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A Review of Spartina Management in Washington State, US

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ABSTRACT

Management of non-native *Spartina* plants including *Spartina alterniflora* Lois., *Spartina anglica* C. Hubb and Spartina *patens* (Ait.) Muhl. in Washington State, U.S. evolved during the 1990s from small-scale field trials to a large-scale integrated pest management program. The development and implementation of the program were significantly hindered by stakeholder conflict, particularly regarding the use of herbicide in estuarine environments. In 1995, Washington State Department of Agriculture was appointed to manage these invasive species. Agency coordination and strategy reviews were undertaken. A wide range of control techniques, including physical removal, mowing and herbicide, were established, with all techniques demonstrating considerable limitations. The combination of mowing and herbicide provided the greatest efficacy but was expensive. Development of biological control options is in progress but will take years to prove effectiveness for *Spartina* management. Program progress based on existing mapping and efficacy data is difficult to gauge. This program demonstrates that *Spartina* plants are difficult and expensive to eradicate. Between 1995 and 2000, infestations increased in area by 250%, affecting more than 8,093 ha of intertidal land. During this period, approximately 15% of the infestation was treated annually. Although the program has evolved considerably, substantially increasing knowledge on the management of *Spartina*, infestations in Washington State continue to present a range of management challenges, including the development of a standardized and integrated mapping procedures, cost-effective control techniques and improvements to stakeholder management.

Key words: Integrated pest management, saltmarsh grass, rice grass, cordgrass, coastal weeds, *Spartina*

INTRODUCTION

The genus *Spartina* includes 17 species, commonly known as saltmarsh or cord grasses, with native ranges in coastal America, Europe and north Africa (Mabberley 1997). Of particular interest in this paper are the three species, *Spartina alterniflora* Lois., with a native range along the Atlantic and Gulf coasts of North America from Quebec and Newfoundland to Florida and Texas; *Spartina patens* (Ait.) Muhl., with a similar native range but also inland in New York and Michigan (Gleason and Cronquist 1991); and the now common tetraploid of Great Britain coastlines, *Spartina anglica* C. Hubb. This latter species arose via polyploidy and hybridization between the British native *S. maritima* (Curtis) Fern. and introduced plants of *S. alterniflora*. During the 19th and 20th centuries, *S. alterniflora*, *S. patens* and *S. anglica* were intentionally or accidentally introduced outside their native ranges in numerous coastal regions of both the southern and northern hemispheres (Ranwell 1967, Boston 1981, Aberle 1993, Kriwoken and Hedge 2000). For the remainder of this article, these plants will be referred to as *Spartina*.

These rhizomatous *Spartina* plants are particularly well adapted to colonizing open soft-sediment habitats in the intertidal zone of estuaries and waterways. In some regions, such as the Pacific Northwest of the U.S. and the coastal states of Australia and New Zealand, continuing concern about the threats of non-native *Spartina* invasion to biodiversity, fisheries, aquaculture and recreation in estuaries (Gray et al. 1997, Dumbauld et al. 1997, Shaw and Gosling 1997, Hedge and Kriwoken 2000, Daehler and Strong 1996) has prompted efforts to control the spread of these invasive grasses (Hedge and Kriwoken 1997, Shaw and Gosling 1997, Kriwoken and Hedge 2000). What has become evident from these ongoing programs is that invasion by exotic *Spartina* is a complex coastal zone management problem that challenges the ability of managers to develop and implement an effective and timely invasion management response. One of the most progressive and intensive *Spartina* management programs has occurred in the State of Washington, U.S.

These three *Spartina* species have been introduced deliberately or accidentally to the coastal zone of Washington (Aberle 1993). *Spartina alterniflora* appeared in Willapa Bay (Figure 1) about 100 years ago (Sheffer 1945), probably as packing material in shipments of the eastern oyster, *Crassostrea virginica* (Sayce 1988). In other regions, such as Puget Sound and the Straits of Juan De Fuca (Figure 1), this species was intentionally introduced to stabilize dike areas or to provide habitat for waterfowl or waterfowl hunters (Aberle 1993). In 1961, *Spartina anglica* was planted in Port Susan Bay, Puget Sound, to provide forage for cattle (Ebasco Environmental 1993). The mode of introduction for *Spartina patens* to Washington is unknown, but it also may have entered the area as packing material (see Hitchcock and Chase 1950, p. 509).

