2007

Oregon Spartina Response Plan

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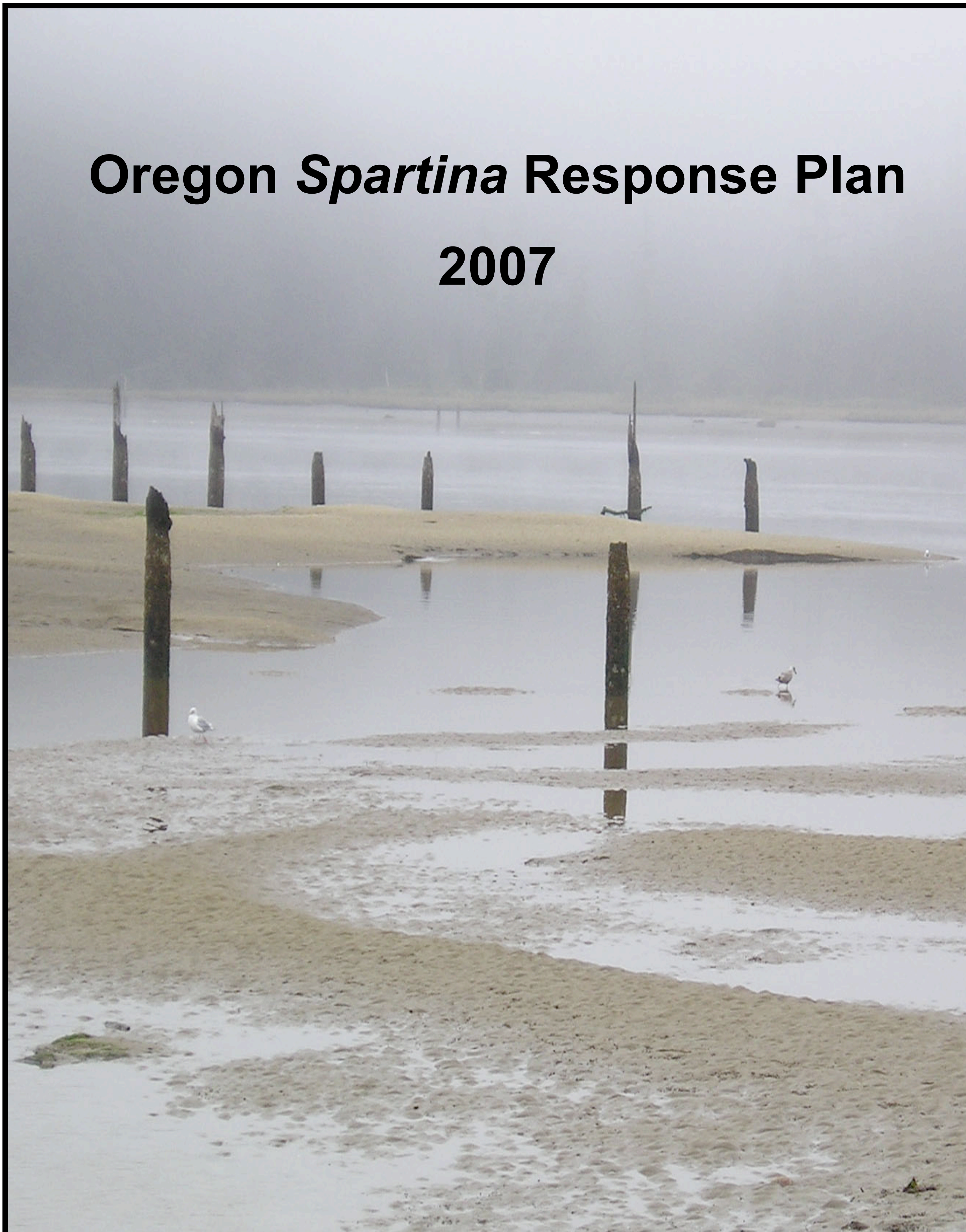

Oregon *Spartina* Response Plan

Prepared for

Oregon Department of Agriculture

By

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EXECUTIVE SUMMARY

Four introduced, invasive species of *Spartina* (cordgrass) have been present in estuarine areas of the U.S. west coast for over a century. These *Spartina* species are ecological engineers – they can cause severe alterations in the hydrology and food webs of invaded estuaries that are detrimental to native wildlife and commercial and recreational uses. Oregon has been relatively free of these weeds, with only three known infestations. One infestation is currently under control measures by The Nature Conservancy of Oregon; a second infestation (previously deemed eradicated by the Oregon Department of Agriculture in 1997) evidently persisted with re-growth found during early detection surveys in 2005; and a third infestation in a new watershed was detected during those same 2005 surveys.

Large infestations of these noxious weeds exist in estuaries in Washington and California. Known vectors for transport of *Spartina* seeds between estuaries include ocean currents, waterfowl, dredging and shipping operations, and intentional and unintentional introductions. The exponential growth rates and huge seed set of these populations in recent years, combined with multiple mechanisms of seed transport to Oregon, mean that Oregon estuaries are likely sites for new infestations by one or more cordgrass species in the near future.

Experience with *Spartina* control elsewhere has demonstrated that the most cost-effective way to eradicate this pest is to detect and eradicate pioneer infestations. Rapid, coordinated response is critical to effective eradication efforts.

This Oregon *Spartina* Response Plan reviews the biology and historical and current information of *Spartina* on the west coast and outlines a strategy to prevent, detect, identify, and eradicate the weed in Oregon. <u>The goal of *Spartina* management in Oregon is to prevent the establishment and spread of any *Spartina* species in Oregon estuaries and coastal wetlands.</u> It identifies the Oregon Department of Agriculture as the lead agency in this effort, but describes a coordinated approach that requires the cooperation of preserve and refuge managers, mariculturists, state and federal agencies, and those who use Oregon's estuaries to protect them from *Spartina* damage.

Outreach and education about the threat and management of *Spartina* and measures to prevent introduction are important elements of the Plan. The many potential pathways of introduction, however, suggest that *Spartina* is highly likely to invade Oregon estuaries. Therefore, early detection and rapid response are key components of the Plan.

Detection will be done using aerial, boat, and ground surveys. Taxonomic experts that are identified in the Plan will positively identify any suspect plants. The Plan provides a scaled response to the detection of *Spartina* in Oregon based on the species, size and stage of growth of the infestation, efficacy of various management techniques, and site characteristics. Management options include digging and covering, mowing, and chemical methods. An integrated strategy that includes a combination of management methods is likely to be required.

In the four years since the original version of the Oregon *Spartina* Response Plan was released, notable events occurred in the management of invasive cordgrasses and our understanding of *Spartina* biology. Novel chemical treatments and persistent manual techniques were developed that are successful in reducing infestation sizes and new locations of *Spartina* have also been confirmed. Turnover in agency staff requires periodic updating of contact information. Research has elucidated dispersal mechanisms and new research approaches are needed to advance the Plan.

The following management actions and research activities were conducted since the *Spartina* Response Plan was adopted in 2003:

- House Bill 2577, in the 2005 legislative session, designated the Oregon Department of Agriculture as the lead agency for weed management in Oregon
- Opportunities for regional coordination of *Spartina* management were pursued
- Annual surveys of Oregon estuaries using fixed-wing, ground, or boat methods were conducted
- Ongoing efforts to control *S. patens* on Cox Island were supported
- Developed agreements with UC Davis & Bodega Marine Laboratory for genetic analysis of *Spartina*
- All species of *Spartina* were designated as "T" listed noxious weeds (2/14/03) and *S. patens* was placed on the “A” list of Oregon noxious weeds (2004)

- Coordinated *Spartina* outreach and education with ongoing efforts by Sea Grant and Oregon Invasive Species Council
- Trained people that can conduct “passive” surveillance, e.g., commercial oyster growers, watershed council members, etc.
- Supported ongoing control efforts in California and Washington aimed at strategies that minimize export of seeds and vegetative propagules
- Acquired base maps of all Oregon estuaries for GIS mapping of potential new infestations
- Evaluated ability of root, rhizome, and stem fragments to resprout
- Examined potential survival and viability of plant fragments, i.e., survival time according to rhizome size, duration of floatation, and salinity
- Evaluated possible spatial and temporal patterns of dispersal from three major *Spartina* infestations along the west coast, evaluating Oregon’s relative risk for invasion by the various populations’ representative species.
- Developed various educational materials including an invasive cordgrass brochure, the *Key to Select Grasses of the Oregon Coast* and distributed the *Key to West Coast Spartina Based on Vegetative Characteristics*.

This update to the Plan reflects the scope and findings of work undertaken in Oregon and elsewhere. Revisions include updated information on infestation sizes, recent improvements in control techniques, the extent and results of surveys in Oregon’s susceptible habitat, and results from research on rhizome survival and potential drift of propagules on ocean currents. We also updated contact information for various collaborators and equipment useful for surveying and/or control efforts.

The following actions are recommended for the future:

Management

- Ensure that the Plan and ODA’s lead role as designated in statute is understood by potential collaborating agencies
- Work toward intra- and interstate coordination of *Spartina* management
- Conduct annual surveys of Oregon estuaries using fixed-wing, ground, and boat methods as appropriate
- Track potential changes in permit requirements for herbicide application
- Support ongoing efforts to control *S. patens* on Cox Island
- Review and clarify the ODFW Live Fish Transport Permit requirements (and their application) to minimize the risk of importing *Spartina* propagules into Oregon with live fish and shellfish.

- Develop list of managed areas susceptible to *Spartina* invasion in Oregon and contact responsible management entity
- Update inventory of equipment currently available and acquire necessary equipment (such as an airboat) for rapid response
- Coordinate *Spartina* outreach and education with ongoing efforts by Sea Grant and Oregon Invasive Species Council
- Identify and train people to conduct “passive” surveillance, e.g., commercial oyster growers, waterfowl hunters, fishing guides, etc.
- Develop best management practices for solid ballast in dredges to prevent spread of *Spartina* (see research items below)
- Support ongoing control efforts in California and Washington – develop strategies to minimize export of seeds and vegetative propagules
- Work with USFWS and other interested parties to develop a management strategy for *S. densiflora* in Humboldt Bay
- Use GIS to map substrate type, tidal height, and wave action to focus surveys on areas most likely to support *Spartina*
- Identify source of funds to implement this Plan

Research

- Evaluate and prioritize dispersal and introduction pathways, including role of shellfish transport in the dispersal of *Spartina*
- Investigate role of solid ballast on dredges and migratory birds in dispersal of *Spartina*
- Investigate use of remote sensing techniques for detection of *Spartina*
- Evaluate the impact of *S. densiflora* on high elevation marsh habitat quality and bird use in Humboldt Bay
- Evaluate changes in carbon and nitrogen flow in food webs of estuaries invaded by *Spartina*

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INTRODUCTION AND PROBLEM DEFINITION

Several species of cordgrass (*Spartina alterniflora, Spartina anglica, Spartina densiflora*, and *Spartina patens*) are exotic, invasive plant species in estuaries of 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 severely disrupt the hydrology and ecology of infested estuaries (Baye 2004, Levin et al. 2006)

The dense stems and thick mat of roots and rhizomes of Spartina are very effective at filtering and trapping sediment particles brought in by river and tidal currents. Because of this effect, Spartina species have been introduced into coastal wetlands for erosion control. Sediment trapping by Spartina increases elevation of intertidal lands. Spartina marsh elevations in southern England rose at rates ranging from 2 to 6 cm (~ 0.8 to 2.4 in.) per year over 50 years (Ranwell 1964). Thompson et al. (1991) showed Spartina-related sediment accumulation in different regions across Europe ranged from 0.2 to 10 cm (0.1 to 3.9 in.) per year (in Lacambra et al. 2004). One year of sediment accumulation data at Willapa Bay, Washington showed an average elevation increase of 1 cm /yr (0.4 in/yr) (Sayce 1988). 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. The cumulative effect of these changes is major alteration of estuarine ecosystems that is detrimental to native species.

