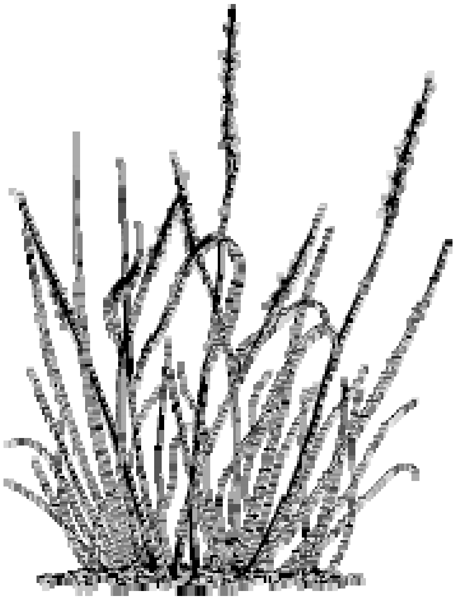

B.C. *SPARTINA* RESPONSE PLAN 2010

PREPARED FOR:

Dan Buffett
Ducks Unlimited Canada
13370 – 78th Avenue, Unit 511
Surrey, BC V3W 0H6

Ducks Unlimited Canada
Conserving Canada's Wetlands

PREPARED BY:

Keri Dresen (*EDI Environmental Dynamics Ltd.*)
Lisa Scott (*Eco-Matters Consulting*)
Gary Williams (*GL Williams & Associates Ltd.*)

EDI CONTACT: KERI DRESEN
(250) 562-5412

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ACKNOWLEDGEMENTS

This report was developed by a team consisting of:

- Keri Dresen of *EDI Environmental Dynamics Inc.* was the lead biologist and author for this project. She completed the information gathering and review, conducted interviews and authored Section 2: *Spartina* History in the Pacific Northwest, Section 4: *Spartina* Eradication Toolkit and Section 5: BC *Spartina* Eradication Program of the report.
- Lisa Scott of *Eco-Matters Consulting* provided an advisor role, project support and co-authored Section 5: BC *Spartina* Eradication Program.
- Gary Williams of *GL Williams & Associates Ltd.* authored Section 3: Ecology of the report as a separate contract in addition to providing project support and advice throughout the project.
- Dan Buffet of *Ducks Unlimited Canada* drafted Section 1: Problem Definition, Section 2.4: Invasion History and Eradication Efforts in BC, provided *Spartina* photos and maps within the report.
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EXECUTIVE SUMMARY

Along the Pacific Coast, there are four species of invasive cordgrass (*Spartina alterniflora*, *Spartina anglica*, *Spartina densiflora*, and *Spartina patens*) that have invaded ecologically critical habitat within the intertidal and low marsh communities of estuaries and the outlets. *Spartina* forms dense monocultures that disrupt the ecology, structure and function of mudflats and intertidal habitat, which provide the basis for a complex food web that includes invertebrates, fish, shorebirds and waterfowl. Monocultures also alter the hydrology of the estuaries by creating deep drainage and surge channels, increasing elevation that can affect navigation and cause coastal flooding.

In 2003, the BC *Spartina* Working Group (BCSWG) was formed as a multi-stakeholder group to control and ultimately eradicate non-native *Spartina* species from the BC Coast. The working group has managed inventory and removal efforts while developing valuable partnerships with counterparts in Washington and Oregon. They developed a BC *Spartina* Response Plan based on ecological principles and applied an integrated vegetation management approach. The working group initiated development of the 2010 BC *Spartina* Response Plan to expand upon the previous plan and guide the *Spartina* Eradication Program in BC. The plan supports the cross border initiatives of the West Coast Governors Agreement on Ocean Health.

The BC *Spartina* Response Plan 2010 consists of a brief summary of the history of *Spartina* in the Pacific North West including in BC, a detailed ecology section, a *Spartina* eradication toolkit section, and the BC *Spartina* Eradication Plan which recommends a practical management strategy. The plan was developed through the following components: conducting a comprehensive literature review, interviewing experts throughout the Pacific Northwest to gain practical information on *Spartina* management and collating this information, and developing strategies with management options specific to *Spartina* in B.C. It is recommended that the plan be updated every five years to reflect new information and methods.

In Washington, Oregon and California where *Spartina* has been identified as a problem for some time, millions of dollars are spent annually on *Spartina* management programs. In Washington, *Spartina* coverage increased by 250 % between 1995 and 2000 and was estimated to inhabit approximately 3642 hectares (ha) by 2003. Following the successful implementation of an intensive integrated *Spartina* management plan, fewer than 506 hectares were reported by 2008. This program was reported to cost $1.79 million between 2007 and 2009.

Prevention and controlling the spread at the early stages of expansion is the most cost effective management approach. Now is time to act in B.C., where known infestations of the species are within the relatively early stages of growth, existing as pioneer infestations characterized by small clones or individual plants and do not yet exhibit vast monocultures. Known infested areas in BC are the Fraser Delta (Boundary Bay, Roberts Bank, Burrard Inlet) and Vancouver Island (Baynes Sound and Courtney Estuary).

The primary restricting factor in managing *Spartina* in BC is funding. As outlined in this plan, it is expected that it would cost $200,000 annually for five years to successfully eradicate *Spartina* from BC. If eradication efforts are not appropriately funded in the near future, eradication will become unlikely and management costs will dramatically increase to address more severe impacts caused by larger infestations.

1 PROBLEM DEFINTION

1.1 WHY IS *SPARTINA* A PROBLEM?

Several non-native species of *Spartina* were introduced in the Pacific Northwest, and have expanded north from California, Oregon and Washington. In 2003, *Spartina anglica* was initially detected at Roberts Bank in BC. *Spartina* causes serious impacts to sensitive ecological communities and native plant, invertebrate, and bird species in addition to causing economic impacts to the mari-culture food industry. Timing is crucial to successfully eradicate species such as *Spartina*. The stage and ecology of *Spartina* infestations currently in BC indicate now is the time for intensive and effective action.

In BC, there are three confirmed invasive species of concern in the cordgrass family: *S. anglica*, *S. densiflora* and *S. patens*. Figure 1 illustrates the distribution of these three *Spartina* species in British Columbia.

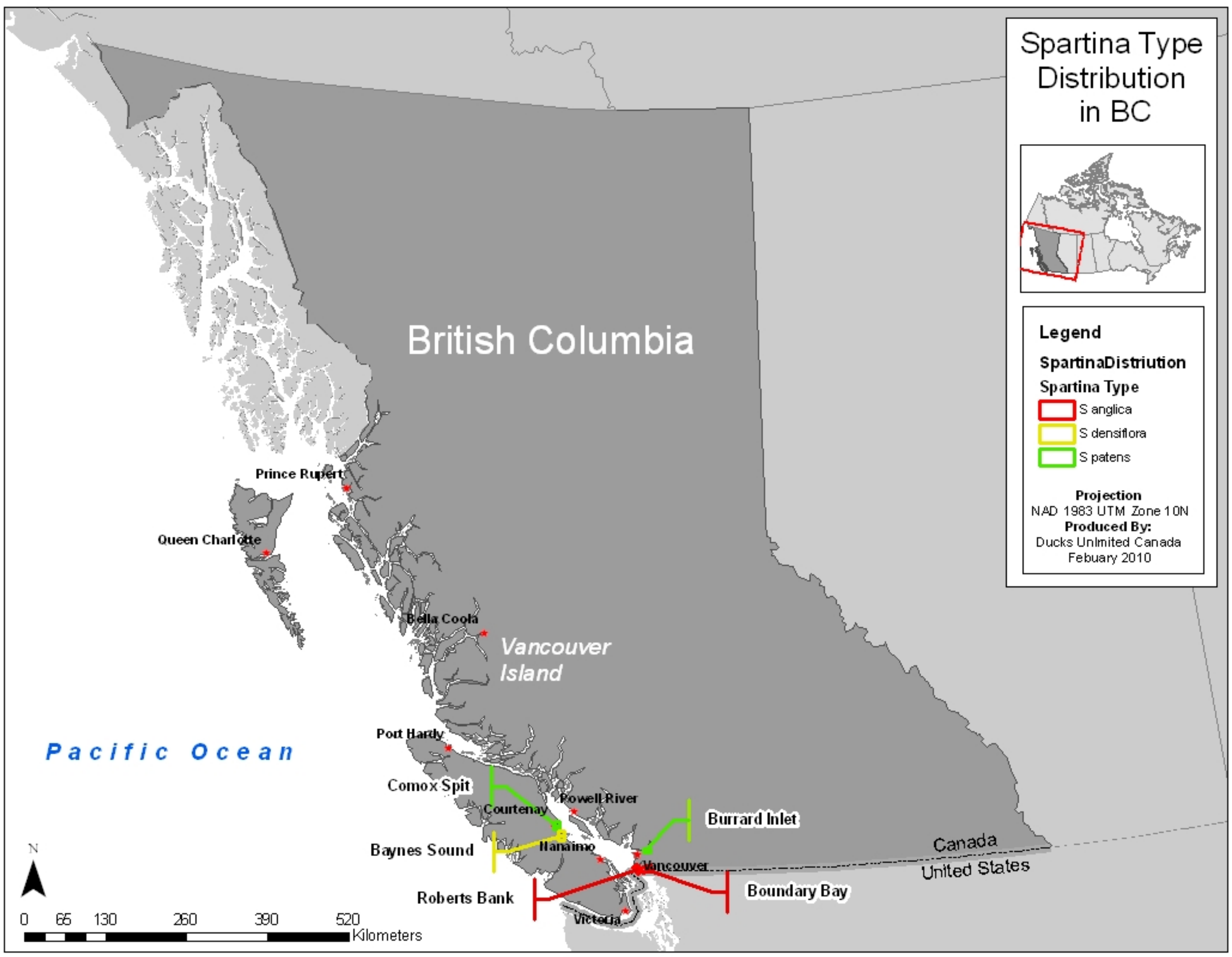


Figure 1. Current distribution of *Spartina* in British Columbia.

S. alterniflora is another invasive species in the cordgrass family which has caused large infestations in Washington State and is considered a likely invader (Williams 2009). As these species invade, natural estuarine habitats can be transformed into elevated *Spartina* meadows with steep seaward edges. These habitats include mudflat, sandflat, gravel, cobble, and sand beaches, salt marsh, brackish marsh, tidal and dendritic channels.

Spartina species can out-compete native salt marsh and brackish marsh species and are capable of forming swards or mono-specific stands (Williams 2009). Other impacts of *Spartina* include: extensive regional loss of tidal flats, tidal sloughs and channels, interference with natural sedimentation processes, increased need for dredging and flood control, production of massive piles of vegetative debris, and spread of non-native cordgrasses to other estuaries (California State Coastal Conservancy 2003). *S. anglica* was shown to cause a shift of invertebrates from infaunal to epifaunal invertebrates (Bouma et al. 2009). *Spartina* has been shown to exclude native plant species such as *Zostera* and *Salicornia* species, which leads to the loss of feeding habitat for wildfowl and waders. The spread of *S. anglica* also threatens the economic interests of commercial oyster fisheries and can reduce amenities in areas relying on tourism (Global Invasive Species Database 2009).

Spartina has invaded the states of California, Oregon and Washington and in response the United States is spending significant funds on *Spartina* management in these areas. *S. anglica* and *S. alterniflora* have been highly aggressive in Washington and Oregon. In 2003, Washington reported over 3642 hectares of solid *Spartina* statewide and the management efforts have cost millions of dollars with $1.79 million spent between 2007 and 2009 (Phillips et al. 2008). *S. densiflora* affects a substantial part of Humboldt Bay in California. In BC, *Spartina* was identified in 2003 and is currently present as clones around the Fraser Delta (Boundary Bay, Roberts Bank, Burrard Inlet) as well as on Vancouver Island (Baynes Sound and Courtenay Estuary).

Invasive species populations typically begin as small populations then increase exponentially once established. The degree of impact correlates directly with infestation size along with cost to control or eradicate the invasive plant. Infestations in BC are currently within the early stages of population growth as pioneer infestations exist mostly as individual plants and clones but have not developed into large monotypic fields. Therefore, it is both economical and practical to remove *Spartina* at this early infestation stage.

Our assumption is that the primary pathway of spread is through seed or vegetative material dispersal within ocean currents or within wrack. Human induced pathways such as shipping or boating recreational activities could definitely spread *Spartina* but are not expected to be the major pathway.

BC has over 27,000 km of coastline, including 59,300 hectares of tidal flats and marsh in over 440 estuaries (Ryder et al. 2007) which are vulnerable to infestation. In the Fraser Delta (Roberts & Sturgeon Banks) and Boundary Bay estuaries alone there are over 28,500 hectares of tidal flats. The potential negative ecological impacts are of specific concern in the Fraser Delta as it is a major staging area and stopover for millions of shorebirds and waterfowl during spring and fall migrations and has the highest wintering concentrations of waterfowl, shorebirds, and raptors in Canada owing to its combination of tidal mudflats and adjacent agricultural land (Butler and Campbell 1987).

The goal of *Spartina* management in BC is to work towards eradication while preventing the establishment and spread of any invasive *Spartina* species in BC estuaries and coastal wetlands. This will contribute to the goal of non-native *Spartina* eradication by 2018 along the Pacific Coast of the United States and British Columbia (West Coast Governors' Agreement on Ocean Health, 2009).

2 *SPARTINA* INVASION HISTORY AND ERADICATION EFFORTS IN THE PACIFIC NORTH WEST

2.1 CALIFORNIA

California has two large *Spartina* infestations: Humbolt Bay and San Francisco Bay. Although the Department of Fish and Game can claim jurisdiction, the California Coastal Conservancy is the designated lead agency. They conduct monitoring, planning, and treatment of infestations in San Francisco Bay through their regionally coordinated Invasive *Spartina* project, and are the lead state agency involved in eradication planning for Humbolt Bay (West Coast Governors' Agreement on Ocean Health 2009).

In 2003, it was reported that *S. densiflora* occupied 90 % of Humbolt's Bay and was abundant in the Eel River and Mad River estuaries (http://www.fws.gov/humboldtbay/spartina.html). Experimental control techniques began in 2004 and 2005 using mowing and digging. They found these methods most effective eradication tools on small infestations with low or medium density. A regional *Spartina densiflora* eradication program is currently being developed for the area (http://www.fws.gov/humboldtbay/*Spartina*summit.html).

The San Francisco Estuary Invasive *Spartina* Project (ISP) conducts annual inventory and monitoring of more than 14,000 hectares of tidal marsh throughout the Bay to prepare an accurate inventory of all invasive *Spartina* and to assess the effectiveness of treatments (Grijalva et al. 2008). They use a combination of aerial photograph interpretation methods and field methods such as by foot, bicycle and boat. Photographic interpretation methods involve analyzing georectified, high-resolution infra-red aerial imagery and digitize invasive *Spartina* patches directly in a geographic information system. However, recently they shifted away from photo interpretation to the more accurate field methods. This also served the purpose of initiating monitoring early in the season to provide more timely results for earlier initiation of *Spartina* treatment (Grijalva et al. 2008).

In San Francisco Bay, 70 to 80 % of treatment is accomplished by aerial or boat application of the aquatic herbicide, imazapyr. The remaining 20 to 30 % of treatment is accomplished by ground application of herbicide (walking or driving a tracked vehicle through the marsh), by digging, and by covering plants.

The *Spartina* management program in San Francisco Bay is severely complicated as a number of non-native *Spartina* infestations support the endangered California clapper rail. As a result, impact mitigation strategies are required. For example, treatment activities are prohibited during the nesting season or in areas with dense populations, and treatment is completed in phases to assure adequate time for rails to adapt to change in vegetation type and cover or relocate to other marshes with minimal disruption (Grijalva et al. 2008).

2.2 OREGON

Oregon prepared a *Spartina* management plan in response to the elevated potential risk for infestation from large core infestations within neighbouring California and Washington (Pfauth et al. 2003). Oregon's strategy is to prevent, detect, identify, and eradicate pioneer infestation utilizing a rapid, coordinated response (Pfauth et al. 2003). This is accomplished in part through the appointment of a lead agency, The Department of Agriculture, and by encouraging a single point of contact within each participating agency (Pfauth et al. 2003). Oregon's *Spartina* management program utilizes an integrated strategy that includes a combination of treatment methods including herbicides, digging, covering and mowing. Treatment is conducted persistently from year to year to maintain a long term response leading to achieve successful eradication (Pfauth et al. 2003).