The subsequent spread of *Spartina* received little attention for decades until 1942 when regional oyster growers expressed their concern about the progressive spread of *Spartina* (Sayce 1990). Nearly 40 years later, in 1979 the Washington State Department of Wildlife recognized the po-

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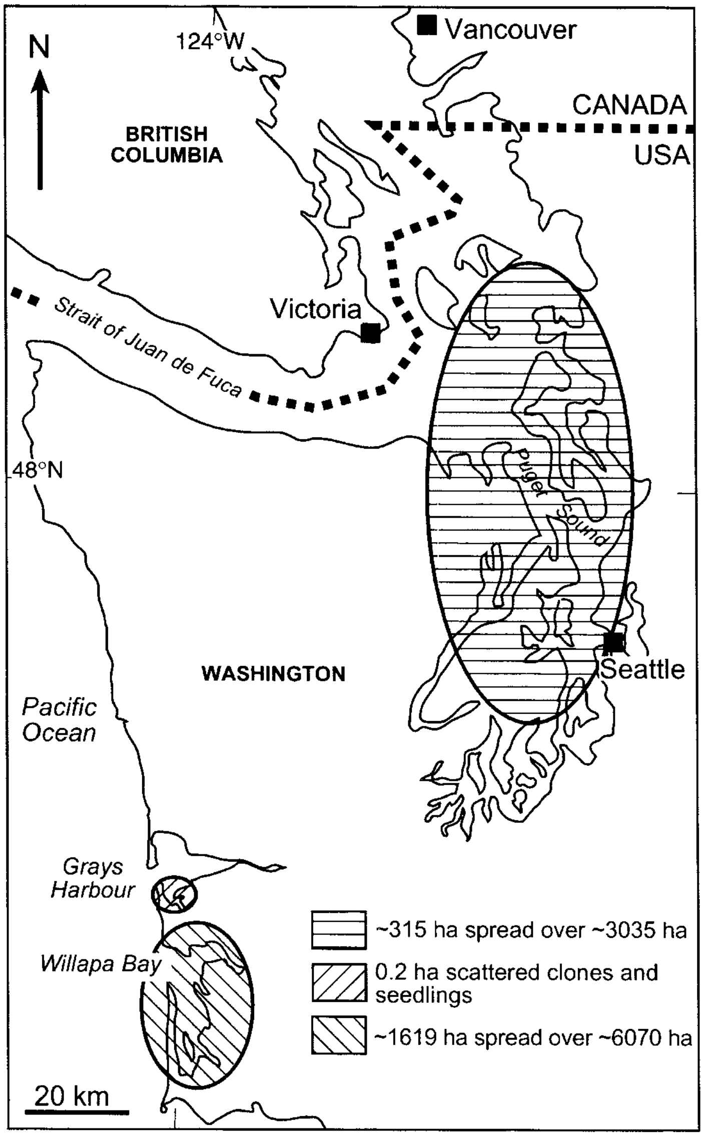

Figure 1. Location of major infestations of the saltmarsh grasses smooth cordgrass (*S. alterniflora*) and cordgrass (*S. anglica*) in Washington State.

tential threat of *Spartina*, recommending eradication from all estuaries in the state (Aberle 1993). By the mid 1980s, numerous small infestations of *Spartina* species were spread throughout Puget Sound, while in Willapa Bay, *Spartina alterniflora* had invaded approximately 120 ha (Aberle 1993). Throughout the 1990s, *Spartina* infestations, predominantly *S. alterniflora*, continued to invade new territory at an exponential and alarming rate (Sayce 1988, Aberle 1993). By this time, predicted adverse impacts associated with invasion were becoming reality. Calls for immediate control from the regional shellfish industry, valued at US$16.4 million in 1993 (Washington Agriculture Statistics Service 1995), were supported by fishers, biologists, government agencies and the community (Sayce 1990). In 1988, the potentially devastating threat of *Spartina* to Washington's coastal zone was acknowledged by local and state government agencies, and management action was instigated with the formation of the *Spartina* Working Group (Mumford 1991). This initiative marked the beginning of an active decade of *Spartina* management in Washington.

The relentless spread of *S. alterniflora* and *S. anglica* throughout the early 1990s affected an estimated 7,031 ha of intertidal habitat by 1996, amounting to 2,350 condensed hectares of *Spartina.* The largest infestation entirely composed of *S. alterniflora,* accounting for approximately 80% of all *Spartina* in Washington, occurred in Willapa Bay. The remaining 20% of infestations were scattered throughout Puget Sound and Grays Harbour (Figure 1). In response, the State of Washington's approach to management evolved from a focus on small-scale control sites and mapping exercises toward a large-scale integrated pest management program. The evolution of this management regime was punctuated with numerous scientific and political developments that both hindered and helped the design and implementation of the *Spartina* Program.