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 1). 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. Recent work from Willapa Bay compares bird use in Spartina meadows, herbicide treated plots, tilled plots, and bare mudflats, and suggests shorebirds return to areas cleared of Spartina within a few years of treatment (Patten 2005). 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).

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

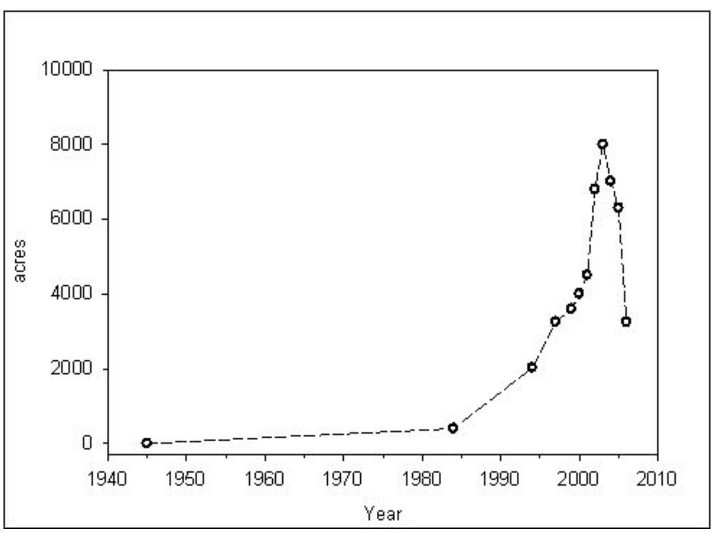

Figure 1. Estimated solid acres of *S. alterniflora* in Willapa Bay, Washington between 1945-2006.

Spartina growth is detrimental to eelgrass, a key species in the food chain of intertidal ecosystems. Eelgrass beds provide refuge from predation for large numbers of small invertebrates, such as juvenile Dungeness crab (McMillan *et al*. 1995). Eelgrass beds provide forage for American wigeon, northern pintail and brant. Brant, in particular, are heavily dependent on eelgrass, which is their preferred forage. As *Spartina* clumps increase in diameter, stem density within the clump also increases. Eelgrass may persist under open canopy conditions (widely spaced seedlings and within *Spartina* clones having very low shoot densities i.e., <10 stems/m2), but eelgrass 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. 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.

Because *Spartina* alters the habitat so drastically, it may facilitate invasion by other invasive species. The non-native green crab (*Carcinus maenas*), a recent invader of west coast estuaries, is an aggressive predator of oysters, clams and other shellfish as well as native crab species. 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 (WA Department of Fish and Wildlife electronic news release 1998). Studies suggest that green crabs are more abundant in areas where *Spartina* is present (Carr & Dumbauld 2000).

Daehler and Strong (1996) evaluated Pacific coast estuaries for risk to *Spartina* invasion based on estuarine physical characteristics and species characteristics. They consider 13 Oregon estuaries north of the Coquille River to be at risk to *Spartina* invasion. River mouths south of the Coquille have steep gradients with little or no tidelands that are vulnerable to *Spartina* invasion (Figure 2) (Cortright *et al*. 1987).

While the entire intertidal area within estuaries is potentially at risk for invasion by one or more species of *Spartina*, two estuarine habitat types – intertidal flats and intertidal aquatic beds – are particularly vulnerable since they are largely open substrate. There are 49,542 acres of intertidal flats and intertidal aquatic beds that account for approximately 30 percent of the total area of the 15 estuaries vulnerable to *Spartina* invasion in Oregon (Table 2) (the authors have added the Salmon River and the Necanicum/Neawanna River system to Daehler and Strong's list of 13). Some areas within these habitat types are more susceptible to *Spartina* colonization than others. For example, intertidal mudflats are far more likely sites of invasion to *S. anglica* than are cobbled flats (Hacker *et al*. 2001). Individual estuaries vary in the proportions of different habitat types; therefore the estuaries will differ in their relative, potential at-risk area.

In addition to the intertidal habitat, there are also over 10,300 acres of salt marsh habitat that could face infestations by *S. densiflora* and *S. patens* (Table 2). Risk of establishment in such areas is less due to competition from native halophytic plants; however, natural or man-made disturbances could lead to initial propagules success and subsequent out-competing by these *Spartina* species specialized to these higher elevations (Kittelson and Boyd 1997).

Estuaries also differ in their spring tidal range, fetch, and latitude, all of which have been found to be significant factors in the spread of *Spartina* in the British Isles (Gray and Raybould 1997). In Willapa Bay, where control measures were not taken until after pioneer populations had been in existence for over 50 years, approximately 8,500 infested acres were spread over 20,000 acres at the height of the infestation in 2003 (Murphy 2005). This constituted nearly 20% of Willapa's total 47,000 acres of intertidal habitat (areas at MHHW = 0.09). In the short term, it is unlikely that *Spartina* will colonize 100 percent of the potential at-risk area. If pioneer infestations are left untreated, however, it is feasible that at least 20 percent of the available habitat could be invaded.

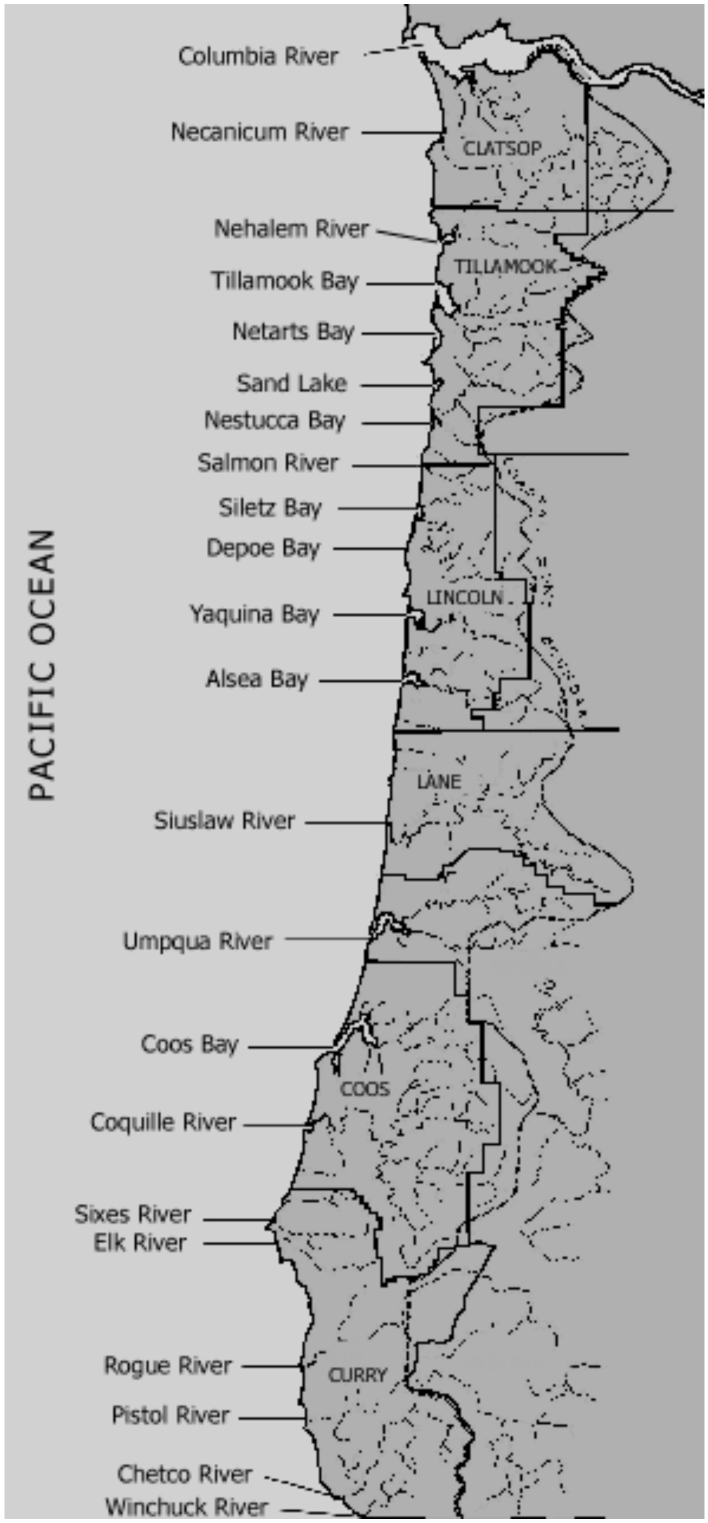

Figure 2. Map of the Oregon coast (from Cortright et al. 1987)

Table 2. Area totals and areas of intertidal mudflats/aquatic beds, and saltmarsh habitat in 15 Oregon estuaries vulnerable to *Spartina* invasion.

Estuary	Total Estuary Area (acres)	Mudflat & Intertidal Aquatic Bed Area (acres)	% of total	Salt Marsh Area (acres)	% of total
Columbia (OR & WA*)	113,739	27,720	24%	2,073	2%
Necanicum	460	113	25%	89	19%
Nehalem	2,765	1,044	38%	517	19%
Tillamook	9,356	6,104	65%	888	9%
Netarts	2,745	2,046	75%	228	8%
Sand Lake	911	293	32%	476	52%
Nestucca	1,186	614	52%	210	18%
Salmon	727	94	13%	520	72%
Siletz	1,536	858	56%	313	20%
Yaquina	4,398	1,531	35%	627	14%
Alsea	2,622	1,277	49%	466	18%
Siuslaw	3,097	708	23%	780	25%
Umpqua	6,757	1,422	21%	1,090	16%
Coos	13,437	5,464	41%	1,766	13%
Coquille	1,104	254	23%	282	26%
Totals	164,841	49,542	30%	10,326	6%

Calculated by V. Howard from The Oregon Estuary Plan Book digital map layers, Oregon Lambert projection, available from InfoRain at: http://www.inforain.org/mapsatwork/oregonestuary/ (accessed on 5/7/06). Features classified as diked ("D") or with blank habitat codes were excluded from calculations. Limited corrections based on know dike breaches or other changes to habitat were made to the Salmon, Siuslaw and Yaquina estuaries figures.
* The acreage presented here for the Columbia River estuary includes habitats in both Oregon and Washington. Previous estimates included only those within the Oregon state boundary.

Loss of wetland habitat, which supports multiple beneficial uses, to *Spartina* invasion would result in substantial economic impact. Some 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. Oysters are farmed in the lower intertidal and upper subtidal areas of estuaries in the Pacific Northwest, so increased elevation of these areas caused by *Spartina* renders them unfit for oyster cultivation. Commercial culture of oysters on state-owned and private lands in Oregon in 2005 produced harvests is valued at $4.71 million. In addition to direct crop losses, coastal communities could also lose jobs associated directly and indirectly with oyster production.

Recreational opportunities such as sport fishing (including shell fishing), boating, and beach access would also be reduced by the infilling of estuaries by *Spartina*. Not only are these quality of life issues, but their loss or reduction also pose significant threats to tourism in Oregon coastal communities. Approximately $1 million was spent on recreational shellfish licenses (three day and annual licenses for residents and non-residents) in both 2004 and 2005 (H. Upton, ODFW, pers. comm.). The value of wildlife viewing in Tillamook Bay was estimated at more than $1,000/acre for intertidal habitat (The Research Group, 1999). Using figures from Radtke and Davis (2000), we estimate economic losses to *Spartina* at $666/acre. Thus, the potential economic loss resulting from a *Spartina* invasion, assuming colonization of all available habitat, is roughly $33 million per year.

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 1) as did *S. patens* on Cox Island, Oregon (Figure 3). 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 4). Given the difficulty of working in estuarine environments and the high cost of all available management methods, early detection and control are critical to a successful effort to protect Oregon estuaries from infestation by *Spartina*.