Detection efforts in Oregon focus on the Northern shoreline as the Southern shoreline is more exposed with higher wave energy and is not expected to be particularly susceptible to *Spartina* (Vanessa Howard, pers. comm.). The Northern section is then divided into three mains areas with each area being inventoried utilizing aerial surveys every three years. The US coast guard provides a helicopter for the aerial surveys allowing good coverage of susceptible areas. If infestations are encountered during aerial surveys, a coordinate is taken along with site photos to be easily revisited by boat or on foot. The inventories are conducted during the height of the growing season (June – September) with the exception of *S. densiflora* which remains green through the winter contrasting the native vegetation, which experiences a die back in the winter. Therefore, winter surveys are most efficient for detecting *S. densiflora*.

In Oregon, approximately $ 15,000 to $ 30,000 is spent annually along with approximately 400 person hours devoted to *Spartina* management with the majority of effort focused on detection. These figures are decreasing each year as the program becomes increasingly efficient (Vanessa Howard, pers. comm.).

2.3 WASHINGTON

Washington State has conducted a large scale integrated pest management *Spartina* management program (Hedge et al. 2003). *Spartina* was introduced to Washington State over 100 years ago. By 1996 it had spread to 2,350 solid hectares with the largest infestation occurring in Willapa Bay and secondary infestations in Grays Harbor and Puget Sound (Hedge et al. 2003). Between 1995 and 2000, infestations increased in area by 250 %, affecting more than 3642 hectares of intertidal area (Hedge et al. 2003). Since then, millions of dollars spent on monitoring and eradication programs have effectively reduced the solid area of *Spartina* invasion by 85 % (Phillips et al. 2008). It was estimated that fewer than 506 solid hectares existed in 2003 (Phillips et al. 2008).

In 1995, the Washington State Department of Agriculture (WSDA) was designated as the lead state agency for the eradication of *Spartina* (Hedge et al. 2003). This designation was described as a critical and necessary change. The appointment improved coordination, provided an information nucleus for program information and resulted more effective sharing of resources among stakeholders (Hedge et al. 2003).

A wide range of control techniques including biological control, chemical control, and physical control have been utilized in Washington with varying levels of success (Hedge et al. 2003). The program has recently transitioned from large-scale treatments of meadows to smaller-scale treatments of scattered infestations (Phillips et al. 2007). This fine-scale work requires more personnel on the ground to cover the larger areas that helicopters or large machines were previously able to cover in a relatively short amount of time (Phillips et al. 2007). The amount and cost of herbicide needed is declining but labor costs are increasing, resulting in steady funding requirements. Between 2007 and 2009, Washington allocated $1.79 million for statewide *Spartina* activities (Phillips et al. 2007).

2.4 BRITISH COLUMBIA

Spartina management efforts have been ongoing in BC since 1997. Below is a historical account of eradication efforts based on the Fraser River Delta based on *S. anglica* project summaries provided by Dan Buffett of Ducks Unlimited Canada (DUC).

2.4.1 PRIOR TO THE INITIATION OF THE BC SPARTINA WORKING GROUP

In 1997 a Transboundary *Spartina* Workshop involving BC agencies (DUC, Canadian Wildlife Service (CWS), Fraser River Estuary Management Program (FREMP) was held in Washington State. At that meeting, there was a preliminary identification by Washington State staff that *Spartina* may exist in BC in the Nanaimo Estuary. In response, a preliminary local survey of the Nanaimo estuary was undertaken in 1999 by DUC and a local work team.

Also in 1999, an initial meeting between BC and Washington Agencies took place at the Canadian Wildlife Service office in Delta attended by: CWS, Department of Fisheries and Oceans, DUC, British Columbia Institute of Technology (BCIT), Washington State Department of Agriculture, Fish & Wildlife, Washington State Dept of Natural Resources and Seattle Aquarium. During the meeting it was acknowledged that *S. patens* had been previously detected in BC with anecdotal identifications at Maplewood Mudflats in Burrard Inlet (detected in 1987 or 1988) and in Comox Harbor in 1975.

In 2000, a preliminary survey of *S. patens* was undertaken in Maplewood Mudflats by a Fish and Wildlife class at BCIT, GL Williams & Associates, and DUC to document the location of *S. patens* along transects. It was estimated *S. patens* covered approximately 0.73 hectares. This survey was repeated in 2001 to verify accuracy of survey results.

2.4.2 2003 – BC *SPARTINA* WORKING GROUP FORMED

In 2003, a group of government and non-government agencies formed the BC *Spartina* Working Group formed in response to their recognition of the potential impacts of *Spartina* on local shorelines and wildlife habitat. They developed a plan to identify, monitor, remove and conduct outreach of *Spartina* in the Fraser River Delta while striving toward full monitoring of the BC coast and complete eradication of *Spartina* species in BC.

Spartina anglica was initially discovered on Roberts Bank in the Fraser Delta by Gary Williams during intertidal marsh surveys conducted for the Vancouver Port Authority in the summer of 2003. Upon discovery and notification to several agencies, the Vancouver Port Authority initiated a response for *Spartina* removal. A number of individuals from Vancouver Port Authority, DFO, DUC, CWS, BC Ministry of Water Land and Air Protection, Tsawwassen First Nations, and Langley Environmental Partners Society, as well as GL Williams & Associates Limited and Hemmera Envirochem Inc. were mobilized to remove *S. anglica* in the Roberts Bank area. Seed heads were clipped to prevent seed dispersal followed by mechanical removal of clones, with some clones left due to access limitations.

2.4.3 2004 – *SPARTINA* ERADICATION PLAN IMPLEMENTED

In 2004, approximately $118,000 dollars was expended in direct and in-kind costs for *Spartina* control. Infestations were located using a rapid assessment method (i.e. hovercraft) and walking shorelines with hand held global positioning systems (GPS). The GPS data was mapped using a geographical information system (GIS) and entered on the Community Mapping Network website allowing all agencies and the general public access to the information. Control was restricted to manual methods, which included digging up individual plants and small clones, and mechanical "deep in situ" burial of large clones using a low ground pressure excavator.

Spartina anglica was estimated to affect over 220 hectares of the 25,000 hectares of intertidal habitat in the Fraser River Delta. *S. anglica* was not found in Burrard Inlet, Sturgeon Banks nor south of the Fraser River Delta in Point Roberts. A final fall assessment using a hovercraft identified a few *Spartina* clones as well as individual plants that were not removed during several *Spartina* removal events. The majority of *Spartina* infestations were individual plants and clones less than 1 meter in diameter and only one area was substantial in size (25m by 25m).

Over 10 separate removal events were conducted in 2004 in Boundary Bay and Roberts Bank. The main manual removal event included approximately 88 person days which resulted in the removal of approximately 7,150 kg of *Spartina* and mud which were subsequently incinerated. An excavator was used to bury *Spartina* clones greater than 1 meter in diameter at a depth between 3 meters and 5 meters below the ground. It is estimated five times the amount that was manually pulled (7,150 kg) was buried using the excavator.

Spartina outreach consisted of many different mediums throughout the year. *Spartina* awareness occurred at several public events (World Oceans Day, eelgrass training seminars) as well as through numerous publications (press releases in the Delta Optimist newspaper, magazine articles in the Vancouver Natural History Society bulletin and Ducks Unlimited Canada Conservator). The Corporation of Delta prepared a website page for *Spartina* and Fisheries and Oceans Canada developed a *Spartina* Factsheet. The Fraser River Delta *Spartina* Project was presented at the 3rd International *Spartina* Conference in San Francisco (November 2004) where the methodology and response was recognized by several agencies.

2.4.4 2005 – BOUNDARY BAY INVENTORY, BURRARD INLET AND VANCOUVER ISLAND, CROSS – BORDER MEETING

In 2005, the *Spartina* program expended approximately $130,000 in direct and in-kind costs. Program components included monitoring, control, coordination and outreach for *Spartina*. The work included an intensive inventory in Boundary Bay, and expanded inventory to Burrard Inlet and estuaries on Vancouver Island. The abundance and density of *Spartina* in Roberts Bank decreased compared to 2004, while more *Spartina* was removed in Boundary Bay because of improved mapping. A hovercraft was used to detect *Spartina* in the tidal areas of Sturgeon banks where access was more difficult. The Community Mapping Network website was used to manage and display locations of *Spartina* monitoring and information was provided to the Invasive Alien Plant Program (IAPP).

A cross border meeting with Washington State was held to coordinate and improve technical knowledge and a *Spartina* Handbook produced by People For Puget Sound was used in BC.

2.4.5 2006 – DRIFT CARD STUDY INITIATED

In 2006, the *Spartina* program expended approximately $130,000 in direct and in-kind costs. Program components included monitoring, control, coordination, drift cards and outreach for *Spartina*. The mapping efforts in Boundary Bay increased over previous years with more people and GPS units available. There was a decrease in the abundance and density of *Spartina* in Roberts Bank compared to 2004 and 2005. However, several large clones were found in areas that had been previously inventoried. In early 2006, a Fisheries and Oceans staff person detected *S. densiflora* in Baynes Sound on Vancouver Island which had the seed heads clipped later that year.

A drift card component was added to the *Spartina* program which entailed the release of 100 orange 4 x 6 bio-degradable plywood cards from 3 sites in Canada and 3 sites in the United States once a month for 12 months to help predict how wind, waves and currents affect the dispersal of *Spartina* seeds and fragments. The study began in June 2006 and continued until May 2007. Ducks Unlimited Canada, Vancouver Port Authority and the Nature Trust of British Columbia were involved in releasing the cards in Canada while the Washington State's Puget Sound Action Team, the state Department of Agriculture and the Nature Conservancy were involved in releasing the cards in the US. The information gathered from the drift cards was managed by the Community Mapping Network (http://cmnbc.ca/).

2.4.6 2007 – MONITORED EXCAVATOR BURIAL METHOD, DEVELOPED OUTREACH MATERIALS.

In 2007, the Spartina program expended approximately $102,000 on program activities which included continued inventory and removal in the Fraser Delta, with some expansion of inventory on Vancouver Island based on the previous year's detection of *S. densiflora*. Burial sites (66) from previous years were revisited to determine the effectiveness of using an excavator to bury *Spartina* clones. There appeared to be no re-colonization from subsurface growth but some individual plants were present likely due to seeds within the sediment or rhizomes that floated to the sites. The outreach program conducted workshops on Vancouver Island and the development of a *Spartina* identification guide and *Spartina* Manual.

2.4.7 2008 – COVERING TECHNIQUE TRIALS INITIATED

In 2008, the *Spartina* program expended over $95,000 in direct and in-kind costs. Program components included monitoring, removal, and outreach which were guided by science and evaluation. The monitoring effort included inventory of approximately 2,630 hectares of shoreline around the Fraser Delta (Boundary Bay, Roberts Bank, Sturgeon Bank, and Burrard Inlet) and approximately 364 hectares of shoreline on the East Coast of Vancouver Island, near Baynes Sound. The abundance and density of *S. anglica* in Boundary Bay and Roberts Bank slightly decreased from 2007 to 2008. Despite these infestations decreasing in density, they increased in their area of distribution. There was no visual notable change in *S. densiflora* or *S. patens*. Removal efforts in 2008 used volunteers to dig out *Spartina* plants and included over 500 person hours of effort. Although this was a reasonable effort, there were still some large clones around the Fraser Delta that were not removed.

Outreach in 2008 focused on four workshops conducted on Vancouver Island. These workshops were intended to raise awareness about *Spartina* and to encourage local communities to become stewards of the shorelines in order to expand inventory and removal efforts. These workshops were attended by 85 individuals.

The BCSWG initiated an evaluation of a new control technique in 2008. This technique involved covering *Spartina* clones with geotextile fabric in order to kill the covered plant. This evaluation was undertaken with assistance from the US Department of Agriculture staff and results are pending. The drift card study, conducted in 2007 in Washington State and BC, was in the final stages of assessment and will produce a report that will help to guide mapping efforts along the coast. Finally, in 2008, further work was done to increase international cooperation on *Spartina* eradication and cross-border meetings were set up to improve information transfer and to increase partnerships.

3 *SPARTINA* ECOLOGY

In British Columbia there are four invasive species of concern: three confirmed invaders (*S. anglica*, *S. densilfora*, and *S. patens*) and one potential invader, *S. alterniflora,* which has caused large infestations in Washington State and is considered a likely invader of BC estuaries. The following discussion focuses on the three known species that occur in BC, but reference is made to *S. alterniflora* as well because of its likelihood of invasion.

Spartina species are perennial grasses with erect (10 - 350 cm height), densely-spaced stems, large smooth, often in-rolled leaves angularly orientated along the stems, and thick mats of roots and rhizomes. Inflorescences (flower clusters) are terminal ranging from 2-24 cm long. The plants spread vegetatively by rhizomes or sexually by seed to form circular clones. The three marine invasive species in BC are quite distinct in appearance and tend to colonize different tidal ranges. *S. patens* has mat forming growth and colonizes the high marsh, *S. densiflora* grows in tufts within the mid-tidal zone, while *S. anglica* grows in clones in the low to mid tidal zone, often colonizing the low mudflats between the eelgrass and saltmarsh zones. All species can out-compete native salt marsh and brackish marsh species, and are capable of forming swards or mono-specific stands. *S. anglica* and *S. alterniflora* are of special concern because they can replace large areas of mudflat and associated ecological functions with mono-specific stands of invasive marsh.

3.1 TAXONOMY

In the latest update of *Spartina*, which is included in the Flora of North America, Barkworth (2003) listed 15-17 species for North America (Table 1): nine native, two introduced and three hybrids (one of which is native and the other two are deliberate introductions). Most species colonize coastal or estuarine areas although *S. gracilis* and *S. pectinata* are native to inland areas and tolerate alkaline substrates.

The main taxonomic references for our area include Douglas et al. (2001), Hitchcock and Cronquist (1998) and Kozloff (2005). Douglas et al. (2001) listed two species of *Spartina* for British Columbia: *Spartina gracilis* (alkali grass) and *Spartina patens* (salt meadow cordgrass). *S. gracilis* is a native species found in inland marshes and wet areas in south central and south eastern BC, while *S. patens* is an introduced species from eastern North America found in salt marshes near Comox and Vancouver. A third species, *Spartina pectinata* (prairie cordgrass) was excluded as it has been identified in only one collection made over 50 years ago at Sea Island.

In the standard flora reference for our region, Hitchcock and Cronquist (1998) list five species for the Pacific Northwest *S. gracilis* (alkali cordgrass), *S. pectinata* (prairie cordgrass), *S. alterniflora* (smooth cordgrass), and *S. townsendii* (Townsend's cordgrass). More recently, Kozloff (2005) listed five species from the Pacific Northwest, including *S. densiflora* (dense-flowered cordgrass), introduced from South America; *S. patens* (salt-meadow cordgrass), introduced from eastern North America; *S. alterniflora* (salt water cordgrass) introduced from eastern North America; *S anglica* (English cordgrass) a hybrid introduced from Europe; and *S.*x*townsendii* (Townsend's cordgrass), a hybrid introduced from Europe.

3.2 DISTRIBUTION IN BRITISH COLUMBIA

S. patens was the first invasive species to be recorded in British Columbia, and is currently distributed in North Vancouver in Burrard Inlet and Port Moody Arm in the Lower Mainland and in Comox Harbour and Baynes Sound on Vancouver Island. *S. anglica* initially invaded Boundary Bay and since has spread to Roberts Bank. *S. densiflora* is the most recent species recorded in the province and with a limited distribution in Baynes Sound.

Table 1. Native, introduced and hybrid species of *Spartina* species found in North America.

Scientific Name	Common Name	Origin
Spartina Spartinae	Gulf cordgrass	native, Gulf Coast
Spartina alterniflora	smooth cordgrass	native, E. North America
Spartina foliosa	California cordgrass	native, California
Spartina maritime	small corgrass	introduced, Europe
Spartina townsendii	Townsend's cordgrass	hybrid, Europe
Spartina anglica	English cordgrass	hybrid, Europe
Spartina bakeri	sand cordgrass	native, SE. North America
Spartina cynosuroides	big cordgrass	native, E. North America
Spartina densiflora	densely-flowered cordgrass	introduced, South America
Spartina gracilis	alkali cordgrass	native, North America
Spartina patens	saltmeadow cordgrass	native, E. North America
Spartina x*caespitosa*	mixed cordgrass	hybrid, North America
Spartina pectinata	praire cordgrass	native, North America

The three species have distinct tidal distributions in B.C. *S. anglica* colonizes the lower mudflat below the elevational range of native emergents up to approximately high tide level of mean tides. It has been observed in a wide range of substrates from mud to sand and gravel. *S. densiflora* grows in the mid-tide zone and colonizes mud to cobble substrates. *S. patens* colonizes the upper tidal zone from just below the mean high tide zone up to higher high water. It typically is found in mud to sandy soil. *S. alterniflora*, not recorded yet in BC, colonizes the entire tidal range between lower low water to extreme high water mark.

