially where motivated and qualified personnel are involved.

Aerial searches from airplanes and helicopters, boat surveys, and shore-based surveys have all been used for *Spartina* detection; each approach has its advantages and disadvantages. The area that can be covered, costs, and reliability vary considerably among these methods. Ground and boat searches are likely to be the most reliable because they usually offer the observer the opportunity to get closer to a suspect site. There are many areas, however, that cannot be surveyed from the shore or by boat. Helicopters can maneuver so that most of the areas at risk can be seen, and they often can bring observers close to any targets. Commercial rentals of a helicopter are typically costly, however, and scheduling of flights can be difficult due to changing weather patterns and helicopter availability. In Oregon, the U.S. Coast Guard has allowed *Spartina* surveyors to ride along on non-rescue, training flights. The use of fixed-wing aircraft, specifically seaplanes, is much less costly than helicopters. Although they cannot maneuver as close to possible infestations as helicopters, they have the advantage of being able to potentially land for immediate inspection of suspect patches of *Spartina*.

According to an assessment done on surveys in Oregon, cost and effectiveness of various survey methods vary considerably (Table 7). Each survey method was assigned a value for the estimated susceptible area that could be assessed (percentage). Costs were primarily based on experience of D. Isaacson (Oregon Department of Agriculture, retired) with the various methods. Methods were ranked for relative reliability, based upon how close an observer could get to potentially infested sites and whether the method involved passive or active searchers. The assumptions and estimates used in this comparison could be debated; however, the approach helps elucidate the relative costs and benefits of the different search options and provides a method for optimizing allocation of limited resources. It is important that detection methods and schedules remain flexible so that variable weather conditions, equipment availability and other factors can be accommodated.

Table 7. Adjusted relative cost effectiveness of detection methods . (Adjusted relative cost effectiveness = Relative reliability x Relative cost effectiveness; 0 = least effective, 4= most effective)

| **Method** | **Risk area % covered** | **Annual cost $K** | **Relative cost effectiveness** | **Relative Reliability** | **Adjusted relative cost effectiveness** |
|---|---|---|---|---|---|
| Volunteers | 25 | 5.0 | 5.0 | 0.1 | 0.5 |
| Ground | 50 | 15.0 | 3.3 | 0.5 | 1.7 |
| Helicopter | 75 | 6.0 | 12.5 | 0.2 | 2.5 |
| Fixed wing | 75 | 2.0 | 37.5 | 0.1 | 3.8 |
| Air-both | 90 | 8.0 | 11.3 | 0.2 | 2.3 |
| Boat - passive | 25 | 5.0 | 5.0 | 0.1 | 0.5 |
| Boat - active | 50 | 24.0 | 2.1 | 0.5 | 1.0 |

This analysis suggests that aerial surveys should play a central role in detection efforts. The analysis does not, however, mean that the other methods do not have a role in early detection efforts. Volunteers with special motivation can certainly be of assistance. Resource managers and private citizens with no official assignment with respect to a *Spartina* threat may also be motivated to help with detection efforts. Such persons could be recruited and trained as a supplement to the main active detection effort. Surveys by boat were ranked low in this analysis; however, boat surveys are likely to be very important for confirmation of sightings, delimiting surveys, or management activities.

## Where to survey?

Habitat requirements for *Spartina* spp. include wave-protected sites with muddy, sandy or cobble substrates within open intertidal areas, as well as existing low to high salt marshes. Because the area in Alaska with high to moderate susceptible habitat is so large, surveys should be targeted to the following sites:

1. Areas with high to moderate suitable habitat as determined by the ShoreZone habitat suitability model (Harney 2008) and/or the US Fish & Wildlife Service predicted range model (HDR 2009). Obtaining the GIS files with the nested query results could aid survey planning and record keeping.
2. High-value habitat for shorebirds, shellfish or other ecological, commercial, social or cultural importance. Vast areas of intertidal lands and salt marshes in Alaska are an invaluable resource to wildlife as well as human economic, aesthetic, and historical interests.
3. Areas closer to known infestations or with known transport of materials from infested areas (i.e., southeast Alaska, beach-based shellfish operations with histories of spat introductions from Puget Sound, Washington, or Baynes Sound, British Columbia)
4. Areas with active monitoring for other invasive intertidal organisms such as tunicates and green crabs and marine debris (Table 8 and Table 9). Outreach and training provided to these groups could significantly augment surveillance efforts in Alaska.

Table 8. General locations and organizations currently conducting *Carcinus* monitoring in Alaska. GBNPP = Glacier Bay National Park and Preserve, USFS = United States Forest Service, PWSRCAC = Prince William Sound Regional Citizens' Advisory Council, KBRR = Kachemak Bay Research Reserve. Monitoring in Seward began in 2009. (Table modified from Davidson et al. 2009)

| **Locations** | **Latitude [a]** | **Longitude [a]** | **Organization** | **Frequency (per year)** |
|---|---|---|---|---|
| Dutch Harbor | 53.918 | -166.53 | PWSRCAC | 2 |
| Ketchikan[b] | 55.345 | -131.7 | AK Sea Grant, USFS | 4 |
| Sitka[b] | 57.044 | -135.31 | USFS, Sitka Tribe | 3 |
| Kodiak | 57.789 | -152.43 | PWSRCAC | 3 |
| Gustavus | 58.452 | -135.89 | GBNPP | 4 |
| Homer | 59.633 | -151.51 | KBRR | 5 |
| Seldovia | 59.436 | -151.71 | KBRR | 5 |
| Port Graham | 59.356 | -151.87 | KBRR | 5 |
| Nanwalek | 59.351 | -151.92 | KBRR | 5 |
| Chenega Bay | 60.076 | -148.02 | PWSRCAC | 3 |
| Seward | 60.105 | -149.43 | PWSRCAC, KBRR | TBA |
| Cordova | 60.541 | -145.76 | PWSRCAC | 3 |
| Whittier[b] | 60.78 | -148.65 | PWSRCAC | 4 |
| Valdez | 61.071 | -146.33 | PWSRCAC | 4 |

[a] Latitude and Longitude are approximations [b] Locations are composed of multiple sampling sites

Table 9. General locations and organizations currently conducting marine debris removal in Alaska.

| Organization | Latitude [1] | Longitude [1] | Location | Paid (P) or Volunteer (V)[2] | Timing[2] |
|---|---|---|---|---|---|
| CoastWalk | 59.57329 | -151.67587 | Kachemak Bay | V | September |
| CoastWalk | 57.79000 | -152.40722 | Kodiak | V | September |
| CoastWalk | 60.10417 | -149.44222 | Seward | V | September |
| CoastWalk | 60.77306 | -148.68389 | Whittier | V | September |
| CoastWalk | 61.49649 | -149.38110 | Palmer | V | September |
| CoastWalk | 60.54859 | -151.26560 | Kenai | V | September |
| CoastWalk | 60.22027 | -149.90690 | Anchorage | V | September |
| Gulf of Alaska Keeper | 60.67318 | -147.12891 | Prince William Sound | V | n/a |
| Tribal Gov. of St. Paul Island | 57.11239 | -170.27710 | Pribilof Islands- St. Paul | P | May |
| Tribal Gov. of St. Paul Island | 56.62602 | -169.62891 | Pribilof Islands - St. George | P | May |

[1] Latitude and Longitude are approximations [2] Marine Debris in Alaska 2008

Detection efforts could be more focused and efficient with more information about some of the pathways of introduction. If some species of waterfowl, for example, are more likely to use core infested areas, surveys could be focused on areas where those birds visit and are therefore at higher risk. Improved understanding of regular operations that occur in estuaries using equipment transported from *Spartina*-infested estuaries, such as those of the U.S. Army Corps of Engineers, represents another opportunity to focus detection efforts.