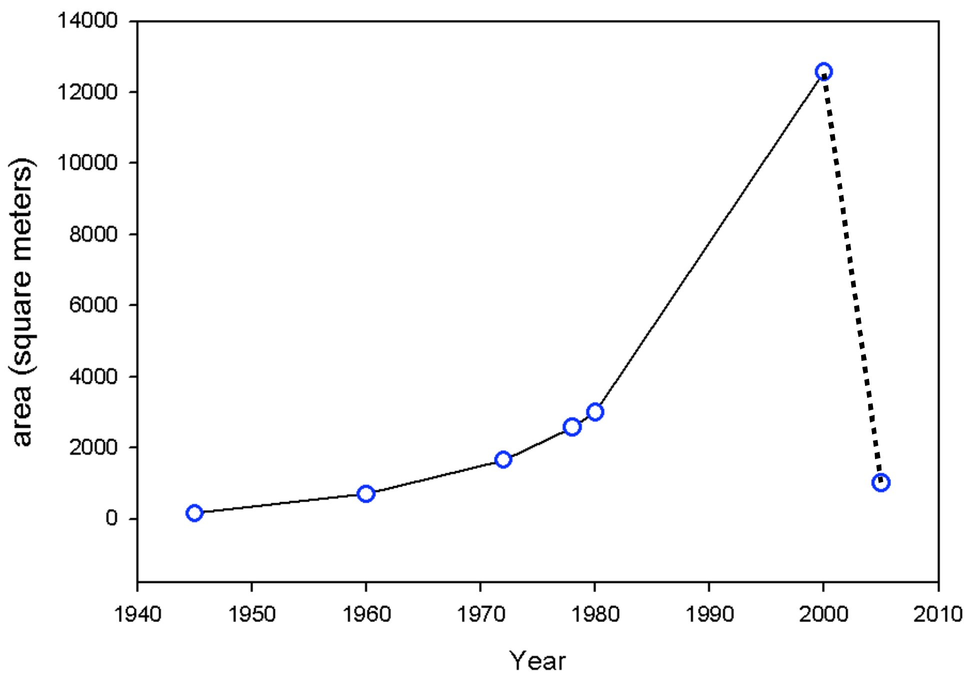

Figure 3. Expansion of cover of *S. patens* on Cox Island, Oregon. The last data point is an estimate based on management records from 2005 (data from Frenkel and Boss 1988, Pickering, pers. comm.)

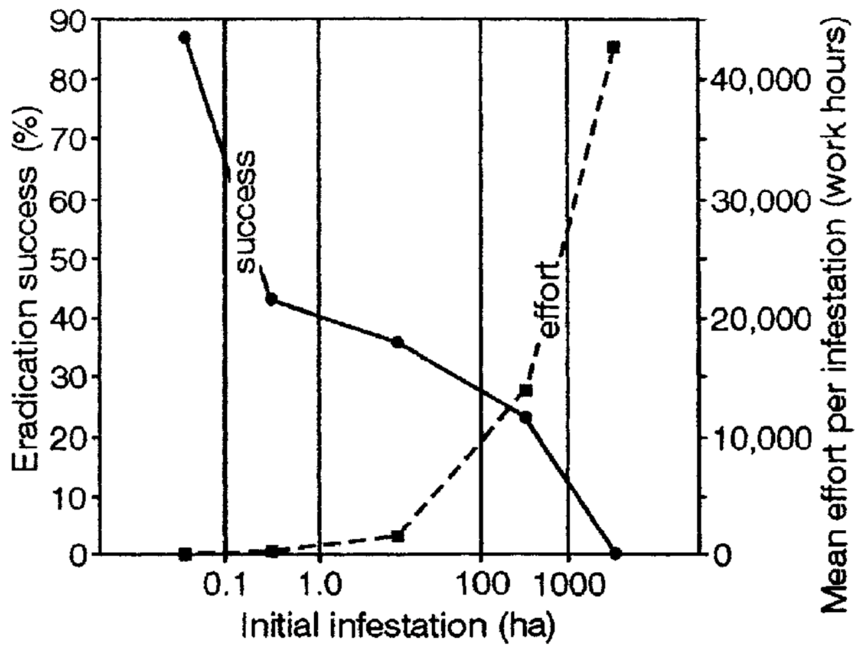

Figure 4. Dependence of eradication success and mean effort on initial infestation size (from Rejmanek and Pitcairn, 2002)

BIOLOGY OF *SPARTINA*

Distribution

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 coastal, estuarine areas on saline substrates; however, a few are native to inland areas and tolerate alkaline substrates (e.g., *S. gracilis, S. pectinata*).

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 5). *S. anglica* colonizes the lower intertidal while *S. densiflora* and *S. patens* are found in the mid to high salt marsh.

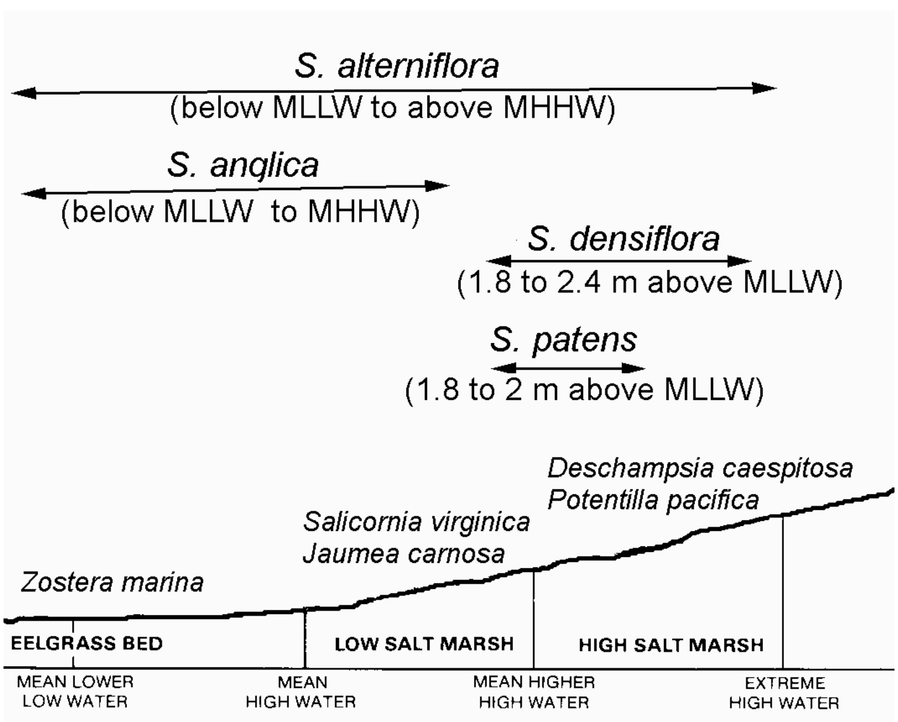

Figure 5. Distribution of exotic *Spartina* species in west coast estuaries. Dominant, native plant species are listed above each zone.

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 typically form circular patches of vegetation; large clones of some species are easily seen from the air while others grow in mixed stands. *S. densiflora* can grow in the same habitat as tufted hairgrass, *Deschampsia cespitosa*, making detection from aircraft difficult at best. In some locations, *S. alterniflora* has formed monospecific swards that have transformed open tidal mudflats into high, salt marsh meadows.

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). A dwarf ecotype has been found in San Francisco Bay, California that is substantially different from the short form that occurs on the east coast. The California dwarf form has thinner stems that are much more densely spaced than either the Atlantic dwarf form or the San Francisco wild type (Daehler *et al*. 1999).

Spartina Profiles

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 *S. maritima X S. alterniflora.*

S. densiflora - Distinguished by its cespitose growth habit. Inhabits mid to high salt marshes. Introduced from South America.

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

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, Gude *et al*. 1981). *Spartina* also uses the C-4 pathway of carbon fixation, which is more efficient at fixing CO2 than the C-3 pathway in some environments (Thompson 1991).

The two most aggressive species of *Spartina* on the west coast, *S. anglica* and *S. alterniflora*, 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.

Reproduction

Spartina reproduces by sexual means and vegetative means. 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, selfing 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 grown 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 (Davis *et al*. 2004).

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). 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. Research conducted Portland State University studied characteristics of fragments produced by rot tilling treatments in Willapa Bay and fragment survival under a variety of treatments in a common-garden experiment (Greenfield *et al.* 2005). 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 6). 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.

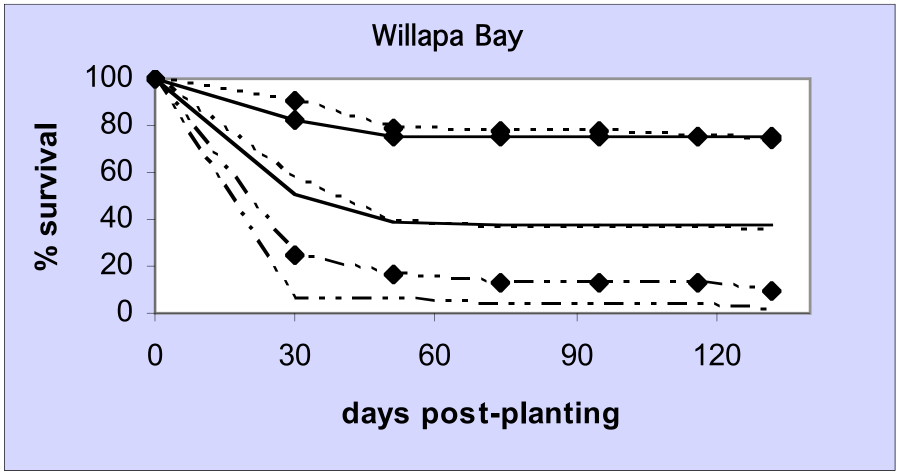

Figure 6. *S. alterniflora* rhizome fragment survival over time for Willapa Bay plants. Treatment groups are noted by salinity (········ 0 ppt, ———— 15 ppt and -- — -- — 35 ppt), and rhizome size (plain line = small, ◆= large)

Dispersal

Spartina can be spread from estuary to estuary by human and nonhuman mechanisms. 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.

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.

Humans were responsible for the initial intentional or accidental introduction of non-native *Spartina* species to the estuaries of the west coast. Although importation is now banned in Oregon and Washington, accidental transport of *Spartina* is likely. Ship ballast and fouling of ship hulls have been the vectors of invasion for numerous marine organisms (Cohen 1997; Carlton 2001). The seeds of *Spartina* are dispersed by the tidal currents and are likely to come into physical contact with ship hulls and rigging, or be present in ship ballast water or 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. Invasive species in ballast water from San Francisco Bay are managed by a required coastal exchange provision in Oregon law.

U.S. Department of Defense vessels, such as those belonging to U.S. Army Corps of Engineers (USACE), are exempt from ballast water exchange requirements. USACE dredge vessels operate regularly between waterbodies 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 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. Transport of oysters from Willapa Bay, Washington to Tillamook Bay, Oregon for the purpose of supplementing local harvests has occurred occasionally for at least the last 10 years (John Johnson, ODFW, pers. comm.). This type of transport is legal and requires an ODFW Permit to Transport Live Fish or Eggs (ORS 498.222, OAR 635-007-0600). The permits for transporting marine shellfish are issued by the ODFW Marine Resources Program, Estuarine Habitat Project Leader.

Restrictions and prohibitions of the permit have been focused primarily on preventing spread of green crabs and the oyster drill. 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.), may mitigate the risk of *Spartina* introduction via this pathway.

The risk of *Spartina* introduction via seed dispersal has increased in recent years due to the enormous increase in seed production in existing populations, especially the Willapa Bay population and the uncontrolled Humboldt Bay population. Thus increased attention to vectors for seed dispersal is warranted.

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 nearshore 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 ripe seeds leave Willapa Bay and move into the nearshore ocean. *Spartina* wrack has been found repeatedly on ocean beaches as far south as Seaside, Oregon and on the outer Washington coast as far north as Neah Bay (F. Grevstad, pers. comm.; V. Howard pers obs.). *Spartina* wrack has also been found on the shores of the Columbia River at Social Security Beach at Ft. Stevens State Park (Jon Graves, pers. comm.). The probable source of this material is Willapa Bay, the entrance to which is only 26 miles north of the mouth of the Columbia River.