Although elevation surveys for *Spartina* in BC have not been conducted, the distribution ranges in US west coast estuaries for the four species reported in the Oregon *Spartina* Response Plan (2007) are:

- *S. alterniflora* from mean lower low water (MLLW) to MHHW (mean higher high water);
- *S. anglica* from MLLW to MHHW;
- *S. densiflora* from 1.8 to 2. 4 m above MLLW;
- *S. patens* from 1.8 to 2.0 m above m MLLW.

These elevations are relative and can not be applied directly to BC because the American tidal system is based on MLLW set at 0.0 m while the Canadian system uses 0.0 m to mean lowest normal tide (Thompson

1981). Water depths on American charts would, therefore, indicate greater depths than a Canadian chart of the same area.

3.3 ANATOMY AND PHYSIOLOGY

S. anglica was created by the hybridization of *S.maritima* and *S. alterniflora* and subsequent chromosome doubling in a process known as allopolyploidy (Raybould et al. 1991a; Raybould et al. 1991b; Gray et al. 1991; Thompson 1991; Ayres and Strong 2001). Allopolyploids have greater vigor and selective advantage over their progenitors due to the genetic diversity resulting from the presence of two genomes inherited from different parents. This diversity can lead to new physiological properties which may in turn enhance colonization and persistence in the new habitats. Allopolyploidy also results in the generation and maintenance of new favourable gene combinations potentially leading to increased adaptive fitness.

The aerial part of *S. anglica*, consisting of stout stems and fleshy leaves is effective in reducing tidal currents and trapping suspended sediment, mostly in the axes of the leaves where they sheath the stem (Thompson 1991). As the plants senesce in the fall, the sediment and leaves are deposited around the base of the plant and incorporated into the below ground sediments by the extensive rhizome network. This process leads to rapid rise and consolidation of the marsh surface, far greater than achievable by other species or unvegetated mudflat. For example, accretion rates range from 0.2 -2.0 cm in marshes in northwestern Europe but increase to 8-10 cm per year with *S. anglica* (Thompson 1991; Ranwell 1964). The trapped sediments are also high in essential macronutrients that enhance soil fertility, which further stimulate cordgrass marsh development.

S. anglica has rapid clonal development, with rates or radial clonal growth exceeding .30 m per year and leading of coverage from 3.5 % to 90 % in two years (Chater and Jones 1957 and Hubbard 1965 cited in Thompson 1991). The rapid spread of *S. anglica* is a direct result of its well developed rhizomes that continue to develop over winter and promote a massive shoot production in the spring. The dissemination and sprouting of rhizome fragments also enhance the spread of *S. anglica* (Ranwell 1964).

Rapid growth of *S. anglica* reduces competition from native plants and increased shade slows evaporation from the marsh surface making it less saline than unvegetated areas (Dethier and Hacker 2004). This reduces the high salinity environment surrounding the clone and enhances growth on unvegetated mudflats.

Rhizomatous perennial species that produce shoots have an advantage over annual plant species. The underground network of rhizomes with their associated roots will increase the probability of capturing nutrients. Shoots of temperate rhizomatous perennials die back each autumn and translocate nutrients from their shoots to the rhizomes.

S. anglica uses the C_4 photosynthetic pathway (i.e. assimilates CO_2 into four carbon compounds), which has the maximum conversion efficiency of intercepted light into biomass 40 % higher than C_3 species (Potter et al. 1995). C_4 plants also have higher water and nitrogen use efficiencies than C_3 plants (Long 1983). The higher rate of photosynthesis of C_4 plants usually leads to much higher productivity at and above 30° C. *S. anglica* shows a much greater rate of photosynthesis than C_3 species above 10° C but a much lower rate below. However, between 5-10° C, it is capable of matching C_3 marsh grass species photosynthesis rates. Thus, *S. anglica* does not seem to be inhibited by lower temperatures in lower latitudes. In North America and Western Europe, *Spartina* species show the most northerly distribution of perennials, extending north of 60° N (Long and Woodhouse 1979).

S. densiflora, *S. patens* and *S. alterniflora* also use the C_4 pathway (Long 1983; Waller and Lewis 1979; Pearcy and Ustin 1984). Most native BC salt marsh plant species utilize the C_3 pathway, including most eelgrass species (Thom 1996; Beer and Wetzel 1982), *Spergularia maritima* (Rozema 1993), *Salicornia virginica* (Pearcy and Ustin 1984), *Trioglochin maritima* (Davy and Bishop 1991; Wang et al. 2006), *Juncus balticus* (Wang et al. 2006), *Scirpus americanus* (Wang et al. 2006) and *Scirpus maritimus* (Rozema 1993), and most grasses, e.g. *Elymus mollis, Deschampsia caespitosa, Hordeum jubatum* (Waller and Lewis 1979). One of the common native salt marsh exceptions is *Distichlis spicata* that utilizes a C_4 pathway (Waller and Lewis 1975; Erickson et al. 2007). *Zostera japonica*, which has a similar ecological niche to *Z. noltii*, may have special adaptations that characterize it more as a C_4 plant, as was postulated for *Z. noltii* by Jiménez et al. (1987). It would appear that *Spartina* spp. have a physiological advantage over most native salt and brackish marsh plant species in BC.

Experimental warming caused rapid loss of high marsh forbs, which were replaced by *S. patens*, another C_4 species (Gedan and Bertness 2009). The overall result was an increase of plant productivity but decrease in plant and zonal diversity.

S. anglica is capable of growing in lower elevations on mudflats than native species and has several ways of dealing with long periods of inundation in salt water including:

1. Two-celled salt glands, hydathodes, on both the leaf surfaces actively excrete aqueous salt solutions.
2. The excess entry of toxic ions into the roots is restricted.
3. Accumulates concentrated solutions of proline and glycinebetaine which replace the salt ions and maintain the ionic balance osmotic potential and intercellular spaces.
4. Root tissue contains a well developed aerenchyma which facilitates physiological performance under anaerobic conditions and diffuses oxygen into the roots and into the interstitial solution surrounding the roots in the substrate where it oxidizes with harmful quantities of salt present. Aerenchyma also lowers metablic demands of the plant. Maricle and Lee (2002) found that *S. anglica* was able to transport oxygen to the roots under flooded conditions and had a more efficient system than *S. alterniflora*.
5. C_4 species have a high water-use efficiency (the ratio of CO_2 assimilated to water transpired) which is advantageous in a high saline environment.

In contrast, *S. densiflora* colonized the mid to upper intertidal, including successful establishment in higher energy rocky intertidal (Bortolus 2006). It does not seem to be as adapted for anoxic, hypersaline and longer inundation periods of the lower intertidal as *S. anglica* or *S. alterniflora*.

A characteristic feature of populations of *S. anglica* is the greater morphological stature and seed production of plants from successionally mature (high marsh) with those in pioneer (low marsh) populations (Thompson 1991). Pioneer populations from different estuarine sites are morphologically more similar than successionally different stages in the same estuary. The increased genetic diversity appears to have conveyed a plasticity and tolerance of environmental variation that may have significantly influenced the capability of *S. anglica* to spread and persist.

3.4 REPRODUCTION

S. anglica has a distinct life stage cycle (Dethier and Hacker 2004). It germinates new seedlings and sprouts new shoots from rhizomes in early spring; undergoes rapid photosynthesis and growth from May to August; flowers mostly in July, and set its seed mostly in September. Most of the above ground biomass dies off in early fall. Kittelson and Boyd (1997) found that *S. densiflora* produced lateral tillers throughout the year in Humboldt Bay in California.

Spartina reproduces by sexual and vegetative means. The *Spartina* inflorescence ranges in length from 3-70 cm composed of 2-25 branches each with 10-70 single flowered spikelets. Each flower can produce a single seed. Bortolus (2006) reported that the maximum number of spikelets per inflorescence ranged from 225 for *S. densiflora*, 750 for *S. alterniflora*, and 1050 for *S. anglica*.

Individual flowers are protogynous (stigmas mature before stamens), but bottom flowers of an inflorescence can have mature stamens while flowers at the top may have only mature stigmas, so selfing (i.e. self pollinating) is possible (Dethier and Hacker 2004). Flowers are wind pollinated and dense populations have a greater chance of fertilization than sparse ones because of high pollen availability.

An Allee effect occurs because the newly invaded, low density areas produce little viable seed until rhizomatous growth brings them into closer contact, reducing the rate of invasion (Davis et al. 2004). However, self pollinated flowers in *S. anglica* have lower seed set than out-crossed flowers and seeds from self-pollination may not germinate (Dethier and Hacker 2004). Location of the clone in the intertidal affects reproductive success. Marks and Mullins (1987) found that lower elevation *S. anglica* plants mature and flower before higher elevation, more mature stands. Populations within an area range from fertile clones to virtually sterile clones.

Vegetative reproduction occurs by the production of new tillers from underground rhizomes. Tillers can usually remain attached to the plant but may thrive if detached. *S. anglica* rhizome fragments with vegetative stems attached, as small as 2.5 cm, raised in 0-15 ‰ salinity water had high survival rates (Howard and Sytsma 2005). Fragments exposed to 35 % salinity had low survival. Fragments without vegetative stems showed 100 % mortality.

Fragments may be affected by site conditions such as type of sediment and waves. Short waves occurring in shallow coastal and estuarine waters where *S. anglica* was established were not strong enough to disturb sediment or dislocate plants (Hammond et al. 2002). However, higher energy waves associated with storm events would erode sediments and could dislodge plants.

At higher densities, *S. densiflora appears* to enhance its own expansion because it constitutes the majority of wrack that creates bare areas (Castillo et al. 2008; Kittelson and Boyd 1997). In areas of high competition, it tends to replace lost culms or stems rather than undergoing lateral expansion as occurs in bare areas.

S. patens was observed to spread by vegetative means on Cox Island in Oregon and even satellite clones nearby were initiated by plant propagules (Frenkel and Boss 1988). Clones had thick rhizomes that inhibited regeneration of native plant species even though the center of patches had low above-ground plant biomass.

3.5 SEED PRODUCTION

In low or high salinity marshes and mudflats, the number of spikes averages 20-30 per 0.25 m^2, but only 15-20 per 0.25 m^2 for cobble beaches (Dethier and Hacker 2004). The number varies with tidal elevation, being highest in the middle to low end of the tidal range of the plant where physical conditions such as salinity and soil water content are optimal. The number of seeds produced per 0.25 m^2 ranges from 175 in cobble beach to 200 in high-salinity marshes to 320 in low salinity marshes to 350 in mudflats, which equates to a large number of seeds in densely populated areas. Mature *S. anglica* monocultures in the high marsh zone produced the greatest density of spikelets but only 5 % were filled with seed, compared to 88 % spikelets filled with seed in younger, lower elevation plants, which were also more viable (Dethier and Hacker 2004).

Physical conditions in low-salinity marshes and mudflats are best suited to seed production, germination, survival and spread of *S. anglica* (Dethier and Hacker 2004). High-salinity marshes and cobble beaches are less favourable for spread and establishment.

S. densiflora seed and seedling production is reduced by high salinities (Kittelson and Boyd 1997). Highest germination of seeds occurred at 11 ‰ and greatest seedling survival was in freshwater or 4 ‰. Post seedling growth is optimum between 0-11 ‰, but growth and expansion can occur up to 18 ‰. An allee effect (i.e. when populations grow more slowly at low densities), has been demonstrated at Willapa Bay and may explain the wide range of seed production as well as the lag phase in spread of an invasion (Davis et al. 2004). High sexual reproduction rates were interpreted as a mechanism for long-distance dispersal and stress response from crab herbivory in Argentina (Castillo and Figueroa 2009).

S. alterniflora seed germinate in 3-4 months under cool, wet storage (Mooring et al. 1971; Broome et al. 1974; Seneca 1974. However, Hubbard (1970) found that *S. anglica* seeds remained viable for up to 4 years, and speculated that seeds need a period of after-ripening prior to germination. They also showed that cutting increased production of flowering shoots the following summer, and that seed germination was inhibited by light. Plyler and Carrick (1993) showed dormancy can be broken in *S. alterniflora* by damaging the scutellum of the embryo and restored by treating with abscisic acid. These results suggest that *Spartina* seeds can remain viable for up to several years and require at least a two step process including mechanical damage to the seed coat and leaching of a dormancy inhibitor. The studies support a process involving seed dispersal in the fall, settlement in a suitable low marsh or mudflat habitat where they are covered with sediment, followed by an overwintering period when a germination inhibitor is leached out of the seed coat, ending with seedling development the following spring.

Spartina seeds germinate in substrates as high as 40 ‰ salinity, but are highest at low salinities (Seneca 1974; Shumway and Bertness 1992; Kittleson and Boyd 1997). Germination may also occur at oxygen concentrations as low as 2.5 % (Wijte and Gallagher 1996). Seedling shoot emergence was faster at lower oxygen concentrations and root emergence was slower, possibly allowing the shoot to provide oxygen to the root. The biomass of germinated seedlings is affected by soil salinity with 50 % reduction in total biomass at salinities of 19.2 ‰ or higher (Lewis and Weber 2002).

3.6 DISPERSAL

Spartina can be spread by human and natural mechanisms. Natural mechanisms include transport of seeds and plant fragments by tidal currents or by water birds. Human mechanisms include ballast water, dredging, aquaculture, intentional plantings for erosion control, etc., or forestry.

Wolters *et al*. (2005) investigated marsh establishment following dike removal and found that rapid colonization from seed dispersal occurred from close proximity pioneer and low marsh species. This provides evidence that *Spartina* spreads via consecutive satellite infestations rather than large distance transport. Where salt marshes do not have a continuous distribution along the coast, successful transport of seed from one estuary to another occurs infrequently (Onaindai 2001).

S. anglica primarily colonizes new areas by floating seeds but pieces of rhizomes can establish new plants (Ranwell 1964). Fresh seed flotation time for *S. alterniflora* ranged from 22 -25 days, while *S. patens* seeds remained afloat for 34 days at 15 ‰ salinity, and 20 and 24 days at 0 ‰ and 36 ‰, respectively (Elsey-Quirk et al. 2009). Seeds of *Distichlis spicata*, a native species, floated for longer periods (i.e. 67 days at 0 ‰, 65 days at 15 ‰, and 59 days at 36 ‰). Residence time for cold stratified seeds was increased to over 100 days with *S. patens* and to over 50 days with *S. alterniflora*.

Spartina plants and fragments float in salt water for at least 2 months (Sayce et al. 1997). During fall and winter, particularly following storm events, floating wrack of *Spartina* may form and be carried seaward. Early to mid-fall is of particular concern because significant amounts of *Spartina* wrack bearing ripe seeds leave Willapa Bay and move into open oceanic waters. Seeds contained in wrack that is remains wet and cool remained viable until the following spring, but were not viable if washed up in rack over a year old (Dethier and Hacker 2004). Several drift card studies have demonstrated that *Spartina* seeds and plant fragments can be potentially be spread throughout the Pacific Northwest. Seeds are transported by tides and currents, assisted by wind. Huiskes et al. (1995) showed that most seeds were transported on the water surface.

S. anglica appears to germinate most successfully in damp cool conditions in brackish water (i.e. 15 ‰ salinity), but some germination occurred at all salinities (Dethier and Hacker 2004). Sediment was less important but germination was higher in sand than mud or cobble.

Vivian-Smith and Stiles (1994) confirmed waterfowl could disperse seeds. They identified 11 plant taxa on the feet and plumage of waterfowl. Of the total number of seed, 30 % were from *S. alterniflora*.

In California, four introduced *Spartina* species have been identified. *S. densiflora* was likely introduced into Humboldt Bay, California, from solid ballast used on returning ships transporting lumber to Chile in the 1800's. Solid ballast in dredges may also be a dispersal mechanism.

In San Francisco Bay, *S. alterniflora* seeds were intentionally planted at a US Army Corps of Engineers site and spread into San Francisco Bay, where it now has hybridized with the native *S. foliosa*. *S. densiflora* was intentionally introduced to San Francisco Bay during a landscape planting. *S. anglica* and *S. patens* also occur in the Bay.

In Oregon, two invasive species of *Spartina* have been identified: *S. patens* and *S. alterniflora*. *S. patens* occurs on Cox Island in the Siuslaw River estuary and was probably introduced with oyster spat (Frenkel and Boss 1988). *S. alterniflora* occurs in the Siuslaw River estuary near Cox Island and Coos Bay. It was intentionally planted in the Siuslaw River estuary in the late 1970's. Unintentional transplantation was the most likely cause for the Coos Bay introduction.

In Washington State, *S. anglica* was deliberately introduced into Port Susan Bay in Puget Sound in 1961 to stabilize dikes and as cattle forage (Hacker et al. 2001). *S. densiflora* was identified in 2001in Puget Sound and Grays Harbor, possibly introduced through solid ballast in dredges or by naturally by ocean currents. In Willapa Bay *S. alterniflora* was likely introduced as part of the transplantation of oysters from the east coast of North America. *S. patens* was introduced but has a limited distribution.