A better understanding of the sites most suitable for growth and reproduction of *Spartina* spp. would be helpful in focusing search efforts. Harney's (2008) habitat suitability model predicts wave-protected areas with wide sediment-dominated flats or estuarine habitat are suitable areas for *Spartina* establishment in Alaska, but only a portion of the Alaskan coastline has been evaluated to date using this model and data collected from the ShoreZone project. Daehler and Strong (1996) give information on substrates, tidal heights, and exposure to wind and wave action that relate to suitability for *Spartina* establishment. If these were areas were mapped using GIS technology, searches could be more focused and efficient.

Remote sensing of *Spartina* infestations is a promising area of research. The challenge with using this method of detection is that the system needs to distinguish between upright grasses and grass like plants which grow in similar habitats. There will likely be no clues to differences based on context and detection will be primarily based on reflectances. Since *Spartina* commonly occurs in mixed stands (i.e., *Spartina* mixed with other look-alike species), and in stands of varying density, there is not a single, "tight" signature that could be used for detection. Additional research may enhance the effectiveness of remote sensing for *Spartina* detection over large areas in Alaska; but, at present, remote sensing should not be relied upon for active detection efforts.

## Early detection and rapid response plan

### Goal of *Spartina* management in Alaska

**The goal of *Spartina* management in Alaska is to prevent the establishment of any new *Spartina* infestations and to eradicate established infestations if detected in the State's estuaries or coastal wetlands.**

Early detection and a rapid response are critical to the cost-effective management of introduced species. Recent drastic reductions in *S. alterniflora* cover in Willapa Bay, however, demonstrate that large-scale control is possible with adequate resources ($1-2 million per year over the last 10 years) (WSDA 1998-2007). Potential obstacles to rapid implementation of a plan include lack of interagency cooperation, public opposition, logistic problems, and availability of funds.

Based upon experience in managing *Spartina* in Oregon, small infestations (less than one-half acre) should be eradicable in three to 10 years (including treatment and monitoring without redetection). *S. alterniflora* management in the Siuslaw estuary was initiated in 1990 when the infestation was about one acre in gross extent and was largely successful, with only one plant detected since 1994. In Coos Bay, the number of hours required to remove all visible growth of *S. alterniflora* was reduced from 320 in 2003 to 1.5 in 2006. *S. patens* control on Cox Island was initiated when the infestation was about 0.9 acres, ten acres have been treated to-date, and less than 100 $m^2$ (0.025 acres) was detected in 2009. Eradication is projected within five years. Other examples of successful eradication are rare and involve sites one acre or less in extent.

We recommend an adaptive management approach to allow modifications as needed to deal with biological, logistical, jurisdictional, or other factors that may occur. Coordinating between agencies will ensure logistical burdens are minimized; however, one agency should be identified as the lead to ease planning efforts and ensure accountability. A flow chart for response (Figure 15) and specific objectives, goals, and specific tasks to meet the goal of the Plan are described below.

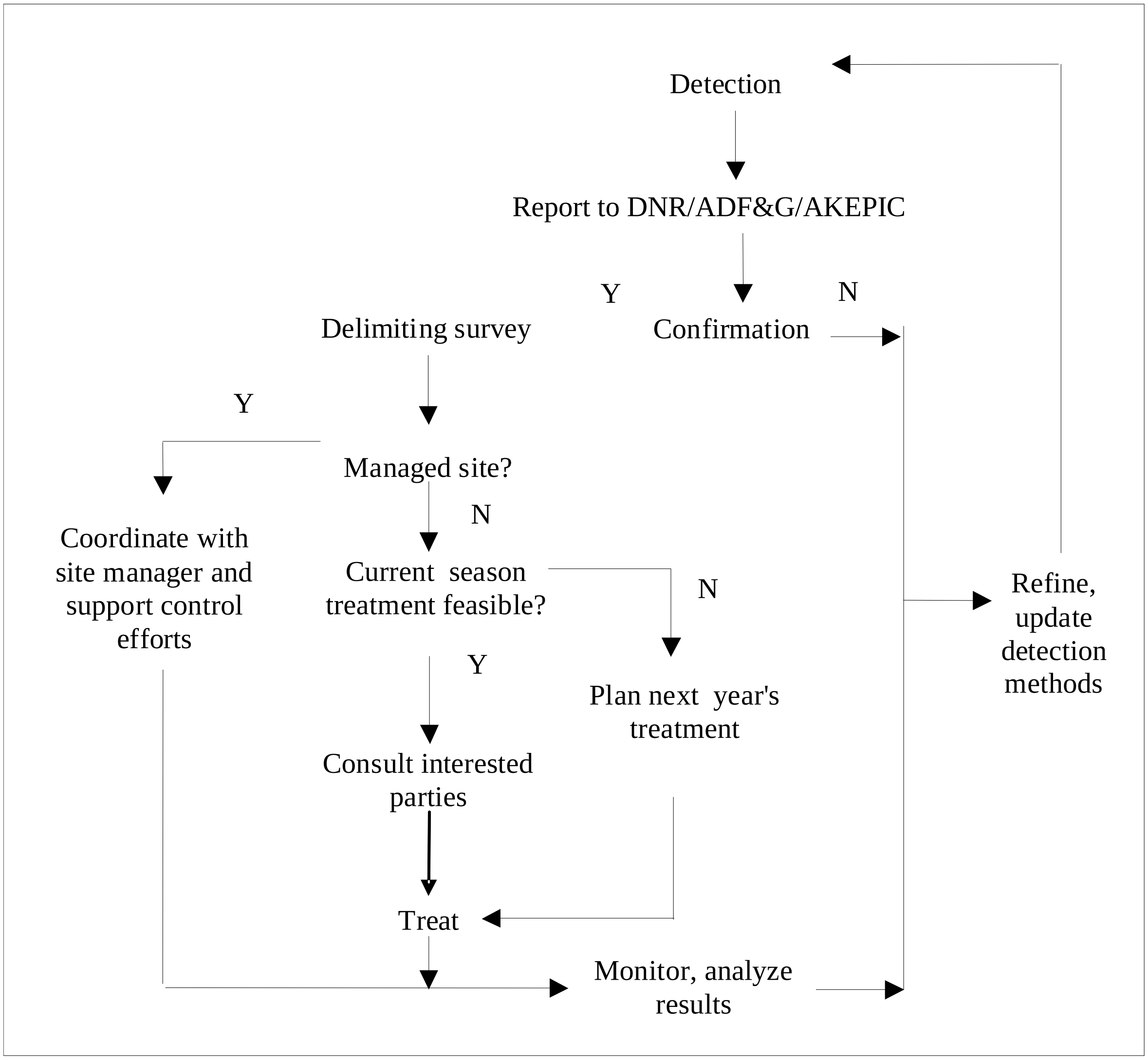


Figure 15. Early detection and rapid response framework to aid the prevention, detection, management, and eradication of *Spartina* in Alaska.

## Objective 1: Prevention of establishment

### *Strategy: Vector and source population management*

**Task 1.1. Support ongoing control efforts in British Columbia and the Lower 48 and British Columbia.**

California, Oregon, and Washington developed a work plan for eradication of *Spartina* from the West Coast as part of the West Coast Governors Agreement on Ocean Health. British Columbia collaborated in development of the plan but was not a signatory to the plan. The Pacific Coast Collaborative may provide a vehicle for British Columbia and Alaska to join with the other west coast states in a coordinated effort to eradicate *Spartina*. Eradication of source populations on the West Coast is the most effective way to prevent infestation of Alaskan waters by *Spartina*.