Long distance ocean current transport of *Spartina* from California estuaries to sites in Oregon and Washington is also possible, especially during El Nino years. The 1982-1983 El Nino events caused increased current velocity as well as 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 Nino 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 156 nautical miles from Humboldt Bay, California north to Coos Bay, Oregon, in five to eight days.

A drift card study was conducted to assess the relative risk posed to sites in Oregon and elsewhere by major infestations 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, WA and Humboldt and San Francisco Bays in California (Figure 7a).

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 (Figures 7b & 7c). Transport southward from Willapa coincided with spring releases and recoveries occurred frequently along the Oregon coast as far south as the Siuslaw River. Transport from San Francisco (Figure 7d) was notably less than from the other two release locations, with cards only occasionally reaching Oregon's coastline and maximum northward estimated velocities of 16 km/day. These results, when paired with the timing of seed ripening, indicate Oregon may be at increased risk for *S. densiflora* from Humboldt Bay. While this study does not account for interannual variability, it does suggest potential dispersal ranges from these specific infestations via ocean currents.

As noted above, waterfowl transport *Spartina* seeds on their feet and feathers (Vivian-Smith and Stiles 1994). Fortunately, no *Spartina* has been detected in waterfowl feeding areas in the Columbia River estuary despite the large number of migrating waterfowl that move there from the heavily infested south end of Willapa Bay (K. Sayce, pers. comm.). Birds cannot be ruled out as possible vectors of transport of viable *Spartina* seeds between infested and uninfested estuaries.

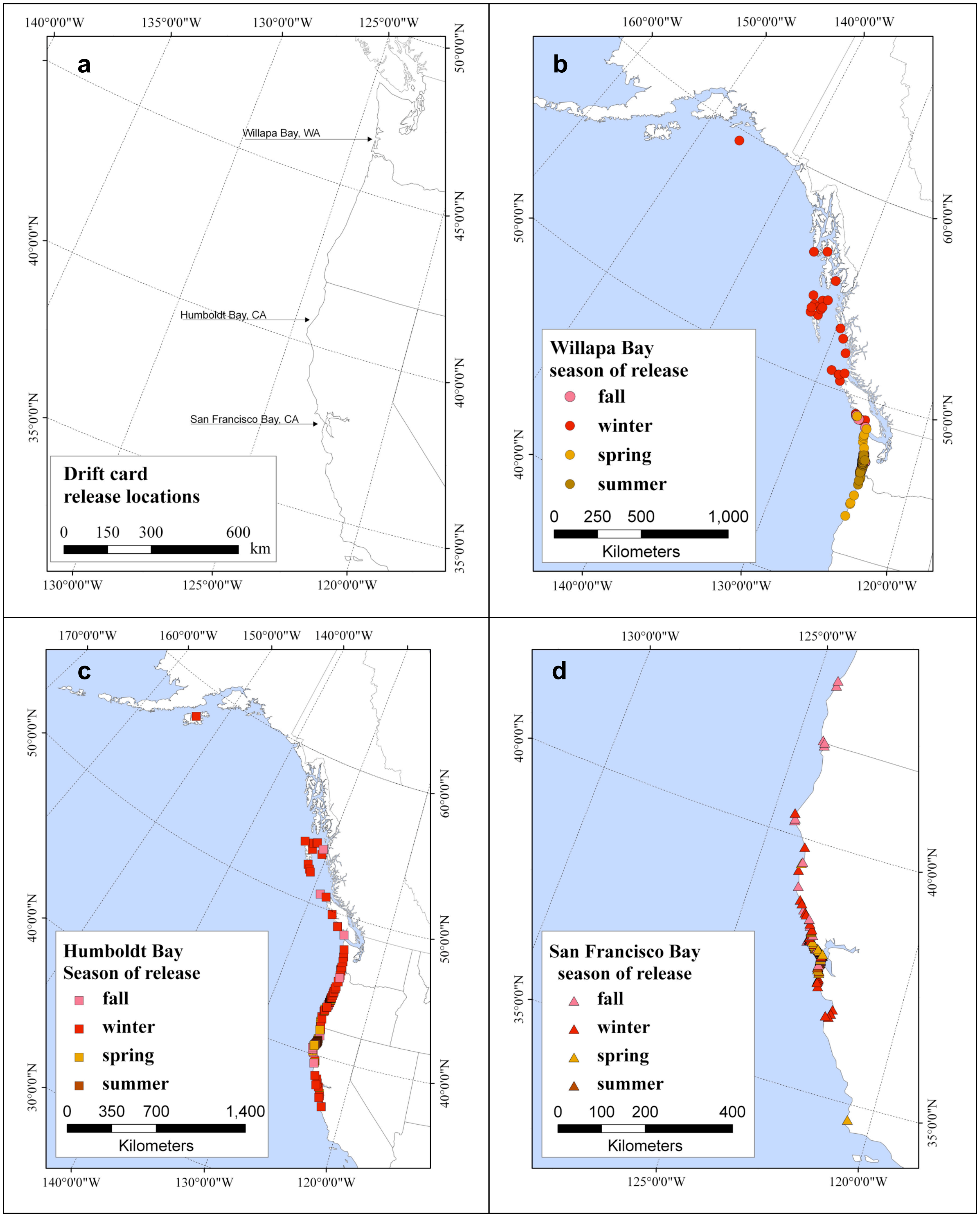

Figure 7. Locations of drift card release sites (a) and distribution ranges, grouped by season of release, for recovered drift cards from Willapa Bay, WA (b), Humboldt Bay, CA (c) and San Francisco Bay, CA (d). Fall releases performed Sept-Nov. 2004; winter releases performed Dec. 2004 – Feb. 2005, spring releases performed March-May 2005 and summer releases performed June-Aug. 2005.

It is critical that the state of Oregon operate on the premise that, even with the best prevention efforts, new *Spartina* infestations in Oregon estuaries are inevitable. It is unlikely that we can prevent all possible accidental or intentional human mediated introductions. It is even more unlikely, if not impossible, to prevent introduction via currents, birds, or other natural vectors. The question that we are faced with is not IF *Spartina* will invade but WHEN. Given the potential negative impacts of *Spartina* invasion, it is imperative that the State of Oregon is prepared to rapidly respond to an introduction.

HISTORY OF *SPARTINA* ON THE WEST COAST

Native *Spartina* in California

Of the five *Spartina* species on the west coast of the U.S., only *S. foliosa* is native. It ranges from Baja California (Mexico) to Bodega Bay, California (U.S.A). *S. foliosa* produces less above and below ground biomass, is shorter, begins spring growth several weeks later, spreads laterally at a much lower rate, and has lower seed output with lower seed viability than either *S. alterniflora* or *S. densiflora* (Callaway and Josselyn 1992; Kittelson and Boyd 1997). *S. foliosa* forms fertile hybrid offspring with *S. alterniflora*. The hybrids are intermediate in phenotype between both parental species and are more robust than the native *S. foliosa*. Physical displacement and genetic "invasion" by *S. alterniflora* will likely cause the extirpation of the native, parental-type *S. foliosa* (Daehler and Strong 1997, Ayres *et al.* 2004).

Non-native *Spartina* in California, Washington, Oregon and British Columbia

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, Canada through deliberate introduction, natural dispersal as well as by unintended transport.

<u>California</u>

Humboldt Bay

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 Oregon. 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.)

San Francisco Bay

S. alterniflora was introduced into San Francisco Bay, California through a combination of circumstances. Seeds were originally planted in a U.S. 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* are estimated in San Francisco Bay (P. Olofsen, ISP, pers. comm.). 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 2004). *S. anglica* was a deliberate introduction from Puget Sound, WA in the 1970's. There is no explanation for the introduction of *S. patens* into California (Spicher and Josselyn 1985).

Small infestations of *S. alterniflora*, *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 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. Late in the 2005 season, 6.5 acres were chemically treated and the remaining 3.5 acres were reportedly treated in 2006 (Murphy et al. 2007).

Willapa Bay

Transplantation of oysters from the east coast of North America at the turn of the 19th 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 originated from a single or a very few introduced clones according to a DNA study (Stiller and Denton 1995). 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 1).

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 nearly $3 million for control efforts in the 2005-07 biennium (Murphy et al. 2007). Eradication of *Spartina* from Willapa Bay has been 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, political issues (e.g., herbicide spraying), and the challenges inherent in coordinating a response among the large number of stakeholders in Willapa Bay (i.e., public agencies, general public, and commercial). However, substantial improvements have come with use of the herbicide Imazapyr and improved GIS maps allowing improved drying times.

<u>Oregon</u>

Siuslaw River, Cox Island

Three infestations of *Spartina* have now been recorded in Oregon. The largest and most persistent is that on Cox Island Preserve, Siuslaw River estuary, Oregon. 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 acquired the site and began efforts to eradicate it in 1996. These efforts are ongoing, with current estimates of approximately 0.25 acres remaining spread across the 182-acre island (D. Pickering, pers. comm.). 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.

Siuslaw River, Port of Siuslaw

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).

Coos Bay

During 2005 early detection survey, *S. alterniflora* was found in Coos Bay, on property owned by the Oregon Department of Transportation 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, there were approximately 26 m^2, spread across a shallow pond infrequently inundated with saline water during winter storm surges.

Unintentional transplantation is the most likely the cause of this infestation; contractors harvested native plant plugs, from the Siuslaw River, Port of Siuslaw property in 1994, transplanting them to the Coos Bay remediation site. Follow-up monitoring in 1995, revealed the aggressive growth of an unidentified grass that was tentatively identified as an invasive genotype of *Phragmites australis*; it was manually removed in 1998, 2003 and 2004 before the positive identification as a non-native cordgrass. Both the Coos Bay and Siuslaw River sites were in areas of low wave-energy and neither population was ever observed flowering. 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.

<u>British Columbia</u>

Frazer River Delta Region

In 2003, *S. anglica* was found in Boundary Bay and Roberts Bank areas near the Frazer River Delta. 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.). Although nearly 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. 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.

Burrard Inlet

S. patens has been documented near the Maplewood Conservation area and has reportedly spread to areas near Port Moody (Brekke 2006).

Vancouver Island

S. patens has also been observed near Comox harbor on the north east side of the 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.H). In late 2005, *S.*

densiflora was confirmed in Baynes Sound near Ships Point, again on the east side of the island. 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. A survey for intertidal invasive organisms, including *Spartina spp*., was begun in 2006 and hopefully will make known any additional populations in this province (T. Therriault, Fisheries & Oceans Canada, pers. comm).

RESPONSE PLAN

Goal of *Spartina* Management in Oregon

The *Spartina* genus of weedy grasses could drastically alter the structure and function of intertidal and low marsh communities of any of the state's major estuaries and the outlets of several smaller streams along the Oregon coast. *S. alterniflora* is an “ecological engineer”; its invasion results in replacement of mudflats that are the natural substrate for a complex food web that includes invertebrates, fish and wildlife, by meadows and deep drainage and surge channels, which do not support the same communities. Recreational and commercial shellfish populations are also jeopardized by loss of mudflat habitat. Habitats used by several species of shorebirds and waterfowl, some rare, would disappear. No other known plant species or plant group has the potential to so seriously disrupt coastal wetlands and estuaries, which are among the most ecologically critical, economically valuable, and extremely limited habitat types in Oregon.

These impacts are not based on conjecture – they can be readily observed in California and Washington. The number and size of affected estuaries in these areas are increasing, and the costs of management are escalating. Management costs in Willapa Bay currently exceed one million dollars per year. Four *Spartina* species are likely to invade Oregon estuaries and have similar impacts.

The goal of *Spartina* management in Oregon is to prevent the establishment and spread of any Spartina species in Oregon estuaries and coastal wetlands.