Such a program can provide a useful and interesting example of an aquatic weed management program designed to tackle a difficult and complex natural resource issue for coasts and estuaries. This paper reviews the development and implementation of the Washington *Spartina* Program, including the legislative framework, institutional arrangements and range of stakeholders involved. The intent is to synthesize information on effective control techniques and identify future challenges of *Spartina* management in Washington State.

Difficulties Associated with *Spartina* Management

These *Spartina* species are hardy pioneer plants that thrive under the numerous environmental stresses associated with the intertidal zone of estuaries and waterways. Unfortunately for managers of exotic *Spartina*, the intertidal zones of many countries are typified as areas of confused management (Sorensen and McCreary 1990, Clark 1996, Kenchington 1990). Intertidal zones are commonly affected by terrestrial-based legislation and institutional arrangements that overlap with those pertaining to marine environments.

In some regions, such as Willapa Bay, management responsibility for intertidal land is shared among numerous federal, state and local government managers and private land holders (Table 1). Consequently, attaining consensus and support among land holders/managers on complex natural resource management decisions for an entire estuary may at best be a lengthy and costly process and at worst, a virtually impossible one. Thus, one of the most important challenges for natural resource managers is to develop effective, practical and realistic management objectives and strategies as soon as possible before infestation size exceeds allocated management resources (Hedge and Kriwoken 1997, Kriwoken and Hedge 2000). In some cases, such as the River Tamar in Tasmania, Australia (Hedge 1997) and Willapa Bay, Washington State (Aberle 1993), a delayed or reluctant management response has allowed the area of infestation to increase to levels where the opportunity to achieve eradication with current control techniques has elapsed.

In some areas sediments are firm enough to traverse on foot or using a four-wheel drive vehicle. However, the majori-

TABLE 1. STAKEHOLDERS AND THEIR ROLES IN *SPARTINA* MANAGEMENT IN WASHINGTON STATE IN 1993.

Government agencies and intertidal ownership	Role in *Spartina* management
State	
Department of Natural Resources	Land management agency and trustee of State owned aquatic lands and associated resources.
Department of Agriculture—The State Noxious Weed Control Board (SNWCB)	A major role in control of noxious weeds and pesticide use; compiles the Washington State Noxious Weed List.
Department of Fisheries	Manages aquatic habitat resources and administers Hydraulic Project Approval (HPA).
Department of Ecology	Regulatory agency instigating EIS process; administers State Environmental Policy Act and Shoreline Management Act; issues Permits for Modification of Water Quality Standards.
Department of Wildlife	Resource/land management agency preserving non-commercial marine wildlife and habitats; also involved in evaluating HPAs.
Federal	
U.S. Fish and Wildlife Service	Land management agency protecting threatened species, migratory birds and anadromous fish.
Army Corps of Engineers	Minor role in engineering and hydrology.
Environmental Protection Agency	Administers Federal Water Pollution Control Act—herbicide implications.
Local	
10 local governments	Land managers administering Land Zoning Codes and various planning permits.
Tribal (indigenous people) ownership	Pesticide free weed management policy.
Private land owners/title holders	100s of owners responsible for control and/or permission to control needed by government agencies.

(Sources: Hauger 1992, Ebasco Environmental 1993).

ty of infestations occur on very soft sediments. In these situations walking is nearly impossible without the aid of floating devices. Thus, a major challenge for managers of *Spartina* is devising cost-effective methods for efficiently traversing and transporting equipment, supplies and personnel across expansive tidal mudflats. In addition, herbicide application and efficacy are encumbered by high winds, short intertidal drying times, foliage covered by sediment and limited access time. Pest management is further complicated by the presence of sensitive and endangered aquatic and avian species that frequent these coastal environments.

Development and Implementation of the *Spartina* Integrated Weed Management Program

Developing an Environmental Impact Statement

Concerns raised in the early and mid 1980s by the U.S. Fish and Wildlife Refuge, Willapa Bay, about *Spartina* went largely unheeded. Their initial efforts to obtain permission to control *Spartina* by mowing or covering with black plastic were blocked by other regulatory agencies concerned about non-target impacts of the control process. The formation of the *Spartina* Working Group in 1988 provided a platform for the initiation of a *Spartina* management program in Washington. The group, consisting of representatives from resource agencies, tribes, environmental groups and industry, recommended the development of *Spartina* management programs and associated research (Mumford 1991). In 1989, the Pacific County, Washington Department of Natural Resources and the Washington Sea Grant Program sponsored a gathering of stakeholders to discuss *Spartina* management.

