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INVASIVE MARINE EXOTICS AS A GROWING INTERNATIONAL PROBLEM

THE INVASION OF THE ESTUARIES

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Abstract

Exotic organisms may pose the greatest single threat to the biological diversity of the world's coastal regions, along with potential impacts on regional economies and public health. Estuaries, bays and harbors throughout temperate latitudes are increasingly recognized as containing a substantial component of nonindigenous organisms, with a smaller but growing number of exotics reported from open coast environments. Effects in the San Francisco Estuary indicate the potential scale of such invasions, where exotic species now dominate in several habitats and biotic assemblages, while the rate of invasion continues to increase. Control efforts have had substantial costs and impacts, with uncertain results. Meanwhile, a variety of transport mechanisms remain virtually or entirely unregulated in terms of preventing species introductions in many parts of the world. With appropriate regulation and enforcement, invasion rates could be substantially reduced.

Introduction

There is a long-standing literary, cultural and, to some extent, scientific tradition that views the earth's marine waters as making up a single, unified, continuous, interconnected system-sometimes described as "the world ocean." However, geographers of the sea have consistently recognized that the organisms inhabiting temperate zone coastal waters are distributed in seven distinct bioregions: four in the northern hemisphere on the eastern and western shores of the North Atlantic and North Pacific, and three in the southern hemisphere along western Africa, around New Zealand and southern Australia, and around southern South America on both coasts (Ekman, 1953; Briggs, 1974). These regions, separated from each other by continents, by vast reaches of deep ocean inimical to the survival of coastal organisms, or by zones of tropical temperature, have developed biotic assemblages in long-term isolation from each other, such that each region has come to host a largely distinct and non-overlapping native biota. Many organisms found in the upper portions of estuaries and restricted to brackish or freshwater environments have even more restricted distributions.

The isolation of these coastal regions, and the evolution of distinct biotas, has enriched our natural, cultural and scientific heritage in several ways. First, the number of species supported by these regions is greater than the number that would have been supported had they been more interconnected, based on what we know of species-area relationships. Second, these separate regions provide scientists with a natural series of parallel evolutionary experiments, where in different instances we can find related species filling similar ecological roles, related species filling quite different roles, or similar roles filled by unrelated species, creating rich opportunities for comparative studies. Finally, the regions' distinct biotas support regionally distinct cultural practices, and provide diversity that is of scenic, intellectual and culinary interest to travelers.

Unfortunately the movement of coastal organisms around the globe in association with human commerce and travel, and the often indiscriminate release of these organisms into coastal environments, threatens to end the benevolent biotic isolation of these regions. Furthermore, the incidental transport of coastal organisms appears to be on the increase, related to the globalization of the marketplace and the rapid expansion of international trade. Unless substantial efforts are made to control the transport and release of these organisms, likely consequences include a significant loss of global biodiversity; local or regional alterations in coastal ecosystem structures and functions; disruptions of some human activities and economic systems; and the loss of irreplaceable opportunities for gaining an understanding ofthe forces that govern the structure and evolution of coastal ecosystems.

An invaded estuary

The extent of change that may result from the global transport of coastal organisms is indicated by studies in the San Francisco Estuary. This ecosystem comprises the waters within the reach of the tides in and tributary to San Francisco Bay and the inland Delta of the Sacramento and San Joaquin rivers, including open waters, mudflats and tidal marshes, and regions of fresh, brackish and salt water. Recent studies have identified over 200 nonindigenous species, including plants, protists and invertebrate and vertebrate animals, that have become established in the Estuary. Exotic organisms now account for 40% to 100% of the common species in several communities, whether calculated as a percentage of total species, of individuals or of biomass. These introductions have dramatically altered species composition, habitat structure and trophic dynamics, and have caused direct economic damage measured in the billions of dollars (Cohen and Carlton, 1995).

Although most invasions of marine organisms have occurred in estuaries, bays and harbors, there are increasing reports of invasions from open coast regions. Exotic mussels have recently colonized and often dominate rocky intertidal and subtidal areas in the Carribean and South Africa (Agard et al., 1992; Hockey and Van Erkom Schurink, 1992; Hicks and Tunnell, 1995). Rocky reefs in the Gulf of Maine have been colonized by Pacific Ocean tunicates and bryozoans (Berman et al., 1992; L. Harris, pers. comm.). In California the New Zealand sea slug, introduced to San Francisco Bay by 1992, has spread out from the Bay and is now one of the most commonly collected sea slugs on soft bottoms along the southern California coast (Gosliner, 1995; D. Cadian, pers. comm.).

Control Efforts

To date, considerably more attention and funds have been applied to controlling nonindigenous coastal organisms after they have been introduced than to preventing their introduction in the first place. Several major control efforts have been implemented to block or reduce impacts from nonindigenous organisms in the San Francisco Estuary (Table 1). These efforts have generally been expensive; have entailed harmful environmental side effects and the risk of harmful side effects, including the effects of applying large quantities of biocides, and the ecological risk involved in introducing additional nonindigenous organisms in attempts at biocontrol; have possibly created occupational health risks or public health risks from the application of biocides; and have on occasion been highly controversial, involving protracted lawsuits and threats of lawsuits (Mitchell, 1985; Cohen, 1992; P. O'Brien, A. Jennings, pers. comm.). None of these efforts has yet eliminated a nonindigenous species from the ecosystem, and the extent of control has been variable.

Table 1. Major efforts to control nonindigenous species in the watershed of the San Francisco Estuary

Target Species	Motivation	Control Methods
Water hyacinth *Eichhornia crassipes*	blocks navigation, fouls marinas, fouls water diversions and pumps, blocks water flow in canals, alters fish habitat	annual applications of herbicide glyphosate; release of 3 insect biocontrols; some mechanical removal
Smooth cordgrass *Spartina alterniflora*	blocks flood channels; prevents establishment of native plants in tidal	application of herbicide glyphosate; mowing; covering; burning

	marsh restoration	
White bass *Morone chrysops*	potential to spread to Delta and prey on rare and endangered fish species	treatment of infested water bodies with the fish poison rotenone
Northern pike *Esox lucius*	potential to spread to Delta and prey on rare and endangered fish species	treatment of infested water bodies with the fish poison rotenone
Red fox *Vulpes vulpes*	preys on endangered California clapper rail	trapping and shooting

Proposed control efforts should be carefully assessed with these issues and limitations in mind. Various considerations suggest that control efforts are in general more likely to be effective and worthwhile if they target plants rather than animals; organisms that are emergent, floating or semi-terrestrial rather than organisms that are submersed or infaunal; and freshwater organisms rather than marine organisms. While efforts at control will remain appropriate in selected circumstances, it should be recognized that such efforts will generally involve some environmental risk, sometimes human health or economic risk, often considerable expense, and sometimes public controversy-and, in addition, that they will often fail. Because the costs and impacts of control efforts are multiplied when these efforts are repeatedly applied or applied routinely on a permanent basis, control should in most cases be attempted only when there is a reasonable likelihood of eradicating the target organisms from the region.

Means of Prevention

Given the costs, impacts and difficulties of controlling nonindigenous species, a greater effort is needed to prevent their introduction. Major vectors introducing exotic species into coastal waters include ships' ballast water; aquaculture and mariculture; the aquarium and ornamental plant trades; and the importation of live seafood and bait. The regulatory actions needed to substantially reduce such introductions are in large part known, and many of them could be promptly put into effect. Such an approach might include:

* **For ballast water**: In the near-term, requiring ships coming from foreign ports to exchange their ballast water over deep ocean water (in at least 2000 meters depth and at least 200 miles from shore) whenever it is safe to do so. Further reductions could be achieved by developing shore-based ballast water treatment in the medium-term and ship-board treatment in the long-term.

* **For aquaculture and mariculture**: Restricting aquaculture and mariculture to native organisms or organisms that are already established in the wild. Permitting the importing of additional nonindigenous organisms only in very compelling circumstances and after full public review, and then only with careful inspection and reliable quarantine or with full isolation from the environment. Treating occurrences of new parasites or disease syndromes in aquaulture or mariculture facilities that are not previously known from the local environment as nonindigenous species (until proven otherwise), and either promptly eradicating them or requiring that they be kept fully isolated from the environment.

*	**For the aquarium and ornamental plant trades**: Restricting commercial imports of aquatic plants and animals to organisms that have been evaluated and determined to be safe for importing. This "clean list" approach contrasts with the current "dirty list" approach in which any organism may be imported unless it is specifically listed as prohibited (OTA, 1993) Engaging in public outreach (perhaps funded by the aquarium industry) to persuade people to not release unwanted aquatic pets into the environment. Monitoring and managing commercial holding and rearing facilities to ensure that nonindigenous species are isolated from the environment.

*	**For the live seafood and bait trade**: Restricting the sale of live seafood and bait to native organisms, or to organisms determined to be safe for importing. Engaging in public outreach to persuade anglers not to release live bait or transfer live bait between watersheds.

The estimated costs to the affected industries of implementing these actions ranges from insignificant costs for some measures to possibly substantial costs for others. However, the certain cost of not implementing these or similar measures is to continue a high and increasing rate of biological invasions in our coastal waters, with likely impacts on biodiversity, ecosystem functions, economic enterprises, human activities and possibly public health.

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PATHWAYS AND MANAGEMENT OF MARINE NONINDIGENOUS SPECIES IN THE SHARED WATERS OF BRITISH COLUMBIA AND WASHINGTON

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The introduction of nonnative or nonindigenous species (NIS) to new environments can cause environmental and economic problems. Such problems have occurred worldwide, including in the shared marine waters of British Columbia and Washington (defined for the purposes of this report as the Straits of Georgia and Juan de Fuca, Puget Sound including Hood Canal, and the smaller straits and waters surrounding the San Juan and Gulf Islands).

This report was commissioned by the Puget Sound Water Quality Authority through an agreement between the U.S. Environmental Protection Agency (EPA) and the Canadian Department of Fisheries and Oceans (DFO). Its purpose is to assist the Washington and British Columbia Working Groups on Minimizing the Introduction of Exotic Species in developing their recommendations to the British Columbia-Washington Environmental Cooperation Council. It assesses the status and management of NIS introductions into the shared marine waters of British Columbia and Washington. Pathways of NIS introduction are evaluated, and the management programs in place to reduce risks from these pathways are described. It is intended that from this report and from the work groups that will consider it, recommendations will emerge that address risk and management of NIS introductions, and needs for further information.

Pathways of NIS introduction to the shared marine waters include aquaculture activities; the aquarium trade; public aquaria; releases of NIS by individuals; commercial, military, and recreational marine vessels; research institutions; and seafood commodity distribution. Risk of NIS introduction from aquaculture is well defined, the industry is highly regulated, and active processes are underway for continuous review of aquaculture activities as they involve NIS. Risk of NIS introduction from aquarium activities and release of NIS by individuals is poorly defined, and only limited information is available to define the risks from research, seafood distribution, and marine recreational vessel activities. The relative risk associated with the large inoculation of marine NIS from ballast water discharges is assessed from shipping industry data and relevant scientific literature. Management of NIS in other selected states and countries is briefly reviewed.

More complete and detailed baseline information regarding the presence and distribution of native and NIS in shared waters is needed because, in some cases, there is disagreement on whether particular species are native or introduced, or whether or not particular NIS are established. Risk standards for genetic effects and ecological interactions are needed if NIS management is going to address these areas.

There is presently an opportunity to reduce the frequency and negative effects of future NIS introductions by expanding and improving a voluntary ballast water exchange program, by developing educational materials addressing several of the NIS introduction pathways, and by enhancing intergovernmental communication. Protocols and operational codes for aquarium activities and research could also reduce the risks of NIS introductions. In order to determine the risk of NIS introduction from aquarium-related activities, research, live seafood distribution, and marine recreational vessel movements, more detailed information is required.

Shipping, food production and processing, and other marine activities with the potential to affect NIS introductions will continue. A zero-risk condition is unattainable; a more realistic objective of NIS management should be to reduce the frequency of unintended introductions, and to understand and minimize negative consequences of introduced species.

THE DISTRIBUTION OF *SPARTINA* IN VICTORIA AND TASMANIA, AUSTRALIA

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Spartina was introduced to Australia during the late 1920s for a variety of reasons. Early attempts to establish rice grass were unsuccessful. Continuing efforts throughout the 1940s and 1950s, however, eventually led to successful colonisation (Boston, 1981). There is some confusion over which species of *Spartina* are actually present in Australia. The literature indicates that *S. townsendii*, *S. anglica* and *S. maritima* were introduced to Australia. It is generally accepted that *S. anglica* is the dominant species and unlikely that *S. maritima* was introduced to Australia (Bridgewater, 1995).

Spartina is currently established in three Australian states: Tasmania, Victoria and South Australia. The vast majority of infestations occur in Tasmania and Victoria (Table 1 and Figures 1 & 2). A small infestation (<1 ha) remains at Port Gawler, South Australia. The largest infestations occur in the Tamar River (420 ha) and the Rubicon estuary (150 ha), Tasmania. Although some dieback has been noted in the Tamar River (Pringle, 1993), most infestations are continuing to increase in area.