**Task 1.2. Review the Alaska Department of Fish and Game requirements for approved shellfish hatcheries and develop rules for cleaning and inspection of products, sterilization of packaging materials and quarantine during transit.**

Varying regulations for oyster culture, especially transport permits, across jurisdictional boundaries is a potential obstacle to oyster growers' efforts to prevent the spread of *Spartina* in Pacific Coast estuaries (Sue Cudd, personal communication; Pacific Shellfish Institute, North American West Coast Shellfish Industry 2010 Goals). Greater uniformity in these regulations could be helpful in preventing the spread of *Spartina*.

Permitting and quarantine authority could be strengthened to prevent infestation. For example, the Seed Transport from a Certified Hatchery and Acquisition and Transport Application permits issued by the ADF&G Commercial Fisheries for import of controlled shellfish are typically general in nature, but restrictions to limit risk of *Spartina* introduction with imported shellfish could be specified. Current efforts that focus on prevention of green crab and oyster drill movement, as well as protection of native shellfish genetic integrity, probably provide some protection against *Spartina* spread, but permit requirements should be reviewed and must be enforced. Additional safeguards against *Spartina* transport with shellfish should include:

- Determination if shellfish are being imported from an infested area
- Voluntary or regulated inspections at the processing facility

- A requirement that shellfish be chlorine-washed before transport into Alaska and quarantined to prevent contamination during transit
- A second inspection and wash upon arrival in Alaska
- Wash water disposal at an upland site or into an appropriate treatment facility

**Task 1.3. Conduct a detailed review of the history of oyster spat/equipment importations to aid selection of high-priority early detection survey areas.**

Some shellfish hatcheries and growers are operating in estuaries heavily infested with *Spartina*, either currently or historically (Willapa Bay and Puget Sound, Washington; Baynes Sound, British Columbia). Workers, oyster-production supplies, and some equipment are moved between sites as needed. Investigating the history of spat and equipment movement may reveal high-priority sites for early detection in Alaska given the known infestations in the Lower 48 and British Columbia.

**Task 1.4. Ensure enforcement of state regulations that prohibit the sale or importation of live marine bait.**

Invasive species commonly arrive as "hitchhikers" in shipments of other, presumably beneficial, organisms. The initial introduction of green crabs (*Carcinus maenas*) to the Pacific coast of North America may have been from the seaweed used with shipments of bait worms (Cohen et al. 1995), and initial introduction of *Spartina* into Willapa Bay occurred when it was used as packing material in live oysters. The release of live bait products or packing material could be a source of *Spartina* in Alaska. The Alaska Administrative Code currently includes regulations on the use of live bait, stating that "live bait may be possessed, transported or released only in the salt waters of the regulatory area in which it was taken" (5 AAC 75.026). Bait is defined as "any substance applied to fishing gear for the purpose of attracting fish by scent, including fish eggs in any form, natural or preserved animal, fish, fish oil, shellfish, or insect parts, natural or processed vegetable matter, and natural or synthetic chemicals" wherein shellfish includes "all shellfish and marine invertebrates" (5 AAC 75.995). Additionally, the use of live nonindigenous fish as bait is prohibited (5 AAC 01.010). Enforcement of these regulations will prevent accidental introduction of *Spartina*, non-native seaweeds, and *Carcinus*.

### Task 1.5. Communicate with USACE regarding movement of dredging vessels and management of solid ballast.

U.S. Army Corps of Engineers (USACE) equipment, and that of their contractors, move up and down the west coast, visiting both infested and uninfested estuaries. While at sea in transit between work sites, dredge vessels may use solid ballast, which could be picked up in infested areas. Contract language should be required for Corps and contract dredges to minimize potential transport of *Spartina* propagules.

### Task 1.6. Identify stopover and breeding locations of bird species that migrate from infested sites elsewhere to susceptible sites in Alaska. These areas should be a priority for surveillance.

Many species of migratory birds are known to utilize major estuaries along the Pacify Flyway some of which are infested with one or more *Spartina* species. Areas in Alaska with susceptible habitat and large populations of bird species returning from over-wintering grounds in coastal British Columbia, Washington, Oregon or California should be targeted for early detection efforts.

## Objective 2: Plan Coordination

*Strategy: Improve the probability of an effective rapid response by establishing clear procedures, authorities, and responsibilities for action, and a framework for comprehensive implementation of this plan*

### Task 2.1. Identify a lead agency

Protection of Alaskan estuaries from the impact of *Spartina* will require cooperation from a variety of preserve and refuge managers, mariculturists, state and federal agencies, and other stakeholders; but weed management programs operate most effectively with a clearly identified lead agency. State agriculture departments have extensive experience with weed management and typically run *Spartina* management programs. The Alaska Division of Agriculture in the Department of Natural Resources is responsible for the management of all state-listed noxious weeds and is the appropriate lead agency for *Spartina* management in Alaska.

### Task 2.2. List ***Spartina alterniflora, S. densiflora, S. anglica*** and ***S. patens*** and ***S. foliosa*** x ***alterniflora*** as noxious weeds in the State of Alaska.

Formal listing of all *Spartina* species will permit legal regulation of transport of *Spartina* spp. in Alaska, clarify lead agency authority, increase general awareness regarding the impacts and potential for infestations within the State of Alaska, and prohibit the intentional planting of *Spartina*.

**Task 2.3. Secure an emergency response fund**

Access to the necessary resources in a timely manner is critical to rapid response. Establishment of a dedicated emergency response fund for *Spartina* eradication would facilitate implementation of a rapid response to a detected invasion. The necessary size of the emergency response fund is entirely dependent upon the size and accessibility of a new infestation. A new infestation less than one acre in area could be controlled with $5000/year, depending on accessibility and the method of control (herbicide treatments are generally less expensive than digging and covering). As the size of the infestation and difficulty in accessing the site increases the costs increase. The Oregon legislature recently created a $350,000 invasive species emergency response fund that is administered by the Oregon Invasive Species Council. The *Spartina* Eradication Workplan that is part of the West Coast Governors Agreement on Ocean Health calls for establishment of a $250,000 emergency response fund for management of new infestations of *Spartina* in Oregon, Washington, and California.

**<u>Task 2.4. Establish legal authority to respond to an invasion</u>**

Develop necessary permits to implement a full complement of responses to an invasion, such as an Alaska Department of Environmental Conservation (DEC) Pesticide Use Permit or a NPDES permit for herbicide application. Chemical control of *Spartina* will require a DEC Pesticide Use Permit from the Division of Environmental Health's Pesticide Control Program; exemptions to this requirement are available under emergency circumstances as determined by the Commissioner of the DEC. The Environmental Protection Agency (EPA) formally approved the state's National Pollutant Discharge Elimination System (NPDES) Program application, which will be called the Alaska Pollutant Discharge Elimination System (APDES) Program. DEC is assuming responsibility in phases between October 2008 and November 2011, but currently addresses wastewater discharge from hatcheries and seafood processing facilities (http://www.dec.state.ak.us/water/npdes/APDESAuthorityTransferSchedule.htm). DEC should track development of the national NPDES permit for aquatic herbicide applications currently under development to ensure that it is protective of the water resources of Alaska. If the national permit is not protective, begin development of a state NPDES permit for aquatic herbicide application.

**Task 2.5. Participate in regional management strategies**

*Spartina* is a regional issue since propagules are distributed on ocean currents. Recent efforts aimed at regional-level management coordination are already in place and have recognized the importance of invasive species to ocean health. The *Spartina* work plan of the West Coast Governors' Agreement on Ocean Health specifically aims to eradicate introduced *Spartina* spp. on the west coast by 2018. The Pacific Coast Collaborative may provide a vehicle for expansion of the work plan to British Columbia and Alaska.