The five main efforts to attain the goal are to

1. prevent, to the extent practical, the movement of Spartina propagules to areas suitable for Spartina invasion;
2. educate and inform agencies and the general public about Spartina and the need to control it;
3. detect and eradicate any pioneer infestations, preferably while they are still small;
4. support the continuation of eradication efforts directed at the S. patens infestation on Cox Island in the Siuslaw River estuary, the only current Spartina infestation in Oregon; and
5. coordinate activities of local, state, and federal agencies and private interests to facilitate cost-effective and efficient implementation of Spartina management activities in Oregon.

Dispersal, Invasion, and Overall Management Strategy

The process of invasions by weedy, alien species can be modeled as a combination of short-range dispersal along margins of established, “core” infestations, and long-range “jumps” from these core infestations to establish outlying, “satellite” populations. It is these jumps that could bring *Spartina* to Oregon from core infestations in California or in Washington. Jumps occur when propagules (either seed or parts of plants that can take root) are carried from existing infestations to new and uninfested areas suitable for *Spartina* establishment, growth, and reproduction. Identification of mechanisms by which *Spartina* propagules make jumps from infested areas to uninfested areas is critical to prevention of introduction of the plant to Oregon.

The most effective management approach for weed infestations differentiates core and satellite populations, and applies appropriate control to each. Willapa Bay and Humboldt Bay represent core infestations of *S. alterniflora* and *S. densiflora*, respectively. Appropriate control of core infestations includes containment and prevention of dispersal. Management of satellite populations in Oregon should include early detection and rapid response with a coordinated eradication strategy.

Preventing the Movement of *Spartina* Propagules

Effective control of *Spartina* in core infestations outside Oregon could reduce production of propagules and would therefore reduce the probability of their arrival in

Oregon. Oregon should support and encourage ongoing control efforts in core infestations in Humboldt and Willapa Bays, particularly efforts to control seed production and potential export of plant parts, e.g., in solid ballast of dredges.

Modes of dispersal and possible pathways of *Spartina* introduction to Oregon were described in detail in a previous section. They include:

- **Movement by wind and water** from existing infestations in California and Washington. Wrack (rafts of floating vegetation) has repeatedly been found in the Columbia River estuary and along the open coast. Wrack may contain seeds or vegetative fragments of Spartina plants

- **Movement with equipment**, which is used in maintenance of infrastructure and traffic lanes for boats and ships in Oregon's estuaries, as they move from one job to another. 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 use solid ballast, which could be picked up in infested core areas.

- **Movement with boats and other equipment of recreational users** of Oregon's estuaries. Kayaking, crabbing, fishing, clamming and other such recreational opportunities exist in most estuaries up and down the Pacific coast. Equipment and gear used in these pursuits could collect seed in infested estuaries that could be deposited in other, uninfested, ones.

- **Intentional planting of *Spartina***, perhaps for erosion control. The Siuslaw River *S. alterniflora* infestation in Oregon was the result of an intentional planting, predating the widespread knowledge of *Spartina's* unwanted ecological impacts.

- **Un-intentional planting of *Spartina***, potential transplantation with wild-harvested native plant stock. This is thought to be the mode of introduction to Coos Bay, Oregon.

- **Movement with boat and ship traffic** into Oregon's estuaries or along the Oregon coast. Wrack in the open seas could be intercepted by transiting craft headed for uninfested estuaries.

- **Movement with equipment, materials and supplies related to commercial shellfish production**. There are oyster producers with interests in both Willapa Bay, the most heavily infested estuary in Washington, and in Oregon estuaries. Workers, oyster-production supplies, and some equipment are moved between sites as needed.

- **Movement by migrations of waterfowl** that visit infested areas in Washington and California. Brant and widgeon are examples of waterfowl that visit and feed within estuaries in areas suitable for invasion by *Spartina*.

Obviously, some movement of *Spartina* propagules is beyond the control of managers or institutions in Oregon, e.g., movement via wind, water and waterfowl. There are opportunities, however, to limit introductions associated with human activity through appropriate regulatory mechanisms. Some state agencies have permitting or quarantine authority that could be strengthened to prevent infestation. For example, the Live Fish Transport Permits issued by the Oregon Department of Fish and Wildlife 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 with oysters probably provide some protection against *Spartina* spread, but the permit requirements should be reviewed and the permit requirements, including safeguards against spread of *Spartina* propagules, must be enforced.

Safeguards against *Spartina* transport with shellfish should include:
1) determination if shellfish are being imported from an infested area; 2) a requirement that shellfish be chlorine-washed before transport into Oregon; and 3) a second wash upon arrival in Oregon with wash water disposal at an upland site or into an appropriate treatment facility. Monitoring of washing procedures and the washed shellfish to ensure

compliance and of potential *Spartina* habitat in the vicinity of shellfish processing facilities are critical components of an effective permit program.

A potential obstacle to oyster growers' efforts to prevent the spread of *Spartina* in Pacific coast estuaries lies in the varying regulations for oyster culture, especially transport permits, across jurisdictional boundaries (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*.

Resource management agencies and interest groups already monitor locations that are susceptible to *Spartina* invasion and pathways of potential *Spartina* movement into Oregon. These agencies and interest groups could incorporate Spartina surveillance into regular activities without additional commitment of resources. Although some pathways of potential introduction of *Spartina* are clear, there are undoubtedly others that are still unknown. Recruitment and awareness of various agencies and interest groups in *Spartina* surveillance and prevention will undoubtedly elucidate new pathways. Since not all potential pathways are known, and because some pathways are not human-mediated, it would be prudent to invest substantial resources in detection of new, small infestations that can be successfully eradicated.

Detection

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 is critical to an effective control strategy. Based upon experience in managing *Spartina* in Oregon to date, very small infestations (less than one-half acre) should be eradicable within about ten years. *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 clone detected since 1994. In Coos Bay, the number of hours required to remove all visible growth of *S. alterniflora* has reduced from 320 in 2003 to 1.5 in 2006, despite the issue of misidentification and intermittent control efforts. *S. patens* control on Cox Island was initiated when the infestation was about 0.9 acres and has treated ten acres so far with approximately 0.25 acres remaining. Eradication is projected within 10 years. Other examples of successful eradication are rare and all involve sites one acre or less in extent.

Initial detection efforts in Oregon were directed almost exclusively at *S. alterniflora*, with a goal of detecting a six-foot (~2 m) diameter clone. Since seeding of *S. alterniflora* in Washington began, new infestations have been found high in the intertidal zone, next to or within existing native vegetation (T. Brownlee, pers. comm), which reduces the likelihood that six foot diameter clones could be reliably detected from boats or aircraft. The current feasible threshold detection size is probably much greater than six feet, perhaps nearer to one-half acre. 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.

Detection efforts could be more focused and efficient if we were better informed about some of the pathways of introduction. If some species of waterfowl, for example, are more likely to use core infested areas, we could focus our surveys on areas in Oregon estuaries 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. Increased communication and cooperation with the Corps would facilitate detection and also provide opportunities to prevent introduction through modification of operations.

A better understanding of the sites most suitable for growth and reproduction of *Spartina* spp. would also be helpful in focusing search efforts. 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 mapped, using GIS technology for example, searches could be more focused and efficient.

<u>Detection Methods</u>

Oregon can increase the probability of successful detection by utilizing active search methods. "Active", in this sense, refers to searchers whose assigned duty is the detection of *Spartina* to the exclusion of any collateral assignments. Passive detection approaches can also be effective and efficient, especially where motivated and qualified personnel are involved. 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 sight a new infestation if they were informed with appropriate information. Commercial oyster growers, who have a significant economic interest in preventing *Spartina* establishment in Oregon, exemplify those who could be recruited for passive detection of *Spartina*.

Aerial searches from airplanes and helicopters, boat surveys and shore-based surveys have all been used in Oregon 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. The Bonneville Power Administration and the U.S. Coast Guard, have generously allowed the use of their helicopters and pilots on occasion. Commercial rentals of a helicopter is typically costly, however, and scheduling of flights can be difficult due to changing weather patterns and helicopter availability. No commercial helicopters are currently available on the Oregon coast. Fixed-wing aircraft are much less costly than helicopters, are available for hire along the coast, and can cover nearly all the areas considered at risk for invasion. However, they cannot maneuver as close to possible infestations and so are not as useful as helicopters for close inspection.

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 mixed stands (i.e., *Spartina* mixed with other look-alike species) and *Spartina* stands of varying densities are not uncommon in estuarine habitats, there is not a single, "tight" signature that could be used for detection. For the present, remote sensing should not be relied upon for active detection efforts.

Table 3 summarizes and compares the effectiveness of several different approaches to searching for *Spartina*. Each method was assigned a value for the estimated area at risk that could be assessed (percentage). Costs were primarily from experience of D. Isaacson 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 the Oregon *Spartina* control effort remain flexible in the detection methods and schedules used so that variable weather conditions, equipment availability, etc. can be accommodated.

Table 3. Adjusted relative cost effectiveness of detection methods . (Adjusted relative cost effectiveness = Relative reliability X Relative cost effectiveness; 0 = least effective, 1= 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 the Oregon *Spartina* management program. Volunteers with special motivation can certainly be of assistance. Resource managers with no official assignment with respect to a *Spartina* threat would likely 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.

Historical Detection Efforts in Oregon

Detection surveys for *Spartina* in Oregon have been ongoing since 1994 when the Oregon Department of Agriculture surveyed five bays along the north coast: Young's Bay, Nehalem Bay, Tillamook Bay, Netarts Bay, and Nestucca Bay (Miller 1994). In September and October of 1998 and 1999, the Oregon Department of Agriculture surveyed thirteen Oregon estuaries (Table 4) for *Spartina* using fixed-wing aircraft or helicopters (Noxious Weed Control Section 2000). No infestations were located during these surveys with the exception of the known *S. patens* location on Cox Island in the Siuslaw River estuary.

Table 4. ODA Spartina survey locations 1998 and 1999

Location
Columbia River estuary
Nehalem Bay
Tillamook Bay
Netarts Bay
Sand Lake
Nestucca Bay
Siletz Bay
Yaquina Bay
Alsea Bay
Siuslaw River estuary
Umpqua River estuary
Coos Bay
Coquille River estuary

In the same survey, the mouths of 27 coastal streams were searched in 1999 for *Spartina* and rated for their risk for invasion using factors cited in Daehler and Strong (1996). Appendix A is a summary of those outlets ranked according to their suitability for *Spartina* habitat, with notes on substrate type, existing vegetation types etc. Several of these coastal stream mouths should be checked regularly, as they have characteristics quite suitable for invasion by *Spartina*.

Additional helicopter detection surveys were made of Winchester Bay in the Umpqua River estuary and of the upper, main portion of Coos Bay in August 2002. In September, 2002 the south shore of the Columbia River estuary was surveyed downstream from Hammond, as was the Lewis and Clark River arm of Young's Bay. The authors conducted a boat survey of the South Slough in Coos Bay in October 2002.

Tillamook Bay was surveyed on two days in September, 2002 by D. Isaacson and ODA Food Safety Sanitarian, John Paeth during a routine water quality sampling trip. Dense fog prohibited a thorough survey on both days. A one mile section of the southwest shore of the bay, near the mouth of the Trask and Tillamook Rivers was able to be surveyed and no *Spartina* was observed. Table 5 summarizes survey efforts undertaken since 2003 including the date and method. Additional details are available in annual implementation reports made to ODA. A field reporting form (Appendix H) is useful to compile information on access locations, vantage points, hazards or local contacts.

A variety of methods have been used in these surveys, including ground, kayak, motorized boat, hovercraft, fixed-wing aircraft and helicopters. Each of these methods has proved useful with the exception of the hovercraft, which has space and weather limitations and cannot navigate over sharp objects (shells, sticks, rocks, etc) that are often exposed at low tides in estuaries. A variable zoom (15-45 x) spotting scope has proved useful in assessing areas from a distance of approximately 400 meters; visual characteristics (such as leaf ranking, the presence of a prominent midrib, or inflorescence shape) of regularly occurring plant species allow many “suspect” stands of vegetation to be determined without closer inspection.