In the Oregon Response Plan, it was noted that certain vessels (e.g. US Department of Defense, including Army Corps of Engineers dredge vessels) were exempt from ballast water exchange requirements. It recommended measures be adopted to reduce the potential for accidental transport of *Spartina* seeds and/or plant fragments (e.g. washing dredge hopper at disposal site following unloading of dredge material).

3.7 NATURAL CONTROL OF POPULATIONS

S. anglica is susceptible to infection by the ergot fungus *Claviceps purpurea*, which attacks the fertile inflorescences and infects all the embryos and prevents viable seed set (Thompson 1991; Gray et al. 1991). This affects future dispersal and recolonization of sites made bare by tidal erosion.

Cornick et al. (2005) investigated fungus populations in stable and declining communities of *S. anglica* and did not find significant differences that could explain die back. They attributed die-back to the *Spartina* induced sedimentary and drainage modifications in the marsh and resulting in anaerobic conditions.

Another problem is die-back, caused by a reduced vigor and death of large areas of successionally mature populations due to soft-rotting of the rhizome (Thompson 1991). The anaerobiosis and toxicity effects induced by prolonged water logging appear to be major influences causing die-back.

There may also be factors intrinsic to the plants themselves (Thompson 1991). Mature plants appear to have less vigor than pioneering populations. Age-related effects in clones such as physiological senescence and/or an accumulation of deleterious somatic mutations and harmful viruses may be transmitted to all vegetatively produced tillers. Die-back also afflicts natural *S. alterniflora* in the US.

3.8 ECOLOGICAL IMPACTS OF *SPARTINA*

Brusati and Grosholz (2000) suggest that introduced plants, such as *Spartina*, act as ecosystem engineers by creating physical and chemical changes and outcompete native plants, without providing any additional subsidy. The modifications have large impacts on native communities.

The main effects of *Spartina* have found to range from elimination of mudflat habitat by *S. anglica* and *S. alterniflora* to outcompeting native marshes with *S. densiflora* and *S. patens*. The loss of mudflat is especially detrimental to shorebirds that prey on infauna or epifauna. Goss-Custard and Moser (1988) documented that numbers of dunlin declined at the greatest rates with the introduction of *S. anglica* and the birds did not return to areas of die-back.

Callaway and Josselyn (1992) list potential impacts from the spread of *S. alterniflora* in San Francisco Bay:

1. competitive replacement of native flora, especially *S. foliosa*;
2. effects on sedimentation;
3. changes in available detritus;
4. decreased benthic algal production;
5. increased wrack deposition and disturbance to upper marsh;
6. changes in habitats of wetland animals;
7. changes in benthic invertebrate populations;
8. loss of shorebird and wading bird foraging areas.

Aerial photography was used to follow the establishment of closed *S. anglica* swards in the Netherlands (Temmerman et al. 2007). Initial lateral clonal expansion of individual plants into tussocks and circular patches gradually coalesced into closed swards over an observation period of 12 years. Modeling results showed that flow velocities and bed shear stresses were reduced within and behind the vegetation patches but increased between the patches. Flows became increasingly concentrated as vegetation expanded laterally resulting in sediments being eroded from the drainage channels between the patches. The landscape scale studies demonstrate that *S. anglica* can have substantial impacts on tidal landforms and functions.

Bouma et al. (2009) and van Wesenbeeck et al. (2008) used flume studies to show density-dependent linkage of scale dependent feedbacks in *S. anglica.* Density dependent sedimentation occurred within the tussocks above densities of about 1500 shoots.m^{-2}, while long distance erosion occurred at lower densities of about 800 shoots.m^{-2}. Transplant growth increased within raised tussocks compared with those in adjacent gullies (van Wesenbeeck et al. 2008).

Brusati and Grosholz (2009) used δ^{13} C and δ^{15} N stable isotopes to investigate the effects of detritus from *S. foliosa* and hybrid *Spartina* (*S. foliosa* x *S. alternifora*) in California salt marshes and mudlfats, finding that in spite of producing four times the amount of detritus the hybrid *Spartina* did not subsidize the food web. *Spartina* detritus only benefited subsurface deposit feeders (e.g. capitellid polychaetes and tubificid oligochaetes) but not the larger epifauna.

Spartina anglica was shown to cause a shift from infaunal to epifaunal invertebrates (Bouma et al. 2009). The dense below ground biomass restricted infaunal colonization. Patchy *Spartina* coverage actually increased species diversity by providing an edge effect compared to dense, larger areas.

Hybrid *Spartina* invasion of San Francisco Bay mudflats caused a shift from algal-based to a detrital based food web (Levin et al. 2006). Capitellid and nereid polychaetes, and oligochaetes consumed *Spartina* detritus, while amphipods, bivalves, and other taxa consumed surficial algae, illustrating a trophic shift to organisms that are not as readily consumed by higher trophic levels (e.g. migratory birds and fish).

S. anglica is capable of replacing eelgrass, *Zostera noltii*, in France and cordgrass eradication led to invertebrate recolonization the following year (Cottet et al. 2007). *Z. noltii* colonizes the low to mid tidal zone similar to *Z. japonica* in the Pacific Northwest.

4 *SPARTINA* ERADICATION TOOLKIT

In managing *Spartina,* a toolkit is necessary to successfully and efficiently remove existing *Spartina* and to detect new seedlings or infestations. A summary of invasive plant management tools available and the advantages / disadvantages of each method are presented in the following sections.

4.1 BIOLOGICAL CONTROL METHODS

The BC Ministry of Forests and Range defines biological control as "the use of an invasive plant's natural enemies-agents (chiefly insects, parasites and pathogens) to reduce its population below a desired level. It is the long-term, self-sustaining treatment method for managing invasive plants (http://www.for.gov.bc.ca/hfp/biocontrol/what.html)." This strategy is used to manage invasive plant populations and not as an eradication tool.

The State of Washington utilized the plant hopper *Prokelisia marginata* as a biocontrol agent which had shown positive preliminary results (Deither and Hacker 2004). However, by 2007 the cooperating agencies in the *Spartina* Eradication Project chose to chemically treat the last of the former bio-control release sites in Willapa Bay (Phillips et al. 2008). The insect was feeding on *Spartina* but was not eradicating the plants thereby allowing them to serve as a seed source for reinfesting other areas of the Bay (Phillips et al. 2008). Herbicide was required at the site to prevent further seed dispersal. Pfauth et al. (2003) stated that biological control on very large *Spartina* infestations using the plant hopper is likely most effective as part of an integrated strategy.

Utilizing biocontrol for *Spartina* management is a subject for further research but is not currently a feasible management strategy due to the inability to prevent seed dispersal or achieve eradication which are priorities for *Spartina* management in British Columbia.

4.2 PHYSICAL CONTROL METHODS

In BC, physical methods including hand removal, seed clipping, covering, and excavator burial have been applied to prevent seed production and to remove plants.

4.2.1 HAND REMOVAL - DIGGING

Hand removal is a method to pull out the plant and root mass with long and short-handed garden shovels. This method has been the most commonly utilized techniques in the Fraser River Delta (Ducks Unlimited Canada 2008).

Hand removal is ideal for small infestations or individual plants where access is good (Diether and Hacker 2004). It becomes more difficult on medium to large clones due to logistical constraints in removing and transporting the large volume of root mass or in substrates where access is more difficult (i.e. soft mud). In addition, the utmost caution must be used to remove all rhizome pieces since they have the ability to establish new seedlings.

Hedge et al. (2003) discuss some of the advantages and disadvantages of hand removal. The advantages of this method include:

- Minimal training of workers and basic, inexpensive equipment such as shovels and pitchforks required;
- Can be done during any season but should be completed prior seed set;
- Can be very effective on seedlings or small infestations;
- Has the potential to remove the entire plant.

The disadvantages of hand removal include:

- It is highly labor intensive due to the difficulty removing the extensive and dense root biomass that can extend deeper than 1 meter into the sediment horizon.
- The wet sediment attached to the large root mass complicates the process and requires a large amount of soil to be removed.
- Unsuitable on infestations more than 30 cm in diameter depending on the density of the clone since removing rhizomes by digging is very difficult.
- Potential for reinfestation since all rhizome pieces must be removed.
- Sites must be accessible by foot.
- Disposal of plants can be labor intensive.

4.2.2 MOWING OR SEED CLIPPING

Mowing or seed clipping is a commonly used management technique to restrict seed production, increase accessibility and weaken the plant by depleting the root and rhizome energy reserves (Hedge et al. 2003). Mowing can be conducted using weed wackers or mowers but should not be conducted on plants that have set seed to avoid dispersal and potential for establishing new plants (Diether and Hacker 2004). Seed clipping can be done using garden clippers but seed heads must collected and be properly disposed. Therefore, treatment timing is extremely important when utilizing this method.

This method can be used on any size of infestation but the equipment required would vary depending on infestation size and level of accessibility (Hedge et al. 2003). However, Diether and Hacker (2004) suggest that even repeated mowing is minimally effective when herbicides are not used. Therefore, it is commonly utilized in combination with other methods and must be repeated to achieve optimal effectiveness (Hedge et al. 2003).

The advantages of mowing are:

- Restricts seed production if done prior to seed set;
- Increases accessibility within the infestation;
- Weakens the plant;
- Machine mowers can cover a large area in a short amount of time compared to work by hand.

The disadvantages of mowing are:

- Does not kill the root system which stores nutrients so plants will regrow;
- May be limited effectiveness in terms of eradication success;
- Would need repeated treatments during one season and over multiple years.

4.2.3 COVERING

Covering has been used as part of an integrated strategy in Oregon (Pfauth et al. 2003) and is currently being investigated as a new control technique initiated in 2008 in the Fraser Delta (Ducks Unlimited Canada. 2008). This method involves covering the infestation with specialized landscape cloth to effectively restrict photosynthesis and growth. It is recommended to mow prior to covering to prohibit seed production and improve ground coverage. In addition, the cloth must extend at least two feet beyond the edge of the patch and remain in place for two years (Pfauth et al. 2003). In Oregon native vegetation reestablished rapidly on sites that were covered to kill *S. patens* (Pfauth et al. 2003).

Covering can be used on small or medium infestations within low energy areas particularly in the high marsh areas where substrates are firm and wave / wind action is reduced. Large infestations are not particularly suited for this method since transporting and installing the fabric can be highly labor intensive (Pfauth et al. 2003).

The advantages of utilizing the covering method are:

- Less initial labor intensive than digging which lowers labor costs;
- Relatively inexpensive material costs for small infestations.

The disadvantages of the covering method are:

- Periodic monitoring following installation of the material is required to ensure that the cover remains intact and in place (Pfauth et al. 2003);
- Unsuitable on open mudflats due to increased wind, wave action displacing the fabric;
- Difficulty in keeping the fabric firmly anchored to the ground;
- Limited to small or medium sized infestations.

4.2.4 EXCAVATOR DIGGING

In the Fraser Delta, excavators have been used to remove *Spartina* infestations. This method is particularly useful for larger infestations or areas with high density of clones to reduce costly travel time of the excavator. However, the infestation also must be accessible to the machine. An amphibious excavator has been used by the BCSWG which has relatively lower pounds per square inch and is recommended in areas with muddy substrates. A regular excavator may be suitable on areas with sandy or firm substrate.

The advantages of excavator digging are:

- The entire root biomass can be removed at one time;
- Do not need to remove plants and dispose away from mudflats;
- Low labor costs relative to hand digging;
- Can be utilized in removing larger infestations.

The disadvantages of the excavator digging method are:

- Disturbance of the physical substrate by the tracks or wheels of the excavator within the estuarine environments;
- May not be appropriate for upper intertidal zones where *Spartina* is intermixed with native vegetation;
- Increased potential for fuel leakage or spillage within the estuarine environment.

4.3 CHEMICAL CONTROL METHODS

To date, herbicide has not been utilized as a *Spartina* management tool in British Columbia. However, due to the exceptional success in other areas such as Oregon, California and Washington which successfully reduced large infestations by 85 % in five years, it has been identified as a potential option to pursue in the near future.

Deither and Hacker (2004) report that even consistent, multi- year mowing without the use of herbicides is unlikely to kill a *S. anglica* patch. This is likely due to the ability of herbicide to kill the extensive root system (Deither and Hacker 2004). They found that when herbicides were used after three years of mowing alone, there was a 50 % decline in one year, as compared with simply mowing. Limited success of concerted mechanical efforts suggests overall that herbicide is necessary for effective removal (Deither and Hacker 2004). However, herbicide must be applied using appropriate methods and at the appropriate time of year (early in the season). Similar to other treatment methods, herbicide must be applied in consecutive years to be effective.

Some advantages of utilizing herbicide as a management tool are:

- Fewer people to conduct the work which results in fewer people entering the estuarine environment;

- Reduced equipment entering the estuarine environment (can be conducted on foot with backpack sprayers.

Although herbicide has been found to be an effective management tool, it has many limitations that are important to be aware of, especially within an estuarine environment. Pfauth et al. (2003) list some of these limitations / disadvantages:

- Soft sediments limit access to infested areas;
- Tides limit application periods;
- Reduced efficacy due to sediment deposition on leaves that limit uptake of the chemical into the leaf tissue;
- Specialized equipment is required.

4.3.1 TYPE OF HERBICIDE USED

Previously in Washington, only glyphospate-based products were used to treat *Spartina* (Pfauth et al. 2003). However, recently imazapyr (Arsenal ®) has been approved for use and is widely used throughout Washington for *Spartina* management. Imazapyr is more effective at lower concentrations, requiring lower carrier volume of water and having shorter persistence in water than glyphosphate (Pfauth et al. 2003). Imazapyr has an average water half life of four days and is primarily degraded in water by photodegradation. It has a low toxicity to invertebrates and according to U.S. Environmental Protection Agency standards is practically non-toxic to fish, birds, and mammals. The LC50 for rainbow trout is > 100mg/L for imazapyr and between 70-170 mg/L for glyphosate (Durkin 2003, Durkin and Follansbee 2004). The USDA Forest Service risk assessments provide a detailed account of potential effects for each chemical (Durkin 2003, Durkin and Follansbee 2004). Currently, Washington utilizes a tank mixture of glyphospate and imazapyr in combination with a blue color dye to effectively mark treated areas (T. Ketel, personnel communication, December 11, 2009). They found that using both herbicides optimized the effectiveness. However, the herbicide to be utilized should be selected based on specific infestation characteristics.

4.3.2 APPLICATION METHODS

The two main types of herbicide application are aerial application (broadcast) and hand application, and specific methods include high powered sprayers, backpack sprayers and wick application (Pfauth et al. 2003). The advantage and disadvantages of each method are presented below.

Aerial application advantages include:

- Cost effectiveness since large areas can be treated in a very short period of time;
- Effective for access to sites that may not be easily accessible by ground application (Pfauth et al. 2003).

Aerial application disadvantages include:

- Only suitable for large-scale infestations since the equipment cost is very high;
- Only appropriate on infestations that are not near sensitive receptors such as residential developments such as schools, or hospitals (Grijalva et al. 2008);
- Longer drying times are required (Pfauth et al. 2003);
- Less selective in terms of the areas treated.

Hand held spray herbicide application advantages include:

- Higher concentrations of herbicide can be used (Diether and Hacker 2004);
- Shorter drying times (Diether and Hacker 2004);
- Higher ability to precisely target individual plants.

Hand held spray herbicide application disadvantages include:

- Fewer acres can be treated per day than aerial (Diether and Hacker 2004);
- The infestation must be accessible by boat or by foot.

4.4 JURISDICTION OF *SPARTINA* OCCUPIED AREAS

Jurisdiction over *Spartina* occupied areas is complex in B.C. It is split among federal, provincial and local governments, depending on the location along the coast and the relationship to the shore. The federal government has exclusive jurisdiction over the nearshore and seabed along the outer coast known as the "territorial sea", which extends from the low water mark out to 12 nautical miles (Fisheries and Oceans Canada and Province of British Columbia, 2003). The Department of Fisheries and Oceans (DFO) is the federal agency responsible for the Fisheries Act. The federal Fisheries Act defines "fish habitat" in Section 34(1) as "spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes."

The Province of British Columbia, through the Ministry of Environment (MoE), is responsible for environmental management and stewardship of terrestrial and freshwater habitats on provincial crown land. The provincial government has exclusive jurisdiction over the seabed and its mineral and attached biological resources throughout the shore lands, seabed and waters located between the mainland and Vancouver Island, often referred to as B.C.'s "inland sea". This includes the Strait of Georgia, Juan de Fuca Strait, Johnstone Strait and Queen Charlotte Strait. Provincial ownership also extends to embayed areas, fjords and inlets bounded by discrete headlands on the outer coast.