Table 1. Location and estimated area of *Spartina* infestations in Tasmania and Victoria, Australia

Tasmania	**ha**	**Victoria**	**ha**
Smithton region	30	Anderson Inlet	130
Rubicon estuary	150	Corner Inlet	45
Tamar River	420	Shallow Inlet	<1
Bridport River	5	Westernport Bay	NS
Georges Bay	0	Barwon River	<10
Little Swanport estuary	15		
Derwent River	<1		
Total	621	Total	186

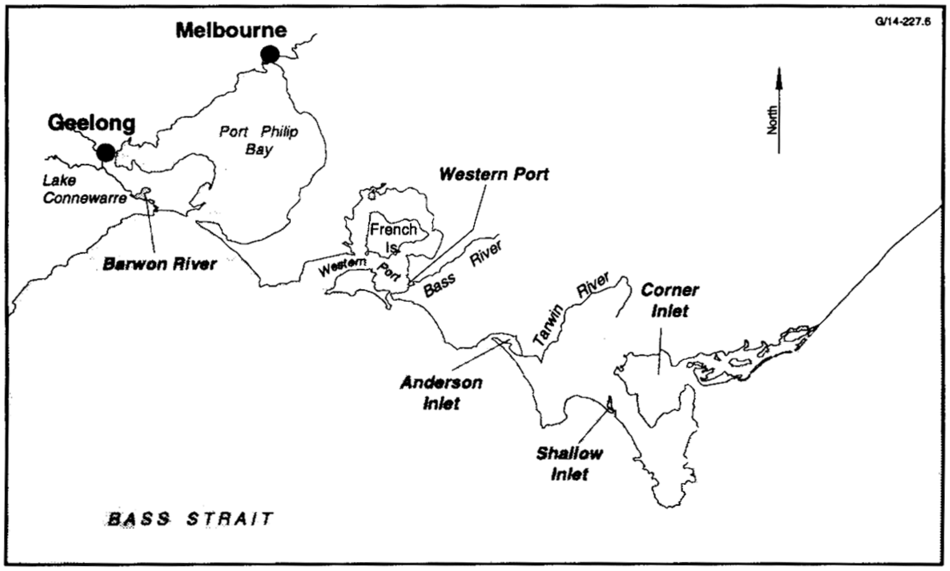
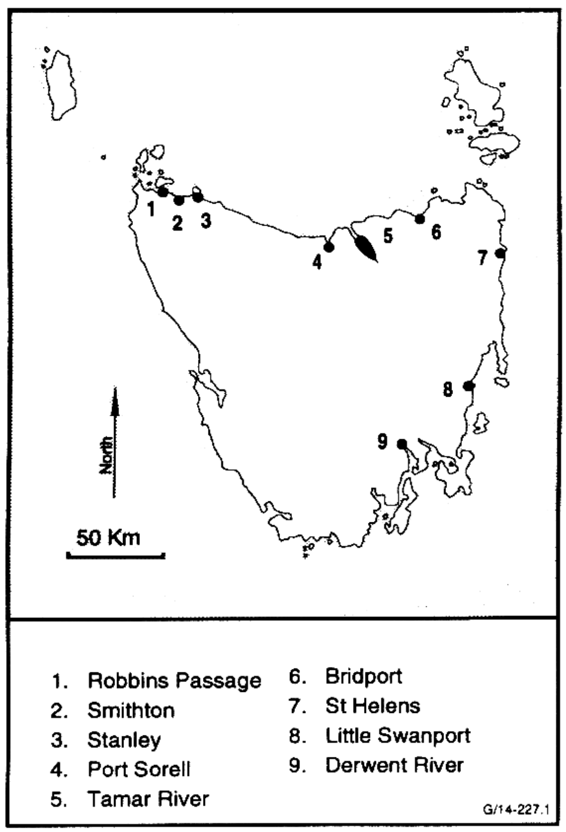


Figure 1: Location of *Spartina* infestations in Victoria (Source: Williamson, 1995).


1
2
3
4
5
6
7
8
9
North
50 Km
1. Robbins Passage
2. Smithton
3. Stanley
4. Port Sorell
5. Tamar River
6. Bridport
7. St Helens
8. Little Swanport
9. Derwent River
G/14-227.1

THE BIOLOGY AND NATURAL HISTORY OF SPARTINA

THE HISTORY AND EVOLUTION OF *SPARTINA ANGLICA* IN THE BRITISH ISLES

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Introduction

The origin of *Spartina anglica* C.E. Hubbard has been well documented (Marchant 1967, 1968; Gray *et al.* 1991). It arose on the south coast of England sometime before 1892 by chromosome doubling in *S. townsendii* - the sterile hybrid between the European species *S. maritima* and the American *S. alterniflora*. Unambiguous evidence of the allopolyploid origin has been provided by isoenzyme analysis, which also points to a single origin (Raybould *et al.* 1991). Another piece of the puzzle was solved recently by Ferris *et al.* 1997, whose analysis of the DNA sequence of the chloroplast leucine tRNA gene intron indicates that *S. alterniflora* was the female parent in the original hybridization (chloroplast DNA is maternally inherited). From this and other evidence, notably the early work of C.J. Marchant, C.E. Hubbard and others, we have built a reasonably clear picture of events in Southampton Water and on the nearby coastline in the latter part of the 19th Century and the early part of this one. The parent species are now both uncommon in the area, *S. maritima* being confined to two or three small populations along the English south coast (its stronghold now being the south-east coast) and *S. alterniflora* to a single (apparently clonal) population at Marchwood, three miles from the site of initial hybridization (and three other small populations on the east coast with known dates of introduction). Participants in this conference will no doubt find supremely ironic the fact that we regard the Marchwood *S. alterniflora* as a national treasure and the UK conservation agencies are anxious to protect it against saltmarsh erosion!

In this paper we briefly highlight those features of the historical spread of *S. anglica* (hereafter "*Spartina*") which not only characterize many biological invasions (Williamson 1996) but may also provide important lessons for predicting and managing similar invasions by related species.

The spread of *Spartina anglica*

A key feature of the early spread of the species is that, largely unaided by man, it moved relatively slowly along the south coast, reaching Poole Harbour 35 miles to the west about 30 years after the initial hybridization, and Pagham, 30 miles to the east, after almost 50 years. The picture of its early spread is clouded by uncertainty as to the exact date of origin of the fertile allopolyploid and the by the fact that deliberate introductions began as early as 1898 (to the Beaulieu Estuary, 10 miles west of the site of origin). Accelerated natural spread observed in the late 1880s (Stapf 1913) almost certainly heralds production of the seed-bearing allopolyploid (the first confirmed record being 1892). Despite the relatively slow spread along the English coast, *Spartina* found its way, apparently unaided, to the north coast of France by 1906. It also made the journey to Rye, 90 miles along the English south coast by 1925.

Having arrived in estuaries such as Poole Harbour, the spectacular natural growth and the development of extensive swards convinced coastal defence authorities that *Spartina* could be planted for coast protection and to reclaim mudflats for agriculture. The first planting outside the area of natural spread was in 1907 (to the Norfolk coast), but most plantings occurred in the 1920s and 1930s. These were on an extensive scale and to most estuaries in southern Britain, many of them from a single source, Arne Bay in Poole Harbour, from which an estimated 175,000 cuttings and numerous seed batches were exported between 1924 and 1936 (Hubbard 1965). By the mid-1960s, more than 12,000 ha of saltmarsh in Great Britain, about a quarter of the total, were dominated by *Spartina*. Ranwell (1967) catalogues many of the introductions of the species around the world, ascribing a variety of reasons for success or failure in particular instances. The most remarkable invasion remains that of China, where by 1980 more than 36,000 ha of *Spartina* marsh had developed from a single batch of seed (producing a mere 21 plants) exported in 1963 (Chung 1990).

A third feature of the spread of *Spartina* in many estuaries has been the sudden rapid expansion of a population which had hitherto grown rather slowly, or even been stable in size over many years. This phenomenon has several possible explanations but appears to involve a lag phase which is more extended than would be predicted from even exponential rates of population growth. It is a key feature of some biological invasions (Williamson 1996), but not all. In the case of *Spartina*, explanations for what we have rather crudely referred to elsewhere as "lurking" (Gray *et al.* 1990), may include the fact that the original introduction was into an area of less-than-optimal conditions, that threshold elevations of mudflat must be reached for planted or invading colonies to expand, or that seed production and/or the conditions for seedling establishment occur infrequently. Observation in particular estuaries suggests that each of these factors may contribute to lags of 20 or even 30 years. The hydrodynamic conditions under which *Spartina* clumps will expand are imperfectly understood, as are the conditions under which seed is produced. Increasingly it appears that high seed production is associated with warm, late summers, which probably facilitate both the breakdown of the self-incompatibility mechanism and the ripening of seed.

The south coast harbours invaded at the turn of the century began to display "die-back" by the 1920s. A typical pattern is that recorded from Holes Bay in Poole Harbour, where *Spartina* arrived in 1899, expanded to produce swards occupying 208 ha - more than 60% of the intertidal mudflats - by 1924, but had retreated to less than half of that area by 1972, and to less than a third (63 ha) by 1994. As with its spread, the extensive die-back of *Spartina* has been well documented and recorded from practically all English south coast and south-east coast estuaries, as well as in South Wales, northern France and south-west Netherlands. Whilst the direct cause of die-back has been related to various phytotoxins produced under anaerobic soil conditions created by poor drainage, or even to rising relative sea levels, we have viewed both the expansion and subsequent retreat as a "natural" process in which a novel species, in exploiting an unoccupied nîche, has paved the way for its own destruction (Gray *et al.* 1991). In these south coast estuaries, *Spartina* populations are retreating to occupy a reduced nîche, in the sense of a reduced elevational amplitude. They may yet reinvade new mudflats, a process currently hampered by a lack of mudflats at suitable elevations and by the blanketing effect of green algal mats.

These changes in southern populations may be contrasted with those further north. The *Spartina* invasion, or at least the rapid expansion to produce dense, monospecific swards on the lower zones of saltmarshes, was generally much later in the north (roughly north of 53^{o}N latitude) - in the Conwy (53^{o}17'N) in North Wales it began in the 1970s, plants having been first introduced in the late 1940s, and in Morecambe Bay (54^{o}10'N) a major expansion began in the early 1980s from only two clumps in 1968. However, in many of these marshes the colonizing *Spartina* has been replaced by other species at higher elevations. Permanent quadrats in the Ribble Estuary (53^{o}42'N) indicate that *Aster tripolium*, *Puccinellia maritima*, *Atriplex portulacoides* and *Atriplex hastata* have invaded *Spartina* swards, and in Morecambe Bay 100 ha of marsh originally dominated by *Spartina* is now a mixed *Puccinellia maritima*/*Atriplex portulacoides* community. Indeed, *Spartina* is quite hard to find over most of the latter marsh. A similar contrast between the invasion patterns occurs in The Netherlands, where dense, persistent, pure swards of *Spartina* have developed on clay soils in the southern marshes of the Rhine Delta, whereas *Spartina* tussocks are successfully invaded by *Puccinellia maritima* in the more northerly Waddensee area (Scholten & Rozema 1991). The latitudinal variation in *Spartina* marshes is unfortunately largely confounded by variation in sediment type - most, but not all, of the northern marshes in both the UK and The Netherlands are on sandier substrates than further south. However, there is evidence that the differences in *Spartina* invasion and saltmarsh development is caused more by variation in climate and day-length than by variation in sediment type (see below, and Gray *et al.* 1997).

<u>The elevational nîche of *Spartina anglica*</u>

A major challenge facing estuarine ecologists is prediction of the environmental impact of a wide spectrum of major changes, ranging from increasing/decreasing pollution levels through major constructions such as docks and harbours to long-term rising relative sea levels. In the 1970s and 1980s, we were asked to predict what would happen to saltmarsh, and particularly to *Spartina* marsh, following the construction of estuarine barrages for the generation of tidal power (see Gray 1992). Tidal barrage schemes were being considered for several (six or seven) west coast estuaries with mean tidal ranges from 5.5 to 7.0 metres. Our approach was to investigate variation in the vertical (*i.e.* tidal) amplitude of *Spartina* (and other plants) in several estuaries, to gain insight into those physical factors controlling its distribution and to generate simple models from which we could predict the potential future distribution of *Spartina* under a changed tidal régime or intertidal profile. The results, (published in detail elsewhere (*e.g.* Gray *et al.* 1991, 1995)), provided some fascinating insights into the ecology of *Spartina* and generated what we believe to be realistic predictive models.

The basic dataset for the study was a series of measurements along 143 transects across saltmarshes and mudflats in 28 estuaries in south-west Britain (from Poole Harbour on the south coast to the Mite Estuary in Cumbria). Each transect line was surveyed by levelling from nearby datum points of known elevation (Ordnance Survey Benchmarks) so that the upper and lower elevational limits of *Spartina* (and other species) could be obtained in metres OD (a standard UK reference level relative to the elevation of a point at Newlyn in Cornwall). From these basic surveys it was possible to derive a total of 27 variables for each of the transects, including the tidal range, marsh size and slope, estuarine area and aspect, latitude, sediment type, and a range of submergence parameters (*e.g.* numbers of hours submerged *per annum*). The relationship between these physical variables and *Spartina* elevational limits was then explored using multiple regression.

It turns out that variation in tidal range, or the relative position of some standard tidal level such as Mean High Water Neap tides (MHWN), accounts for most of the variation in the upper (89%) and lower (86%) elevational limits of *Spartina*. However, other variables did significantly improve the prediction, and the equations which accounted for most variation were:

(i) for variation in the lower limit (LL) in metres OD:

$$LL = -0.805 + 0.366(R) + 0.053(F) + 0.135\,(\log_e A)$$

$$(r^2 = 93.7,\ S = 0.35)$$

where R = Spring tide range (m), F = fetch in the direction of the transect line (km), and $\log_e A$ = $\log_e$ estuary area (S = residual standard deviation in m)

(ii) for variation in the upper limit (UL) in metres OD:

$$UL = 4.74 + 0.483(R) + 0.068(F) - 0.099(L)$$

$$R^2 = 90.2,\ S = 0.50)$$

where R and F are as in Equation (i) and L = latitude (in degrees north expressed as a decimal)

The first equation indicates that *Spartina* is able to grow further downshore than would be predicted from the effects of tidal range alone on transects with a shorter fetch (less exposed?) and in smaller estuaries (relatively few wind-generated waves?). The second equation shows that upper limit is also affected by the fetch, but that it also varies with latitude in that the upper limit is progressively lower down the marsh than would be predicted from tidal range as one goes further north. This finding supports the idea that competitive displacement by other species, particularly the grass *Puccinellia maritima*, is facilitated by the lower temperatures (and shorter spring day-lengths) in northern estuaries (see Gray *et al.* 1992).

Predicting from the model

The regression equations above provide a powerful tool for predicting the potential spread of *Spartina* in a particular estuary where it may not have invaded yet, or where mudflat profiles are changed by major construction works. The variables are all readily obtainable from tide tables (range) or maps (fetch, area, latitude) and an elevational survey will provide an estimate of the potential area to be invaded (initially, of course, within the area of survey, southern or western Britain - other factors may affect the elevational limits of marshes on, say, the east coast).

The question arises as to why the regression equations have such remarkably high R^2's, apparently accounting for more than 90% of the variation in elevational limits (a proportion unheard of in biological models!). We believe that three main factors contribute to the explanatory powers of the model. First, tidal range provides a good general estimator of the overall energy in the system, and thus variation in more proximate factors such as turbidity and current speeds. Secondly, *Spartina* is the lowest species on the shore and, having created a new nîche below the *Puccinellia* zone, its distribution is more likely to be controlled by physical variables than by biological interactions. Finally, the relatively recent evolution and remarkable genetic uniformity of the species have precluded population differentiation and possible adaptation to a range of habitats within the saltmarsh.

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INVASIONS AND HYBRIDIZATION OF CORDGRASSES, SPARTINA SPP.