**Task 2.6. Establish a rapid communication system (phone tree, robo-dialed messages, or official listserv) for all agencies and organizations that have *Spartina* management responsibilities and any other interested parties.**

If an invasion of *Spartina* is confirmed, it is important to notify the proper agencies and resource managers. A rapid communication system is needed to contact all agencies and organizations that have management responsibilities for *Spartina* (Table 10) and other interested parties (property owners/leasers and adjacent owners/leasers, local weed management area, etc). A point of contact within each participating agency and interest group should be identified; an initial list is provided in Appendix D.

Table 10. Government agencies with potential management responsibilities for *Spartina*.

| Agency | Responsibility |
|---|---|
| ADEC, Division of Environmental Health, Pesticide Control Program | Drinking water, food and sanitary practice, Pesticide registration, applicator training and licenses; Pesticide Use Permit; emergency exemptions from requirement for Pesticide Use Permit |
| ADEC, Division of Water | Regulates discharges to waters and wetlands; implements CWA & NPDES (APDES) program1 |
| ADFG | Management of native fish and wildlife for sustainable and harvestable surplus; tide-lands permitting |
| ADNR, Coastal Management Program | Stewardship, coordination, oversight for Alaska's coastal resources |
| ADNR, Division of Agriculture | Noxious weed control, inspections, and quarantines |
| ADNR, Division of Parks and Outdoor Recreation | Protects and interprets areas of natural and cultural significance; Maintenance of state-owned park lands supports the state's tourism industry |
| Alaska Federation of Natives | Protection of cultural and natural resources for Alaska indigenous peoples |
| Alaska Sea Grant, Marine Advisory Committee | Outreach and technical assistance for use of marine/coastal resources |
| Bureau of Land Management | Coastal land management |
| National Park Service | Coastal land management |
| NOAA Fisheries, Habitat Conservation Division: | Sustainable fisheries, Endangered Species Act, marine coastal ecosystem health |
| U.S. Army Corps of Engineers: | Navigation, dredging; authorizes leases for aquatic farms; Wetland fill permitting (section 404 permits of CWA) |
| U.S. Environmental Protection Agency: | Herbicide registration, implement Clean Water Act |
| U.S. Fish and Wildlife Service: | Habitat conservation, Endangered Species Act, refuge management |
| U.S. Forest Service | Coastal land management |

[1] Environmental Protection Agency (EPA) formally approved the state's National Pollutant Discharge Elimination System (NPDES) Program application, which will be called the Alaska Pollutant Discharge Elimination System (APDES) Program. DEC is assuming responsibility in phases between October 2008 and November 2011, but currently addresses wastewater discharge from hatcheries and seafood processing facilities. http://www.dec.state.ak.us/water/npdes/APDESAuthorityTransferSchedule.htm

### Task 2.7. Develop regional inventories of equipment/resources/volunteers available for rapid response efforts.

The lead agency should request inventories of available equipment and human resources from all cooperating agencies and organizations. Access to a boat and a qualified pilot are critical for access to estuarine sites. No single type of watercraft will be usable in all potential site types encountered when conducting *Spartina* surveys. Small boats are limited in that they cannot operate in very low water conditions; hovercraft and airboats can overcome this limitation to some extent, but have not been particularly useful – they have a small payload for their size, are difficult to maneuver in restricted areas, and have high maintenance costs. Airboats have proven to be more practical and cost effective in Willapa Bay due to their greater maneuverability. Maintenance costs are comparable to other equipment that is regularly exposed to salt water (C. Stenvall, USFWS, pers. comm. 2002). Hovercraft and airboat use are limited by weather conditions, especially wind. They are most useful in late spring and summer when weather conditions on the coast are most calm. Management of large infestations would likely require specialized pieces of equipment. Amphibious machinery is needed for work in areas of soft sediments. Specialized spray equipment such as boom-sprayers and precision-sprayers (which target herbicide application only on vegetation and do not spray over bare ground) may be needed in case of very large infestations.

**Task 2.8. Develop a list of managed areas susceptible to *Spartina* invasion in Alaska and contact responsible management entity to engage them in this plan.**

Protected areas and privately owned and managed estuarine habitats may require additional coordination for management of *Spartina*. Identify or develop a method for quickly identifying a landowner for a new site. Conduct a tabletop exercise with management authorities to simulate an actual *Spartina* discovery to determine where additional information gaps exist - e.g. where to find equipment or herbicide.

**Task 2.9. Provide annual reports on status, progress, and efficacy to all stakeholders and the general public.**

To ensure transparency and to facilitate coordination of activities the lead agency for implementation of the plan should produce an annual report on progress and status of *Spartina* management in Alaska.

**Task 2.10. Periodically assess the progress and efficacy of management strategies.**

A critical assessment of progress and efficacy of the management strategy is important. Future advances in *Spartina* management may require modifications of the approach necessary to ensure successful control/eradication of a *Spartina* infestation.

## Objective 3: Detection and Monitoring

*Strategy: Increase the likelihood of economical and successful eradication by detecting small infestations and regularly monitor treated populations in order to prevent reestablishment.*

**Task 3.1. Implement early detection surveys in susceptible areas using fixed-wing, helicopter, boat, and ground methods where appropriate/available.**

*S. alterniflora*, *S. anglica*, and *S. patens* surveys must be conducted during the growing season prior to senescence in the fall. *S. densiflora* has a perennial, evergreen growth habit and may be most visible in the high marsh following senescence of native salt marsh vegetation. Specific areas for active surveys are identified in the Shorezone *Spartina* habitat suitability model (Harney 2008).

**Task 3.2. Identify and train people to conduct "passive" surveillance, e.g., commercial oyster growers, waterfowl hunters, fishing guides, birders, clammers, boaters, agency employees, etc.**

Concerned citizens can be effective in early detection. Large-scale volunteer efforts like the CoastWalk program and other organized coastal marine debris removal groups could contribute to passive surveillance efforts in Alaska. Established programs for invasive *Carcinus* and tunicates have many people regularly walking or boating to habitat suitable for *Spartina* infestation; providing these volunteers with training and weather-resistant identification materials could efficiently target early detection of multiple invasive species. Such collaborative efforts could lead to increased funding opportunities through matching funds and increased networking between groups.

**Task 3.3. Establish protocols for confirmation of identification of suspected populations by trained personnel using photographs or specimens.**

Any *Spartina* sighting should be confirmed at the genus level as quickly as possible to avoid the costs and redirection of resources that would result from responding to false reports. There are several native grass species that resemble *Spartina* and grow in the same habitat, and identification of grasses can be difficult due to their unique morphology and the specialized terminology used in their classification. Identification to the genus level can be done quickly by personnel at Division of Agriculture or the Alaska Natural Heritage Program. Determination or confirmation to the species level may require consultation with taxonomic experts. A list of taxonomic experts is included in Appendix E. This list should be periodically updated to keep contact information current (last updated September 2009).

Molecular identification techniques have been applied in the study of the biology of *Spartina* on the west coast. The *S. densiflora* infestation recently discovered in Grays Harbor, Washington, for example, was determined by D. Strong's lab at UC Davis to be identical to the *S. densiflora* growing in San Francisco Bay (W. Brown, pers. comm.). Samples of any confirmed *Spartina* spp. should be submitted to researchers having the capability to employ such analyses in an attempt to determine the potential source of any Alaska infestation.

**Task 3.4. Upon confirmation, conduct delimiting surveys in nearby similar habitat**

Following positive identification, ownership of the site needs to be determined, notification made to pertinent parties and a comprehensive, delimiting survey should be initiated. The purpose of this survey is to gain information needed to support several decisions, some of which may need to be made quickly – such as whether control efforts should begin immediately or whether they can be safely delayed (i.e. is flowering/seed set evident, will disturbance potentially spread rhizomes). The delimiting survey should include estimates of net (area occupied if all plants in the infested area were a monoculture in one patch) and gross (area encompassed by lines connecting the outlying plants) infested area. Areas can be determined with GIS software using GPS coordinates of plants located in the field or using GPS units capable of recording polygon data. In addition to the exact location and physical extent of the infestation, information necessary for effective control includes data on plant height, reproductive state (e.g., flowering or shedding seed), and substrate type. Other data, such as site history, would be useful to optimize future prevention and detection efforts. A checklist of important questions that should be answered when doing the survey is provided in Appendix F. Photos of the plant and site should also be taken.