4.5 PERMITTING

Biological, physical and chemical control treatments have differing permitting processes. This section briefly discusses the regulatory steps for each method.

4.5.1 BIOLOGICAL CONTROL

Although biological control is not a recommended management tool, for completeness the permitting steps are included. The steps in selecting a biological control agent in British Columbia from the Ministry of Agriculture and Lands website: http://www.agf.gov.bc.ca/cropprot/bioweed.htm are:

- Candidate natural enemies that feed on targeted weed and show promise for control are studied in their native habitat.
- Exhaustive studies are carried out to ensure the insect will attack only the targeted weed and not other vegetation.
- Long-term results are reviewed by North American Biocontrol agencies. If the natural agent is proven to damage the weed without attacking other vegetation, it is approved for release.
- The B.C. Plant Protection Advisory Council approves or rejects the release of federally approved natural weed control agents to British Columbia.
- Initial releases in British Columbia are made under controlled conditions to enable the control agents to become established and to increase populations for redistribution in the province.

Insect breeding tents, maintained by the Ministry of Forests and Range in the southern interior, are used to initially establish most new insect species. When populations warrant, the insects are then redistributed throughout the province.

4.5.2 PHYSICAL CONTROL

Physical control measures, including removal by hand pulling, excavator, mowing, seed clipping, and covering, may require permitting depending on where the work is being undertaken and if there is potential for adverse effects on aquatic resources.

Permitting for physical controls are necessary on all lands managed by BC Ministry of Environment (MoE). Works in areas such as Wildlife Management Areas and provincial parks require an approval from MoE. Within the Vancouver Lower Mainland, the Fraser River Estuary Management Program (FREMP) has an integrated permitting process, where any physical work affecting tidal areas is submitted to FREMP and all referrals to government agencies are coordinated through FREMP.

When managing *Spartina* if there is potential that works may cause harm or pollute fish habitat, those involved with implementing the control measures should contact and work with the local DFO office to avoid the harmful alteration, disruption and destruction (HADD) to fish habitat and thus be in compliance with subsection 35(1) of the Fisheries Act. In cases where a HADD is likely despite contemplated preventive measures, and adequate fish habitat compensation has been proposed and the HADD is considered acceptable to DFO, the proponent will need to apply for a Section 35(2) Authorization in order to complete the work.

4.5.3 CHEMICAL CONTROL

The Pest Regulatory Management Agency (PRMA) of Health Canada is responsible for registering pesticides for use and sale within Canada. Once a pesticide is registered, provincial regulations control their use in each province. In BC, there are three different types of authorization required for pesticide use: licenses, pest management plans (PMP's) and pesticide use permits. The type of authorization needed depends upon the extent and type of pesticide use, and the type of property on which the pesticide is to be applied. The types of authorizations required for pesticide use are defined in BC Government's Integrated Pest Management Act (IMPA) and in the supporting Integrated Pest Management Regulations (IMPR). The three authorization types are (http://www.llbc.leg.bc.ca/public/pubdocs/bcdocs/362961/regulatory.pdf):

<u>Licenses</u> – management of noxious weeds or invasive plants on up to 50 hectares of public land.

<u>Pest Management Plans</u> - management of noxious weeds or invasive plants on more than 50 hectares of public land.

<u>Pesticide Use Permits</u> – use of pesticides on public lands that cannot be authorized under a License or Pest Management Plan.

The primary herbicides that have been used to control *Spartina* in intertidal areas in the United States, imazapyr and glyphosphate, are registered for use in Canada by the PRMA, but are currently not authorized for use in aquatic environments. In the absence of full registration, these herbicides may be permitted under an emergency registration.

Emergency registrations are time limited registrations, granted by the Pest Management Regulatory Agency (PMRA) for a period of one year or less (http://www.al.gov.bc.ca/pesticides/j_2.htm).

They are only granted in situations when the following criteria are met:

- A pest outbreak or pest situation occurs that can cause significant economic, environmental or health problems.
- There is no effective product or application method registered in Canada for the control of the pest.
- There is no effective, alternative control method available.

The pesticide emergency registration is normally limited to one year for a maximum of three years and is strictly limited to a location and a specific use.

4.6 *SPARTINA* DETECTION METHODS

One of the major challenges in detecting *Spartina* is the large elevation distribution which it occupies from high marsh to open mudflats. The survey methodology, survey timing, and the infesting species affect the minimum detectable size of a new *Spartina* infestation (West Coast Governors Agreement on Ocean Health 2009).

Pfauth et al. (2003) defines two different types of detection:

Passive detection – refers to utilizing searchers who have duties and interests other than searching for *Spartina*, but who might be in areas where *Spartina* could become established and could detect a new infestation if they were informed with appropriate information.

Active detection – refers to utilizing searchers whose assigned duty is the detection of *Spartina* to the exclusion of any collateral assignments.

Table 2. Adjusted relative cost effectiveness (ARC) of detection methods where ARC = relative reliability x relative cost effectiveness. 0=least effective, 1=most effective (from Pfauth et al. 2003)

Method	Risk area (% covered)	Annual cost (x $1,000)	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

Table 2 presents a comparison of the cost effectiveness of several *Spartina* detection methods including both active and passive detection methods (Pfuath et al. 2003). Passive detection methods such as boat and volunteers were found to be the least cost effective strategy whereas active detection methods such as fixed wing were found to be the most cost effective. The limited effectiveness of passive detection is likely due to the grasses are commonly difficult to identify and require a trained eye in identification. Therefore, although passive detection in BC could be utilized, it may not be cost effective compared to active detection methods.

The area covered, costs and reliability, and infestations detection size also vary considerably among the following active detection methods:

- Aerial detection from helicopters and airplanes;
- Boat detection;
- Ground or Shore-based walking surveys of the intertidal areas;
- Orthophotos / Remote Sensing.

4.6.1 AERIAL DETECTION

Utilizing aerial methods is particularly useful for surveying large areas with great distances between infestations or areas that are difficult to access by ground or boat. If an infestation is encountered, a GPS location and photo of the site would be recorded so the site can be subsequently located for further inspection.

In Oregon, the Northern section of the coastline is suitable for *Spartina* growth. This section of coastline is split into three sections and a three year rotation is utilized in which each section is surveyed every third year (V. Howard, personal communication, December 11, 2009).

When selecting a type of aerial detection to be used for the program one may consider:

- Helicopters can fly at much lower altitudes and slower speeds than fixed wing aircrafts and have beneficial maneuverability but can be much more expensive.
- Cost estimates from specific helicopter, fixed wing companies.
- The availability of the necessary method (helicopters may be unavailable at the height of growing season).

4.6.2 BOAT DETECTION

Airboats

The State of Washington utilizes an airboat within their *Spartina* management program and recently partnered with the BC *Spartina* Working Group for a demonstration of its capabilities. It was found to be extremely efficient as large areas difficult to access on foot could be covered in a short period of time. For example, the demonstration for the BC *Spartina* Working Group covered 20 km of coastline in approximately 5 hours (Ducks Unlimited Canada, 2008). Airboats can also be used during removal to transport personnel and equipment. They are particularly useful in detecting infestations a few years old (T. Ketel, personnel communication, December 11, 2009).

Airboats are somewhat limited in where they can operate being suitable in mudflat habitats, along open water with limited winds or wave action but are not suitable in open water areas with winds > 1 meter. Travelling long distances with airboats is also not appropriate.

Other Boats

The BC *Spartina* Working Group also conducted monitoring tours with assistance from Parks Canada and the Washington State Department of Agriculture utilizing a ridged haul inflatable and a Whaler. These two kinds of boats were very effective for monitoring a variety of shorelines as they both have a shallow haul so are capable of operating in shallow water. The boats could also be parked to permit searching the mudflat areas by foot while ensuring safety of personnel.

It is recommended to have further discussions with other agencies such as the Canadian Coast Guard and Parks Canada to determine if they could assist the BC *Spartina* Eradication Program by providing these boats on an annual or regular basis for *Spartina* detection.

4.6.3 SHORE-BASED WALKING

The method of walking the intertidal habitat with hand-held GPS units is the most reliable technique in detecting *Spartina* within certain areas as personnel can conduct a detailed investigation of suspect areas. This method is especially useful for small seedlings less than one year old intermixed with native vegetation in the high marsh areas (T. Ketel, personnel communication, December 11, 2009). However, it is relatively labor intensive particularly in areas with soft ground or areas with difficult access.

4.6.4 ORTHOPHOTOS AND REMOTE SENSING

In Washington, high resolution orthophotos which were geographically referenced were created from aerial infrared photographs to reveal where *Spartina* remained in the estuaries (Phillips et al. 2007). T. Ketel (personal communication, December 11, 2009) provided the following information on this project. This project was estimated to cost between $10,000 and $30,000. The costs of this method vary depending on the elevation of the helicopter, the number of orthophotos necessary, and the resolution required. This method is suitable for detecting large meadows as opposed to relatively small clones. It is also not suitable for detecting *Spartina* infestations mixed in with native vegetation. The *Spartina* management program in Washington has discontinued this method due to its decreased value given that *Spartina* distribution has trended from large meadows to small infestations.

The West Coast Governors Agreement on Ocean Health (2009) describes utilizing remote sensing for detecting *Spartina* as an area that requires further research. This is due to the present difficulty to find a characteristic of *Spartina* that would differentiate it from intermixed native vegetation. Given that the infestations in BC are currently within the early stages of population growth as pioneer infestations exist mostly as individual plants and clones orthophotos and remote sensing methods are considered currently unsuitable.

5 BC *SPARTINA* ERADICATION PROGRAM

In 2003, The British Columbia *Spartina* Working Group (BCSWG) developed a *Spartina* eradication program which includes inventory / monitoring, removal and outreach. The purpose of this document is to expand upon the existing *Spartina E*radication Program and provide a comprehensive plan for BC. The goal of the BC *Spartina* Eradication Program is to work towards eradication while preventing the establishment and spread of any *Spartina* species in BC estuaries and coastal wetlands.

The effectiveness of the program is dependent on the following elements being carried out as a whole, in a unified and coordinated manner.

- Program Management and Coordination
- Prevention
- Early Detection and Rapid Response
- Removal / Control
- Monitoring
- Science / Evaluation
- Outreach

5.1 SPARTINA PROGRAM MANAGEMENT AND COORDINATION

The success of the BC *Spartina* Eradication Program ultimately hinges upon effective management and coordination. Currently, BCSWG effectively manages and coordinates the program by allocating specific activities such as detection, removal and outreach to a specific agency or a group of participants. Individuals within Ducks Unlimited Canada have led the *Spartina* Eradication Program in BC. Table 3 presents the contributions of stakeholders involved in the BC *Spartina* program in 2008.

Table 3. BCSWG stakeholder contributions to the *Spartina* project. (From Ducks Unlimited Canada 2008)

Agency	Contribution to *Spartina* Project
BC Ministry of Environment	Mapping, removals, and GIS support facilitation of permitting.
Canadian Wildlife Service	Staff and students for *Spartina* removal.
City of Surrey	Staff and students time for removals through the Surrey Natural Areas Partnership and Salmon Habitat Restoration Program.
Community Mapping Network (CMN)	Database management through website.
Corporation of Delta	*Spartina* pickup and transportation to incineration, use of the gaotor, and removals.
Ducks Unlimited Canada (DUC)	Financial contribution, project coordination, removals, mapping , and GIS support.
Friends of Semiahmoo Bay	Promote awareness of *Spartina* through educational events and mapping and removals.
G.L. Williams & Associates	Expertise in estuary ecology/management, mapping, removals, and outreach.
Metro Vancouver	Disposal of *Spartina* (incineration).
The Nature Trust of BC	Summer students mapping and removal.
Vancouver Aquarium (VA)	Staff and crew for mapping, removal, and outreach.
Vancouver Port Authority	Committee member
Washington State Department of Agriculture	Technical expertise to develop a strategy for *Spartina* removal, provide lessons learned in *Spartina* removal efforts in Washington State.

Three options are presented for managing the *Spartina* program in the future:

1. Continue with BCSWG managing and coordinating the program by allocating specific activities such as detection, removal and outreach to a specific agency (e.g. DUC) or a group of participants. The advantage of this situation is its flexibility during funding uncertainties, and a disadvantage is the time commitment from member agencies.

2. Lessons learned from neighbouring programs in the Pacific Northwest suggests that a lead agency be designated in BC. For example a government agency would manage the program. A staff member(s) within that agency would coordinate and implement the Eradication Program.

3. The third option is to utilize the BCSWG to manage the program and provide direction to a *Spartina* program coordinator. Specific roles and responsibilities would need to be clearly defined between the BCSWG and the program coordinator. Regular meetings with the working group could be established to ensure that effective communication between the *Spartina* coordinator and the working group. Stakeholders could continue to provide in-kind support, but their time commitment would be lessened. Either the working group would house funding in various member agencies and pool it towards the program that would be managed by the Coordinator, or the working group

would form a non-profit society to provide a central funding pool with which to implement the Eradication Program.

The high level of coordination necessary to implement the BC *Spartina* Eradication Plan requires a program coordinator. Some key tasks or responsibilities of the Program Coordinator are:

- Communicating and working closely with the Regional Invasive Plant Coordinators, the Invasive Plant Council of BC and various stakeholders;
- Developing an evolving program mandate.
- Develop partnerships and seek consistent funding.
- Defining roles and responsibilities of government, non-government agencies involved in *Spartina* management.
- Planning and implementing prevention activities such as distribution of awareness materials, conduct targeted workshops.
- Planning and implementing the *Spartina* detection program.
- Develop site specific management strategies for core populations and satellite population strategies.
- Coordinate removal activities.
- Receive and manage data.
- Conduct monitoring of various methods on *Spartina* infestations and populations, analyze population trends.
- Manage and coordinate field crews to conduct detection, removal and program delivery assistance.

5.2 PREVENTION

Preventing invasions from becoming firmly established infestations is widely recognized as the most effective, economical and ecologically sound approach to managing invasive plants (NISC 2008, Wittenberg and Cock 2001). Prevention measures can take many forms, but typically involve impeding dispersal and hindering establishment of invasive plants (MFR undated).

Pfauth et al. (2003) identified several modes of *Spartina* seed dispersal including wind, ocean currents, waterfowl and equipment (e.g. recreational and commercial boats). Removal of sources of seed and propagules from recreation equipment and avoidance of moving invasive plants from one body of water to another will assist in preventing unintentional human mediated dispersal (Clark 2003).

Spartina is somewhat unique among invasive plants in that natural dispersal via ocean currents is the most successful seed dispersal vector (V. Howard, personal communication, December 11, 2009). Thus, preventing existing plants from producing seed by removal or seed clipping is essential.

Key preventative measures to act on **immediately** are:

- Remove seeds heads of existing plants prior to seed set (August).
- Inventory in August to ensure that there are no missed plants.
- Distribute existing awareness material and conducting targeted workshops to stakeholders and the general public including but not limited to:
  - Nature enthusiasts, garden centers to prevent the sale and exchange of *Spartina*.
  - Kayak groups, boat rental areas, docks, marinas to encourage passive detection and promote prevention / awareness.
  - Government agencies such as coast guard, parks personnel to encourage passive detection and promote prevention / awareness.

Key preventative measures to **work towards** are:

- Develop protocols to limit boat traffic and activity through areas identified to be core infestations. Have discussions with transport Canada and coast guards to determine how to go about this.
- Develop protocols to restrict the movement of culture trays and other equipment such as shellfish aquaculture (culture trays) from or into infested areas.
- Contact Fraser Estuary Management Program and request dredging activities be restricted within core infested areas.
- Developing best management practices for control of *Spartina* in tidal restoration projects and coordinating with restoration managers and associated regulatory agencies.

5.3 EARLY DETECTION AND RAPID RESPONSE

Integrally connected with prevention is an approach commonly referred to as early detection and rapid response (EDRR). It is considered to be a critical second defense against the establishment of invasive populations because even the best prevention efforts cannot stop all invasive species (NISC 2008). EDRR is based on the premise that if localized invasive populations are found, contained, and eradicated before they become widely established, it will be less costly than post-entry maintenance and control activities that depend on continued commitment and resources (Simberloff 2003, Mack et al. 2000).

EDRR requires collaboration among federal, provincial, local and aboriginal governments, non-government organizations, and the private sector. The Invasive Plant Council of BC (IPCBC) identified aquatic invasive plant awareness as a priority for coordinated action in BC. In February 2009, the IPCBC struck an Aquatic Plants Advisory Committee to collaboratively develop an Aquatic Invasive Plants Action Plan (2009-2011). Within this plan, the three species of *Spartina* currently found in BC (*S. anglica, S. densiflora* and *S. patens*) are listed as the high priority unwanted aquatic invasive plants (IPCBC 2009). One of the priority activities identified in the plan is the development of an EDRR Action Plan that links with the BC EDRR Plan for Invasive Plants (2007), which is currently in draft form.