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Spartina spp., cordgrasses, are notoriously dominant plants and aggressive invaders of salt marshes to which they have been transported by man. Their dense monocultures suppress other organisms and are a bane to conservation and he maintenance of estuaries worldwide. Two invasions are known to have led to hybridizations with native species. The first is the famous hybridization in England between smooth cordgrass, Spartina alterniflora, which was introduced there from the Atlantic seaboard of North America in the 18th or early 19th century, and the European S. maritima. Subsequent chromosomal doubling created a new, fertile species, S. anglica, which spread widely to transform much of the intertidal UK. We have discovered a second hybridization in San Francisco Bay between S. alterniflora, introduced in the 1970's from Maryland, and the native California cordgrass, S. foliosa. Hybridization, identified with RAPD markers occurs in the Bay. The hybrids have low self fertility but high fertility when backcrossed with S. foliosa pollen. Hybrids growing in San Francisco Bay appear vigorous and to be recruiting rapidly. Our studies suggest that although the alien competes directly with California cordgrass, introgression and competition with hybrids is an even more serious threat to the native.

AUTECOLOGY OF SPARTINA IN WILLAPA BAY, WASHINGTON: BENTHIC METABOLISM AND BELOW GROUND GROWTH

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Introduction

The invasion of intertidal mudflats by Spartina alterniflora in Pacific Northwest estuaries has been dramatic over the past two decades, and potentially represents a major shift in the communities and processes of the mudflat system. The present study is part of a larger investigation designed to evaluate and quantify changes in both the ecological communities and processes caused by Spartina invasion of mudflats in southern Willapa Bay (Principal Investigators are Charles Simenstad, Kurt Fresh, Deanna Stouder, University of Washington; sponsor is University of Washington Sea Grant). Willapa Bay is one of three major estuaries on the coast of Washington State where the effects of Spartina invasion on commercial resources (e.g., oyster) and disruption of ecological conditions supporting estuarine communities are of major concern.

As part of the larger study examining the comparative ecology of Spartina vs. mudflats, we 1) contrasted sediment-associated metabolism (photosynthesis and respiration) within Spartina patches of varying sizes and between Spartina patches and unvegetated mudflats; 2) documented below-ground growth rate in spring through summer at the center and edges of the patches; and 3) analyzed the organic matter content (as volatile solids) by depth within cores collected in Spartina patches, unvegetated mudflats, and native marshes. By measuring benthic metabolism we tested the impact of Spartina invasion on two important benthic processes in the intertidal mudflat systems: fixation of carbon and the use of organic matter.

We also conducted a simple experiment to test whether we could effectively kill Spartina by clipping, burying, or clipping and burying the shoots. The hypothesis was that reducing oxygen flow to the roote/rhizome complex would ultimately kill the below-ground structures.

Methods

The study site was located at Pot Shot, a small embayment on the U.S. Fish and Wildlife Service property in southern Willapa Bay. Sampling was conducted in 3-, 6-, and 12-m patches and >50-m meadows. Three replicate patches were sampled within each patch-diameter class. Net primary productivity (NPP) of intact sediment cores contained in plexiglass cylinders was measured in ambient daylight using oxygen flux methods. Community respiration (CR) rates were measured for the same cores using incubations in the dark. NPP and CR were measured in duplicate for each core. Chlorophyll-a and phaeophytin concentrations were determined from small cores collected next to the location where metabolism cores were extracted. Metabolic measurements were made in April 1995, typically a month of high NPP in Pacific Northwest mudflats.

Below-ground growth was estimated from growth of roots and rhizomes into which were buried mesh bags containing only sediment placed in duplicate at the edge and in the center of each patch. The bags were placed out in April and collected in August 1995.

Triplicate cores (ca. 50-cm deep) were collected from the meadows, as well as from native salt marshes and unvegetated mudflats at the study site, for organic matter measurement. Cores were sectioned at 2-cm intervals; the volatile solid content was determined by ashing in a muffle furnace.

For the burial experiment, sod with Spartina was collected from a patch located in Washington Harbor near Battelle's Marine Sciences Laboratory (MSL). Twelve sod units, consisting of 30- x 30-cm x 20-cm deep sections, were cut from the marsh. The sod units were placed on a layer of sand in a 30-cm deep water table with wooden dividers to separate each individual sod unit. The below-ground portions of the units were then surrounded with sand. Four treatments were initiated on 27 September 1995; a) no burying, no clipping of shoots (control); b) burying with 10 cm of sand on the surface of the groudn (i.e., on top of the sediment surface of the unit, no clipping; c) clipping shoots near surface of sediment and burying with 10 cm of sand; and, d) clipping shoots, no burying. The units were watered periodically to maintain moist sediment condition. On 26 June 1996, the new above-ground growth was harvested, dried to a constant temperature, and weighed for each unit separately. Finally, any new growth of above-ground material was clipped on 25 July 1996, dried, and weighed as a test of the ability of the root and rhizome to produce new growth.

Results

Although Spartina dominates the patches, benthic microalgal abundances and the the processes of NPP and CR at the site were not detectably different between patches and native mudflats at this site. We found non-significant or poorly-defined differences between the patches and the unvegetated mudflats for chlorophyll-a concentration, NPP, and CR. Gross community productivity (GCP = NPP + CR) was not detectably different between mudflats and Spartina patches. The metabolic state of the benthic system, as measured by the GCP:CR ratio, indicated that the community was autotrophic in both the Spartina patches as well as in the mudflat. Spatial variability in parameter values was generally greater within the patches than between the patches and unvegetated mud.

The invasive nature of Spartina was demonstrated by active root/rhizome growth. We documented a mean rate of 71 g dry wt/m^2/mo during the study period. Mean below ground annual production approximately equaled Spartina mean annual net aerial primary productivity (426 g dry wt/m^2).

Spartina invasion profoundly increased organic matter content of the sediments, as compared with native mudflats. Organic matter in the Spartina sediment profiles was on the order of three times greater than that in mudflat sediments, and approximately 50% greater than that in native pickleweed (Salicornia) sediments. The Spartina sediments contained about one-half the amount of the organic matter recorded in the native sedge (Carex lyngbyei) sediments. The results show that Spartina rapidly colonizes unvegetated areas at the edge of the patches and continues to increase its below ground biomass via active root/rhizome growth.

The plant control experiment showed that burial only (no clipping) was not different from untreated controls (Table 1). Clipping with burial resulted in he least regrowth, on average, than in any other treatment. In two out of three replicates of the clipped and buried treatments, regrowth did not occur and roots and rhizomes appeared dead. The third replicate showed regrowth of above-ground standing stock approximately equal to the other treatments and also showed the greatest growth between September 1995 and June 1996. The results of the control experiment suggest that killing of the roots and rhizomes, through cutoff of oxygen sources, is effective in killing Spartina. Furthermore, simply clipping the plants still allowed sufficient oxygen to reach below-ground portions of the plant to support substantial regrowth a year later.

In summary, the basic processes of NPP, R, and GCP:R were not detectably different between Spartina patches and mudflats. We speculate that high variability within both habitat types partially explained the results. In addition, the Spartina patches sampled at this site were in very soft mud and have not formed dense mats of live and decaying vegetation. Hence, the surface sediments in the patches appear similar to surface sediments outside the patches. The effect of shading from the Spartina canopy was not investigated but potentially could reduce NPP within the patches. Vigorous below-ground growth allows Spartina to expand rapidly onto the mudflats and probably needs to be investigated further as a major contributor to the spread and control of the species. Below-ground production accounts for substantial increases in organic matter in the sediment profile. Finally, clipping Spartina shoots and removing oxygen sources to the below-ground portions of the plant can effectively kill the plant.

Table 1. Results of the plant control experiment to test clipping and burying.

Treatment	**n**	**Mean biomass after 9 mo (g dry wt/replicate)**	**SD**	**Mean biomass 1 mo after final harvest (g dry wt/replicate)**	**SD**
Control	3	21.60	10.05	0.76	0.72
Not clipped; buried	3	21.39	5.9l	1.03	0.88
Clipped; buried	3	8.91	10.94	0.47	0.81
Clipped; not buried	3	15.75	4.71	1.25	1.41

POLLEN SWAMPING OF THE NATIVE CALIFORNIA CORDGRASS (*S. FOLIOSA*) BY INTRODUCED SMOOTH CORDGRASS (*S. ALTERNIFLORA*) IN SAN FRANCISCO BAY.

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The introduction of *Spartina alterniflora* (smooth cordgrass) to San Francisco Bay for marsh mitigation in the 1970s has brought a more robust alien congener in contact with native populations of *S. foliosa* (California cordgrass) (Callaway and Josselyn 1992, Daehler and Strong 1994). The geologically young estuaries of San Francisco Bay are characterized by open mudflats that are highly vulnerable to invasion by alien *S. alterniflora* (Daehler and Strong 1996). Currently, the mud flats and channels of five sites within south San Francisco Bay have been colonized by more than 1000 rapidly growing clones of alien *S. alterniflora* (Cohen and Carlton 1995, Daehler and Strong 1996). In some marshes the circular *S. alterniflora* clones have grown together to form solid stands (Daehler pers. obs.). In two San Francisco Bay marshes, Callaway and Josselyn (1992) found that alien *S. alterniflora* produced six times more above ground biomass and significantly more below ground biomass than native *S. foliosa*. The native *S. foliosa* occupies a mean tidal range of < 1 m in San Francisco Bay (Callaway and Josselyn 1992) and cannot survive on the extensive lower mudflats. Biomass and growth rate differences likely contribute to the competitive superiority (Guadet and Kennedy 1988) and enhanced colonization ability of introduced *S. alterniflora* over *S. foliosa*.

In addition to the competitive superiority of *S. alterniflora* over *S. foliosa*, recent DNA analyses have shown that native *S. foliosa* is interfertile with the alien *S. alterniflora*, suggesting that the alien may threaten the genetic integrity of the native. Hybrid clones in the field were identified at two of three marshes surveyed using RAPD (Random Amplified Polymorphic DNA) markers (Daehler and Strong in press). Where the two species are sympatric, hybridization is facilitated by considerable overlap in flowering phenology. Cross-pollination is by wind. In several marshes alien *S. alterniflora* now completely surrounds or directly borders native *S. foliosa*. Two-meter tall flowering culms of *S. alterniflora* tower over 0.5 - 1.25 m tall flowering culms of native *S. foliosa* during the late summer (Anttila pers. obs.). In these areas, pollen that is shed by *S. alterniflora* can be easily transferred to the stigmas of native *S. foliosa*. The open stretches of intertidal habitat may then provide abundant sites for colonization by the hybrids. In contrast, there are few remaining open sites in the upper intertidal needed for colonization by *S. foliosa* seedlings. After establishing, hybrids may grow into *S. foliosa* stands, as *S. alterniflora* currently does.

Given that *S. alterniflora* and *S. foliosa* are interfertile and wind-pollinated, the actual rate of hybridization and the threat to *S. foliosa* will depend on the relative amount of viable pollen produced by each species. No quantitative comparison between male fertility of *S. alterniflora* and *S. foliosa* has been made from San Francisco Bay. The purpose of our work was to assess the potential for pollen swamping of native *S. foliosa* by introduced *S. alterniflora*.

We compared *S. foliosa* and *S. alterniflora* pollen production, pollen germination, and viable seed set rates following inter-specific crosses. We found *S. alterniflora* pollen averaged significantly higher germination than *S. foliosa* pollen (38% versus 20%) *in vitro*. *In vivo* pollen germination tests on conspecific stigmas, *S. alterniflora* had significantly higher pollen germination than *S. foliosa* (42% versus 19%). Following interspecific cross-pollination, *S. alterniflora* pollen germinated at a higher rate on *S. foliosa* stigmas (28%), than *S. foliosa* pollen on *S. alterniflora* stigmas (11%). Viable seed set of *S. foliosa* with *S. alterniflora* pollen was significantly higher than seed set for selfed *S. foliosa* (20% versus 5%), indicating that hybridization can readily occur when *S. alterniflora* is the pollen donor. In contrast, viable seed set of *S. alterniflora* was not increased by *S. foliosa* pollen. *S. alterniflora* produces more inflorescences, larger inflorescences and more dehiscent anthers per inflorescence than *S. foliosa*, per m^2. We estimate that *S. alterniflora* produces about 4 times more pollen per m^2 than *S. foliosa*.

Our results suggest that the spread of *S. alterniflora* will threaten the genetic integrity of *S. foliosa* populations wherever the two congeners become sympatric. The ability of *S. alterniflora* to produce more pollen with twice the germination rate of *S. foliosa* pollen reduces the chances that pure *S. foliosa* seed will be produced. Furthermore, because *S. foliosa* pollen was apparently unable to fertilize *S. alterniflora* ovules, *S. alterniflora* has an additional reproductive advantage in that none of its ovules are lost to fertilization by *S. foliosa.* With the continued spread of the *S. alterniflora* in San Francisco Bay, pollen swamping by alien *S. alterniflora* poses a serious threat to native populations of *S. foliosa*.

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MODELING *SPARTINA* IN WILLAPA BAY

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Introduction

Models of ecosystem dynamics are mathematical simplifications designed to replicate complex, three dimensional, and time dependent real world processes (Steyaert 1993). Simulation modeling is an attempt to imitate real world processes and provide resource managers with useful information about potential future states of an ecosystem. In ecosystem modeling, knowledge of the kinds and rates of key processes that are important within the ecosystem being modeled are combined with data that characterize the initial state of the system.

Automated geography has become increasingly important in environmental modeling (Wheeler 1993). Satellite remote sensing is an important source of data for determining the spatial distribution of phenomena that exist throughout an ecosystem of interest. Geographic Information Systems (GIS) provide a data management and analysis structure for executing the sequence of logical procedures that correspond with scientific consensus regarding the kinds and rates of changes occurring within an ecosystem (Davis *et al.* 1991). This paper reports on research that incorporates both remote sensing and GIS in environmental modeling.

Spartina Expansion in Willapa Bay, Washington:

Spartina alterniflora Loisel. (smooth cordgrass) is native to estuaries of the east coast of the United States and was introduced unintentionally in Willapa Bay, presumably with the introduction of the eastern oyster (*Crassostrea virginica*) in the late 1800s. While the spread of *Spartina* in Willapa Bay was very slow for close to 80 years, it recently has undergone a more rapid expansion (Sayce 1988, Harrington and Harrington 1992, Harrington and Harrington 1993). The rate of spread of *Spartina* between 1980 and the early 1990s corresponds to an exponential growth curve. Acreage data for 1982 and 1988 were used to fit an S-shaped (or sigmoidal) growth curve (exponential growth with resistance). In the case of Willapa Bay, resistance is provided by the intertidal acreage available for *Spartina* colonization (approximately 50,000 acres). Observation of the expansion of *Spartina* during the late 1980s and early 1990s suggests that: 1) new shoots and clonal expansion are not limited by the presence of eelgrass (*Zostera*), 2) a majority of new plants are found at upper tidezone elevations, and 3) there is a distance decay effect away from existing seed sources.