**Task 3.5. Establish timelines for control measures and remove inflorescences prior to seed set.**

Determine if treatment is feasible for the current year. Allow for acquisition of any required permits and/or exemptions, acquisition of equipment and supplies, and identification of a safe, effective treatment window. If the timing of detection does not allow for treatment in the same year, all inflorescences should be removed prior to seed set if possible (late summer to early fall) and the windows for treatment should be scheduled in the following year.

**Task 3.6. Develop mapping/database capabilities to record surveyed areas and collect baselayers for all susceptible habitat.**

Obtain base maps and maintain a database for mapping new infestations and active and passive survey activities (including confirmed absence data), suspect sites, results of follow-up visits, and location of access points. Ideally, record keeping would include geo-referenced data with minimum data standards established in advance and communicated to all survey parties. Protocols already developed for the AKEPIC program (http://akweeds.uaa.alaska.edu) cover standards for data collection and submission, as well as data management; these protocols could provide a suitable framework for collecting information on survey results and management efforts.

**Task 3.7. Plan for multiple year treatments, long-term monitoring, and use an adaptive management approach**

Treatment cannot be considered as a one-time operation; experience with other *Spartina* infestations and with other weed species shows that several years will be required to eradicate any *Spartina* species. Rhizomes of *Spartina alterniflora* are extremely robust and may survive long periods with little above-ground growth. A commitment to long-term management is critical to the success of any weed control efforts; data from Puget Sound shows that if *Spartina* is left untreated for just one year, vigorous regrowth exceeds the amount of cover reduction achieved with the previous year's treatment (Reeder and Hacker 2004). A minimum of six years with no regrowth at a site should be required to declare a population eradicated.

A critical assessment of the total progress and efficacy of the management strategy is also important. Modifications to management techniques or the entire strategy might be necessary to ensure successful control/eradication of a *Spartina* infestation.

## Objective 4: Education and Outreach

*Strategy: Increase public recognition and understanding of the threat of invasive Spartina to Alaska's natural resources and to recruit more citizens and agency personnel in passive surveillance.*

### Task 4.1. Streamline reporting of suspected *Spartina* infestations and response to reports.

There are currently three different venues for reporting invasive plants and/or animals in Alaska.

1. The Alaska Department of Fish and Game maintains a phone number for citizens to report suspected invaders, both plant and animal at 1-877-INVASIV (1-877-468-2748). Calls go to Tammy Davis.
2. The Alaska Natural Heritage Program maintains the Alaska Exotic Plant Information Clearinghouse (AKEPIC) (http://akweeds.uaa.alaska.edu/; accessed September 4, 2009). This database collects data on distributions and abundance, requires a log-in and adherence to clearly stated minimum data requirements; allows batch entries; and makes data publicly available through downloadable spreadsheets that are periodically updated. Reports go to Alaska Natural Heritage Program and are displayed on EDDMapS.
3. The EDDMapS Alaska - Early Detection Reporting Form targets reporting of new invasives to Alaska and new sightings in areas previously uninfested which require immediate attention; it focuses on five high priority weeds, one of which is *Spartina alterniflora*. The others are spotted knapweed, purple loosestrife, giant hogweed, and leafy spurge. The reporting form requires personal contact information, infestation description, location, and addition of images for confirmation purposes. (http://www.eddmaps.org/alaska/report/report.cfm; accessed December 22, 2009). Reports go to Gino Graziano at the Alaska DNR Division of Agriculture

Multiple reporting methods are not detrimental if reports to all venues result in the same response. The EDDMapS Alaska form should be modified to allow for reporting of all *Spartina* species, in order to send a clear message of the threat posed by all invasive cordgrasses. Additionally, protocols for sharing of reports, and results from reports, should be implemented in order to reduce duplicate responses.

### Task 4.2. Publicize and reinforce opportunities for citizens to report new invasives

Public service announcements, press releases, and web sites should be used to publicize methods of reporting invasive species sightings.

### Task 4.3. Conduct outreach and education about the risks and impacts of *Spartina* to citizen scientists, shellfish growers, researches, educators, and other Alaskans.

Outreach should target specific groups or stakeholders with an interest in the habitat or wildlife which *Spartina* is likely to impact, often such interest groups include beach combers, birders, shell collectors, amateur naturalists, eco-tourists, and recreational fishermen and clammers that frequent habitats where *Spartina* spp. may become established. Commercial oyster growers, clam growers and other mariculture professionals, particularly, should be targeted for outreach due to their knowledge of marine species, extensive time spent in or near suitable habitat, and the likelihood that their industries will be negatively impacted by *Spartina*. General outreach to citizenry on invasive species may aid in prevention of introduction and result in support for management efforts should an infestation be found. Outreach can include presentations at meetings, club events, or special events (such as fairs or sportsmen/fishing expos), the distribution of printed materials, or by meeting with the leaders of special interest groups. Written outreach materials such as pamphlets, booklets, informational sheets/cards, and scientific reports can augment and enforce first-hand training and field experience.

Many government organizations actively produce and distribute materials on non-native species: Alaska Department of Fish and Game, University of Alaska Fairbanks Cooperative Extension Service, Alaska Committee for Noxious and Invasive Plants Management (CNIPM), Prince William Sound Regional Citizens' Advisory Council (PWSRCAC), and Kachemak Bay Research Reserve (KBRR). Efforts to inform the public about *Spartina* and other non-native species at these and other public access points should be continued and expanded when possible.

**Task 4.4. Modify or expand outreach materials to include *Spartina*-specific information on susceptible habitats, identification and reporting guidelines.**

Outreach materials that target *Spartina* specifically, and that send consistent, coordinated messages on susceptible habitat, impacts, and reporting guidelines for *Spartina* would be useful to increase successful detection efforts. General interest materials regarding the entire genus may be helpful to reach broad demographics with lay-level understanding of invasion dynamics and/or knowledge of the intertidal habitats in Alaska. More detailed outreach materials for targeted audiences, green crab (*Carcinus maenas*) monitors for example, would be helpful to minimize false alarms generated by native plant look-alikes. Develop outreach materials with identification and reporting guidance targeted at specific groups, such as birders, clammers, and boaters.

Floral characteristics are typically used in plant identification; however, detection may not coincide with flowering. The Portland State University Center for Lakes and Reservoirs developed "Key to West Coast *Spartina* Based on Vegetative Characters" to enable identification by vegetative characteristics. This key is available from the Alaska Invasive Species Working Group website (http://www.uaf.edu/ces/aiswg/resources-links.html#InvasivePlants) and should be widely distributed among botanists across coastal Alaska.

## Objective 5: Research

*Strategy: Expand knowledge about vectors, susceptible habitat, and management to enhance efficacy of prevention, detection, and management.*

**Task 5.1. Investigate use of remote sensing techniques for detection of *Spartina*.**

Survey of the long coastline of Alaska for *Spartina* infestations would be most cost-effectively done if reliable remote sensing capabilities existed. Satellite imagery is useful for detecting new invasions of *S. alterniflora* and *S. anglica* in intertidal areas, but it is less useful for detecting *S. patens* and *S. densiflora* in high-elevation marsh where they are intermixed with native salt marsh vegetation. Improvement in spatial and spectral quality of remote sensing techniques may make the methodology more useful.

**Task 5.2. Investigate migration pathways of migratory birds that use susceptible habitat.**

Birds are known vectors for *Spartina* seed. Identifying locations in Alaska used by migratory birds that use infested habitats on the west coast would assist in identification of high-risk habitats.