The workshop addressed major management issues, including the biology, distribution, associated impacts, control and management strategies. Agreement was reached (Mumford 1991) on: (1) giving top priority to preventing the spread of *Spartina* to uninfested areas; (2) recommending that a task force for British Columbia, Canada and the U.S. States of Washington, Oregon and California be formed to address the problem of *Spartina* invasions on the West Coast; (3) appointing a person to the position of *Spartina* Management Coordinator in Washington State; and (4) compiling an immediate inventory of *Spartina* infestations in Washington.

This workshop also triggered two important developments for *Spartina* management. The three regionally exotic species of *Spartina (S. alterniflora*, *S. anglica* and *S. patens*) were listed on the Washington State Noxious Weed List in 1991 (Hauger 1992), and *Spartina* was added in a weed management initiative titled the Noxious Emergent Plant Management Environmental Impact Statement (EIS) (Ebasco Environmental 1993).

This EIS was required under the Revised Code of Washington (RCW 43.21C.030) because State agencies determined "that management of these noxious emergent plant species could have probable significant adverse impacts on the environment" (Ebasco Environmental 1993 p. xiii). The document was drafted and reviewed by several government agencies and distributed broadly for public comment. *Spartina* featured prominently in the final draft of the EIS, reflecting the increasing concern for *Spartina* invasion during the 1980s and the need for a rapid management response. The document discussed the history and current status of *Spartina* in Washington, the legislative framework and institutional responsibility. Management alternatives and their associated impacts were evaluated. In particular, the EIS was designed to establish a framework for the development of management plans at the local level and provide a basis for making informed decisions (Ebasco Environmental 1993). Consideration was also given to stakeholder coordination, determination of management objectives, collection and storage of data, public education, funding and research.

The final EIS, accepted by six co-lead agencies, recommended that Washington should adopt an integrated weed management option for management of noxious emergent plants. This alternative was preferred because it offered a comprehensive approach that combined a management process with the best components of the other alternatives including biocontrol, mechanical and chemical options (Ebasco Environmental 1993).

Implementing the Management Program

Although the EIS provided the framework for the development and implementation of management plans at the local level, it soon became apparent that it was merely the first stage in a lengthy process to bring about effective *Spartina* management in Washington. Despite the EIS being voluminous and informative, its broad focus on various noxious emergent weeds was too general. More importantly, the authors acknowledged that during the compilation of the EIS, little was known about efficacy, potential impacts, and mitigation associated with several of the evaluated control techniques (Ebasco Environmental 1993). Furthermore, much of the available information was anecdotal or related to limited studies, sometimes without adequate experimental design.

During the 2 years that followed acceptance of the final EIS, the focus and strategies of *Spartina* management became clouded by highly charged stakeholder conflict (Patten and Bishop 1997). In 1995, the situation deteriorated to the point where the Senate for the State of Washington intervened describing the situation as "... frustrated by interagency disagreements, demands for an undue amount of procedural and scientific process and information, dilatory appeals, and the improper application of laws and regulations by agencies that have in fact undermined the legislative purposes of those same laws while ignoring the long term implications of delay and inaction" (Revised Code of Washington 90.48.1).

To remedy this frustration the Senate passed new legislation (Engrossed Substitute Senate Bill 5633 - ESSB 5633) in an attempt to procure effective *Spartina* management in Washington. Legislative reform enacted the following changes to *Spartina* management: (1) appointment of the Washington State Department of Agriculture (WSDA) as the agency responsible for leadership and coordination of *Spartina* management (WSDA was also required to submit biannual reports to Legislature); (2) removal of the requirement for Hydraulic Project Approval from the Washington Department of Fish and Wildlife for the management of *Spartina*; (3) a simplified and streamlined process for acquisition of a Water Quality Permit, issued by the Washington State Department of Ecology (WSDOE), to allow approved herbicides and surfactants to be used for *Spartina* management; and (4) declaration of a state of emergency for *Spartina* management.

The appointment of a single agency as leader and coordinator for *Spartina* management in Washington was a critical and necessary change. Although not guaranteeing improved management, the appointment improved conditions for creating a coordinated and integrated management program focused on *Spartina* management. It also provided an information nucleus for many stakeholders and the dissemination of new and updated information related to control techniques, environmental monitoring, mapping techniques and program developments. Further, it resulted in a sharing of resources among some of the federal and state stakeholders. However, a fully developed and coordinated management program has yet to be realized because of multiple differences in strategies and priorities among stakeholders. Most interagency coordination has been limited to within the state level.