Satellite Image Processing:

Because location within upper portions of the intertidal zone is important in the spread of *Spartina*, a satellite-derived elevation map of the intertidal wetlands for Willapa Bay, Washington, was created. Four dates of Landsat satellite data from differing tidal levels (April, 1973; May 1986; June, 1988; and September, 1989) were used to generate an “elevation map” for intertidal areas of Willapa Bay. Geographically registered Landsat multispectral scanner (MSS) and thematic mapper (TM) imagery were used to derive a map showing areas of deep water, three intertidal elevation zones (low, middle and high), and upland areas. The four dates of image data were combined into one file and a two-step unsupervised classification procedure was used. The first step separated water and intertidal areas from upland and the second step provided the detail on variations with the intertidal zone. To date, satellite imagery has not been used to map elevation variations of intertidal wetlands, and areas of the Willapa Bay intertidal zone do not have contours on USGS topographic-bathymetric maps.

GIS Modeling of Spartina Expansion:

Several items were needed to model the geographic distribution of *Spartina* for future time periods: 1) a mathematical model of the rate of *Spartina* acreage increase, 2) the intertidal elevation map, and 3) knowledge of initial locations of *Spartina*. Areas of intertidal, emergent, aquatic macrophytes within Willapa Bay were obtained from a digital copies of the National Wetlands Inventory data for the ten USGS 7.5 minute topographic quadrangles that cover Willapa Bay; these were used as approximate initial locations of *Spartina* in 1982. Modeling was done using a six year time step; the increase in areal coverage of *Spartina* for each six year period was determined from the mathematical model based on the sigmoidal growth curve. A grid cell or raster-based GIS environment (ERDAS Imagine software) was used to assign new growth to geographic locations throughout Willapa Bay. A GIS neighborhood function was used to determine areas (rings) around existing plants. Estimated probabilities that new growth would occur in specific locations were a function of both distance from existing plants and intertidal elevation. For each six year increment of the model, locations within 600 meters were given a 60% chance of getting new growth, the middle ring (between 600 and 1,800 meters from existing *Spartina*) were given a 30% probability, and areas more than 1,800 meters were given only a minimal chance (10%) for new *Spartina*. Intertidal elevation information was superimposed on the distance rings. Upper intertidal elevations were assigned a 75% probability for new growth whereas middle elevations had a 20% chance and the lower intertidal zone had only a 5% probability of new *Spartina*. Probabilities for each combination of distance and elevation were determined by multiplying the respective percentages [*e.g.* upper elevation and middle distance ring (.75 X .30 = .225) or a 22.5% probability]. After each six year time-step in the model identified new locations for *Spartina*, new distance rings (of 600 and 1,800 meters) were identified.

<u>Discussion</u>:

Raster-based GIS modeling was used to examine the possible spread of *Spartina* in Willapa Bay, Washington. Figures 1 and 2 provide one indication (scenario) of possible changes in Willapa Bay associated with uncontrolled growth of *Spartina*; gray areas depict the intertidal zone and black dots are modeled locations for the two time periods, 1988 and 2006. GIS algorithms needed to accomplish the modeling task included a routine to overlay and compare the data values in two maps, a program to determine distance away for an existing map category, a random points within a polygon generator, and a routine to reclassify or group data values. While it is possible to modify the GIS procedures used in this modeling effort to build in integrated weed management activities (such as mowing or application of glyphosate), the modeling procedure reported on here was based on a BAU scenario (“Business As Usual”) where no management activities were incorporated. The primary value of modeling activities is the identification of possible future states of the system being studied. In the case of *Spartina* and Willapa Bay, this modeling effort produced maps that clearly depict the potential acreage of *Spartina* in 2006. Allen (1994, p.134) has pointed out that "... many anachronistic land-use situations exist where a graphic presentation of present ecological status, current trends, and possible future conditions under different management scenarios could serve to productively focus public attention on deadlocked issues and thereby catalyze action toward solutions." Therein lies the value of this modeling approach.

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IMPACTS OF SPARTINA INFESTATION

SPARTINA ECOLOGY, CONTROL AND ERADICATION - RECENT NEW ZEALAND EXPERIENCE

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Introduction

Spartina (*S. alterniflora, S. anglica* and *S.* x *townsendii*) is widely distributed in New Zealand estuaries (Partridge 1987). Spartina control is of considerable concern to natural resource managers in New Zealand, with increasing awareness of the impacts of *Spartina*, and also a growing awareness that *Spartina* appears to have a lag phase between initial establishment and a later rapid expansion phase. Consequently there are substantial ecological and cost benefits to be obtained from the control or eradication of *Spartina* while populations are relatively small (some New Zealand populations are substantial, covering large areas).

Shaw and Gosling (1996) reviewed *Spartina* control in New Zealand (the paper was written in 1995). This current paper is an update of the 1995 review, and should be read in conjunction with that account. No further information is provided for distribution, history, reasons for introduction/movement, ecological impacts, and previous control methods - refer to Shaw and Gosling (1996) and Partridge (1987).

Legislation and Policy

There have been no legislative changes since 1995. However, Regional Councils have been developing Regional Pest Management Strategies under the Biosecurity Act 1993, and assigning responsibilities for *Spartina* control. Much of the responsibility lies with the Department of Conservation, under the Foreshore and Seabed Endowment Revesting Act 1991 (the department also administers some land below Mean High Water Springs (MHWS) under other legislation such as the Reserves Act 1977 and the Marine Reserves Act 1971). Some local government agencies and private landowners also have land below MHWS with *Spartina* infestations. *Spartina* is now commonly recognised as a plant pest of regional significance in Regional Pest Management Strategies, with responsibilities for control assigned to either the Department of Conservation, local government, private landowners, or shared.

Regional Updates

The only control work being undertaken in New Zealand is using herbicides, primarily using Gallant. The reasons for using herbicides in New Zealand are similar to those outlined by Williamson (1996) for Victoria, Australia;

> "A variety of techniques have been tried to remove *Spartina*. These have included slashing, burning, sluicing, digging it out, and covering it with black plastic. All are either ineffective or are only practical for small infestations.
>
> Therefore, in the search to find an effective control method it was accepted quite early that large infestations of *Spartina* could only be effectively controlled through the use of a herbicide."

Brief accounts are provided below of control work undertaken since 1995.

Northland

The following information was contributed by G. Coulston (pers. comm.).
The initial 1993 survey of Whangarei Harbour found eight sites encompassing approximately 8 hectares. To date six of these sites have been eradicated, with no sign of regrowth over the last six months. At the other two sites the density has been reduced by *c*.90% leaving a sparse scattering of plants over a wide area which is going to take longer than expected to eradicate. The lack of success is attributed to the stunted nature of the plants, due to harsh site conditions and sporadic cattle grazing and trampling. These factors have resulted in plants with limited leaf surface area, affecting herbicide uptake and translocation.

An aerial survey in 1996 found a previously unknown site of 1000 m^2. This site has been sprayed twice, with an excellent kill of around 95%. The original Resource Consent for spraying Gallant was for four years and expires in May 1997. A two-year extension has been applied for to complete the three remaining sites. The four year programme has reduced the total area from 8 hectares of dense *Spartina* to under 1 hectare of scattered plants. This was achieved by undertaking two applications/year with Gallant 1.5%.

Research in 1996 at the main treatment sites during and after herbicide application concluded that the current spray programme is having little impact, if any, on the environment (refer to Roper *et al*., 1996).

Auckland

No control work has been undertaken to date. Auckland Regional Council is in the final stages of drafting a resource consent for the use of Gallant and Roundup G11 for a region-wide control operation (A. Moore pers. comm.). *Spartina* infestations (1994 data) vary widely in the various harbours and estuaries; Kaipara (111.5 ha), Whangateau (8,250 m^2), Mahurangi (2,530 m^2), Puhoi (210 m^2), Waitemata (250 m^2), Wairoa/Clevedon (1.6 ha), Manukau (11.97 ha) - the total area in the region is 125.8 ha (A. Moore pers. comm.).

Waikato

No recent control operations have been carried out. The Department of Conservation resource consent from Waikato Regional Council for herbicide control using Gallant expired in 1996. This approval included several monitoring conditions (see section below on Ecological Effects of Gallant) (J. Roxburgh, pers. comm.). *Spartina* is listed as a Regional Pest Plant in the Regional Pest Management Strategy and control is considered to be a regional issue, with future control/eradication work to be funded jointly by the Department of Conservation (2/3) and the Regional Council (1/3) (J. Simmons, pers. comm.).

Many of the Coromandel estuaries and harbours are considered to be a high priority for control, as the *Spartina* populations are still in a lag phase. Some of the *Spartina* in those harbours is up to 2.0 m in height, and may be difficult to treat with herbicide (J. Roxburgh pers. comm.).

Bay of Plenty

<u>Tauranga Harbour</u>

Spartina is present at 24 known sites in the harbour, and it is considered very important to achieve eradication before there is significant expansion. A small trial area was sprayed with Gallant in December 1996, with a high level kill, and no damage to mangroves or indigenous saltmarsh species. All known sites were sprayed with Gallant (2% + Codicide crop oil to minimise spray drift). This operation was only completed in early March 1997. An airboat was used to transport herbicide (100*l* tank) and spray equipment (hose reel and gorse spray gun), and was found to be very effective (airboats will operate on water and on mud substrates, but not on sandy substrates - an airboat with retractable wheels may be an option in the future). Some spraying was done using knapsacks, where airboat access was not feasible (R. Keyser, pers. comm.).

The Regional Council (Environment Bay of Plenty) required a resource consent, including written consents from tangata whenua (Maori people of the harbour) before a consent would be issued. Department of Conservation staff met with tangata whenua and other interest groups (such as the local Toxin Action Group), and discussed the ecological role(s) of *Spartina*, viable options for control, and the effects of Gallant, before consent was received to proceed with the operation.

An initial inventory was carried out in September 1996. Historical records were assessed and field checks were made at each known site. Further survey work is to be carried out, to search carefully for any further infestations. This may be done using a hovercraft, with a GPS to record locations (R. Keyser pers. comm.). A feature of the work to date has been the close liaison between the Department of Conservation, Bay of Plenty Regional Council, and the two District Councils.

Treatment with liquid fertiliser might be trialed on a small scale, to see if any resultant boost to *Spartina* growth will promote herbicide uptake, and manual control using weedeaters will also be assessed (R. Keyser pers. comm.).

Ohiwa Harbour

A comprehensive control trial was undertaken in Ohiwa from 1991-1993, using mainly herbicides but also a limited evaluation of steam treatment (Shaw and Gosling 1996). In 1993 the evaluation of different techniques was terminated due to the obvious success of Gallant as a control method, and all *Spartina* were treated with Gallant, in an attempt to eradicate *Spartina* from the harbour. Since 1994 there have been annual inspections and detailed searches for *Spartina* regrowth. A few plants have been found on each occasion, and they have been treated with small scale knapsack spraying. Ten were found in November 1996 around the top of the high tide level, intermixed with saltmarsh species and were likely to have been missed during earlier control work. The most recent assessment was in February 1997, and 11 small plants were found. All were in sandy substrate, among rocks along the upper tidal margin. Careful searching is required to find such plants but they are easily killed with a minimal application of Gallant using a knapsack. Ongoing site monitoring and searches will be maintained for at least another two to four years, to ensure that *Spartina* does not re-establish. It is tempting to say that *Spartina* has been eradicated from Ohiwa but such a conclusion could only be drawn after no plants have been found for at least two to three years.

Gisborne

No recent control work has been undertaken. Earlier trial work by Gisborne District Council indicated little success with Roundup (Glyphosate) (C. Whiting, pers. comm.).

Wanganui

No further field control work has been undertaken due to the lack of success of previous treatments using Roundup (Glyphosate). The Department of Conservation is currently preparing an application for a resource consent to use Gallant in the Manawatu Estuary. No control is envisaged at other infestation sites until staff are happy that they have reliable and effective techniques (J. Barkla, pers. comm.).

Wellington

There are *Spartina* sites in the Wellington region, but no control work has been done, or is planned at this stage (J. Sawyer, pers. comm.).

Nelson

Control work is undertaken by the Tasman District Council (Waimea Estuary), Nelson City, and the Department of Conservation (M. Hawes pers. comm.). All Nelson control work is now done using Gallant. The former extensive Waimea estuary infestations has been reduced to a scale similar to Ohiwa (see above), with annual monitoring and small scale knapsack application of Gallant to remove regrowth.

Nelson has a wide tidal range, and by carefully selecting appropriate tides it is possible to apply herbicide at times when daily tidal inundation does not occur (D. Nottage, pers. comm.).

There has been no observed damage to indigenous saltmarsh species, and careful searches for *Spartina* are made each year (using a 2 m grid in saltmarsh). One operator has adopted the practise of marking individual *Spartina* plants (with a small stake) before treatment with Gallant. No marked plants have survived. Only *c*.0.5*l* of spray mixture was used in the 1996/97 treatment.

Eradication has almost been achieved but the intensive work now required (with a very low density of *Spartina*) requires a high level of political and operational will. Obtaining zero density will be particularly difficult where *Spartina* is present among denser stands of indigenous vegetation, but poses no problems on open mudflats. Vegetation transects were established in the early stages of the herbicide programme, and these are now due for remeasurement, to assess whether adjacent indigenous vegetation spreads on to sites which were previously occupied by *Spartina* (D. Nottage and R. van Zoelen, pers. comm.).

Some infestations have been found recently (post-1995) in the Golden Bay - Farewell Spit area, where *Spartina* was previously considered to be eradicated. These are sites that are likely to have been missed when the New Zealand Wildlife Service carried out control work from the 1970's to the mid-1980's. There is ongoing control work in the Marlborough Sounds, and the main Havelock estuary is under consideration for control (M. Hawes, pers. comm.).

Canterbury

The Christchurch City Council has an ongoing control programme in the Avon-Heathcote estuary. This programme has run for *c*.15 years and has dramatically reduced the formerly extensive infestations. Some initial unsuccessful control attempts were made with machine excavation (K. Gledhill pers. comm.). Good records (including maps) have been kept of the sites and their treatments. Two herbicide applications are made each year (February and April) using Dalapon and Weedazol. This was previously a large operation, involving weeks of field work, but is now three days/treatment, with most effort expended in searches for remaining plants (only *c*.10*l* of spray mixture is used annually) (B. Hazeldean, pers. comm.).

A field inventory has been carried out in the Lyttleton Harbour (an earlier report from the Ashley River estuary was a misidentification), (C. Woolmore, pers. comm.).