**Task 5.3. Determine the effects of ocean acidification and salinity on vegetative growth on *Spartina* spp. and germination/establishment of *Spartina* seed.**

**Task 5.4. Develop new management strategies**

More effective and environmentally friendly management techniques are needed for *Spartina*. In particular, new herbicides and application methods that minimize nontarget impacts are needed to manage *S. patens* and *S. densiflora*, which inhabit the high marsh where native plant species are present.

**Task 5.5. Develop more sophisticated coastal transport models to predict dispersal of *Spartina* propagules from infested sites on the west coast to susceptible Alaska habitats.**

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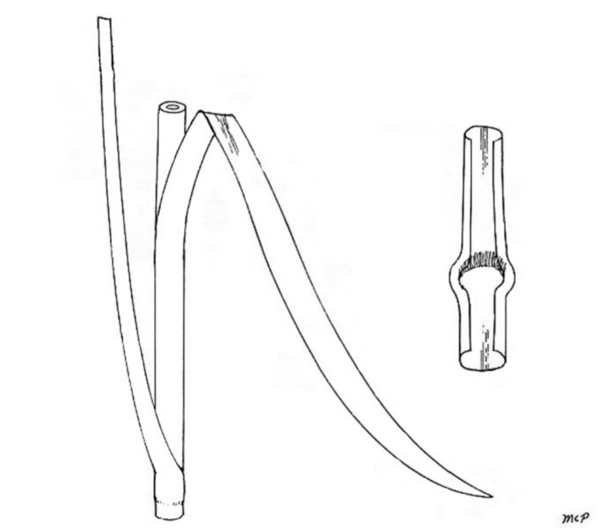
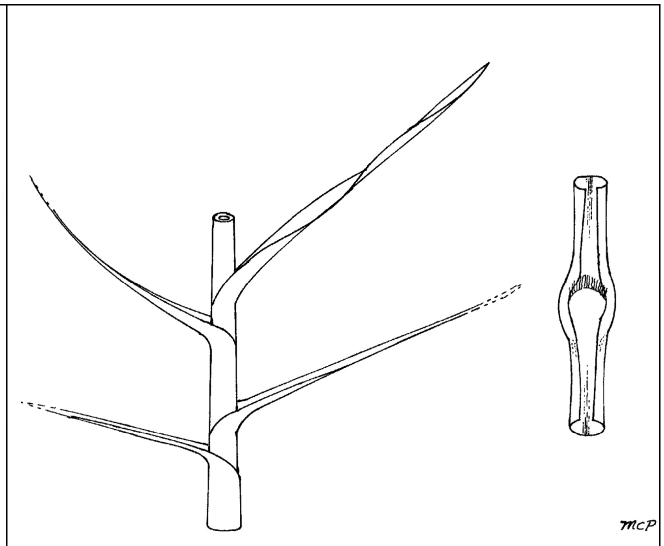
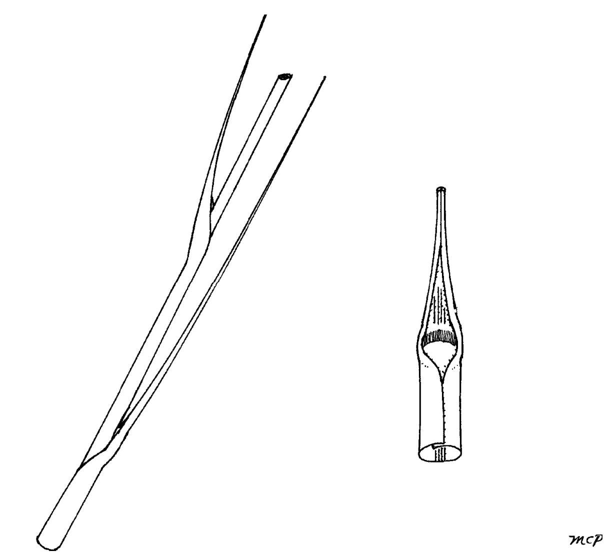
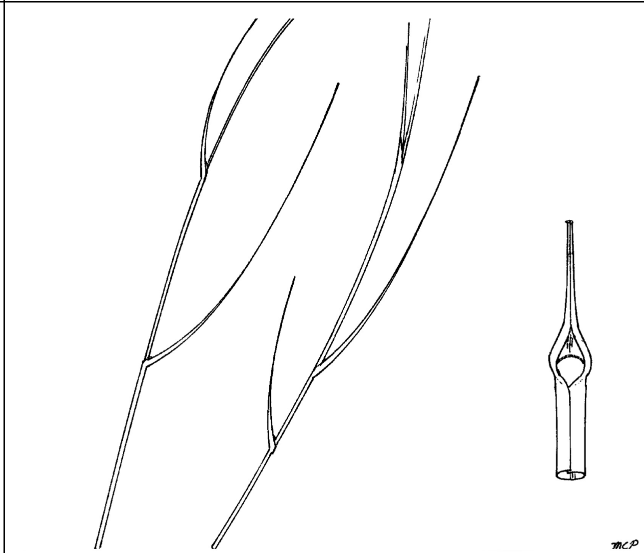
## Appendix A: Vegetative characteristics of invasive *Spartina* spp. – line drawings and comparative table (Adapted from the *Key to West Coast Spartina species based on vegetative characters* (Pfauth and Sytsma 2007).

| | |
|---|---|
|  |  |
| *Spartina alterniflora* Loisel. (smooth cordgrass) | *Spartina anglica* C.E. Hubbard (common cordgrass) |
|  |  |
| *Spartina densiflora* Brongn. (denseflower cordgrass) | *Spartina patens* (Aiton) Muhlenb. (saltmeadow cordgrass) |

| | *S. alterniflora* | *S. anglica* | *S. densiflora* | *S. patens* |
|---|---|---|---|---|
| **Stems** | | | | |
| Diameter at base | 5-14 mm | 5 mm | 3-16 mm | 1.5-4 mm |
| Height | Up to 3 m | Up to 1 m | Up to 1.5 m | Up to 1.2 m |
| Ridges around stem | 2 per mm | 3 per mm | 2 per mm | 6 per mm |
| Internodes | Fleshy | Fleshy | Firm | Fleshy |
| Surface | Glabrous | Glabrous | Glabrous | Glabrous |
| Shape | Terete | Terete | Terete | Terete |
| Color | Often red at the base of health young shoots | - | - | - |
| **Leaves** | | | | |
| Fresh condition | Flat | Flat | Inrolled | Inrolled |
| Width at base | 4-25 mm | 5-12 mm | 4-8 mm | 1-4 mm |
| Length | 20-55 cm | 5-40 cm | 12-43 cm | 10-50 cm |
| Nerves on upper surface | ± 6 per mm | ± 6 per mm | ± 2 per mm | ± 3 per mm |
| Tip shape | Acuminate | Acuminate | Acuminate | Acuminate |
| Upper surface | Glabrous | Glabrous | Glabrous, with pronounced ridges, ridges, and leaf margins minutely ciliate | Glabrous |
| Lower surface | Glabrous | Glabrous | Glabrous | Glabrous |
| Ligule length | 0.7-2 mm | 2-3 mm | 1-2 mm | 0.5 mm |
| Angle between leaf and stem | 15° - 18° | 30° - 90° | - | - |
| **Rhizomes** | | | | |
| Texture | Fleshy | Fleshy | none | Thin, wiry |
| Color | Whitish | Whitish | - | Whitish |
| **Growth Habit** | Dense stands | Dense stands | Caespitose | Dense stands |
| **Habitat** | | | | |
| Intertidal range | Intertidal to mid/high salt marsh | Intertidal to low salt marsh | Lower salt marsh to upper intertidal | Mid-upper salt marsh |
| Substrate | Mud, sand, cobble | Mud, sand, cobble | Mud, sand, cobble | Mud, sand |