CURRENT CONTROL TECHNIQUES

The Noxious Emergent Plant Management EIS for Washington evaluated a diverse range of potential *Spartina* control techniques. Techniques discussed in this paper are only those currently used by *Spartina* control crews: hand removal, mowing, application of glyphosate (Rodeo® formulation) and a combination of mowing followed by an application of glyphosate. The Rodeo formulation of glyphosate contains a 53.5% active solution of isopropylamie salt of glyphosate, but lacks the polyethoxylated tallowamine (POEA) surfactant found in the Roundup formulation. The POEA surfactant is more toxic to aquatic animals than glyphosate and therefore has been removed to allow the user to select a surfactant that meets their specific needs (Giesy et al. 2000).

The Washington State Department of Agriculture has not defined efficacy, nor do they provide guidelines on determination of efficacy of *Spartina* control techniques. In this paper, efficacy, expressed as a percentage, is defined as the proportion of an infestation that is killed as a result of treatment. Efficacy is typically determined by comparing the area of an infestation before and after treatment.

Hand removal

Although hand removal of *Spartina* can be an effective technique (Norman and Patten 1997a), its widespread use is severely limited by practicality. The major advantage of this approach is that minimal training of workers and simple equipment such as shovels and pitchforks are required. However, limitations become apparent during the implementation phase.

The most limiting factor with hand removal is the time required to remove subterranean biomass. These three species of *Spartina* produce an extensive and dense rhizome and root biomass that on mature clones can extend deeper than 1 m into the sediment horizon. For hand removal to be effective the entire subterranean biomass must be removed.

Therefore, to effectively control a 1-m^2 mature clone infestation and the wet sediment adhering to the root per rhizome mass, a large amount of soil needs to be removed. The removal of *Spartina* and adhering sediments is considered to cause significant environmental impacts to estuarine systems (Ebasco Environmental 1993).

Hand removal of seedlings less than 1 year old may be an effective method of control. Seedlings can be easily removed by hand and transported in a shoulder strap bag. This technique has been used for preventing infestation establishment at Rhodesia Beach, Willapa Bay, a vast intertidal mudflat that is invaded by thousands of seedlings each year. However, as long as nearby mature infestations exist, this form of control requires continual and indefinite application.

Mowing

Mowing, either alone or used in conjunction with herbicide, has been one of the most widely used methods for *Spartina* management in Washington (Patten and Bishop 1997). This technique appears to control *Spartina* infestations by reducing seed production and weakening the plant by depleting root and rhizome energy reserves (Ebasco Environmental 1993). The gasoline powered, hand-held, brush cutter has been the most commonly employed device for mowing. During the late 1990s, trials were conducted with industrial-size amphibious mowing machines. These machines were mounted with a sickle-bar mower on either a straight-head or flail-mower head. The former proved too fragile for use in an estuarine environment.

Efficacies vary considerably and appear to be highly dependent on treatment repetition, substrate type and infestation characteristics (Ebasco Environmental 1993, USFWS 1997, Pacific County 1998). Reports suggest that repeated mowings produce efficacies ranging from 61 to 93% (Pacific County 1998). Although overall control is increased with multiple mowing, cost effectiveness decreases (USFWS 1997). Patten and Bishop (1997) point out that mowing with hand-held equipment is neither efficacious nor cheap. Estimates suggest that the cost to eradicate mature infestations would exceed $2,471 per ha (USFWS 1997). With industrial-size amphibious mowing machines, the cost is only a third as much but this difference does not account for the initial machine expense. It should be noted that mowing techniques alone have not resulted in any *Spartina* eradication. However, a well-timed single mowing event can effectively control seed production (USFWS 1997). Mowing of large *Spartina* meadows has also been the only way that the meadow interiors can be made accessible for airboats to apply herbicides.

Roto-tilling/disking

Other means of mechanical control have been recently investigated. The use of a roto-tilling machine that disturbs the soil to a depth of 8 to 12 cm and 3 m wide attached to an industrial-size amphibious vehicle has produced greater than 90% efficacy during winter trials, but was less than 70% effective during spring trials (Patten and Stenvall 2002). The operation is slow at 0.25 to 0.5 ha per hour. Testing continues on other techniques for mechanical sub-soiling, such as ripping or disking.