Past surveys, conducted during the low or minus tides between May and October, concentrated predominantly on inter-tidal zones where *S. alterniflora* and *S. anglica* are more likely to establish initially. To a lesser extent, these same detection efforts have looked at salt marsh habitat where *S. densiflora* and *S. patens* colonize. Finding either of these higher elevation species is confounded by both the difficulties of traversing large expanses of highly-channelized marshes and the presence of native plants. Surveyors looking for *S. densiflora* in Washington and California note improved detection of this species in late winter or early spring when most natives are dormant. Adding dormant season surveys may be critical to detecting this species.

Table 5. *Spartina* survey locations between 2003 to 2006 by method (H – helicopter, FW - fixed wing aerial; G - ground; B - motorized boat; K – kayak) and date.

Estuary	2003	2004	2005*	2006**
Columbia	H[x] (7/1) G (8/1) FW (9/22)	B[y] (12/15)	B[y] (5/25)	H (8/17) B (10/25)
Necanicum/Neawanna	K (8/2 & 8/8) FW (9/22)			G & K (8/11) H (8/17)
Nehalem	B (9/10) FW (9/22)			G (8/10) B (8/14) H (8/17)
Tillamook	G (7/26) FW (9/22) HV (10/14)			H (8/17)
Netarts	FW (9/22)			G (8/15)
Sand Lake	G (8/16) FW (9/22)			G (6/30)
Nestucca	G (8/21) FW (9/22)			G (7/2)
Salmon	G (8/22) FW (9/22)			K (7/1)
Siletz	G (8/23) FW (9/22)			G & K (6/29)
Yaquina	FW (9/12)		K & G (9/28)	
Alsea	FW (9/12)		B &G (8/9)	
Siuslaw	G (9/4) FW (9/12)		G (7/1) B (7/19)	
Umpqua	FW (9/12)		B (8/7)	
Coos	G (9/6) FW (9/12)		G (7/1) H (9/6)	
Coquille	FW (9/12)		K (10/13)	

* During 2004, V. Howard & M. Pfauth additionally surveyed the lower Rogue River and the following creek outlets: Beaver, Reynolds, Siltcoos, Tahkenitch, Tenmile, Euchre and Hunter Creeks.
** During 2005, V. Howard and/or M. Pfauth additionally surveyed Ecola Creek and Depoe Bay.
[x] Conducted by Dave Ambrose, Clatsop County SWCD from Fort Stevens State Park to Youngs Bay, Astoria waterfront up to Tongue Point.
[y] Boat and local expertise provided by Al Clark, US Fish & Wildlife Service.

Response to Detection

Rapid response is critical to effective control of the spread of *Spartina* and for eradication. Of special concern are pioneer infestations, which could produce propagules and be a potential source of further infestation. It is particularly urgent to act quickly if an infestation is flowering or setting seed so that dispersal can be limited.

A sequence of events can be anticipated upon report of a *Spartina* sighting. A summary of these events is represented in the flow chart in Figure 8. Actual events leading to reports have been somewhat less direct, thereby emphasizing the need to direct potential sightings to the Oregon Invasive Species Hotline (1-866-INVADER). We assume that reports will eventually be made to the Hotline or to the Oregon Department of Agriculture Noxious Weed Program. Education and outreach efforts should direct individuals to note pertinent details (size, location and appearance), get a sample when possible, and to phone the Hotline as soon as possible. The ODA Noxious Weed Program will coordinate and implement the response plan.

Confirmation of Report

Any *Spartina* sighting must 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 grass species that resemble *Spartina* and which grow in the same habitat. Identification of grasses can be difficult due to their unique morphology and the specialized terminology used in their classification. Identification to genus level can be done quickly by personnel at ODA, Portland State University, and/or Oregon State University. Determination to the species level may require more time. The best way to ensure accurate identification of suspect plants is to rely on recognized taxonomic experts for this task. A list of taxonomic experts that should be consulted for confirmation of *Spartina* identification is included in Appendix B. This list should be updated at least every two years to keep contact information current (last updated August 2006).

Plants are typically classified using floral features, however, detection may not coincide with flowering. The PSU Center for Lakes and Reservoirs developed "Key to West Coast *Spartina* Based on Vegetative Characters" to enable identification by vegetative characteristics. This key is small, portable, and available from the Center for Lakes and Reservoirs (www.clr.pdx.edu/projects/ans_research/*Spartina*/images/*Spartina*key.pdf) and the Oregon Department of Agriculture Noxious Weed Program.

The use of DNA identification techniques has 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 location of the *Spartina* most closely related to any new Oregon infestation.

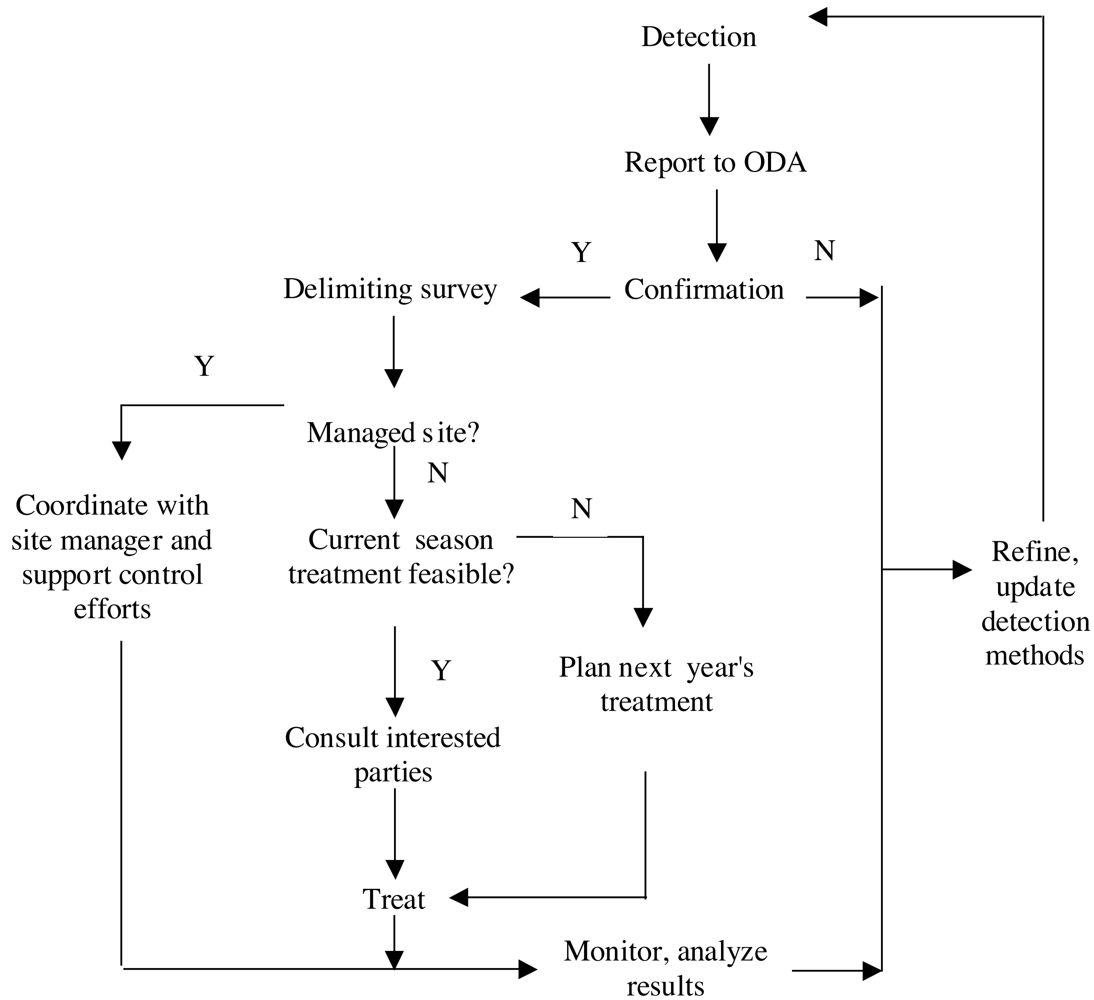

Figure 8. *Spartina* response plan flowchart.

Ownership and Delimiting Survey

Following positive identification, ownership of the site needs to be determined. Local tax lot information can be used for determining ownership in most cases. Tax lot information is available from local county assessor's offices or from the Oremap project of the Oregon Department of Revenue. Oremap includes tax lot maps in PDF format on their website (www.gis.state.or.us/data/ormap/statemap.htm). Appendix C provides an overview of ownership of property adjacent to estuaries.

Most potential *Spartina* habitat in Oregon is not under active management by any federal, state, or local agency. Significant exceptions include the South Slough National Estuarine Reserve, which is administratively supported by the Division of State Lands and has an eight-member management commission appointed by the Governor; the Cox Island and Blind Slough Preserves, which are managed by The Nature Conservancy; and the Siletz Bay and Lewis and Clark National Wildlife Refuges, managed by the US Fish and Wildlife Service.

Response may occur more quickly and require less consultation to determine ownership and to evaluate treatment options if *Spartina* invades a managed site. It is imperative, however, that site managers inform ODA of new infestations – whether it is suspected *Spartina* or another species - to ensure that statutory requirements of Oregon weed law are met and adequate delimiting surveys are conducted on adjacent or nearby non-managed sites that are susceptible to infestation. Furthermore, ODA may be able to provide financial and personnel assistance for *Spartina* control efforts. A list of managed sites that are susceptible to *Spartina* invasion should be produced to ensure that site managers are aware of this response plan as well as to fine-tune coordination within Oregon.

Notification

Several persons and or institutions need to be informed if there is a confirmed site that is infested with a *Spartina* species. These include:

- site owners and owners of adjacent sites,
- lessees of the site or any person or organization managing the site,

- other site managers that may be impacted by *Spartina* in Oregon,
- state agencies with estuarine and/or *Spartina* management responsibilities,
- federal agencies with *Spartina* management responsibilities,
- the county Noxious Weed Control officer,
- *Spartina* management agencies in neighboring states, and
- Oregon Shellfish Commission and aquaculturists.

Landowners and lessees, and possibly the county Noxious Weed Control officers, are especially important because ODA and other parties will need permission to access the site. Development of an Oregon *Spartina* Work Group (OSWG) that includes all agencies with *Spartina* management responsibilities or concerns is recommended. The OSWG could form the nexus of a response network that would facilitate communication of sightings and responses. It could also work with the shellfish industry to ensure that shellfish regulations across jurisdictional boundaries are compatible. The OSWG should meet periodically to keep abreast of developments in *Spartina* management.

<u>Delimiting survey.</u>

Upon confirmation of a *Spartina* infestation, 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. ODA, which is responsible for enforcement of noxious weed laws in Oregon, should have the primary responsibility for coordinating the delimiting survey although other agencies and organizations should be prepared to provide personnel and equipment assistance if needed. Although seldom used, ODA may use its quarantine authority (see box at right).

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. ODA, ODFW, DSL, and DEQ have GIS capabilities. Base maps of all potential infested areas should be on file for rapid calculation of infested area and for use in planning management activities. 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 in optimizing future prevention and detection efforts. A number of important questions have been consolidated into a checklist that should be used when doing the survey (Appendix D).

Quarantine

The Director of the Oregon Department of Agriculture has the authority to quarantine products or areas if they contain pests that threaten the State. This authority could be used to prevent traffic through a *Spartina*-infested area that could spread the plant, to ensure access for management activities, and to prohibit movement or sale of products or materials into or from the site. While quarantines are rarely invoked, it is a tool that may be appropriate in some situations. (ORS 561.510-561.600)

Access to a boat and qualified pilot are critical for access to estuarine sites. Oregon Department of Agriculture Food Safety Division and the Oregon Department of Fish and Wildlife may be able to provide boats for the delimiting survey. 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. Oregon Department of Environmental Quality (ODEQ) owns a hovercraft capable of carrying two people with their equipment (4 people without) although those experienced in *Spartina* control in Willapa Bay have not found hovercraft to be 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.). Both 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. Appendix E lists equipment/resources already owned by state agencies that are likely to be needed for survey work (and control work). ODA, or another appropriate state agency, should obtain an airboat for survey and management work on *Spartina* (see Appendix F for a list of resources needed).