5.3.1 EARLY DETECTION

Detection of new, small infestations is the most cost effective strategy as the size of weed infestation is inversely correlated with the probability of eradication and directly correlated with resources required for eradication (Pfauth et al. 2003). If new infestations are controlled while they are small, they only require minimal effort and have relatively few impacts associated with their treatment (Grijalva et al. 2008). This is especially true for *Spartina* since older clones develop dense, deep root mass making mechanical removal difficult at best.

Incorporating an early detection program is a key element within the BC *Spartina* eradication plan. The early detection program should be developed through an extensive planning process that utilizes a combination of detection methods.

The **detection methods** that should be utilized include **shoreline walking, boat detection** and **aerial detection**.

- Aerial detection can be utilized to gain a snapshot of *Spartina* along BC coastline outside of the Fraser Delta (Fixed wing or helicopter).
- Airboat detection can be used in the Fraser Delta and in suitable areas to follow up suspect areas identified through aerial detection.
- Boat detection (rigid haul or whaler) to follow up suspect areas identified through aerial detection on Vancouver Island.
- Shoreline walking can be used to detect small seedlings particularly in the high marsh areas and to follow up suspect areas found through the aerial and boat surveys.

The **detection program** should be highly methodological and requires an **extensive planning process**. This process may include the following steps:

1. A detailed mapping exercise would be cost effective to focus detection on geographical areas highly susceptible to *Spartina* while avoiding unsuitable areas.
    - Information collected from the habitat suitability model for *Spartina* along the Pacific coastline from Washington to Alaska (J. Harney, 2008) should be utilized.
    - Gary Williams (2009) recommends higher detection efforts in brackish intertidal mudflat and marsh habitats in estuaries or coastal areas with freshwater inputs. He found that seeds appear to remain viable and have higher germination rates in brackish water, compared to high salinity areas.
    - Gary Williams (2009) also recommends working outwards from core populations towards less dense areas could be used as an approach.

<u>Aerial detection</u>

2. Conduct a mapping exercise to stratify the coastline into three areas which would be inventoried on a rotation with each area inventoried every third year utilizing aerial detection;

3. Once the area to be inventoried is selected, an inventory field strategy should be developed utilizing a standardized approach such as the BC Resource Information Standards for species inventories (RISC 1998, 2002).

4. A route should be developed incorporating the steps 2 and 3.

Airboat or boat detection

5. Suspect areas identified through aerial detection would be assessed with airboat or boat detection.

Shoreline walking

6. Suspect areas inaccessible using boat methods would be assessed.

7. Utilize shoreline walking in the high marsh areas where plants or infestations are intermixed with native vegetation and inaccessible for boats.

8. Work outwards from core populations towards less dense areas could be used as an approach.

Additional elements that should be incorporated into the **detection program** include:

- If an infestation is encountered, estimates of infestation size and distribution, substrate type, reproductive state (flowering or shedding seed) and site accessibility should be collected.
- The majority of detection activities should be conducted by a consistent team of paid trained personnel to ensure accuracy of information.
- Photos and GPS locations of suspect sites during aerial surveys will be collected to permit further investigation utilizing boat or shoreline walking.
- Gary Williams (2009) recommends early monitoring of the area to locate and remove seedlings before flowering in July and seed set in August. Early flowering produces the most abundant and viable seeds.
- Winter surveys may be conducted on *S. densiflora* since it remains green throughout the winter whereas the surrounding vegetation dies back (V. Howard, Personal Communication, December 11, 2009).
- Fall surveys may be conducted for *S. anglica* since it remains green longer than commonly neighbouring species (Dan Buffett, Personal Communication, February 19, 2010).
- All detections should be logged utilizing GPS. The GPS units can record track lines for use in determining which areas have been surveyed and which still needed to be surveyed. The BCSWG has developed a standardized mapping protocol which should continue to be utilized along with tracking this information within databases and utilizing the Community Mapping Network (http://cmnbc.ca/atlas_gallery/invasive-species-spartinaca). Current infestations and new detections should also be entered into the Invasive Alien Plant Program (IAPP) provincial invasive plant database (http://www.for.gov.bc.ca/hra/Plants/application.html).

- Continue to utilize survey flags to identify sites as this has worked well in previous seasons in the Fraser Delta (Ducks Unlimited Canada, 2008). Protocols should be established to ensure the flags are removed following treatment and do not become debris.

5.3.2 RAPID RESPONSE

Rapid response entails the quick mobilization of resources to eradicate or contain *Spartina* while infestations or plants are still localized. Once the infestation is detected, it is critical that a coordinated approach is in place for reporting to ensure correct identification and implementation of a removal / control method. The *Spartina* coordinator would follow a predefined process to deal with newly reported plants or infestations.

The rapid response process may include the following steps:

- Ensure correct identification and that all pertinent information is collected including infestation and site characteristics, location and jurisdiction.
- Developing point of contact within key organizations and stakeholder groups in advance is useful so if an infestation is reported, prompt communication can proceed to determine an action plan.
- Follow the *Spartina* treatment decision matrix for determining a site specific treatment plan.
- Ensure that funding is available within the program for treating newly detected infestations.

5.4 REMOVAL/CONTROL

Removal or control will be the key component to achieve the ultimate goal of eradicating *Spartina*. Various treatment options have been applied to *Spartina* infestations along the U.S. west coast during the last two decades. As is typically the case with invasive plant management, utilizing integrated vegetation management is the best approach suiting the treatment strategy to specific site characteristics such as infestation size, distribution and associated environmental impacts. Combining treatment methods allows for the advantages of each method to be optimized to successfully prevent seed dispersal, decrease the size or eradicate an infestation / individual plant.

Control methods on *Spartina* must be applied consistently and long term to achieve eradication. Deither and Hacker (2004) found that consistent removal must be applied at least 3-4 years to achieve successful eradication. They found that removal gains were compromised if a site was not treated every year primarily due to the extensive root biomass and its clonal growth pattern.

The program must utilize management strategies at both the landscape level where *Spartina* populations are considered and the site level where the focus is *Spartina* infestations.

5.4.1 LANDSCAPE MANAGEMENT STRATEGY FOR SPARTINA IN BC

The landscape strategies for managing *Spartina* in BC are:

- Eradicate all known core populations working from the least dense areas or satellite populations towards the core populations;
- Eradicate all newly detected satellite *Spartina* infestations;
- Employ strategies to prevent seed production and dispersal within all populations.

S*partina* is characterized by having a clear center of distribution, with the largest and densest populations being described as the core populations, and many outlying or "satellite" populations (Deither and Hacker 2004, Pfauth et al. 2003). The difference between a core population and a satellite population is individuals from the core populations will disperse widely and produce new satellite populations, which in turn will continue to grow, form their own patch, and eventually behave as a new source (http://www.weedcenter.org/textbook/3_rados_invasion.html#Summary). The assumption is that core populations will grow as fronts while satellite populations will expand more rapidly and potentially cover greater area than the front of a core population.

Five areas have been identified to have the largest, densest known infestations and as a result are identified as core populations (Figure 2). Two core populations of *S. anglica* have been identified at Boundary Bay and Roberts Bank while two core populations of *S. patens* have been identified at Burrard Inlet and Comox Spit and one *S. densiflora* core population in Baynes Sound (Figures 3 & 4). Further investigation on Vancouver Island in Comox estuary and Baynes Sound should be conducted to determine the current population status as these populations may be satellite populations. Newly detected infestations or plants outside of these areas are considered satellite populations.

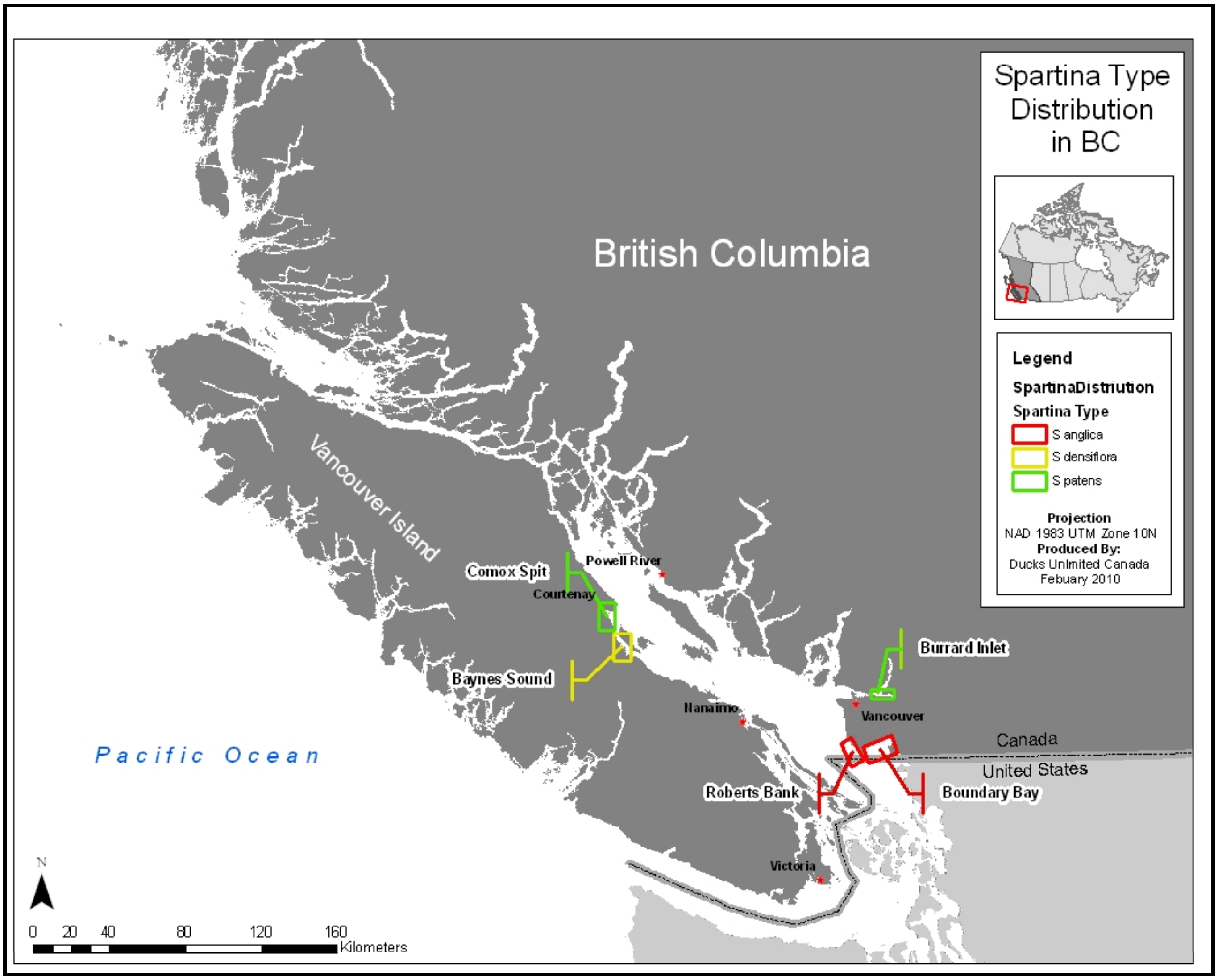


Figure 2. Distribution of *Spartina* in BC – core populations.

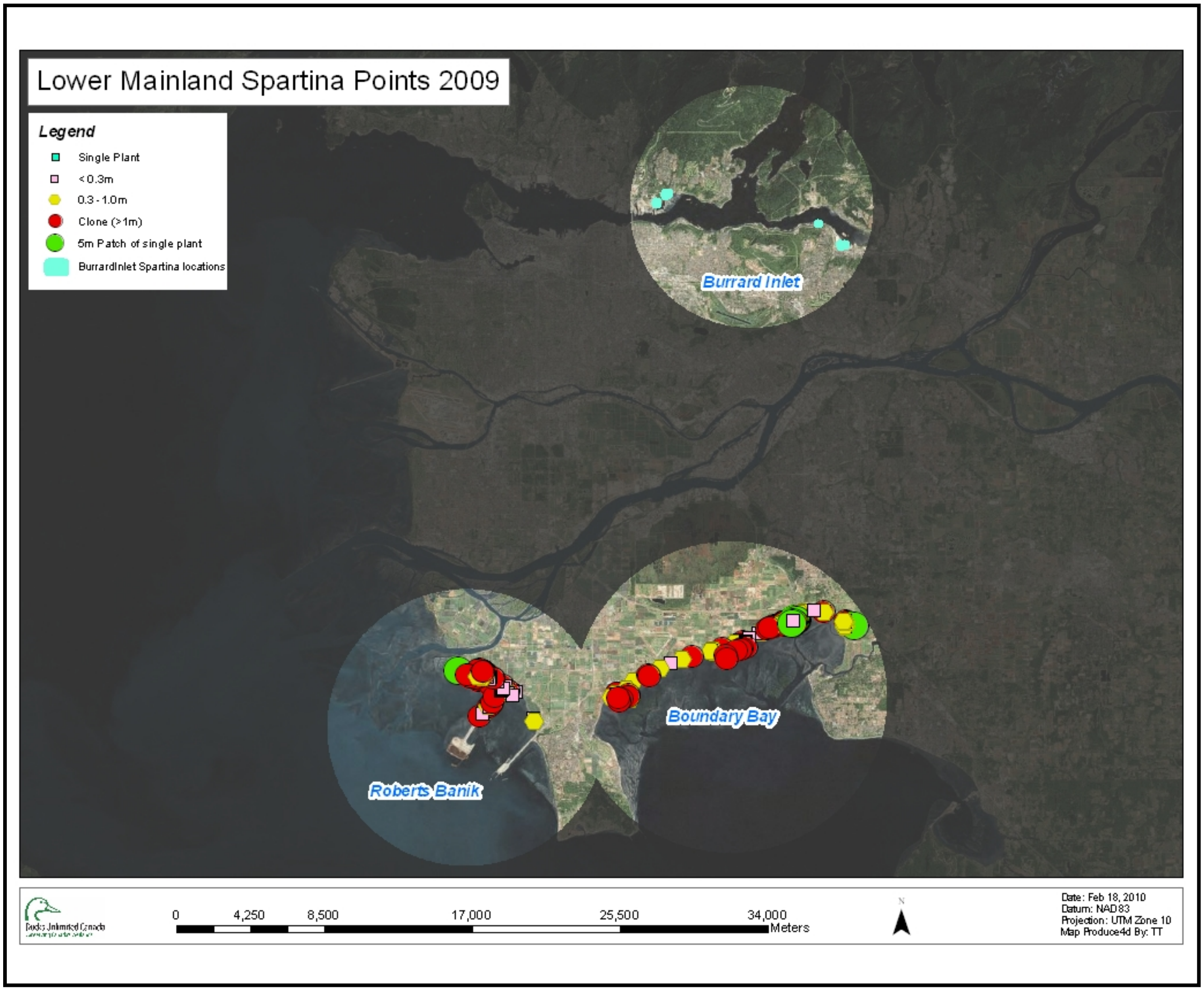


Figure 3. Boundary Bay and Roberts Bank core *S. anglica* populations and Burrard Inlet core *S. patens* populations.