Herbicide

The ineffectiveness of hand removal and mowing has focused considerable attention and hopes on the potential of herbicide to control infestations. Globally, a spectrum of herbicides have been used and tested for effectiveness against *Spartina* species (Pritchard 1995, Hedge and Kriwoken 1997, Shaw and Gosling 1997, Norman and Patten 1995, 1997a & b, Patten 2000). The Washington Aquatic Plant Management Program Environmental Impact Statement restricts or limits the use of herbicides for emergent plants to Rodeo (Ebasco Environmental 1993). The application of Rodeo for *Spartina* control is currently regulated by six water-body specific Water Quality Permits issued by the Washington Department of Ecology. The permits list a range of treatment, chemical and timing requirements for *Spartina* control crews (Table 2).

The effectiveness of Rodeo on *Spartina* infestations appears to be highly variable with considerable variation between application methods. Low volume aerial application at permitted concentrations, although relatively inexpensive at approximately $420 per ha (Norman and Patten 1997a), has been far from impressive with combined mean efficacies of

TABLE 2. SUMMARY OF 1998 PERMIT CONDITIONS FOR THE APPLICATION OF RODEO TO CONTROL *SPARTINA* IN WASHINGTON STATE.

Method	Rodeo application (maximum l/ha)*	Major limitations**
Aerial (low volume 93 l/ha)	8.8	Helicopter only, efficacy poor or non existent.
Backpack and non-aerial broadcast spraying (high volume 930 l/ha)	8.8	Limited surface area treated per day per person (<0.125 ha).
Hand-held, high volume equipment (930 l/ha)	19.8	Requires airboat for access; 2 ha maximum per crew per day; cannot access meadow interiors; and logistical difficulties of transporting large volumes of water.
Wicking and wiping	33% solution no per ha limit	Inconsistent efficacy and limited surface area treated per person per day.

(Source: WSDE water quality permits 1998).
*Permit approved surfactants LI-700®, R-11® and X77®.
**Legal restrictions were changed in 2000 on drying time from 6 to 4 hours; 14 days minimum between treatment of same area; and no spraying if wind speed >8 km/ hour.

approximately 30% (Norman and Patten 1995, 1997b, Major and Grue 1997); the WSDA ceased aerial spraying in 1999. Patten and Bishop (1997) point out that given permit constraints on the rate of Rodeo (Table 2), the potential for control with aerial application of this herbicide is extremely limited. Wicking and wiping methods have also produced variable results (Ebasco Environmental 1993, Norman and Patten 1995). These methods are not cost effective and only suitable for small infestations (Norman and Patten 1995).

High volume hand held spray applications have been the preferred Rodeo application methods for *Spartina* control in Washington. Some trials report that Rodeo produces efficacies from zero to 50% (Ebasco Environmental 1993, Norman and Patten 1995, Patten 2000). However, others (Crockett 1997, Major and Grue 1997, Patten 2000) report efficacies ranging from 85 to 97% control with 1 to 5% solutions of Rodeo sprayed to wet. The major parameters influencing efficacy appear to be the interaction of tidal elevation and period of time from post-spraying to tidal inundation and leaf cleanliness (Crockett 1990, 1997, Ebasco Environmental 1993, Patten and Bishop 1997, Patten and Stenvall *in press*).

The most effective *Spartina* control technique used in Washington combines a single mowing followed by Rodeo application once new *Spartina* growth reaches 30 to 45 cm in height (Patten and Bishop 1997, Crockett 1997, Norman and Patten 1997a). Unfortunately, this dual treatment approach is time consuming and expensive with costs ranging from $1,700 to $3,700 per ha (Norman and Patten 1997a). Patten and Bishop (1997) point out that improved tools are needed for *Spartina* control. However, research to develop and evaluate improved control tools has been a minor program focus. A cooperative effort among government agencies to utilize an industrial-size amphibious mowing machine may help reduce mowing or mow/spray combination costs. Research on alternative herbicides for *Spartina* control in Washington indicates that Imazapyr applied at 6 to 12 l/ha, at the rate of 19 to 38 l per ha spray volume, has shown excellent efficacy and could provide cost effective control at approximately $600 per ha over large areas greater than 20 to 100 ha per day (Patten 2000).