Management Options

Biological, physical, and chemical weed control methods have been applied to *Spartina* in Willapa Bay, with mixed success. Biological control of *Spartina* using the plant hopper, *Prokelisia marginata,* is under study at Willapa Bay, however, it is not considered an eradication technique and is likely to be most effective on very large infestations as part of an integrated management strategy that also uses physical and chemical methods. Cost-effectiveness of physical methods, such as digging, mowing, covering, and tilling vary with size of the infestation to be controlled, location of the infestation in the estuary, and possibly species. The use of herbicides containing imazapyr or glyphosate has been effective in some situations, but a National Pollution Discharge Elimination System (NPDES) permit would apparently be required. A NPDES permit does not currently exist for herbicide application for *Spartina* control in Oregon and would need to be developed by DEQ prior to use of any aquatic herbicide.

Size of the infestation is the primary determinant of the efficacy of various methods of controlling *Spartina*. 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 to 5 acres) infestations. As noted above, the infestation size that will require chemical control for eradication 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. Table 6 lists a range infestation sizes with combinations of control techniques that are applicable to the scale of the infestation.

Table 6. Control strategy/method based on size of initial infestation and cost effectiveness of each method.

Category	Infestation Size (net/gross acres)	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

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 goal. Large infestations would require much more resources than are currently available in the ODA weed program budget. More details on treatment methods are in Appendix G.

Small sites (categories 1 and 2 in Table 6) can be eradicated relatively quickly, perhaps in ten years. Containment may be a more appropriate initial goal for larger infestations (categories 3 and 4 in Table 6) until an eradication strategy can be developed. With regards to large infestations, such as those found in Willapa Bay, a model of different control strategies on *S. alterniflora* demonstrate that targeting an infestations' outliers, rather than concentrated meadow areas, results in up to 44% less time and effort to eradicate a population (Grevstad 2005).

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.

Rototilling of *Spartina* has been somewhat effective in Willapa Bay, especially 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 mesohaline conditions (Figure 6) and could reestablish 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 used for four to six years (Pickering, 2002). Native vegetation rapidly reestablishes once the fabric is removed. The Nature Conservancy is using covering to attack 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 slowly 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).

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 in Washington and California will inform use of herbicides for management of *Spartina* in Oregon. Given the likely need for specialized equipment, costly permits, and extra monitoring, herbicides are appropriate only on large infestations. In some cases, however, handsprayers or wick application using wands may be appropriate for small infestations. Given the limited resources available in Oregon to respond to *Spartina* invasions, such applications may be required. ODA and other agencies could probably address small infestations fairly quickly with available resources using herbicides if required permits could be obtained.

Imazapyr and Glyphosate are currently being used for control of *Spartina* in both 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), is now the preferred choice for chemical treatment since the EPA granted registration for its use in aquatic environments in 2004 (Murphy 2004). While the cost of imazapyr is over twice that of Glyphosate ($180 vs. $81 per acre treated) it is more consistent and 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) result in greater cost effectiveness.

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.

Permits

Oregon's Department of Environmental Quality (DEQ) does not require a National Pollutant Discharge Elimination System (NPDES) permit or other water quality permit for pesticide applications provided the application is performed according to the approved Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) label instructions. This position is consistent with longstanding EPA policy and was clarified by EPA in federal regulations adopted November 2006.

The need for a permit was called into question when the U. S. Ninth Circuit Court in Headwaters, Inc. v. Talent Irrigation District, 243 F. 3d 526 (9th Cir. 2001) ruled that an NPDES permit was required for pesticide applications made directly into surface waters. This decision and other court decisions prompted EPA to clarify its policy that NPDES permits are not required by adopting federal regulation to that effect. The regulations are being challenged by a variety of parties, however, they have not been stayed. DEQ advises that it does not intend to issue NPDES permits for pesticide applications made in compliance with FIFRA requirements unless the federal regulations are revised

Under EPA's November 2006 ruling, pesticides do not fit the term "pollutant" as described in the Clean Water Act and, for that reason, applications of pesticides in compliance with the federal label do not require a NPDES permit when either:

- The application of the pesticide is made directly to waters of the United States to control pests that are present in the water
- The application of the pesticide is made to control pests that are over, including near, waters of the United Sates

Regulatory agencies in both Washington and California require permits for pesticide applications. In Washington, the Department of Ecology has developed a general use permit, which allows the control of noxious and quarantine-list weeds along lake and river shorelines, in rivers, wetlands, and estuaries; the spraying programs for *Spartina* fall under this general permit. In California, the State Water Resources Control Board issued a statewide general NPDES permit in 2004 for the discharge of aquatic pesticides for aquatic weed control. Additionally, the California Department of Pesticide Regulation requires Use Permits, which local County Agricultural Commissions issue for specific projects.

<u>Integrated Management</u>

The most appropriate method, or combination of methods, should be used for *Spartina* management in Oregon. As noted above, biocontrol is under investigation for *S. alterniflora* control in Willapa Bay as part of an integrated strategy that also includes chemical and physical methods. A small infestation of *S. alterniflora* was eradicated using a combination of herbicides and digging in the Siuslaw estuary; and a combination of mowing and covering is being used effectively on some relatively large *S. patens* patches on Cox Island. Thus, successful *Spartina* control requires the availability of a variety of control techniques that are applied in a manner that is most appropriate for the site and the size and stage of growth of the infestation. There is clearly no single *Spartina* control technique that can be applied successfully under all circumstances. Rather, an integrated response will be most effective in protecting Oregon estuaries from *Spartina*.

<u>Costs</u>

Estimates of the cost per acre of each of four control methods are shown in Table 6. Manual methods of control (digging and covering) are appropriate for small infestations due to their high cost per acre. Mechanical and chemical methods, with their lower per acre costs, are appropriate to use on large treatment sites. Intermediate sized sites could be treated using a combination of methods.

Table 7. Cost per unit area of *Spartina* control methods.

Digging[1]	Covering[2]	Mechanical[3]	Chemical[4]
$2-$3/ft^2	$0.22 - $30/ft^2	$390-$2000/acre	$300-$780/acre

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.

Multiple Year Treatments and Long-term Monitoring

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 an infestation. Without a long-term commitment to management, the realization of the goal to exclude *Spartina* from Oregon will fail. 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). Success of treatment, even when repeated consistently, varies with habitat type; mudflats and low salinity marshes show appear to be the least responsive to control measures (Hacker et al. 2001) Rapid, effective, and persistent implementation of the *Spartina* management plan is essential for successful control. Potential obstacles to rapid implementation of a plan include lack of interagency cooperation, public opposition, logistic problems, and availability of funds.

Outreach and Education

Outreach and education on invasive species in general and *Spartina* specifically may be useful in increasing ability to detect *Spartina* and facilitating management activities. Outreach and education activities should be incorporated into existing efforts in Oregon, including the aquatic invasive species outreach efforts of Oregon Sea Grant to watershed councils on the coast and the Oregon State Marine Board efforts with boaters. The Oregon Invasive Species Council is currently preparing an outreach and

education strategy that should also include a clear and consistent *Spartina* message.
Coordination of *Spartina* Management

A number of state and federal agencies with resource management responsibilities, as well as private interests, will be impacted by *Spartina* invasion (Table 8). Since *Spartina* threatens a variety of beneficial uses, a coordinated response from water resource management agencies is critical. A point of contact within each participating agency and interest group should be identified; an initial list is provided in Appendix H. The Oregon Department of Agriculture (ODA) is the lead agency in noxious weed management (Oregon Department of Agriculture 2001) in Oregon, although all state agencies have a requirement to control noxious weeds (ORS 570.510). Other programs and/or agencies in Oregon that already have management responsibilities applicable to *Spartina* control include the Oregon Aquatic Nuisance Species (ANS) Management Plan (Hanson and Sytsma 2001), the Oregon Division of State Lands, the Oregon Department of Environmental Quality, and the Oregon Department of Fish and Wildlife. Several other state and federal agencies also have key roles in implementing this *Spartina* Response Plan.

The Oregon Aquatic Nuisance Species (ANS) Management Plan provides the overall framework for developing coordinated, comprehensive management plans aimed at all aquatic nuisance species within the state of Oregon. The ANS Management Plan uses four management classes to prioritize the current and potential threats posed by ANS. Management class 1 pertains to species which "are currently not known to be present in Oregon, but with a high potential to invade…" and class 2 pertains to those which "…are present and established in Oregon with impacts that can be mitigated or controlled with appropriate management." *S. alterniflora*, *S. anglica*, and *S. densiflora* would all fall into class 1 and *S. patens* into class 2.

The ODA Noxious Weed List currently classifies *S. alterniflora*, *S. anglica*, *S. densiflora* and *S. patens* as Class A noxious weeds. Their listing prohibits their importation, sale, purchase, transportation, and propagation in the state of Oregon (OAR 603-052-1200). These species have as additionally been listed as class T weeds (so listed by the state weed board 2/14/03). A class T weed is a "priority noxious weed designated by the State Weed Board as a target weed species on which the Department will implement a statewide management plan" (Oregon Department of Agriculture 2002). This document provides the necessary management plan.

Table 8. Governmental agencies with resource management responsibilities that will be impacted by Spartina

Agency:	Responsibility
OR Department of Agriculture:	Noxious weed control; herbicide registration; applicator licensing
OR Division of State Lands:	Submersed and publicly owned tidelands
OR Department of Environmental Quality:	Clean Water Act; herbicide permitting, ballast water management;401 certification of US Corps of Engineers permitting
OR Department of Fish and Game:	Protection of native wildlife and habitat
OR Parks & Recreation Department:	Maintenance of state-owned park lands
OR State Marine Board	Boater education, environmental protection
OR Department of Land Conservation and Development:	Coastal Zone Act
Lower Columbia River and Tillamook Estuary Partnerships:	Coordinate stewardship activities in estuaries
Center for Lakes and Reservoirs, PSU:	Implement Aquatic Invasives Species Management Plan
U.S. Environmental Protection Agency:	Herbicide registration, implement Clean Water Act
NOAA Fisheries:	Sustainable fisheries, Endangered Species Act, marine coastal ecosystem health
U.S. Fish and Wildlife Service:	Habitat conservation, Endangered Species Act, refuge management
U.S. Army Corps of Engineers:	Navigation, dredging, wetlands fill permits (404 permitting)

FUNDING

Adequate funding is critical to effective prevention and control of *Spartina* in Oregon. While there may be some flexibility to reallocate resources within current agency budgets, it seems unlikely that all the recommendations here can be implemented without supplemental funding. There are a number of different possible sources of funding that may be explored, but it should be understood that if a large *Spartina* infestation develops, current funding and soft monies will clearly not be adequate to realize the goal of keeping Oregon *Spartina*-free. Capitalizing on ongoing efforts in Oregon estuaries, including use of passive surveillance is necessary. Developing additional funding mechanisms is also necessary. Depending upon federal funding appropriation, some support for *Spartina* surveys may be available through the Oregon ANS Management Plan. Specific management tasks may be funded through the OWEB or State Weed Board programs.