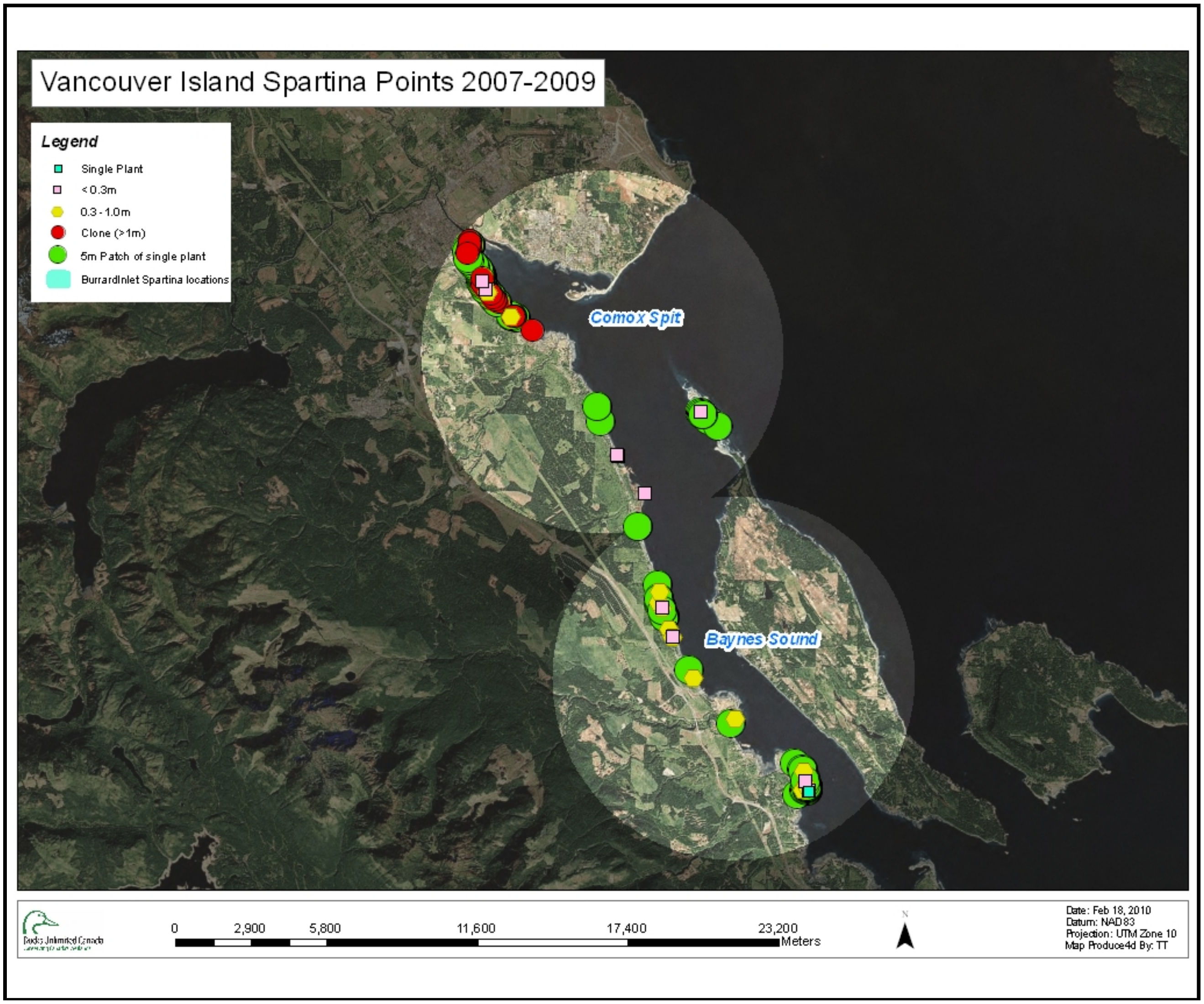


Figure 4. Comox Spit and Baynes Sound core *S. densiflora* populations.

The core *Spartina* populations are growing successfully in all intertidal zones and substrates from sand to heavy mud up to the high tide line and exist in all size classes from single seedlings to clones greater than one meter in diameter. Table 4 provides the size class distribution in Boundary Bay and Roberts bank from 2004 to 2008.

Table 4. *Spartina anglica* Size Classes Mapped From 2004-2008 in Boundary Bay and Roberts Bank. *Note an increase from 2004-2008 resulted from an increased search area. (Ducks Unlimited Canada, 2008)

Size	2004*	2005	2006	2007	2008
Single plants	89	167	107	41	56
Clone < 0.3 m	203	329	229	111	110
0.3 m < clone < 1.0 m	88	204	210	108	60
Clone > 1.0 m	53	90	42	33	61
Patch approx 5 m	0	0	97	49	47
Size Unknown	50	0	0	0	0
Total	483	790	685	342	334

Core population management strategy:

Core *Spartina* populations are much larger, denser populations than satellite populations. They require higher level planning and greater resources to control and eradicate than satellite populations. A site specific treatment strategy should be developed for each core population based on infestation and environmental characteristics. When developing a core population treatment strategy the following steps are essential:

1. Conduct detailed initial assessment to determine and document size of infestation, distribution, site accessibility, potential environmental impact issues;
2. Devise cost estimates based on the environmental variables.

Site – specific treatment strategies of **core populations** should include the following elements but are not limited to:

- Treatment should include both removal methods and preventative measures to restrict seed production, seed dispersal;
- Treatment methodology (chemical, mechanical etc.);
- Location where treatment will begin (especially if treatment cannot be conducted in one session). Treatment may occur from least dense areas towards more dense areas although trials could be conducted to compare the effectiveness of differing treatment approaches;

- Equipment which will be utilized / best suited to the site;
- Time of year treatment will be conducted and repeated;
- Time of year monitoring should be conducted.

Satellite management strategy:

Satellite populations are generally sparse, smaller populations commonly existing as individual plants or seedlings. Individually they require fewer resources to eradicate once detected. Developing a treatment strategy for satellite populations in general as opposed to each encounter would likely be suitable.

Treatment strategies of **satellite populations** should include the following elements but are not limited to:

- Common treatment methodology – mechanical / hand pulling;
- Equipment which will be utilized for removal;
- Time of year removal and monitoring should be conducted.

5.4.2 DEVELOPING SITE SPECIFIC STRATEGIES

One of the goals of this report is to identify the potential invasive plant control tools available then develop criteria that should be used to determine the most appropriate control technique suitable for specific infestations based on characteristics of the site and species of *Spartina*.

When developing site specific strategies, the *Spartina* species present at the site, and the characteristics of the infestation especially the size and distribution will heavily influence the method(s) suitability.

5.4.2.1 *SPARTINA* SPECIES PRESENT

The site specific strategy depends on the species of *Spartina* that occupies the site. A major difference between the four species of *Spartina* is their tidal habitat range. *S. anglica* is more commonly found in the mudflats found in lower intertidal areas compared to *S. patens* that grow in slightly higher elevations within the marsh areas (Pfauth et al. 2003). *S. alterniflora* has a large habitat range from the mean lower low water zone to the extreme high water zone (Pfauth et al. 2003). *S. patens*, commonly poses fewer logistical problems in accessing a site and may be more amendable to physical control methods. Table 5 presents a summary of the ecological characteristics of the four invasive *Spartina* species that occur in North America. Information was summarized from the *Spartina* ID cards produced by the B.C *Spartina* Working group (http://cmnbc.ca/files/atlas_files/2009*Spartina*%20ID%20Cards.pdf).

Table 5. A summary of the ecology of each of the four *Spartina* species present in North America.

Spartina **Species**	***Spartina anglica*** **(English cordgrass)**	***Spartina densiflora*** **(dense flowered cordgrass)**	***Spartina patens*** **(salt meadow cordgrass)**	***Spartina alterniflora*** **(smooth cordgrass)**
Origin	England	South America	Atlantic Coast	Atlantic Coast
Location in BC	Fraser River Delta Mudflats (Boundary Bay, Robert's Bank)	Baynes Sound on East Coast of Van. Island	Burrard Inlet (Maplewood) and Port Moody Arm; Comox estuary, spreading into Baynes Sound.	Not yet sighted in BC. Potential to spread northward from Washington State.
Tidal Range	High marsh zone to intertidal mudflat	High marsh to mid-intertidal; can tolerate higher energy sites than other *Spartina* species	High marsh zone	High to low marsh range including mudflats
Stems	Up to 1.5 m, Red.	Up to 1.5 m	Up to 1.2 m	Up to 2.5 m
Growth Pattern	Seedlings spread vegetatively to form circular clones	Grows in tufts	Matt forming growth	Seedlings spread vegetatively to form circular clones
Flowers	June – September, mostly in July			
Produces Seed	August – October, mostly in September			
Reproduction Method	Vegetatively by underground rhizomes and sexually by seeds			

5.4.2.2 SIZE OF THE INFESTATION

The following infestation size classes are utilized in the Fraser Delta Program from 2004 - 2008 are:

Class 1 - single plants,
Class 2 - clone < 0.3 m diameter,
Class 3 - 0.3 m diameter < clone < 1.0 m diameter
Class 4 - clone > 1.0 m diameter

(Photos provided courtesy of Claire de la Salle – Ducks Unlimited Canada)

Class 1: Single Plants

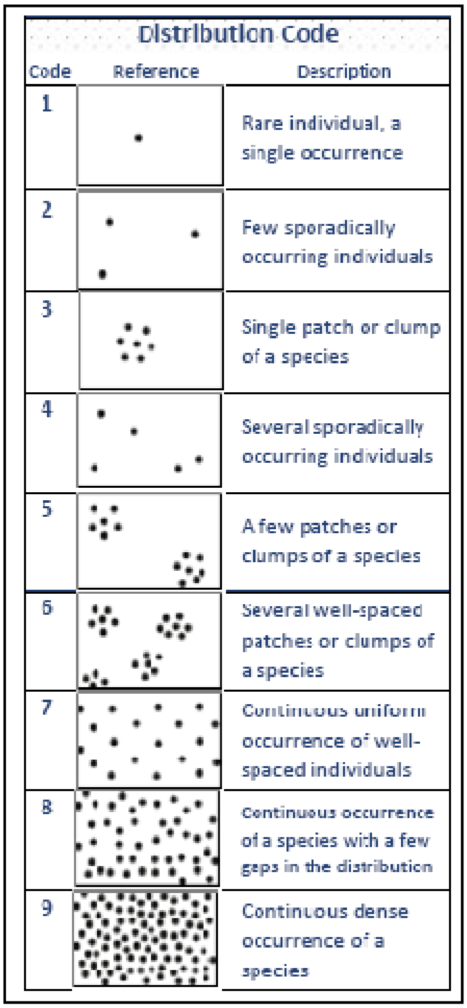
Class 2: Clone diameter < 0.3 m

Class 3: 0.3 m < Clone diameter < 1.0 m

Class 4: Clone diameter > 1.0 m

5.4.2.3 SPATIAL DISTRIBUTION

The spatial distribution of an infestation is a description of the plant or clone in relation to other plants or clones of the same species. This is an important characteristic in determining a management technique since resources can be optimized by treating multiple clones if they are in close proximity. The Invasive Alien Plant Program (IAPP) database for invasive plant management in BC lists distribution codes from 1- 9 with 1 being described as rare individual, a single occurrence and 9 being described as continuous dense occurrence of a species (Figure 6).



Distribution Code

Code	Reference	Description
1		Rare individual, a single occurrence
2		Few sporadically occurring individuals
3		Single patch or clump of a species
4		Several sporadically occurring individuals
5		A few patches or clumps of a species
6		Several well-spaced patches or clumps of a species
7		Continuous uniform occurrence of well-spaced individuals
8		Continuous occurrence of a species with a few gaps in the distribution
9		Continuous dense occurrence of a species

Figure 5. Invasive plant distribution codes (from IAPP Invasive Plant and Survey Record).

5.4.3 TREATMENT RECOMMENDATION MATRIX

It is important to consider the size, distribution of the infestation in combination with the tidal habitat range when selecting a treatment method. Table 5 presents a treatment recommendation matrix presenting ten management categories with treatment methods based on the size, distribution of the infestation and tidal habitat range occupied. It is assumed that tidal habitat range is a surrogate for *Spartina* species since this is one of their most prominent ecological differences. In this category, Low includes areas in the intertidal mudflats and High includes sites in the High Marsh Zone. The accessibility of site could also be accounted for by this category since areas that are considered high in the tidal habitat range generally also have better access.

Table 5. Treatment method recommendation decision matrix based on infestation size, distribution and tidal habitat range.

Infestation Size	Spatial Distribution Code	Tidal Habitat Range	Treatment Methods	Management Category
Class 1: Single Plants	1 - 9	Low High	**Physical** – digging, seed clipping	1
Class 2: Clone diameter < 0.3 m	1 - 9	Low High	**Physical** – digging, seed clipping	2
Class 3: 0.3 m < Clone diameter < 1.0 m	1 - 3	Low	**Physical** – digging, seed clipping	3
		High	**Physical –** digging, seed clipping	4
Class 3: 0.3 m < Clone diameter < 1.0 m	4 - 9	Low	**Physical** – seed clipping, excavator digging **Chemical**	5
		High	**Physical** – seed clipping, covering, excavator digging **Chemical**	6
Class 4: Clone diameter > 1.0 m	1 - 3	Low	**Physical** – mowing, excavator digging **Chemical**	7
		High	**Physical** – mowing, covering **Chemical**	8
Class 4: Clone diameter> 1.0 m	4 - 9	Low	**Physical** - excavator digging, mowing **Chemical**	9
		High	**Physical** - excavator digging, mowing, covering **Chemical**	10

Once a treatment method is selected using the treatment recommendation matrix above, ensure that the method is also appropriate while considering the following variables:

- Potential environment impact;
- Infestation Accessibility;
- Stage of growth of the plant or clone;
- Management cost;
- Permitting requirements.

5.4.3.1 POTENTIAL ENVIRONMENTAL IMPACT

The mudflats and salt marshes are extremely sensitive ecological areas that support a complex food web that includes invertebrates, fish and wildlife (Pfauth et al. 2003). Some areas supporting biofilms may be important for shorebirds (Elner et al. 2005; Kuwae et al. 2008). Treatment methods in these areas may differ.

Environmental impacts exist for both not managing the site thereby allowing *Spartina* to expand and inhabit these valuable areas and by managing the area by creating a temporary disturbance within the estuarine environment. Selecting the most suitable treatment method for the infestation involves considering the environmental impact of each method and altering plans to reduce the impact. The following best management practices will assist in reducing the impact of treatment methods:

- Train treatment crews on species identification, recognition of nesting habitat and appropriate responses, and minimizing treading on vegetation.
- Minimize the number of people and number of revisits to the particular site.
- Minimize the amount of equipment entering the area.
- Select specialized equipment where possible particularly suited for estuarine environments with lower pounds per square inch (eg. amphibious vehicles).
- Avoid any unnecessary disturbance of established vegetation.
- Prevent release of deleterious substances entering the area by ensuring the use of well-maintained vehicles and the on-site use of spill kits equipped with the appropriate clean-up products (e.g. absorbent pillows/pads, disposal bags, etc.) to ensure rapid response to spill.;
- Equipment must be in good operating condition and power washed prior to being transported to the work site. This has the dual benefits of preventing contamination from residual petroleum products and helping to prevent the spread of invasive plants. Where appropriate, equipment should have spill trays installed to contain potential leaks.

- Proper refuelling and fuel storage procedures must be followed (e.g. refueling away from sensitive habitats).
- Undertake treatment options during seasonal timing to create the least impact on birds, amphibians etc. (eg. Nesting season).

5.4.3.2 INFESTATION ACCESSIBILITY

It can be quite challenging for managers to devise cost effective methods for efficiently traversing and transporting equipment, supplies and personnel across expansive, ecologically sensitive tidal mudflats (Hedge et al. 2003). Since equipment and personnel can cause significant environmental impacts on these sensitive environments, ensuring that strategies are designed to reduce the number of people and the amount of equipment transported onto or across the mudflats should be incorporated.

5.4.3.3 STAGE OF GROWTH

The stage of growth of the plant or clone is important when considering a management tool. The first priority of *Spartina* management is eradication, but where infestations occur and are beyond immediate removal, preventing seed dispersal is imperative (Pfauth et al. 2003). Seedhead clipping while the plant is flowering would be suitable followed by removal methods. Early flowering is found to produce the most abundant and viable seeds so clipping seed heads during this time would be an effective approach.

5.5 COSTS COMPARISONS OF TREATMENT METHODS

The BC *Spartina* Working Group has provided approximate cost estimates for treatment methods including material necessary, labor costs and a total labor costs per acre (Table 6). However, costs can vary significantly with the size of the infestation, location of the infestation in the estuary, and species present (Pfauth et al. 2003). The distribution of the infestations in relation to one another greatly influences the cost of treatment methods (D. Buffett, personal communication, December 11, 2009).

Table 6. Cost comparison of *Spartina* treatment methods.