Otago

Spartina control is continuing at three sites. At the Merton tidal arm (Waikouaiti River) excellent progress is being made using Roundup (Glyphosate) at 2% with codacide oil. This is applied from handguns and 200 metre hoses. Timing of applications has been critical here with earlier applications before development of seedheads (January/February) providing best results. Control in the same manner is also continuing at the nearby Hawkesbury Lagoon although application is from backpacks. The third site is at Taieri River mouth again using Roundup at 2% applied from a backpack unit, with good results (J. Barkla, pers. comm.).

Southland

There has been considerable ongoing control work, all using Gallant, with near removal from Bluff Harbour, and a high level of control in the Aparima estuary (G. Miller, pers. comm.). New application techniques have provided an opportunity for potential eradication of even the massive infestation in the

New River estuary. Application has been made using a small helicopter (Robinson) flying at very low elevations (with the spray nozzles almost touching the plants) and at very slow speeds. It is essential to ensure that the *Spartina* is well covered with herbicide. This type of application has achieved *c*.95% kill on the first treatment. Smaller infestations and follow-up work is being done using an Argo, an amphibious vehicle that provides a good transport mechanism for spray equipment (G. Miller pers. comm.).

The removal of *Spartina* from sites has led to the establishment of bachelor's button (*Cotula coronopifolia),* and to wading birds using these sites again (K. Crothers, pers. comm.).

ECOLOGICAL IMPACTS OF GALLANT

Further work has been done on the ecological impacts of Gallant (Roper *et al.* 1996), and the following extract is from that report;

> "Gallant contains the active ingredient haloxyfop-ethoxyethyl (etotyl) ester at a concentration of 100 g 1^{-1}. On application the haloxyfop-ethoxyethyl ester breaks down to the parent acid: haloxyfop. Haloxyfop-ethoxyethyl is practically non-toxic to birds, although it is regarded as being moderately to highly toxic to fish. By comparison, haloxyfop acid is low in toxicity.
>
> Laboratory toxicity tests showed that a 1% Gallant solution (the strength at which Gallant may be applied) is strongly toxic. However, at an assumed application rate of 9 1 of Gallant per ha (i.e. 0.9 ml m^{-2}) lower levels of toxicity were seen.
>
> In a field application some toxic effects are likely for benthic organisms, especially where spray ponds on the sediment surface. With the dilution by tidal flushing, however, toxic effects will be reduced. While spraying may cause a temporary decline in densities of some species, toxicity will not persist and benthic communities will recover.
>
> Field measurements showed that measurable quantities of haloxyfop were washed off an intertidal site following spraying with Gallant. The resulting concentrations in the water column were well below those known to be toxic.
>
> Shellfish could accumulate haloxyfop residues up to about twice the ambient water concentrations. However, the levels in the shellfish would diminish very rapidly (by about 50% per day). As a precaution, a 5-day ban on harvesting of shellfish within a specified distance (say 500 m) of an intertidal area sprayed with Gallant is recommended."

A monitoring technique has been designed to assess the effects of control work using Gallant (Turner and Hewitt, 1997). The sampling programme has been designed to collect information on :

- plant death and decay
- sediment characteristics
  - depth of sediment disturbance
  - sediment transport
  - surficial sediment grain size
- floating wrack (floating rafts of decaying *Spartina*)
- macrobenthic invertebrates
- fish assemblages
- non-target vegetation

Turner and Hewitt (1997) suggest that additional information could be collected from :

- chemical analysis of decaying vegetation, and surficial sediment for Gallant (haloxyfop acid)
- water velocity
- low level aerial photography to monitor changes in vegetation cover
- multivariate analysis of community composition

CONCLUSIONS

There is no national co-ordination of *Spartina* control in New Zealand. However, the Department of Conservation now has national policy and guidelines for pest plant control, and assigns control priorities on the basis of relative conservation value and threat (C. F. Shaw and Beadel 1996). With the passing of the Biosecurity Act 1993 and the development of Regional Pest Management Strategies there is very good regional co-ordination of control, often involving combined responsibilities and resources of relevant management agencies and private landowners. Department of Conservation input to Regional Pest Management Strategies has been co-ordinated nationally.

Spartina control in New Zealand is now done mostly with the herbicide Gallant (Haloxyfop) (one programme is using Dalapon/Weedazol and one is using Roundup). Gallant is very effective, and has been found, from the work to date, to have acceptable environmental impacts. Recent refinement of application and transport techniques such as helicopter application, the use of airboats, and amphibious vehicles means that eradication of *Spartina* from many New Zealand estuaries is now viable. Without Gallant, or another herbicide with a similar level of effectiveness, effective control or eradication is not viable. Even using a highly effective herbicide this can only be achieved with very careful planning and execution of control operations.

The principles involved in successful *Spartina* control and eradication are the same as for the planning for the sustained control or eradication of any problem plant or animal species. It requires the use of control techniques known to be successful (and environmentally acceptable), adequate funding, sound planning (including planning for contingencies such as new finds or unsuccessful treatments), a commitment to many years of hard work, and close attention to the requirements of human communities and legislation and policy. Effective information sharing, often via informal channels such as telephone inquiries, has been a feature of the development of effective control in New Zealand. For each operation it is critical to have good information on the location and extent of infestation before an operation starts, and to be prepared to follow control operations with meticulous searches for missed populations or regrowth. This follow-up work, and related control may need to go on for five or more years to ensure eradication. Without this level of planning and commitment, control operations are unlikely to be successful.

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THE ENVIRONMENTAL IMPACT OF SPARTINA ANGLICA: PAST, PRESENT AND PREDICTED

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Introduction

In the previous paper we outlined the origins and history of *Spartina anglica* (hereafter "*Spartina*") in the British Isles. Here we consider the environmental impacts of the species which currently occupies in excess of 10,000 ha of the 44,000 ha of saltmarsh around the British coast (Burd 1989) and discuss some of the key questions which need to be solved to improve the prediction of future impacts.

Past impacts of *Spartina*

Despite the fact that, in a little over a century, *Spartina* has increased the area of saltmarsh in Britain by something in the order of 25%, evidence of its impact on intertidal plant and animal communities is largely indirect or circumstantial. Data on the actual numbers of any species displaced are difficult to obtain and it remains impossible to establish, except on a very local scale, that a single species has gone extinct as a result of the advent of *Spartina*. Indeed, in the sense that it is itself a new species and has a small, but growing, fauna, it can be said to have actually increased the overall biodiversity of UK saltmarshes!

The impact of *Spartina* on the distribution of sediments and on the hydrographic changes to seaward have been much easier to measure, particularly in the enclosed embayments and estuaries of the south coast. In Poole Harbour, for example, its arrival at the end of the last century and rapid expansion to cover 800 ha by 1924 is estimated from stratigraphic studies to have removed more than 7 million cubic metres of sediment from circulation (Hubbard & Stebbings 1968, Gray *et al.* 1995). Subsequent die-back of the *Spartina* swards had, by the mid-1980s, released around half of that volume back into the system. Because the stabilisation of sediments was of previously mobile sediment rather than new material (Green 1940), these fluxes are reflected in the changes in the bed levels of the major navigating channels in the Harbour. Analysis of successive hydro-graphic surveys reveals that during the expansion of *Spartina* marshes in the early part of the century, many of the major channels deepened, but that between 1934 and 1954 there was considerable shoaling of all channels in the main Harbour as sediment was released (Gray *et al.* 1991, Raybould 1997) (Figure 1). The present deepening can be related to modern dredging patterns and probably to the loss of sediment from the Harbour mouth as the tidal régime becomes ebb-dominated under rising relative sea levels.

Figure 1. Changes in the depths of major navigation channels in Poole Harbour

Although inadequately quantified, many millions of tons of intertidal sediments around the British coast must have been immobilised, and subsequently recirculated in southern estuaries, as a result of the growth of *Spartina* marsh. Clearly, too, saltmarshes will have accreted in areas where formerly they could not have developed and the hydrological conditions of many estuaries will have been irreversibly altered, particularly where they have facilitated land claim for port expansion or agriculture.

As indicated earlier, the ecological impact is less easy to quantify. On a local scale, *Spartina* swards have displaced eelgrass (*Zostera* sp.) beds and mudflats previously occupied by benthic invertebrates. Although one study on the east coast disclosed a surprisingly rich invertebrate fauna associated with the sediments in *Spartina* marsh (Jackson *et al.* 1985), most observers have found that the benthic fauna of *Spartina* swards is generally depleted when compared with nearby tidal mudflats (*e.g.* Millard & Evans 1984). The potential impact of the loss of *Zostera* on waterfowl, notably the widgeon, *Anas penelope*, and the Brent goose, *Branta bernicla*, and of the loss of feeding grounds on shorebirds, has been the major cause for concern of wildlife conservation agencies (and the most common justification for controlling the spread of the plant). In fact, an impact on shorebirds is difficult to detect and, with one exception, the UK populations of overwintering species have increased or remained stable since national counts began in the early 1970s. The exception is a tide-edge-feeding species, the dunlin, *Calidris alpina*, the numbers of which declined at a faster rate between 1971 and 1986 in those estuaries where *Spartina* had expanded most in that period (Goss-Custard & Moser 1988). Whilst the expansion of *Spartina* removes feeding area and reduces feeding time for the dunlin, the spread of the grass and decline of the wader may have occurred independently or be linked by a third factor such as a change in sediment type. Again, the evidence is unsatisfyingly indirect and there are few local studies to support or quantify the scale of the impact. Two exceptions are those in the Dyfy Estuary in mid- Wales, where oystercatchers, *Haematopus ostralegus*, ringed plover, *Charadrius hiaticula*, and sanderling, *Calidris alba*, also declined in number during *Spartina* expansion during the 1970s (Davis & Moss 1984), and at Lindisfarne on the north-east, where Millard & Evans (1984) made similar observations.

<u>The present status of *Spartina*</u>

Spartina marshes, as described previously, are continuing to die back along the south coast, in South Wales and in most of the east coast as far north as Norfolk (53^{o}N). North of this, some populations are expanding and others appear relatively static. Between the surveys of 1967 (Hubbard & Stebbings 1967) and 1990 (Charman 1990), 20 new populations had become established along the west coast with a 40% increase in area. In that same period, the south coast, where marshes had already declined substantially in area, showed a further 11% reduction; and the east coast apparently declined by 44% (there is a strong possibility of error in the 1967 survey of this coast). Some recent population expansions in the north-west coast have, as described in the first paper, resulted in rapid successional replacement of *Spartina* by other saltmarsh species.

Arguably the most interesting question raised by the current pattern of change is whether the south coast marshes have in any sense returned to their pre-*Spartina* state. Judging from early photographs of the pre-invasion marshes in Poole Harbour, and elsewhere, the major difference in the mudflats around and below Mean High Water Neap tides is the presence today in many estuaries of extensive carpets of free-living algal species, notably *Enteromorpha* species and *Ulva lactuca*. Possibly resulting from estuarine eutrophication, these algal mats may have been responsible for the apparent failure of shorebird numbers to increase when the area of *Spartina* was decreasing (Goss-Custard & Moser 1988).

However, a recent analysis of wader numbers in the period 1971-1994 has indicated that, in the past 25 years, there has been a greater increase in wader numbers in areas where *Spartina* is declining. In a study of 16 estuaries divided into those where *Spartina* had increased between the surveys of Hubbard & Stebbings (1967) and of Burd (1989) and those where *Spartina* had decreased between the surveys, Raybould (1997) found a significant difference between the two categories in both the strength and the magnitude of the trends in bird numbers (which have increased overall). The group of nine estuaries in which *Spartina* has decreased tends to have stronger positive trends (higher average yearly increases) in wader numbers than the group in which *Spartina* increased (when differences were tested with a Mann-Whitney test). The difference between these results and those of Goss-Custard & Moser (1988) may reflect a time-lag between the regression of *Spartina* swards and the recolonisation of mudflats by invertebrates, either because algal mats prevented this or some other factor made the die-back areas unsuitable. Certainly the recent increase in winter peak wader counts for Poole Harbour suggest an exponential recovery from 1969-70 to 1993-94. There was a highly significant upward trend in total wader numbers (r_s = 0.633, P <0.01) and an exponential regression of number on year was also highly significant (b = 0.0301, R^2 = 41.5%, P <0.001), showing an average annual increase of more than 3% (Figure 2). Of particular interest is the recovery in the numbers of the black-tailed godwit, *Limosa limosa*, a species which is of international conservation importance and which feeds on the muddier embayments of the south Harbour where algal mats had formerly been most extensive. Overwintering populations of black-tailed godwit have increased in the past 25 years at almost twice the rate of the total wader count (Figure 3, and Raybould 1997).

Figure 2. Total wader numbers in Poole Harbour (exponential regression)

Figure 3. Exponential regression showing the annual rate of increase of black-tailed godwit numbers in Poole Harbour.

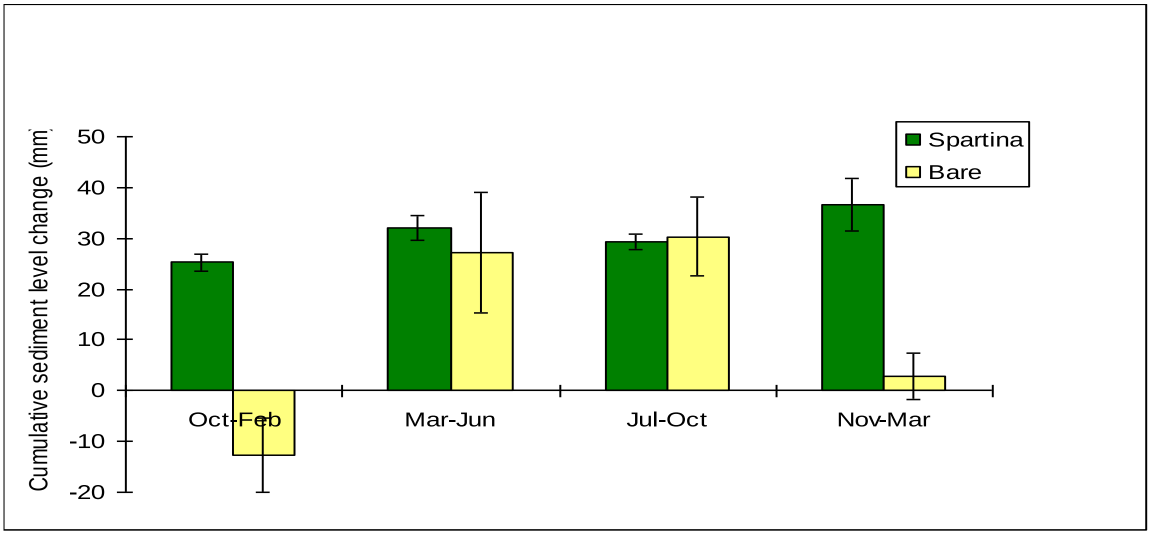
Predicting the future impact of *Spartina*

What trends can we foresee in the future development of *Spartina*-dominated marshes in the UK, and what research would help to clarify the picture as we see it?