Biological Control

The most promising biocontrol agent appears to be a Homopteran plant hopper (*Prokelesia marginata*) that feeds on the vascular fluids of *Spartina* species by piercing the leaf with its stylet. Studies by Daehler and Strong (1997) and Wu et al. (1999) on the associations of *Prokelesia* species and *Spartina* species have shown that *S. alterniflora* from Willapa Bay was particularly vulnerable to the phytophagous stresses caused by moderate population densities of *P. marginata*. More recent research, in collaboration with federal and state agencies, suggests that in greenhouse trials, *P. marginata* has caused significant reductions in biomass of both *S. alterniflora* and *Spartina anglica* from Washington State. This research has provided evidence that *P. marginata* may be an effective biocontrol agent for *Spartina*.

Since its inception in 1997 with the Coastal Resources Alliance, the *Spartina* Biocontrol Program is now well advanced, having benefited greatly from stakeholder cooperation. The major components of the program are risk analysis for non-target plants, investigation of the causes of *Spartina* vulnerability to *P. marginata*, pre- and post-release baseline studies, integration of biological control into the *Spartina* management program, public education, and agency coordination (Chew 1998). Risk studies have now been completed, and a research team is currently releasing *P. marginata* populations into Willapa Bay.

Daehler and Strong (1997) argue that that there is substantial variation in tolerance and resistance to *P. marginata* among *Spartina alterniflora* clones in Willapa Bay. The introduction of *P. marginata* is likely to evoke selective pressure resulting in the survival of resistant plants. Clearly, if eradication is to be fulfilled, the integration of biocontrol into the *Spartina* Management Program will have to be strategically planned. What is not known is the percentage of the *Spartina* population that possesses the potential for resistance to the phytophagous stresses caused by *P. marginata*.

Progress on *Spartina* control and eradication

Efforts to control the spread of *Spartina* in Washington began in the 1980s (Sayce 1990, Crockett 1997). It wasn't until 1995, however, that *Spartina* management received sufficient state government authority through the Revised Code of Washington 90.48.1 to ensure the necessary leadership, coordination and funding. Thus, the focus here is on the 6-year period from 1995 through 2000. Information used to determine progress is based on WSDA *Spartina* progress reports to the state legislature. Infestation variables used in the reports are affected area (general area infested by *Spartina* including gaps of dispersion patterns) and *Spartina* area (condensing all populations into a continuous meadow). For example, an infestation of a solid ("condensed") hectare may be randomly spread over 5 infested ha.

From 1995 through 2000, *Spartina* infestations in Washington State increased its range by 250% to 8,097 ha (Table 3). During this period, *Spartina* control teams treated 2,536 ha at an average of 423 ha per year; an average of 15% of the total infestation was treated every year. These data indicate that control efforts have been grossly insufficient to stop the continued spread of *Spartina* in Washington State.

Analysis of progress reports also suggests that progress data may be subject to considerable inaccuracy. For example, the 1995 WSDA *Spartina* report included mapping as part of the control effort, but the mapping data may be incomplete or

TABLE 3. SUMMARY DATA FOR *SPARTINA* INFESTATIONS IN WASHINGTON STATE, 1995 TO 2000.

Year	*Spartina* area (ha)	Affected area (ha)	Treated area (ha)	Treated area (% of total infestation)
1995	(not available)	>3237	554	17
1996	2310	7031	348	15
1997	1315	6073	477	8
1998	2751	7446	324	12
1999	2023	8094	367	17
2000	2226	8097	465	20

(Source: WSDA Spartina Progress Reports 1995-2000 unpublished).

prone to inaccuracies due to a lack of consistent standards or use of qualitative visual estimations. Furthermore, treatment data for this period combines the effort of all control techniques such as hand pulling, mowing and spraying, and does not provide any quantitative estimates of projected or actual treatment efficacies. Treatment data have not been collated or reported in a consistent, objective or expeditious manner by the lead agency. In addition, there is disagreement among control crews as to what constitutes control. Legislative reports by agencies document acreage controlled by surface area treated per year, but multiple years of treatment are required for eradication. Thus, the degree of control of *Spartina* presented as the area treated does not reliably indicate progress on the reduction of plant infestations, and the costs of control are underestimated. Progress reports appear to provide general subjective data on the amount of work accomplished with the resources provided, rather than accurate quantitative data on the progress of *Spartina* control.

In the absence of reliable data, other progress measures provide useful information. From this same 6-year period, there were considerable advances in increasing the productivity of control efforts. For example, the decision to replace hovercrafts with airboats substantially reduced the time and cost required to transport personnel and equipment across expansive muddy habitats invaded by *Spartina*.