## Appendix B: Evaluation of *Spartina* spp. using the Invasiveness Ranking System for Non-Native Plants of Alaska (Carlson et al. 2008)

(Available online: http://www.fs.fed.us/r10/spf/fhp/invasive/invasiveness%20ranking%20report.pdf)

Ranking Summary

| | | |
|---|---|---|
| Ecoregion known or expected to occur in | | |
| South Coastal | | Yes |
| Interior Boreal | | No |
| Arctic Alpine | | No |

| | Potential Max. | Score |
|---|---|---|
| Ecological Impact | 40 | 40 |
| Biological Characteristics and Dispersal | 25 | 17 |
| Amplitude and Distribution | 25 | 23 |
| Feasibility of Control | 10 | 6 |
| Relative Maximum | | 86 |

Climatic Comparison

| | Collected in Alaska regions? | CLIMEX similarity? |
|---|---|---|
| South Coastal | No | Yes |
| Interior Boreal | No | No |
| Arctic Alpine | No | No |

No species of *Spartina* has been collected in Alaska (AKEPIC 2004, UAM 2004). *Spartina alterniflora* is native to the Atlantic and Gulf coasts of North America, occurring from Newfoundland south to Florida and Texas (USDA 2002, WAPMS 2004). Using the CLIMEX matching program, climatic similarity between Juneau and Grand Banks and St. Johns, Newfoundland is high (55% and 54% respectively). There is a 45% similarity between Juneau and Eastport, Maine. Further, aquatic species are generally less impacted by variation in terrestrial climates. It is likely to establish in the south coastal region of Alaska.

| Ecological Impact | Score |
|---|---|
| Impact on Ecosystem Processes (0–10) | 10 |

The dense stands of smooth cordgrass trap and holds sediments, decrease waterflow and circulation and lead to flooding. Invertebrate communities associated with unvegetated mudflats are replaced by saltmarsh species due to *Spartina* invasion (Daehler 2000, Jacono 1998, WAPMS 2004).

Impact on Natural Community Structure (0–10) — 10

*Spartina* colonizes bare sites, creating a new vegetative layer (Daehler 2000, Walkup 2004, WAPMS 2004).

Impact on Natural Community Composition (0–10) — 10

*Spartina* displaces native plants, such as *Zostera marina, Salicornia virginica,* and *Triglochin maritinum* (WAPMS 2004). It also results in decreases in benthic invertebrates and algae populations. Studies indicate that populations of invertebrates in the sediments of *Spartina alterniflora* clones are smaller than in mudflats (WAPMS 2004, Jacono 1998).

Impact on Higher Trophic Levels (0–10) — 10

*Spartina* stands lower light levels and cause decreases in algae production (Walkup 2004). Subsequently, it causes a reduction in refuge and food sources for clams, fish, crabs, waterfowl, and other marine life (Daehler 2000, WAPMS 2004). In Alaska, chum salmon (*Oncorhynchus keta*), English sole (*Pleuronectes vetulus*), and Dungeness crab (*Cancer magister*) depend on mudflat habitats; they would likely be affected by cordgrass invasion (Jacono 1998). Large populations of *Spartina* can also cause loss of important foraging and refuge habitat for shorebirds and waterfowl (WAPMS 2004). In its native range, it is a favorite of muskrats, nutria, and other grazing animals (Materne 2000, Waklup 2004).

Total for Ecological Impact — 40/40

| Biological Characteristics and Dispersal | Score |
|---|---|
| Mode of Reproduction (0–3) | 3 |

Smooth cordgrass reproduces both by seed and rhizomes. While seeds are important for colonizing new areas, the expansion of established stands is primarily due to vegetative growth. Clones spread laterally by vegetative shoots often more than 3-feet per year, producing a characteristic circular growth pattern (Daehler 2000, WAPMS 2004).

Long-distance dispersal (0–3) — 2

The seed can be dispersed by water. Waterfowl can potentially transport seeds to new areas. Dispersal by floating wracks of vegetation is probably the most important long-distance dispersal mechanism (Sytsma et al. 2003). Vegetative fragments may be spread to sites prone to erosion (Daehler 2000).

Spread by humans (0–3) — 3

It was intentionally introduced on the west coast for erosion control. Additional pathways of introduction include shipping, commercial shellfish operations, ballast water, boats, and other equipment (Sytsma et al. 2003, WAPMS 2004).

Allelopathic (0–2) — 0

This species has no known allelopathic effects (USDA 2002).

Competitive Ability (0–3) — 1

Once it is established, smooth cordgrass outcompetes native vegetation (Jacono 1998). It does not compete well with mature established plants (Walkup 2004).

Thicket-forming/Smothering growth form (0–2) — 2

Smooth cord grass forms dense, monospecific stands in salt and brackish marshes (Jacono 1998).

Germination requirements (0–3) — 0

Seedlings are unable to survive under the vegetative canopy, maximum establishment is recorded on bare patches (Waklup 2004, WAPMS 2004).

Other invasive species in the genus (0–3) — 3

*Spartina anglica* C.E. Hubbard, *S. densilfora* Brongn., and *S. patens* (Ait.) Muhl. are considered invasive on the west coast (Daehler 2000, Sytsma et al. 2003).

Aquatic, wetland or riparian species (0–3) — 3

*Spartina alterniflora* is a plant of the intertidal zone, colonizing, bays, lagoons, ponds, and ditches (Walkup 2004, WAPMS 2004).

Total for Biological Characteristics and Dispersal — 17/25

| Ecological Amplitude and Distribution | Score |
|---|---|
| Highly domesticated or a weed of agriculture (0–4) | 4 |

A few cultivars have been developed, and they are commercially sold. They are used for erosion control and oil spill mediation along shorelines (Materne 2000, USDA 2002, Walkup 2004).

Known level of impact in natural areas (0–6) — 6

In Willapa Bay, Washington, *Spartina alterniflora* has displaced approximately 20% of critical habitat for wintering and breeding aquatic birds (WAPMS 2004). In California, it has invaded San Francisco and Humboldt Bays, threatening to transform open mudflats into a single-species tall grass community (Daehler 2000, Daehler and Strong 1994). A population established in the Siuslaw estuary in Oregon, and numerous sites are known from Washington (Jacono 1998).

| | |
|---|---|
| Role of anthropogenic and natural disturbance in establishment (0–5) | 5 |

*Spartina* has been recorded as established on sites with no anthropogenic disturbances (Daehler 2000, Jacono 1998, WAPMS 2004).

| | |
|---|---|
| Current global distribution (0–5) | 3 |

Smooth cordgrass is native to the Atlantic and Gulf Coast marshes of North America. Its introduced range includes the west coast of North America, Europe, and New Zealand (Baird and Thieret 1993, Daehler 2000, WAPMS 2004).

| | |
|---|---|
| Extent of the species U.S. range and/or occurrence of formal state or provincial listing (0–5) | 5 |

*Spartina alterniflora* occurs in all coastal states from Newfoundland to Florida and Texas (USDA 2002, WAPMS 2004). It is declared noxious in Oregon and Washington (Invader Database System 2003).

| | |
|---|---|
| Total for Ecological Amplitude and Distribution | 23/25 |

| Feasibility of Control | Score |
|---|---|
| Seed banks (0–3) | 0 |

The seeds remain viable for only 8–12 months, and they do not withstand desiccation. The species does not have a persistent seed bank (Daehler 2000, Mooring et al. 1971, WAPMS 2004).

| | |
|---|---|
| Vegetative regeneration (0–3) | 2 |

After removal of aboveground growth plant can resprout (WAPMS 2004).