First, it appears that the die-back of *Spartina* marsh continues unabated in the south and east. In those areas such as Poole Harbour and Langstone Harbour where die-back began early, *Spartina* remains as a narrow fringe at the marsh front, in receding clumps on some mudflats, and in low-lying areas such as pans and creeks on the upper marsh. This regression may be aided by the extensive spread of a fungal pathogen, the ergot fungus, *Claviceps purpurea*, which first appeared in Poole Harbour, for example, in the early 1970s and since 1986 has remained at an extremely high level of infection (more than 70% of inflorescences being infected) (Gray *et al.* 1990, Raybould 1977). The reduced growth rate of *Spartina* plants from the mature zones of long-established marshes such as those in the Dee Estuary (Thompson *et al.* 1991) also points to a possible build-up of pathogens, notably viruses, in long-lived clonal individuals. Seed-set in these southern estuaries is sporadic and seedling recruitment extremely rare. The lower zones of most east coast marshes below 53^{o}N are being extensively eroded, probably under rising relative sea levels, and *Spartina* is increasingly confined to creeks and pans. Die-back now occurs in several estuaries in South Wales and may spread north to those areas in which *Spartina* expanded rapidly in the 1970s.

In the central and northern parts of its UK range (above 53^{o}N), pioneer *Spartina* clumps are either expanding or appear relatively static. In some estuaries such as the Humber (53^{o} 40'N), isolated *Spartina* clumps in an apparently pioneer phase of growth actually create erosion hollows (a phenomenon which one can mimic by establishing an artificial *Spartina* clump using small canes or kebab sticks!). A current study of marshes in this part of eastern England, from Norfolk (53^{o}N) to Lindisfarne (55^{o} 41'N), suggests that the hydrodynamic conditions under which *Spartina* is able to expand to form extensive swards are imperfectly understood. A comparison of sediment accretion rates in *Spartina* clumps and on the open mudflats between them (short- term studies over 2-14 tidal inundations using double filter papers, and longer-term measurements over 18 months) has revealed no consistent evidence that *Spartina* at the marsh edge enhances sediment deposition on the east coast. It seems more likely that here *Spartina* is more important as a sediment stabilizer, in which binding by the plant root systems, combined with lower resuspension and erosion of bed sediment within the vegetation, result in net accretion after cycles of deposition and erosion, and which may only be apparent after longer time periods. Figure 4 shows much greater variation in accretion/erosion on bare mudflat than in adjacent *Spartina* patches where a gradual increase in sedimentation occurred. The size of the vegetation patches (continuous swards *vs* isolated clumps) is also likely to influence the effects of above- ground vegetation on sedimentation; greatest deposition is often observed in the area of continuous vegetation behind the marsh front. The east coast study suggests that variation in factors such as slope, topography, sediment supply, and wave climate creates a range of conditions not all of which are conducive to the development of swards (Brown, unpublished data). In other areas such as Morecambe Bay on the west coast, some populations have in the past two or three years generated a large number of seedlings (1995 and 1996, both warm summers, appear to have been good years for seed-set in this area). This may herald the end of a lag phase of growth and the rapid expansion of swards.

Figure 4. Sediment level changes at the marsh front in *Spartina* and adjacent bare mudflat (mean ± SE). Easington, Humber estuary, Oct. 1995-March 1997.



The successional replacement of *Spartina* swards is likely to occur more rapidly on these northern marshes and the nîche which *Spartina* finally occupies may be narrower than in the south. However, the fate of these swards and the potential of *Spartina* for a northward expansion may depend on longer-term climate change. Anticipated global warming and increase in CO_2 is likely to affect the competitive interactions between *Spartina* and the pioneer species on marshes to the north, almost exclusively *Puccinellia maritima*. *Spartina*, one of only eight species in the British flora which utilises the C_4 photosynthetic pathway (in which the first product of photosynthesis is oxaloacetate, in contrast to phosphoglycerate in C_3 species), does not display significant canopy development until the mean air temperature exceeds 9°C (Long 1983). Its inability to form pure swards and out-compete *Puccinellia* in northern marshes is thought to be related to the earlier spring growth of the latter species (Scholten & Rozema 1990, Gray *et al.* 1991). Whilst increased CO_2 levels might favour *Puccinellia*, higher spring and summer temperatures could alter the competitive balance to the advantage of *Spartina*. We are currently exploring competition between the two species in the Institute's experimental glasshouses (solardomes) which allow either CO_2 concentration or temperature or both to be maintained above ambient conditions. Higher global temperatures may also enable *Spartina* to spread further north in Europe - its current range being from 48°N to 57.5°N (the range in China being from 21°N to 41°N, and in Australia and New Zealand from 35°S to 46°S).

These speculations about the future of *Spartina* have largely ignored the (very strong) possibility of human intervention, notably in controlling the spread of the plant. Although UK experience suggests that once *Spartina* is established in an estuary its control or eradication is either costly or impossible, the threat it is seen to pose for sensitive areas (especially to wildfowl and shorebird feeding grounds) could lead to its exclusion from estuaries in the northern part of its geographical range. Any attempt to control the species (and, indeed, to make predictions about its future) will be helped by a better understanding of the conditions

controlling vegetative expansion in the lower zones, controlling seed-set and seedling recruitment, and influencing its competitive interactions with *Puccinellia maritima* and other species.
The escape from competitors and pathogens which followed *Spartina*'s *de novo* polyploid origin and its ability to exploit a formerly vacant nîche is likely to be only temporary and must be balanced against the limited evolutionary flexibility imposed on it by the severe genetic bottleneck that occurred during this process. Whatever the outcome of this fascinating interplay between physical, ecological and evolutionary forces, it is clear that the "*Spartina* story" (Lambert 1964) is far from over.

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ECOLOGY, IMPACT AND CONTROL OF *SPARTINA* IN LITTLE SWANPORT ESTUARY, TASMANIA

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Introduction

Tasmania's response to the spread of *Spartina* has relied heavily on information from interstate and overseas. Until recently, research on *Spartina* in Tasmania was mostly descriptive or relating to distribution. The need for more research and information on Tasmania's *Spartina* infestations was targeted as a necessity by the Rice Grass Advisory Group (RGAG). In September 1996, the RGAG received funding from the Federal Government, through a Fishcare Program, to investigate the ecological impact of *Spartina* on fish habitats and suitable methods to control *Spartina* infestations. A Scientific Sub-Committee was formed within the RGAG and a pilot project was designed. Preparation for the project began in October 1996. Results are expected to be released in May 1997. This account will point out the objectives of the project and briefly outline the methodology and expected outcomes.

Pilot Project Objectives

The pilot project has four main objectives:

- investigate the impact of *Spartina* on the macroinvertebrate infauna of Little Swanport estuary;
- determine the efficacy of several *Spartina* control techniques (physical removal, smothering and the herbicide Fusilade");
- investigate the impact of Fusilade on macroinvertebrate infauna; and
- monitor the degradation of Fusilade residues in water and sediments.

Methodological Outline

Location and site description. The project is being conducted in the Little Swanport estuary located on Tasmania's east coast. Five replicate sites have been selected along a 500 metre intertidal section of the estuary. Each site contains a mosaic of *Spartina* infestations and uncolonised mudflats.

Impact of Spartina on macroinvertebrate infauna. At each site, core samples (15m cm diameter x 10 cm deep) were taken from *Spartina* colonised areas and uncolonised mudflats. Cores were sorted in a 1 mm sieve to separate macroinvertebrates from sediments, debris and plant material. Species diversity and abundance of each core will be recorded. Analysis of Variance (ANOVA) will be used to make a comparison between the community structure of colonised and uncolonised areas.

Efficacy of Spartina control techniques. Three cells (3x3 m) were marked out at all sites. A separate treatment was assigned to each of the three cells: black plastic (smothering), herbicide (Fusilade) and a control cell. An assessment of efficacy (regrowth and kill rate) will be conducted in late spring/early summer 1997.

Impact of Fusilade on macroinvertebrate infauna. Core samples were taken from the control and Fusilade treated cells at all sites approximately one week after application of Fusilade. Macroinvertebrates were separated from sediments, debris and plant material. A BACI (before vs. after; control vs. impacted) approach, using species diversity and abundance, will be used to investigate the impact of Fusilade on macroinvertebrate infauna.

Degradation of Fusilade residues. Water and sediment samples were taken from the Fusilade treated cells of three sites. Control samples were taken before the application of Fusilade. After spraying, five samples were taken over seven days from each of the three sites. Samples are being analysed for total residues (acid and ester).

Expected Outcomes

The information provided by this project will form the basis for future *Spartina* research in Tasmania and will assist the RGAG in there goal to control *Spartina*. More specifically, this report will:

- provide baseline information on the impact of *Spartina* on macroinvertebrate infauna in Tasmania's estuaries;
- determine the efficacy of techniques used to control *Spartina*; and
- provide more information on the impact of Fusilade on estuarine ecology in Tasmania.

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DOES EXOTIC *SPARTINA ALTERNIFLORA* CHANGE BENTHIC INVERTEBRATE ASSEMBLAGES?*

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INTRODUCTION

This research utilizes a natural experiment, the invasion of the exotic cordgrass *Spartina alterniflora* (Loisel) into the littoral mudflats of Willapa Bay, to investigate the effects of a known exotic species within the context of a relatively 'pristine', yet highly managed, estuarine system. The primary objective of our study was to compare the benthic macroinvertebrate assemblages of uncolonized mudflat and progressively larger patches of *S. alterniflora* within one site in Willapa Bay. Our secondary objective was to characterize the physical in order to examine potential mechanisms for any observed differences in macroinvertebrate assemblages over progressively larger areas of *S. alterniflora* colonization.

METHODS AND MATERIALS

Our study site, Potshot Slough, is located at the southeastern end of Willapa Bay and is a broad expanse of littoral mudflat which has been extensively colonized by *S. alterniflora*. We focused on four sizes of *S. alterniflora*: 3-m diameter patches (~2 years old), 6-m patches (~ 4-5 years old), 12-m patches (~ 8-10 years old), and expansive *S. alterniflora* meadows formed by the coalescence of adjacent large patches. The meadows selected for this study were all >12 m2 and are believed to be the oldest areas of *S. alterniflora* colonization (~15-30 years old) based on the aerial photographs, their size, and elevation.

We chose degree of colonization (adjacent uncolonized mudflats and *S. alterniflora* patch centers) and increasing patch size as the two main factors to investigate relative to progressive *S. alterniflora* colonization and its potential effect on benthic invertebrate. We haphazardly selected three replicate series of the four *S. alterniflora* sizes of approximately equal intertidal elevation and their adjacent and then collected eight samples from the adjacent mudflat and eight samples from the center of the *S. alterniflora* patches/meadows. Although this sampling design was seasonally replicated during April and August, 1994, this discussion will focus primarily on the August data.

Benthic macroinvertebrates were sampled using a 5.5-cm diameter X 10-cm deep PVC push-corer. All mudflat cores were collected fully 1 m away from the outer edge of the *S. alterniflora* patches. All invertebrates were identified to the lowest taxonomic level feasible and were classified into four established feeding groups. Based on trophic role and numerical prevalence, 11 of the 43 taxa were selected for statistical analysis using two -factor, multivariate analysis of variance to test for both univariate treatment effects on each individual taxon/trophic group and for multivariate effects on all taxa/trophic groups together.

Uncolonized mudflats and progressively larger *S. alterniflora* patches were physically characterized by measuring aboveground structure, belowground standing stock, and sediment grain size. The aboveground structure created by *S. alterniflora* shoots was estimated by counting the number of shoots contained within a 0.0625 m2 quadrat at the edge and center of each *S. alterniflora* patch. The aboveground structure created by the *S. alterniflora* patches ranged from 343-474 shoots/m2 (+/- 51.15-18.58) during August. There was no consistent pattern of aboveground structure with respect to patch edges or centers during either month.

Belowground standing stock was estimated from the root mass contained within the *S. alterniflora* center cores collected for macroinvertebrates. During both months, belowground standing stock increased with progressively older/larger *S. alterniflora* patches with the larger areas (12-m patches and meadows) having nearly twice the belowground standing stock of the smaller 3 and 6-m patches. The 12-m patches had the greatest August standing stock (841.0 +/- 67.00 g/m2).

One sediment grain core (2.2-cm diameter X 10-cm deep) was collected from the adjacent mudflats and *S. alterniflora* patches. Adjacent mudflats, the 3-m and 6-m patches had grain size distributions dominated by coarse to medium silts (phi classes 5 and 6), while the 12-m patches had more evenly distributed grain sizes with phi classes 5, 6, 7, and >10 being most prevalent. Phi class >10 composed the largest portion of the sediment within the meadows.

The physical variables were regressed against the mean density of four selected species which showed distribution trends with respect to degree of colonization and increasing *S. alterniflora* patch size, were representative of distinct trophic groups, and showed no significant interaction effects evident from the MANOVAs.

RESULTS

When considered at a coarse taxonomic level, the invertebrate assemblages of adjacent mudflats and the *S. alterniflora* were similar. During both months, the mudflats and the *S. alterniflora* patches/meadows were dominated (10,000-100,000 organisms/m2) by polychaetes, oligochaetes, and mollusks. The mudflats generally had higher densities of crustaceans than the *S. alterniflora*, while the patches and especially the meadows, had greater densities of insects and arachnids. During August, the adjacent mudflats had higher total densities and lower taxa richness than the *S. alterniflora* patches.

The MANOVA revealed a significant, multivariate treatment effect of degree of colonization (mudflat or *S. alterniflora*) on overall mean invertebrate densities during both months. Degree of colonization also significantly affected the densities of several individual taxa, although the magnitude and direction of the effect varied between species. During August, the dipteran larvae and *Capitella capitata* had higher densities within the *S. alterniflora* patches, while the polychaetes *Streblospio benedicti*, *Aphelochaeta* sp., the crustaceans *Nippoleucon hinumensis*, *Corophium* spp., and *Grandidierella japonica* had greater densities within adjacent mudflats. Degree of colonization also significantly affected the densities of individual trophic groups during both April and August. Buried deposit feeders and predators showed higher densities within the *S. alterniflora* during both April and August, whereas surface deposit feeders exhibited higher densities within the adjacent mudflats than the *S. alterniflora* patches during August.