ACCOMPLISHMENTS SINCE 2003

The following management actions and research activities were accomplished since the *Spartina Response Plan* was adopted in 2003:

- House Bill 2577, in the 2005 legislative session, designated the Oregon Department of Agriculture as the lead agency for weed management in Oregon
- Opportunities for regional coordination of *Spartina* management were pursued
- Annual surveys of Oregon estuaries using fixed-wing, ground, or boat methods were conducted
- Ongoing efforts to control *S. patens* on Cox Island were supported
- Developed agreements with UC Davis & Bodega Marine Laboratory for genetic analysis of *Spartina*
- All species of *Spartina* were designated as "T" listed noxious weeds (2/14/03) and *S. patens* was placed on the “A” list of Oregon noxious weeds (2004)
- Coordinated *Spartina* outreach and education with ongoing efforts by Sea Grant and Oregon Invasive Species Council
- Trained people that can conduct “passive” surveillance, e.g., commercial oyster growers, watershed council members, etc.
- Supported ongoing control efforts in California and Washington aimed at strategies that minimize export of seeds and vegetative propagules
- Acquired base maps of all Oregon estuaries for GIS mapping of potential new infestations
- Evaluated ability of root, rhizome, and stem fragments to resprout
- Examined potential survival and viability of plant fragments, i.e., survival time according to rhizome size, duration of floatation, and salinity
- Evaluated possible spatial and temporal patterns of dispersal from three major *Spartina* infestations along the west coast, evaluating Oregon’s relative risk for invasion by the various populations’ representative species.

- Developed various educational materials including: an invasive cordgrass brochure, a *Key to Select Grasses of the Oregon Coast*, and also distributed the *Key to West Coast Spartina Based on Vegetative Characteristics*.

FUTURE ACTIONS

While several important accomplishments were made in *Spartina* management and research since 2003, additional work is needed to meet the goals of the Plan. Future management and research activities are listed below.

Management

- Ensure that the Plan and ODA's lead role as designated in statute is understood by potential collaborating agencies
- Work toward intra- and interstate coordination of *Spartina* management
- Conduct annual surveys of Oregon estuaries using fixed-wing, ground, and boat methods as appropriate
- Track potential changes in permit requirements for herbicide application
- Support ongoing efforts to control *S. patens* on Cox Island
- Review and clarify the ODFW Live Fish Transport Permit requirements (and their application) to minimize the risk of importing *Spartina* propagules into Oregon with live fish and shellfish.
- Develop list of managed areas susceptible to *Spartina* invasion in Oregon and contact responsible management entity
- Update inventory of equipment currently available and acquire necessary equipment (such as an airboat) for rapid response
- Coordinate *Spartina* outreach and education with ongoing efforts by Sea Grant and Oregon Invasive Species Council
- Identify and train people to conduct "passive" surveillance, e.g., commercial oyster growers, waterfowl hunters, fishing guides, etc.
- Develop best management practices for solid ballast in dredges to prevent spread of *Spartina* (see research items below)
- Support ongoing control efforts in California and Washington – develop strategies to minimize export of seeds and vegetative propagules
- Work with USFWS and other interested parties to develop a management strategy for *S. densiflora* in Humboldt Bay
- Use GIS to map substrate type, tidal height, and wave action to focus surveys on areas most likely to support *Spartina*

- Identify source of funds to implement sections of the Plan that cannot be covered by existing State programs

Research

- Evaluate and prioritize dispersal and introduction pathways, including role of shellfish transport and migratory birds in the dispersal of *Spartina*
- Investigate role of solid ballast on dredges in dispersal of *Spartina*
- Investigate use of remote sensing techniques for detection of *Spartina*
- Evaluate the impact of *S. densiflora* on high elevation marsh habitat quality and bird use in Humboldt Bay
- Evaluate changes in carbon and nitrogen flow in food webs of estuaries invaded by *Spartina*

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APPENDICES

Appendix A. Stream outlets surveyed for Spartina in 1998 & 1999 (from Noxious Weed Control Section ODA 2000)

Name/Location	Rating*	Remarks
Necanicum River/Neawanna Creek	1	Extensive suitable areas about 1 mile (each) above their confluence
Ecola Creek	2	Sandy substrate, subject to movement by wind, water
Depoe Bay	2	Limited area, deep water at high tide
Salmon River	1	Extensive mudflat areas
Beaver Creek	2	Small, susceptible spot north of pedestrian bridge, west bank
Big Creek/Reynolds Creek	2	Small, susceptible spot west of highway bridge
Yachats River	3	Wave action, river course channeled
Tenmile Creek	3	Substrate of cobbles subject to movement, competing vegetation
Big Creek	3	Substrate of cobbles subject to movement, competing vegetation
Sutton Creek	3	South-flowing behind primary dune, ephemeral channel, vegetated
Siltcoos River	2	Marshy area ~300 m east of mouth, west of Waxmyrtle campground
Tahkenitch Creek	2	South-flowing behind primary dune, ephemeral channel, vegetated
Tenmile Creek	2	Marshy areas, somewhat ephemeral, sedges present
Twomile Creek	3	Sand substrate, ephemeral
Fourmile Creek	3	Sand substrate, ephemeral
Floras Creek	2	Stream course channeled, current, competing vegetation
New River		
Sixes River	3	Current, coarse substrate subject to movement
Elk River	3	North-flowing, coarse substrate, vegetation
Port Orford	3	Considerable wave action
Mussel Creek	3	No pooling, coarse substrate
Euchre Creek	2	Long, low-relief entry to ocean
Rogue River	2	Substrate tends to coarse types, substantial current, some marshy vegetation
Hunter Creek	2	Some small unvegetated flats, marshy vegetation
Myers Creek	3	No pooling, coarse substrates
Pistol River	3	One main channel, coarse substrates

*** Ratings: 1 = Extensive areas suitable for *Spartina* invasion, 2 = Limited area, 3 = No expectation**

Appendix B: List of identification experts

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Appendix C: Ownership of lands adjacent to estuaries

Estuary	Private	City	County	State	Federal
Columbia	+	Astoria, Hammond	Clatsop	State Parks	Fish & Wildlife
		Warrenton		Dept. of Forestry	
Necanicum	+	Gearhart	Clatsop		
		Seaside			
Nehalem	+	Brighton, Nehalem, Wheeler, Wheeler Heights.	Tillamook	State Parks	
Tillamook	+	Barview, Bay City, Garibaldi, Tillamook	Tillamook	Dept. of Forestry	
Netarts	+	Netarts, Wilson Beach	Tillamook	State Parks	Forest Service
Sand Lake	+		Tillamook		Forest Service
Nestucca	+	Pacific City	Tillamook	State Parks	Forest Service
Salmon	+		Lincoln		Forest Service
Siletz	+	Cutler City, Kernville, Taft	Lincoln	State Parks	
Yaquina	+	Newport, Weiser, Yaquina	Lincoln	State Parks	
Alsea	+ (1)	Bayview City, Waldport	Lincoln	State Parks	Forest Service
Siuslaw	+	Florence, Glenada	Lane		Forest Service
					Coast Guard
Umpqua	+	Gardiner, Reedsport, Winchester Bay	Douglas	State Parks	Forest Service
					Coast Guard
Coos	+	Barview, Charleston, Coos Bay, Cooston, Empire, Glasgow, North Bend	Coos	State Lands	BLM, Forest Service, NOAA, Navy
Coquille	+	Bandon, Bullards, Burner, Prosper	Coos	State Parks	

1. Simpson Timber Co., Boise Cascade Corp., Georgia Pacific, & other private owners

Appendix D: Delimiting survey checklist

1. Exact location of infestation (GPS coordinates, 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
        i) Vegetative only
        ii) Flowers
        iii) 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

   F) Is there evidence of dredging, or of deposition of dredge material

7. 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 paper

8. 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*

9. In what way might information about the infested sight be used to improve detection efforts?

Appendix E: Resources available

Type	Owner (#)	Location	Comments
SHOVELS	ubiquitous		
MUDDERS	ODA (2 sets)	ODA Noxious Weed	Tim Butler, 503-986-4621
	USFW	[2] Willapa Bay NWR, Washington	Charlie Stenvall, 360-484-3482
SMALL BOATS			
-various	USFWS	[2] Willapa Bay NWR, Washington	Charlie Stenvall, 360-484-3482
-small Boston whaler	WSDA	[3]Willapa Bay, Washington	Chad Phillips, 360-902-1923
- 17' Boston whaler & trailer	ODA - Shellfish Program	Coos Bay	Steve Palmer, 541-756-2911
- 16' Arima & trailer	ODA - Shellfish Program	Newport	John Paeth, 541-336-1402
16' Klamath & trailer	PSU – CLR	Portland	Mark Sytsma, 503-725-3833
-outboard skiffs	WDSL (3)	South Slough estuary, Charleston	Mike Graybill, 541-888-5558
-kayaks	WDSL	South Slough estuary, Charleston	Mike Graybill, 541-888-5558
-canoes	WDSL	South Slough estuary, Charleston	Mike Graybill, 541-888-5558
AIRCRAFT	none		
AIR BOATS	USFWS (10)	[2] Willapa Bay NWR, Washington	Charlie Stenvall, 360-484-3482
	WDNR (1)		
	WDFW (4)	[3]Willapa Bay, Washington	
AMPHIBIOUS VEHICLES	USFWS (4 platforms)	[2] Willapa Bay NWR, Washington	Charlie Stenvall, 360-484-3482
-Marshmaster	WSDA	[3]Willapa Bay, Washington	Chad Phillips, 360-902-1923
-Marshmaster	WDNR	[3]Willapa Bay, Washington	

HOVERCRAFT	ODEQ	Portland, Oregon	Larry Caton, 503-229-5983
[1]SPRAY EQUIPMENT			
-backpack type	ODA	Salem	Tim Butler, 503-986-4621
-ATV mounted	ODA	Salem	Tim Butler, 503-986-4621
-boom ("smart") sprayers	USFWS	[2] Willapa Bay NWR, Washington	Charlie Stenvall, 360-484-3482
GEOTEXTILE FABRIC			
-Propex 2002 or 2006 (formerly Amoco)	NW Geosynthetics, Inc.	8951 SE 76th Dr. Portland, OR 97206	1-800-878-5115 FAX 503-771-1161
- Mirafi 500	CSI Geosynthetics, Inc.	3400 SE Columbia Way #43 Vancouver, WA 98661	360-699-1426
GUTTER SPIKES/STAPLES	local purchase e.g., building supply store		

1. Herbicide spraying can only be done if necessary state and federal permits have been issued.
2. Any equipment owned by USFWS at Willapa Bay NWR is available for loan on a very limited basis (subject to their own needs) – not a reliable source. Loan of motorized equipment may require "borrowing" one of their pilots/operators.
3. Equipment owned by State of Washington agencies may be available for loan on a very limited basis (subject to their own needs) -not a reliable source. Loan of motorized equipment may require "borrowing" one of their pilots/operators.

Air boats - none owned by the state of Oregon; USFWS at Willapa Bay NWR has a fleet of 10 plus a "smart" sprayer which fit on the airboats and the amphibious vehicles; airboats not usable in windy condition or on sand, gravel, or rocky substrates; some special training required for pilots - training sometimes available in March or April at Willapa Bay ; those based in Willapa Bay are heavily used from May - October for *Spartina* control (contact: Charlie Stenvall, USFWS, 360-484-3482)

Appendix F: Resources needed

Type	Cost	Need	Priority	Comments
Mudders	$109.00/pair	20 pair	HIGH	Ben Meadows Co.(www.benmeadows.com)
				Forestry Suppliers, Inc.(www.forestry-suppliers.com)
Airboat	~$40,000			

Appendix G. 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. Mowing- cut plant at, near, or just below the soil surface for best results Chemical mowing- use weak concentration to stop seed set and preserve standing biomass for clapper rail refugia 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.

Appendix G. Summary of Proposed Treatment Methods (continued)

	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 a high level of 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 H. Field notes for early detection surveys

Bay/Creek Mouth:	
Date	Year
Surveyed by:	Tide (low/high)
Estimated time (hours):	Weather:
Gear Cleaned After Use:	
Description (area in relation to local landmarks, elevation, dominant substrate/vegetation, complications/safety issues, methods used – boat, kayak, ground, scope, aerial). Use decimal degrees (WGS 84) to record specific lat/longs.	
Follow-up required? (Y / N) If yes, where/why?:	