| | |
|---|---|
| Level of effort required (0–4) | 4 |

Smooth cordgrass can grow on very soft, deep mud, making infestations nearly inaccessible by foot or boat. Hand pulling or digging seedlings is suggested for small infestations (less than 5 acres). Special care should be taken to remove both shoots and roots. Shading small *Spartina* clones with woven geotextile fabric was successful in Oregon. Mowing and herbicide treatment can limit growth and seed set (Daehler 2000, Sytsma et al. 2003).

| | |
|---|---|
| Total for Feasibility of Control | 6/10 |
| Total score for 4 sections | 86/100 |

## Appendix C: Summary of Proposed Treatment Methods (modified, with permission, from San Francisco Invasive *Spartina* Project)

| | Hand-pulling and Manual Excavation | Covering/Blanketing | Pruning, Mowing & Burning |
|---|---|---|---|
| **Appropriate Setting** | Seedlings, particularly in newly infested areas. Appropriate for small clumps and isolated clones, or sparse infestations. | Small to medium size clones. Larger stands are not easily covered due to the labor-intensive nature of transporting and installing the fabric, and high cost. | Small to medium area. To reduce biomass and facilitate other methods, or to remove inflorescences to prevent cross-pollination. Use repeatedly to stress and kill plants. |
| **Removal Technique** | Removal of plant and below ground material up to 4 feet deep. | Covering blocks light from reaching the plants and interrupts photosynthesis. | Pruning- clip seed heads.<br>Mowing- cut plant at, near, or just below the soil surface for best results<br>Chemical mowing- use weak concentration to stop seed set and preserve standing biomass for clapper rail refugia<br>Burning- use handtorch to burn seed head, or controlled burn to clear standing necromass to expose seedlings |
| **Equipment Requirements** | Shovels, trowels, bags, wheelbarrows, handcarts, sleds, trucks for transport of removed material. | Geo-textile fabric (Amoco 2002 or 2006, or Mirafi 500); 7"-9" spikes/stakes; grommets or washers. Fabric should extend 2 ft. beyond edge of patch on all sides. | Clippers, weedeaters, small mechanical cutters, handtorches, helicopter with boom for chemical mow. |
| **Workforce Requirements** | Depends on the age and density of the population. An approximate 10-person workforce would be required to pull or dig out a low-density seedling area of about 0.25-acre in an 8-hour day. | Approximately 2-5 persons would be required to place covers over treatment areas, depending on the size of the area. Requires periodic monitoring for tears or movement of covers. | Varies depending on method & height and density of vegetation. Approximately 2-3 persons required to treat a 0.25-acre area with weedeaters over 8 hours. |
| **Timing** | This method can take place during any season, but is most frequently done in the spring. 1-2 visits per location per year are needed to prevent reestablishment or resprout. | Placing covers early in the growing season would eliminate the need for mowing. Covers must remain in place for two growing seasons to kill plants. | Mowing can be done during growing season. Seed heads form in summer and fall. Eradication by mowing alone would require up to 4-6 treatments annually, for a minimum of 2 years. Burning to expose new growth would be conducted in spring. |
| **Effectiveness** | Depends on the diligence of the work crew. Any portion of rhizome left behind can potentially sprout and re-establish the clone. Complete removal results in eradication. | Covering has been successful in the S.F. Estuary on small patches up to 36 feet in diameter. Failure results from improper installation and/or maintenance. Improperly sealed seams (or lack of sufficient overlap) allow plants to grow through or around the covers. Wind or tidal action may dislodge covers. Sediment may accumulate on the covering. | Results of field tests are variable, and dependent on the frequency and the start date. Repeated application eventually weakens rhizomes and reduces energy reserves. One application may invigorate a plant. Therefore, multiple treatments are necessary. |

| | Mechanical Excavation & Dredging | Herbicide, Ground or Boat Application | Herbicide, Aerial Application |
|---|---|---|---|
| **Appropriate Setting** | Large individual clones >25 feet in diameter or clusters of clones in the mid to lower tidal zone that can be accessed by floating dredge, or by excavator in the upper marsh. | Small, medium, and large individual clones and meadows. Application of herbicide may be used in conjunction with seed head clipping and mowing; must allow sufficient regrowth after mowing to absorb herbicide. | Large, heavily infested areas, meadows, or difficult to access sites. |
| **Removal Technique** | Cutterhead dredge (or similar) on floating barge or excavator removes entire plant and root mass to a depth of 1 foot, and disposes in upland. | Imazapyr and/or glyphosate herbicide is combined with a surfactant & colorant and is sprayed, wiped, or painted on foliage, or applied as a paste on cut stems. | Imazapyr/surfactant mix applied by spray apparatus attached to a helicopter consisting of a boom with multiple nozzles for broadcast delivery |
| **Equipment Requirements** | Dredge or excavator, trucks to remove material (if not slurried and piped to destination) | Imazapyr or glyphosate herbicide, surfactants, colorants, backpacks, spray truck, shallow-bottom boat, airboat, tracked amphibious vehicle, hovercraft. | Imazapyr herbicide, surfactants, colorants, helicopter with boom or spray ball. |
| **Workforce Requirements** | One operator per vehicle, and 1-2 persons needed on site during operations. | 1-2 persons needed for small infestation. Backpack crews in heavily infested areas with difficult access would range from 2-6 persons. Typical crews for large infestations would include 2-3 persons per ground application vehicle, or 1-3 persons per boat with support from 1-3 trucks. | Pilot and a ground crew of approximately 2-4 persons. |
| **Timing** | Any time of year. | Mid-summer through early fall. | Mid-summer through early fall. |
| **Effectiveness** | Large-scale demonstration work in Washington and British Columbia indicates moderate efficacy. | The length of time from application to high tide (i.e. dry time), wind and weather conditions, application method, and timing of application in the plant's life cycle are all important factors. Efficacy can range from 0-100 percent. | See previous method. |

## Appendix D: Contact information for participating agencies and interest groups.

Alaska Department of Fish and Game - Division of Sport Fish
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Kachemak Bay Research Reserve
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Prince William Sound Regional Citizens' Advisory Council
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NOAA Marine Debris Program
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OR:
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US Fish and Wildlife Service - Aquatic Invasive Species Program
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## Appendix E: Partial list of recognized *Spartina* experts on the Pacific coast of North America

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## Appendix F: Delimiting survey checklist

1) Exact location of infestation (GPS coordinates, datum, directions, etc.):
2) Extent of infestation:
   a) Net acreage (infested acreage):
   b) Gross acreage (affected acreage):
3) Stage of maturity:
   a) Seedling
   b) Juvenile
   c) Mature
   d) Vegetative only
   e) Flowers
   f) Seeds
4) Might there be similar areas infested?
5) Is there a need for additional detailed detection surveys?
   a) Adjacent to the site determined to be infested
   b) In other areas having apparent similarities
6) What characteristics of site use might have led to its being infested?
   a) History of use of the site
   b) Recent changes in site use
   c) ”Risky" uses of the site
   d) Has the site been disturbed
   e) Is it a shellfish harvest site
      i) Are shellfish produced commercially on or near the site
      ii) Are shellfish harvested on or near the site
7) Is there evidence of dredging, or of deposition of dredge material
8) What are the physical characteristics of the site?
   a) Height in relation to tidal heights
   b) Substrate composition
   c) Salinity and salinity variation
   d) Exposure to wind, waves and currents
   e) How does this site compare with those outlined in Daehler & Strong's 1996 paper
9) Who owns, uses, and/or manages the site?
   a) What do owners/users/managers of the site know of the infestation, the history of the infestation and/or history of the site itself?
   b) When did they become aware of the infestation
   c) If they know of the infestation did they report it
   d) If they knew of the infestation before, did they know that it was *Spartina*
10) In what way might information about the infested sight be used to improve future detection efforts?