The MANOVA revealed no significant multivariate effect of *S. alterniflora* diameter on overall invertebrate densities during either month. However, diameter significantly affected the densities of several individual invertebrate taxa during both months. Large differences in density within the meadows was the most evident manifestation of a diameter effect. During August, *C. capitata* densities increased within progressively larger *S. alterniflora* patches, with highest densities in the meadows. *Corophium* spp. amphipods also occurred in the higher densities within the *S. alterniflora* meadows. *Aphelochaeta* sp. densities declined within the meadows. Diameter also significantly affected the densities of the surface and suspension feeding trophic groups, but only during April. While surface feeders showed higher densities within the meadows, the density of suspension feeders inside the meadows was much lower than in the smaller patches.

The August densities of the four selected individual species were significantly related to the physical site characteristics. Densities of the surface deposit feeding polychaete, *Aphelochaeta* sp., were negatively related to both *S. alterniflora* shoot density and belowground biomass. Densities of the buried deposit feeding polychaete, *C. capitata*, were positively related to increasingly finer grain sizes within the *S. alterniflora*, shoot density, and belowground biomass. Densities of suspension and surface deposit feeding *Corophium* spp. amphipods were positively related to increasingly finer grain size within the mudflats, but negatively related to *S. alterniflora* shoot density. Finally, predatory dipteran larvae were positively related to both increasingly finer grain size and belowground biomass within the *S. alterniflora.*

DISCUSSION

The degree of colonization, whether uncolonized littoral mudflat or patches/meadows of exotic *S. alterniflora*, did significantly effect the overall density (April and August) and trophic character (August) of the benthic macroinvertebrate assemblage as indicated by the multivariate MANOVA results. Progressively larger *S. alterniflora* diameter, on the other hand, did not significantly effect either the overall density or the trophic character of the benthic invertebrate assemblage during either month of this study. However, both colonization and diameter did significantly effect individual taxa and trophic groups as indicated by the univariate MANOVA results. The varied magnitude, direction, and seasonal nature of these effects illustrate the necessity of examining invertebrate communities at both assemblage and individual taxa scale. While both uncolonized mudflats and areas of *S. alterniflora* have dense, diverse assemblages of benthic macroinvertebrates, the character of those assemblages clearly differs.

Although *S. alterniflora* patch size did not significantly effect the overall assemblage, the smaller patches shared aspects of their assemblages with the mudflats and the larger patches shared assemblages similar to the meadows. Clearly the most distinct difference in invertebrate species composition, density, and trophic organization was evident within the *S. alterniflora* meadows. The meadows characteristically had high taxa richness and greater densities of predatory invertebrates. Reduced tidal exposure and increased physical structure within the meadows may have provided a habitat more suitable to such 'terrestrially' associated invertebrates.

These documented differences in diversity and availability of benthic invertebrate prey resources between uncolonized mudflats and areas of *S. alterniflora* may negatively impact larger consumers which feed primarily on the littoral mudflats of Potshot Slough, such as chum salmon, English sole, great blue heron, dunlin, sandpiper and plover. Prey resources for consumers such as chinook salmon and shiner surf perch which feed on invertebrates within the water column or floating at the surface may be increased by the presence of *S. alterniflora.*

THE POTENTIAL INFLUENCE OF THE AQUATIC WEED *SPARTINA ALTERNIFLORA* AND CONTROL PRACTICES ON CLAM RESOURCES IN WILLAPA BAY, WASHINGTON.

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Smooth cordgrass *Spartina alterniflora*, a native salt marsh plant along the Gulf and mid-Atlantic coasts of the U.S., was introduced into Willapa Bay, Washington with oyster spat in the late 1800's. It spread slowly and was little noticed until the late 1970's and early 1980's when it began to set seed and spread rapidly (Sayce 1988). By 1992 an estimated 2,000 acres were covered and *Spartina* had been declared a noxious weed in Washington state. Because it forms dense monotypic stands in the upper intertidal area, traps sediment, and raises the elevation of the mudflat, we hypothesized that it could alter habitat and thereby affect the distribution of intertidal clams. The Washington State Department of Fish and Wildlife (WDFW) is charged with managing clam populations on state owned tidelands in the estuary. WDFW actively participated in the process of completing an environmental impact statement on *Spartina* control practices (WSDA et al., 1993) and developing an integrated pest management plan to implement control operations. As part of this effort, we studied the distribution of adult clams on several beaches where recreational clam harvest was likely to be impacted by *Spartina* encroachment and began an investigation into the processes by which this might occur. WDFW instituted its own *Spartina* control program in 1995, and we have also initiated a study to monitor the effect of *Spartina* removal on clam distribution.

Surveys of adult clam distribution around *Spartina* clones were made in 1992 and 1995. A shovel was used to excavate a 930 cm^2 sample at multiple locations around two clones at each of three recreational clam beaches in Willapa Bay (Fig. 1). The beaches were purposely chosen to represent three different habitats including gravel/cobble (Long Island, Sta 1), clean sand (Nemah Beach, Sta 2), and muddy sand (Cedar River, Sta 3). Five samples each were collected from 3 locations within each clone, 3 locations around the edge of each clone, and at 3 locations 20 m from the edge of the clone for a total of 45 samples per clone. Clams were sorted on a board by hand on site, but measured and weighed in the laboratory. Results differed by location with more clams (all species) present in the gravel habitat at Sta 1. *Macoma spp*. were significantly reduced in abundance inside *Spartina* clones at all locations (Fig. 2). The introduced Manilla clam *Venerupis phillipinarum*, and Eastern softshell clam *Mya arenaria* displayed no overall pattern, but were significantly more abundant inside *Spartina* clones at the Nemah location (Sta 2) when sites considered independently (ANOVA, $p<0.01$).

A second survey was conducted at Sta's 1 and 2 in 1995 in order to determine whether distance within a clone and hence clone size had an effect on the density of clams present. Samples were taken along a transect running parallel to the beach and from 10 m outside to the center of each clone. Five samples were taken at each of several distances (0.5 m, 2 m, 5 m and 10 m) from the inside and outside edge of the clone. Sampling technique was the same as in the 1992 survey and 2 clones were sampled at each beach. *Macoma spp.* were present at reduced density at all distances within the clone, and trends again differed by location for *V. phillipinarum* and *M. arenaria* (Fig. 3) Abundance of both of these species was reduced at distances of 5 and 10 m inside the clone at the Long Island location, yet at the Nemah public beach, *V. phillipinarum* density was higher inside the clone and no trend was evident for *M. arenaria*. We suspect that both substrate and hydrodynamic regime are the reason for the consistently different pattern occurring at the more exposed Nemah location. Greater current speed, sandy substrate, and decreased *Spartina* stem density (x = 15 stems m^{-2} versus 32 stems m^{-2} at Long Island) likely caused clams to be more equally distributed or even trapped and enhanced in abundance within clones at this site.

Figure 1. Map of Willapa Bay, WA showing the location of our sampling stations. Sta 1 on the northwest side of Long Island (grael substrate), Sta 2 along the Nemah Public Beach (sand), and Sta 3 on the north shore close to the Cedar River (muddy sand) were sampled in 1992 and 1995. Sta 4 located at Stackpole along the Long Beach Peninsula (sand) was sampled for small clams in 1993 and

Sta's 2 and 5 (north shore near North River, mud) are part of an ongoing survey in 1997.

Figure 2. Density of adult (>10 mm length) clams found inside, on the outside edge, and at 20 m from *Spartina* clones at all beaches combined (left, Sta 1-3, see Fig 1) and at the Nemah Beach (right, Sta 2 only in 1992. Note the significant negative effect of *Spartina* on density of *Macoma spp.* (top) at all beaches but mixed results for Japanese littleneck *clams Venerupis phillipinarum* and eastern softshell clams *Mya arenaria* where enhanced density was observed within *Spartina* at the Nemah site.

Figure 3. Density of adult (>10 mm length) clams found at selected distances from the edge of *Spartina* clones at the Long Island (Sta 1) and Nemah Beach (Sta 2, see Fig 1) sites in 1995. Note the lower density of *Macoma spp.* Found inside *Spartina* clones at both sites but enhanced density of *Mya arenaria* and *Venerupis phillipinarum* inside the clones at the Nemah site.

An investigation into the effect of *Spartina* on settlement and recruitment of small clams was initiated at a separate location (Stackpole, Sta 4, Fig. 1) in 1993 (Ratchford, 1995). Clams were sampled at 4 locations (center, inside edge, outside edge, and mudflat > 5m from clone) around each of 10 *Spartina* clones using a corer with a surface area of 34 cm^2 inserted 5 cm into the sediment. Samples were frozen, seived through a 0.25 mm screen, and sorted in the laboratory under a dissecting scope. Only *M. arenaria and Macoma spp*. were found in significant abundance at this location. The density of *M. arenaria* was highest at the inside edge of the clones right after settlement, highest outside on the mudflat in October, but no difference in density by location could be detected one year later (Fig. 4). Although settlement pulses were not as distinguishable for *Macoma spp*., density was significantly lower inside the patches than on the mudflat. Density at all locations was reduced one year later, but remained significantly lower at the center of the patches. Clearly settlement could be influenced by *Spartina* (negatively in the case of *Macoma* and positively for *M. arenaria)*, but post-settlement processes were also important.

A third and ongoing survey was initiated in 1997 to further examine post settlement events influencing the distribution of clams around *Spartina* clones including active and passive movement via bedload transport as well as predation. Since *Spartina* control has been initiated we will also investigate the effect of removing cordgrass on clam distribution. Even live *Spartina* is reduced to stubble during the winter period and is therefore likely to have less of an effect on water movement, while in the summer the tall plants would be expected to slow flow and perhaps movement of clams. Predation is also expected to be higher during summer months. We placed small trays with sediment, but no clams, in them flush with the sediment surface at the Nemah site (Sta 2) and at Smith Creek (Sta 5, Fig. 1). Trays were placed outside (10 m distance) and in the center of five *Spartina* clones at each site . Trays placed in January were sampled 26 to 40 days later to determine movement of clams during a period of winter storm activity. Ambient density of clams outside the trays was measured using a 550 cm^2 core to 10 cm depth as well as in a set of 5 clones that were killed the previous year. All samples were seived to 0.5 mm, frozen, and sorted for clams in the laboratory. We found small < 10 mm clams in most of the trays (Fig. 5) confirming previous work documenting movement of younger age classes (Emerson and Grant 1991; Roegner 1997). Although there appeared to be fewer clams in the trays located inside clones, there was no statistically significant difference at either location indicating that transport in the winter months is broad on the scale of a 5 - 10 m clone. We expect to repeat this work during the summer months for comparison, we use cages to investigate the effect of predation, and continue to monitor clam density in clones that were killed in 1995.

Finally, we compared growth of *Venerupis phillipinarum* in *Spartina* clones with growth on the open mudflat. Clams were marked, measured and placed in small mesh bags inside, along the outside perimeter and at 10m distance from 2 clones at Sta's 1-3 (Fig. 1). Clams placed in May were retrieved in October after a full summer of growth. Results indicated that growth was significantly reduced inside the *Spartina* clones versus outside the clones (ANOVA, $p<0.01$; Fig. 6).

Spartina alterniflora clearly has a significant effect on the structure of the habitat available to intertidal clams in Willapa Bay and our study documents a distinct effect on the distribution of some species. *Macoma spp.* are significantly reduced in abundance inside large clones. Other species are at least initially affected and abundance may even be enhanced within *Spartina* clones, which likely act as traps for juveniles and even adults of mobile species like *V. phillipinarum*. No studies have shown what happens when clones coalesce to form meadows , although Zipperer (1996) found no significant effect of *Spartina* on mollusc density (not identified to species) at her study site near the south end of Willapa Bay. Tidal elevation of the resulting habitat, which in the case of a *Spartina* meadow is likely to approach that of a native saltmarsh, will eventually preclude existence of intertidal clams. This may not occur for some time however, in areas that are highly erosive like the Nemah beach, where we found sparse stem density and little effect or even enhanced clam density. Work remains to be done in order to clearly elucidate the mechanism causing observed results, but we suspect that the physical barrier produced by the plant significantly affects movement patterns as well as growth of intertidal clams.

Figure 4. Density of small (<4 mm) *Mya arenaria* found in the center, along the inside perimeter, outside perimeter and at >5 m distance from Spartina clones at Stackpole (Sta 4, Fig 1) from June 1993 - June 1994.

Significantly more clams were found along the inside perimeter right after settlement in June 1993, but no differences could be detected one year later.

Figure 5. Density of clams, *Mya arenaria* (top) and *Macoma balthica* (bottom) found in trays of defaunated sediment placed within *Spartina* clones and at 10 m distance during 1997 winter storm activity. Trays were recovered 42 and 26 days after deployment at the North River (left, Sta 5 and Nemah Beach (right, Sta 2) locations respectively (see Fig 1).

Figure 6. Average survival and growth of Japanese littleneck clams *Venerupis phillipinarum* placed in large mesh bags inside, on the outside edge and at 20 m distance from *Spartina* clones at Sta's 1-3 (Fig 1) for 5 months during the summer of 1993. No difference was detected in survival, but clams inside the clones grew slower than those on the edge and outside the clone.

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PUBLIC ACTIVISM AND SPARTINA

LOCAL SPARTINA MANAGEMENT PLANNING FOR COMMUNITY ORIENTED RESEARCH AND DEVELOPMENT

Edward S. Cohen, Ad hoc Coalition for Willapa Bay

The last few years in southwest Washington have been a battleground on fundamental issues of watershed management. First, there is the terrible toll of wasted money and resources--time and effort--as a result basically of the rising hysteria over spartina cordgrass. Problems have been misidentified, basic research has been lacking and so the wrong problems have the wrong solutions. Gangs of bureaucrats and scientists fight for prominence in endless meetings and infinite theories on how to eradicate spartina.

Though posed as a major threat to the Willapa region, spartina actually is only a facet of much larger forces affecting southwest Washington and the life of the Willapa estuary. These include population growth and development and the major social issues; dredging, draining, bulldozing and paving; clearcutting. Pollution from runoff of contaminants from roads, vehicles, lawns, construction sites and dumps run off into streams, rivers and into the estuaries. Vast climate change and ocean current patterns have their role in shaping the life of estuaries. When habitat along stream channels is destroyed by poor agriculture or forestry activities, fish die because their nesting and feeding areas are destroyed. Fewer fish returning to the estuary wreaks havoc among the many living organisms in the food web that depend on healthy fish populations.

The hysteria over the cordgrass was fostered by a number of different institutions, including chemical companies led by Monsanto, producer of Rodeo; government agencies, the Nature Conservancy and Ecotrust and the Willapa Alliance. Oyster industry executives are afraid that if they lose the fight to use Rodeo, the whole question of their use of carbaryl (SEVIN) and other industry practices will gain the spotlight.

This is past history. Now is a time for enlightenment; to take the positive path; to work constructively to put the spartina questions where they belong.