Increased agency coordination, cooperation and reviews of management between 1995 and 2000 did change the approach toward *Spartina*. In 1997, the lead agency developed and implemented "fireline" management strategies for infestations in Puget Sound and Willapa Bay. The Fireline Strategy initially targets outliers while working toward the heart of the infestations. The priority to treat regrowth and re-infestation was an important component of this strategy. The Fireline Strategy appeared to be marginally effective for the smaller infestations of Puget Sound and Hood Canal but was ineffective and unrealistic for the massive Willapa Bay infestation. During 1999, a new management strategy was developed to contain the Willapa Bay infestation. This strategy focused on protecting uninvaded, sparsely invaded, or ecologically sensitive habitat from invasion and controlling seed set, while abandoning heavily infested areas where control efforts were previously focused. Furthermore, government agencies have tailored their roles and responsibilities to specific tasks to promote productivity and eliminate redundancy and inefficiency. For example, the USFWS focuses on mechanical mowing while the Washington Department of Natural Resources followed up with chemical control.

The new management approach for Willapa Bay, while fostering greater cooperation and protecting some habitats, is problematic for several reasons. First, agencies are far from agreement on what constitutes the highest priority habitat on which to focus. Second, it does not address long term solutions for effectively eradicating *Spartina*. Clearly, Washington State faces a number of challenges with *Spartina* management, particularly in Willapa Bay.

Future Challenges for Washington

Although the Washington *Spartina* management program has evolved considerably during the last decade, many challenges remain. Perhaps the most important, is the provision of sufficient and continued funding arrangements to manage public and private lands. What has become clear is that effective *Spartina* management in Washington is a costly and complex practice.

The mosaic of land ownership creates a situation where questions arise as to who should pay for *Spartina* management. At present, private land holders volunteering to manage their infestations are expected to cover at least portions of control costs if they agree with the conditions of the WSDA cost-share scheme. However, where *Spartina* is established, control costs for one season can exceed the value of privately owned intertidal land (USFWS 1997). Assuming that infestations on private land produce seed and other propagules that infest and reinfest public land, it is imperative that the lead agency implements and funds strategies that simultaneously, and above all, effectively manage both public and private lands. Unfortunately, inadequate funding continues to be a major obstacle for coordinating *Spartina* management in Washington.

Research and experience in other countries demonstrates that cost-effective, practical, safe and effective control techniques are available. The use of the herbicides Gallant (active ingredient haloxyfop) in New Zealand (Shaw and Gosling 1995, 1997) and Fusilade (active ingredient fluazifop-P-butyl) in Australia (Pritchard 1994, 1995, Williamson 1995, Hedge 1997, Hedge and Kriwoken 1997) have proven to be particularly effective for *Spartina* control. The search for a cost effective, practical and efficacious control technique remains a critical challenge for *Spartina* control efforts in Washington.

The Washington State Legislative provisions, administered by the WSDOE, considerably impede the search for a suitable control technique. The use of herbicides for use on emergent aquatic plants is restricted to glyphosate and requires U.S. federal level approval from the Environment Protection Agency and United States Department of Agriculture. Permits that regulate glyphosate use are severely limiting such as: (1) minimum of 6 hours drying time until 1999, which was reduced to 4 hours in 2000, before tidal submersion after treatment with Rodeo; and (2) no application if wind velocity exceeds 8 km per hour. Permit conditions are critical, for even under ideal tide and wind conditions, and allowing for 4 hours drying time, the window of opportunity only allows between 4 to 8 hours work per day. If chemicals are to be used as a cost-effective and practical control technique for *Spartina*, a review of legislative provisions regulating the use of herbicides on emergent vegetation in aquatic environments may be required.

A range of mapping techniques has been used to document *Spartina* infestations. Color infrared aerial photography provides an accurate estimate of infestation size and location in Willapa Bay. Other methods include visual estimates of infestation size and location. The lack of consistency with mapping techniques has resulted in considerable uncertainty in infestation sizes. The development of a standardized, cost-effective and relatively accurate mapping technique that can be used expeditiously by *Spartina* control stakeholders would strengthen the program, particularly when reporting efficacy of control techniques and program progress.

As *Spartina* infestations increase, so will the requirement for cooperation and alignment among all stakeholders, especially state government agencies. This requirement is likely to become greater and considerably more important in areas such as Willapa Bay, where government agencies have tailored their roles and responsibilities to specific management tasks. The successful integration of biocontrol within the Washington *Spartina* Management Program will also warrant effective cooperation among stakeholders.

Although this Program may not have effectively controlled *Spartina* infestations in Washington State, it continues to provide valuable pioneering information on the management of exotic *Spartina* for other countries (e.g., Canada, Australia, New Zealand) dealing with similar problems.

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