Management Tool	Materials necessary	Materials Costs	Labor Costs[1]	Labor cost per Acre	Labor Cost per meter [2]
Hand removal/ digging	Shovel Heavy duty bags	Shovels 10 @ $20 = $200; Bags $500	1 hour /2 m² 2000 hours/acre x $ 50/hr	**$100,000/acre**	**$24.71 /m²**
Seed Clipping – by hand	Clippers Heavy duty bags	Clippers $200 Bags $250	1 hour /12 m² 337 hours/ acre x $ 50/hr	**$16,850 /acre x 2 cuts/yr = $33,700/acre**	**$4.16 /m²** **$8.32 /m²**
Seed Clipping – mechanical	Brush cutter	$500	1 hour / 300 m² 13.5 hours/ acre x $ 50/hr	**$675/acre x 4 cuts/yr =$2,700/acre**	**$0.17 /m²** **$0.67/m²**
Excavator digging	Amphibious: mud Standard: sand substrate	Amphibious to Mobilize = $3,400 Standard to mobilize = $500.00	Amphibious 1 hour = $350 Standard 1 hour = $150 Amphibious 16 hours/acre x $5600 Standard 16 hours / acre x $2400	**Amphibious - $9,000/acre** **Standard - $3,000/acre**	**$2.22/m²** **$0.74/m²**
Covering	Fabric, anchoring (rebar, plastic, stakes, sandbags)	Fabric: $4800/acre Anchoring $50,000/acre (low intertidal) $15,000/acre (high intertidal)	100 hours/acre $5000/acre	**$60,000/acre - low intertidal** **$20,000/acre - high intertidal**	**$14.82/m²** **$4.94 /m²**
Herbicide - aerial	Helicopter or Crop Duster, Herbicide	Herbicide = 200 $ acre	$100- $ 200/acre	**$300-$400/acre**	**$0.07 m²- $0.10/m²**
Herbicide - backpack	Backpack, Herbicide	Backpack $ 120 Herbicide $200/acre	8 h/acre $400/acre	**$800/acre**	**$0.20/m²**

1. **Labor effort was estimated in acres as a practical unit of measure. Labor costs are provided in square meters to provide standard metric measurements and to allow comparison to references of hectares. 1 hectare = 10,000 m².**

Table 6 was estimated based on the following assumptions:

- The entire acre is infested;
- Labor cost is $ 50 hour which may be conservative;
- The amphibious excavator can travel 2.5 km/hour and remove about 40 clones/day (based on spacing at Brunswick Point);
- 1 acre = 4046.86 m^2;
- Since herbicide has not been utilized to date in British Columbia herbicide application costs are from US *Spartina* programs.

Additional comments related to treatment costs:

- **Hand Removal:** The price does not include the disposal costs. The larger the clone the longer it takes to dig/area because of more extensive root
- **Seed Clipping – Mechanical:** This must be conducted prior to seed heads developing. Plants must be clipped 4 times per year to prevent seed head development.
- **Seed Clipping – by hand:** This can be conducted on plants with seed heads. Seed heads must be clipped at least 2 times a year.
- **Excavator digging:** Two different excavators have been used in by the BCSWG: An amphibious excavator for the muddy areas with very low ground pressure, and a regular excavator for sites with sand substrate. The prices differ between the two due to reasons such as regular excavator can travel much faster than amphibious excavator
- **Covering:** The largest cost involved with this method is the rebar/anchoring cost. Covering in the intertidal requires more anchors plus additional monitoring and replacement of anchoring if needed.
- **Herbicide aerial:** The price depends on whether a helicopter or crop duster can be used. Helicopters must be used in more populated areas as the application of the herbicide is more precise and they have a higher safety rating. Prices can also go up if there is negative publicity. Herbicide rates are based on US prices for Imazapyr.
- **Herbicide backpack:** Normally there is only a 1-1.5 hour treatment window, 4 - 5 people are needed to treat an acre. Note: High volume hand held spray applications have been the preferred tactic for *Spartina* control in Washington (Hedge et al. 2003). Given the relatively small infestation sizes in British Columbia it is recommended to utilize the hand held spray method for herbicide application (Tanner Ketel, pers. comm.).

5.5.1 SITE SPECIFIC STRATEGY IMPLEMENTATION

The effectiveness of site specific strategies depends upon strategy implementation. Some key elements of strategy implementation are:

- Sites must be treated in consecutive years and long term over several years to be effective (Deither and Hacker 2004).
- It is also recommended to conduct multiple rounds of treatment at least twice a season to ensure that any missed areas that could produce seed and any new seedlings can be treated prior to seed set.
- Treatment must also be applied at the appropriate time of year.

5.5.1.1 TIMING OF TREATMENT

Ensuring that the timing of treatment is appropriate to effectively reduce the plants resources is particularly important. The first priority of management efforts is minimizing the amount of seed produced by *Spartina* species through appropriate timing of efforts before seed production in the late summer and early fall (West Coast Governors Agreement on Ocean Health, 2009). This reduces the risk of seeds germinating and reestablishing *Spartina* after treatment in the late summer or fall after localized eradication. Optimal timing of application varies depending on the treatment method.

Hand Removal and Excavator Digging – can be conducted any time of year but consideration of tidal cycles to schedule treatment during daytime low tide exposure of the plants, occurs from May to September, but additional care is necessary during removal if the plant has set seed to ensure that seeds are not unintentionally dispersed.

Clipping – clipping of inflorescences to control new seed production and dispersal should be conducted early in the season. However, it has been shown that clipping can increase the production of flowering shoots the following summer, so clipping should be a conducted each year (Gary Williams 2009). It is also not recommended in late fall when plants have set seed (Diether and Hacker 2004).

Covering – can be conducted any time of year but it is recommended to mow prior to installing the fabric to prevent seed set if installed during the growing season.

Herbicide - The timing of herbicidal spraying has large implications on the effectiveness of this method. Diether and Hacker (2004) recommend spraying early in the growing season (July) since it is more effective in reducing plant growth and seed production that doing so late in the season (after mid – August). At that time, the plant has most of its resources invested in producing biomass and the chemicals are most effective (Deither and Hacker 2004). Weather and tidal conditions are important factors to ensure maximum drying time on the plant and low tide exposure.

5.6 MONITORING

The goal of the monitoring component of the program is to measure the effectiveness of various control techniques in suppressing or eradicating *Spartina*. The program should monitor *Spartina* at both the population level and the site level. Monitoring at the population level will be useful in determining population trends (increasing, decreasing, stable) of *Spartina* to assist in developing management goals in future seasons. Monitoring at the site level will permit the efficacy of various treatment methods to be evaluated.

The monitoring program should include the following information at the *Spartina* population level:

- The extent of area shoreline monitored / inventoried (km^2 or ha);
- Detailed information on the polygon and point data on current populations.

A documented procedure should be developed and implemented to determine efficacy of all treatment methods at the site level and resulting infestations characteristics. The treatment efficacy evaluation should include:

- Include detailed information on the amount of *Spartina* removed / treated by species including polygon and point data of plants or infestations;
- Compare area of an infestation before and after treatment;
- Be consistent among treatment methods where applicable (herbicide vs covering) to ensure it is repeatable to permit multi-year comparisons;
- Evaluate sites at least once each season, at similar times each year;
- Record pertinent data and information (eg. location, stem density, area of infestation);
- Report outcomes using standard units (e.g. square meters searched).

5.7 SCIENCE/EVALUATION

When managing invasive species, it is important to take an adaptive management approach. The effectiveness of the methods taken to manage *Spartina* in BC should be monitored for the effects on *Spartina* populations but also the potential impacts on other species. Methods should be researched and regularly evaluated, so appropriate adaptations can be implemented over the following years.

Another consideration is the impacts of climate change and how that may affect BC's coastal ecosystems and the impacts of *Spartina*. As temperatures warm, precipitation regimes fluctuate, and nutrient flows change, ecosystems may lose their ability to support a diverse set of native species becoming more vulnerable to invasion as new resources become available (U.S. Environmental Protection Agency 2008). Consequently, it is clear that until the science is more fully understood, there is a need for increased monitoring, ongoing evaluation of *Spartina* distribution, spread and response to treatment options, and continued interagency relationships.

Gary Williams (2009) identified the following data gaps:

- Lack of knowledge of the distribution of *Spartina* in BC.

- Confirming tidal range of the growth to assist in determining the physical conditions operating at the site.
- Further investigation into remote sensing, infrared or other photometric techniques.
- Research to develop improved removal methodologies especially for the 1 – 5 m diameter clones that require considerable labor to remove.
- Development of a sieving procedure, with collection of plant fragments, would facilitate removal especially in sandy sediments.
- Research into restoration of large stands of *Spartina* since removal activities can lead to remnant areas of elevated sediments or below-ground mats that may need to be restored to promote re-establishment of native marsh vegetation. However, based on the observations conducted to-date, it would appear that the large swards have not yet established in BC.
- Increased attention of human transport mechanisms through detection (e.g. incorporating seed or plant fragment observations into ballast water invasive species research) or adopting measures to reduce potential of accidental translocation of *Spartina* material during dredging operations should be considered.

Additional knowledge gaps which may be evaluated are:

- Evaluate new detection methodologies utilized in the program. This may involve cost benefit analysis of each method.
- Conducting a thorough literature review to determining if there is documented evidence of the impact of *Spartina* on fish or fish habitat.
- Evaluate new treatment methodologies through research trials.

5.8 OUTREACH

Outreach activities should be planned in conjunction with IPCBC's Aquatic Plants Advisory Committee and in cooperation with relevant regional committees. Four regional committees are located along BC's coastline and could play a pivotal role in community education and outreach, which will pave the way to effective early detection and rapid response.

As part of IPCBC's outreach initiative, they are in the process of developing an *Aquatic Invaders Module* for their "Spotters and Specialists" program. This is a standard orientation workshop for local community groups on invasive aquatic plants in their area, how to report them, and basic management recommendations. In spring 2010, this PowerPoint presentation will be downloadable from the Council's website www.invasiveplantcouncilbc.ca and applicable provincially. Additional activities noted in the action plan include: development of a detailed outreach plan; public service announcements via radio and/or targeted publications, news releases, articles, giveaways (e.g. magnets, floating key chains for anglers, brochures, booklets, poster, plant tags with key messaging), and the development and installation of signage. *Spartina* is one of the fourteen species being targeted by IPCBC's Aquatic Plants Advisory Committee, therefore outreach planning and the development of outreach tools for *Spartina* is already underway in the province.

The BCSWG has been conducting outreach as part of the eradication program by utilizing methods such as workshops, press releases and print media. They have developed numerous excellent *Spartina* awareness materials complete with photos and excellent descriptions including pocketsize *Spartina* ID cards and more detailed ID cards along which are available on the Community Mapping Network website http://cmnbc.ca/atlas_gallery/invasive-species-spartina.ca. This website also has mapped locations of *S. anglica*. Given the extensive array of outreach materials, focusing efforts on distributing the materials already available and conducting targeted workshops or press releases may be an effective approach.

Targeted outreach and education will likely be useful in increasing the ability for certain audiences to detect *Spartina*. In BC specific groups which could be targeted for *Spartina* outreach include:

- Kayak groups;
- Birding enthusiasts;
- Shellfish growers;
- Local stewardship groups;
- Coast guard personnel;
- Government staff especially personnel which will be frequenting *Spartina* infested areas.

5.9 FUNDING REQUIRED

The BC *Spartina* Working Group has developed a funding requirement to effectively implement an eradication plan for *Spartina* in BC in the next five years. It has been calculated that $ 200,000 annually for the next five years is required.

The funding requirements are based on the following assumptions:

- The dominant activities in the Lower Mainland are inventory, detection, and removal.
- The dominant activities on Vancouver Island are inventory and detection efforts with limited removal efforts as infestations are expected to be relatively limited;
- A significant increase in the early detection and rapid response program expanding along the BC coastline.

The goal is to make significant progress towards eradicating *Spartina* within 5 years and meet the 2018 goal of *Spartina* eradication on the Pacific Coast.

However, once the existing infestations are eradicated, these areas must be monitored for at least six years to meet the definition of eradication. This shift in the program will result in a greater effort and resources into detection / monitoring activities and no removal efforts.

It is recommended to develop a *Spartina* program with the following elements, implemented as described, and to the budget provided in Table 7. All elements are necessary to fulfill the overall strategy and are made effective by being overseen by a *Spartina* Coordinator.

Table 7. Proposed funding requirements to implement the BC Spartina Response Plan.

Element	Funding	Strategy
Full-time BC *Spartina* Coordinator. • Coordinate activities and among stakeholders • Produce and distribute outreach materials • Conduct targeted *Spartina* workshops and presentations • Plan and conduct aerial and boat detection surveys • Evaluate new techniques such as herbicide	$50,000	● Prevention ● EDRR ● Removal/Control ● Monitoring ● Science/Evaluation ● Outreach
2 person Crew: Vancouver Island • 4 months, June – Sept; inventory and removal 2 person Crew: Fraser River Delta • 4 months, June – Sept; inventory and removal $15/hour, 8 hours/day, 20 days/month +overhead & expenses	$30,000 $30,000	● Prevention ● EDRR ● Removal/Control ● Monitoring ○ Science/Evaluation ○ Outreach
Aerial Surveys: • Rotation of portion of coastlines in 3 year cycle • Bell 206: $1200 / hr • Fixed wing Cesna 185: $840 / hr	$40,000	○ Prevention ● EDRR ● Removal/Control ● Monitoring ○ Science/Evaluation ○ Outreach
Airboat / Boat Surveys • Annual rental, operation, and maintenance costs	$10,000	○ Prevention ● EDRR ● Removal/Control ● Monitoring ○ Science/Evaluation ○ Outreach
Science/Evaluation • Confirm tidal range in BC of the *Spartina* species • Develop research trials for new removal methodologies • Evaluate new detection methodologies	$5,000	● Prevention ○ EDRR ○ Removal/Control ○ Monitoring ● Science/Evaluation ○ Outreach
Outreach • Distribute existing materials • Conduct workshops • Targeted outreach (shellfish growers, local stewardship groups, kayakers etc.)	$5,000	● Prevention ○ EDRR ○ Removal/Control ○ Monitoring ○ Science/Evaluation ● Outreach
Materials costs: herbicide, covering material, machine time etc.	$30,000	
Total annual budget	**200,000**	

5.10 BC RESPONSE PLAN OVERVIEW

A brief summary of the recommended key components of the BC *Spartina* Eradication Plan is presented below:

- Utilize a landscape management strategy to eradicate all known and newly detected *Spartina* infestations working from the least dense areas or satellite populations towards the densest or core populations while employing strategies to prevent seed production and dispersal within all populations.
- Incorporate preventative measures such as: limit equipment or boat activity through infested areas, develop and promote awareness material and prevent seed dispersal from existing plants.
- Utilize Early Detection and Rapid Response (EDRR) strategy to detect, contain and eradicate *Spartina* infestations.
- Employ a comprehensive active detection program utilizing a combination of detection methods including aerial, boat and shoreline walking to obtain a snapshot of the current distribution of *Spartina* in BC and detect new infestations. The aerial method will involve stratifying the BC coastline into three groups to permit a three year rotation to cover each area every three years.
- Work towards eradication through intensive removal activities by trained personnel utilizing an integrated vegetation management strategy. Removal activities would focus on satellite areas by removing small seedlings and work toward larger core infestations while preventing seed dispersal.
- Incorporate a monitoring program to measure the effectiveness of detection and control methods and resulting *Spartina* population trends.
- Utilizing an outreach component to inform both targeted audiences as well as the general public through such methods as the continuation of workshops and print media.
- Utilizing an adaptive management strategy to regularly evaluate and adapt the effectiveness of the methods taken to manage *Spartina* in BC.
- Hire a *Spartina* program coordinator to develop and implement the BC *Spartina* Response Plan.
- The total annual program budget required is approximately $ 200,000 to effectively implement an eradication plan for *Spartina* in BC in the next five years.

5.11 CONCLUSION

Spartina management in BC requires a proactive approach with the objective of preventing new infestations and limiting the expansion of existing infestations. It is imperative to encourage partnerships among different levels of government, non-government organizations, and the private sector to effectively manage *Spartina* infestations in BC. The ongoing guidance and cooperative decision making of the BC *Spartina* Working Group is key in this regard. Critical to success is a mechanism for international cooperation to stop *Spartina* at its source and to foster the sharing of lessons learned in preventing and dealing with invasions (Wittenberg and Cock 2001).

Strategic planning to prevent continued *Spartina* establishment and spread should focus on limiting the dispersal of plant propagules, maintaining or increasing the ability of native ecosystems to resist invasion and systematically searching for and eradicating new infestations (Davies and Johnson 2009). A combination of ground, boat, and aerial surveys should be utilized to effectively determine the extent of *Spartina* along BC's coastlines. Trained volunteers can assist with *Spartina* detection; however, paid personnel should be utilized for the majority of the detection program and removal activities.

A variety of control and management tools are needed to assess, remove and contain *Spartina* populations and guide management decisions. These tools should be applied within coordinated and integrated management strategies that are adjusted, as needed. Control techniques that have been successfully utilized in the western US states should be applied on a trial basis in BC, and carefully evaluated, to determine their suitability along BC's coastline. Management actions should be regularly monitored such that results can be used to demonstrate where actions are effectively and successfully meeting *Spartina* management objectives, and to more quickly detect and modify actions that are ineffective.

Climate change may enhance environmental conditions and facilitate the range expansion of *Spartina* along BC's coastline; therefore it is imperative that monitoring and survey efforts are ongoing. Monitoring efforts may need to be modified to focus on weakened or changing ecosystems that are more vulnerable to invasion (Hellman et al. 2008).

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