Spartina is a natural resource that has many benefits to civilization. Taken as a resource, spartina has valuable attributes. Protein laden and loaded with sea trace minerals, the grass is an important biofilter and aids in shoreline erosion control. Self-harvesting in the fall as it dies back, the grass produces large quantities of mulch and composting material. Harvesting the young grass permits ongoing composting on farms, in home gardens, public parks and other public gardens. It serves as animal fodder and is being tested and used as medicinal solutions for illnesses like urinary tract infections, hepatitis and diabetes. It is a valuable source of cellulose and may be used in both artistic and commercial paper making. As a harvestible commodity instead of something to kill opens many possibilities for economical exploitation.

These include the exploitation of spartina for diverse agricultural, paper and packaging production; governmental procurement and future resource development. Moving in productive directions can improve commerce and employment and lead in direct ways toward more self-respect in the Willapa region with emphasis on quality of rural and small community economies.

The basic research and development plan for spartina goals

1. Help redirect public debate through outreach and education on the productivity and economic gains (economic velocity and quality employment) of spartina and other fibrous materials. Continue efforts to turn non-productive control methods (chemical control) to productive methods (harvesting). Efforts should be continued to provide guidance to public agencies and private landowners on agricultural opportunities of this specially endowed natural resource.

2. Continue research on spartina growth and dieback patterns to advance knowledge on harvesting locations and techniques. It is important to identify other fibrous materials for economic study and utilization.

3. Improve harvesting and storage techniques and processing of grass material. Develop new products and markets for products.

4. Put the acrimonious debate over agricultural chemicals in Willapa Bay to rest by establishing a public policy ending their use in our waters.

SPARTINA AND THE ROLE OF THE COMMUNITY

Chrys Bertolotto, Adopt-a-Beach

Consider these two questions:

How many places can we, as paid staff, elected officials, regulators and as individuals, be?
How many places can Spartina be?

In systems as large as Puget Sound or Willapa Bay, it is clear that the only way to reach our goal of eradicating Spartina from Washington State is to engage the community in the battle. Spartina is much too pervasive to be tackled by a small number of individuals. Community members are the eyes and ears who can seek out Spartina in all its nooks and crannies, who can remove small seedlings when first discovered and attack the clones that have been forgotten by us and, lastly, can tell others in the community that they should be alarmed and involved. The job of eradicating Spartina is simply too large to leave in the hands of government and scientists alone.

Who is the Community?
The community, in this context, is defined very loosely. It includes homeowners and recreationalists, marine park visitors and civic clubs, hunters and fishers, shellfish growers and school groups, tribal members and retirees, bird watches, and us. Community members have many skills and interests that can be employed in the fight against Spartina.

What can the community do about Spartina?

Hunt it out!
Kill it!
Talk about it!

1) Hunt it out: We need to know where Spartina is before we can remove it. Simple fact. In Puget Sound alone, there are approximately 2100 miles of linear shoreline. Let’s say that 50% of that shoreline is suitable for Spartina infestation. That leaves us with approximately 1050 miles of potential Spartina habitat, without even considering the width of that shoreline. Community members can be trained to accurately record their observations, identify Spartina and then “deployed” to actively hunt it out.

In Puget Sound, over 200 people have been trained in 2.5 years to do just that. Just over 600 documented miles of shoreline have been surveyed for unknown Spartina infestations. Many of those areas have been surveyed four or five times in the past 2.5 years because specific community members have adopted that shoreline for the long term.

In those 600 miles of paddling or walking, over 80 distinct Spartina infestations have been found. They have ranged from one plant to 20+ feet clones to a mudflat scattered with one - three foot clones. They have been found in lagoons, along marine shorelines, in mudflats and in river mouths.

Community members can be involved in a more passive manner: Let them know what Spartina looks like, why it is a problem and who to call if it is found. For $300, Adopt-a-Beach blanketed an island community (Bainbridge Island) with flyers. Two unknown infestations were reported, both fairly substantial.

2. Kill it: While Adopt-a-Beach started Spartina Watch to purely hunt out new infestations, our Technical Advisory Committee urged us to become involved in removal. In just under two years, community members (including tribes, homeowners, military dependents, and local groups) have removed or are in the process of removing 25 infestations. Six infestations have been part of large orchestrated “Spartina Digs” that occur on an ongoing basis. The others were removed as they were discovered or soon after.

The beauty of involving the community in Spartina removal is that some individuals will continue to go to that area and dig a little here or dig a little there. Community removal efforts are ongoing. Our goal in the six areas where we have done large digs is to support a local effort, show them how to do the dig if necessary and become less involved over time with that community taking on more and more of the leadership and organizing role. This _______________

3. Talk about it: Community members can recruit others into the Spartina fight, they can write letters to the editor, they can organize others to do a removal project or divide up a shoreline for surveying twice a year, they can ask their elected officials what they are going to do about the Spartina threat. Community members can motivate others to stop Spartina's spread and to attack it where it exists. Community members are excellent resources in helping to get the word out about an event or an urgent issue.

How does community involvement happen?

1. The community needs to be educated/trained.

   What is Spartina? Why is it a problem (why should I care)? How do I identify this grass? Who do I call if I see it? What can I possibly do to help? How do I document my observations? What are proper removal methods?

Adopt-a-Beach and Washington Water Trails have a large training program which covers all of these questions. The trainings are held locally and co-sponsored by local groups, naval bases, homeowners associations (members of the community). The most successful trainings are those in which co-sponsorship has occurred with clear understanding of each entity's different role. Spartina Watch trainings are focused on preparing community members to be aggressive Spartina hunters.

2. The community needs tools.

   Is there some format for documenting observations? How can I be sure I'm not surveying the same area as someone else? What are the areas of most concern? Where do I dispose of Spartina? Can you help us with shovels and a disposal vehicle?

You can't expect to train a community and say, "Go to it!" It won't happen. You will most likely get many passive Spartina foes (if I see it, I'll call someone). Initial time investment in working with a community is substantial, but the longevity and involvement of the community makes it worthwhile.

3. The community wants feedback and information.

   How are we doing? What has my neighbor found? Did we remove it right? Are we improving the situation instead of making it worse? What do those new regulations mean in terms of Spartina eradication? What's our long-term plan? Can you help me with this other problem I noticed while on my beach?

Community members are not just volunteers to be used by us but are active participants in the Spartina fight. They have much to contribute, many with legal experience, scientific backgrounds, etc. It is important to let them know how they are doing and what new items will affect them. In reality, you are helping to build the capacity of the community to address many resource issues in the long-term.

Issues to consider when involving the Community:

Quality Assurance/Quality Control (QA/QC): Citizen monitoring is still not unanimously embraced by our scientific and regulatory community. There are several ways you can build faith in your community survey efforts:

- Involve the scientific and regulatory community in a Technical Advisory Committee (along with community members). The Advisory Committee can let you know if the data collection method is adequate, if the target areas you have are appropriate and provide you with valuable insights into planning your project. The Committee members are invested in the direction of the program and can communicate any concerns they have to the Program Manager.

- Have a QA/QC plan.
- Require volunteers to send in samples when they find Spartina. Let them know it is better to send in a suspicious pickleweed sample than pass by a suspicious Spartina plant.
- Involve experts in the training program. They become familiar with the training and also are more acquainted with the type of education community members are receiving.

Digging is Frivolous: Many people shake their heads at the thought of digging up a 6 foot clone of Spartina. They say it is inefficient and a waste of time. They reality is, however, that these clones would be ignored while more pressing infestations are mowed and treated by paid crews. The reality is that community members want an avenue to address a local problem. The reality is that digs are a way for social quality time with one's neighbors and bring a sense of fulfilment (with exhaustion) to each person who does not do this for a living. Community members aren't paid and if they want to dig up a clone a bit larger than I'm willing to, I say go for it. As long as they are not unduly disturbing the mudflat or adjoining area or removing Spartina in such a way as to create a bigger problem, community removal efforts are always worthwhile and are a savings on our strained budgets.

Community members will be near involved in the Spartina fight long after our priorities have changed. They provide on-going witness to the growth or demise of Spartina infestations and, if prepared, can respond to the Spartina threat. They are more invested in their local shore than we will ever be because of NSIMBY: No Spartina in My Backyard.

Spartina Watch is a program funded by Washington Department of Agriculture worked in partnership with many tribes, community groups, Washington Water Trails Association, naval bases and more. The two year operating budget for Spartina Watch is $60,000, enough to hire two to three government FTEs for one year.

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THE TRIBAL EFFORT TO CONTROL *SPARTINA*

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Several tribes in Western Washington have taken a keen interest in the control of several *Spartina* spp. The reasons prompting this could easily be broken down into three categories: cultural, ecological and economic. Since time immemorial, fishing and shellfish have sustained the coastal tribes. Not only in feeding the physical body, but spiritually as well. *Spartina* spp. currently threaten to alter the environment that has provided for this culturally significant segment of Indian life. Habitat for both shellfish and salmon are being impacted so as to reduce or eliminate stocks due to the encroachment of *Spartina*. This is directly connected to economic impacts on sport, subsistence and commercial harvesting. Census statistics indicate that mean family incomes for Native American families are generally lower than surrounding populations, thus the economic benefits derived from supplemental shellfishing and fish harvests are all the more important.

Tribal *Spartina* eradication programs have been limited due to budget constraints, but have been a creative mix of funds and efforts to begin meaningful control.

Swinomish

- Public Involvement and Education (PIE) contract with the Puget Sound Water quality Action Team for public education and outreach on the environmental impacts of *Spartina*
- Surveyed Reservation shoreline to develop a comprehensive inventory of the infestation.
- Utilized digging and repeated mowing of infestations on the Reservation.
- No-spray policy.

Port Gamble S'Klallam

- Removal by excavation of recently located infestations on Port Gamble Bay.
- Will conduct a comprehensive survey of Port Gamble Bay shoreline.

Shoalwater Bay

- Recently acquired funding to conduct removal work through FSA.
- Will use excavation and repeated mowing for control.
- No-spray policy.

Suquamish

- Assisting the local community both on and off Reservation to conduct comprehensive surveys of Kitsap County shorelines.
- Assisting the local community in removal efforts.
- No-spray policy.

Tulalip

- Public Involvement and Education (PIE) contract with the Puget Sound Water Quality Action Team for public education and outreach on the environmental impacts of *Spartina*.
- Assisting the local community both on and off Reservation to conduct comprehensive surveys of Snohomish, King and Kitsap County shorelines.
- Digging and repeated mowing of infestations on the Reservation.
- Assisting the local community in removal efforts.
- Equipment research and development.
- No-spray policy.

SUSTAINABLE DEVELOPMENT AND SPARTINA CONTROL - A CASE STUDY ON THE CRISIS OF CIVIL DIALOGUE

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Sustainable Development:

At a meeting hosted by the Northwest Policy Center sustainable development was defined in part as follows: "*A sustainable community meets the needs of the present generation without compromising and where possible, enhancing the ability of future generations to meet their own needs...It requires new forms of cooperation among government, business and individuals."*

This is a good definition with which to begin, but the **true definition** of sustainability is one that **each community develops on its own**. Because communities and ecosystem are always evolving, there are many miles of road to be traveled before arriving at a definition that captures our hopes for the future of our community. We can only venture out, learn, and apply what we have learned, and learn again.

In order to understand why a sustainable development organization such as The Willapa Alliance would support an integrated pest management control solution, it is important to keep in mind the definition of sustainable development. From my perspective it even more important to keep in mind the following explanation of our approach to ecosystem management and environmentalism. Because we, like other organizations in our community and around the Pacific Northwest, are wrestling with what that **local community definition of sustainability looks like**. We haven't got it all figured out, but my guess is the defining will always be a work in progress. So here is our take on community based sustainable development that gives context to why The Willapa Alliance and the majority of our community have come to the difficult decision to support an IPM approach.

Pacific Northwest rural watershed communities face daunting economic, social, and ecological challenges as the timber and fishing industries have experienced major restructuring and down-sizing. For the Willapa this includes a long term rate of high unemployment, salmon habitat degradation, declining per capita wages, decreasing number of middle income earners and a disturbing flight of the area's best and brightest youth to areas of more educational and economic promise, while those who remain find it difficult to compete in the limited and usually low paying local job market. These challenges, rather than uniting communities have often further fragmented them. Most such communities are going through a long term leadership crisis. Political gridlock through mean spirited political and policy strategies and spurious law suits seem to rule the day. Natural resource/environmental problems abound, and are usually fraught with complex biological, social, economic, and political scenarios - answers are not easy to come by nor are they perfect.

The Willapa Alliance board, purposely made up of a cross section of the community at large, attempts to provide a forum for gaining new insight into the working of the Willapa ecosystem and for finding creative ways to ensure the long-term well-being of Willapa's communities, lands, and waters, and economy. *This is done through an abiding and overriding Alliance mode of operation that puts a premium and priority upon conflict resolution, collaboration, and cooperation between traditional adversaries in order to benefit our rural, natural resource based community - its environment and economy.*

Our mission is unlike that of traditional, narrower focus environmental groups who simply campaign to protect endangered species, reduce sewage discharges into an estuary, or regulate land use. Neither is it a traditional economic development program that ignores issues of long term productivity and sustainability in favor of maximizing financial values. We embrace a broader, a more encompassing vision.

The Alliance's development of its four complimentary program areas of Science & Information, Public Education & Involvement, Natural Resource Management, and Sustainable Economic Development has demonstrated our commitment and what we think is our community's desire to bring the essential linkages of these disciplines together to foster community well-being.

This work is being accomplished in the context of a complex and sometimes highly charged political, economic and social environment in which we seek to do valuable conservation education, natural resource management, and science work wherein the people of Willapa participate. We are experimenting with an approach that is non-confrontational in manner as we build an informational base of knowledge and understanding to kindle the conservation and community spirit in concrete ways so ordinary small town and rural people who probably never would call themselves "environmentalists" can become "activists" of sorts by supporting good laws, plans, and practices that sustain and restore the culture, economy, and ecosystem in a co-reinforcing way.

We are sobered though, because we are committed more to long term strategies than to short term solutions. And because this sustainable community development work involves dealing with complex issues around fisheries, water quality, forest health, social well being, all saddled with histories of debate and division. Any one issue is loaded with enough diversity of opinion to create significant controversy at almost any juncture - spartina case in point. But our community is too important and our place too lovely to not continue to try this new community based conservation approach in spite of the differences and difficulties. We have even learned that civil disagreement and civil conflict are not necessarily bad or a sign of failure, but perhaps more than needful, they can be useful.

Sustainability and Spartina Control

I have explained the mission, goals, philosophy and structure of The Willapa Alliance as a sustainable development organization as it gives context to the approach community based sustainable development organizations take to deal with environmental issues - an approach uncommon to the environmental community at large. So, why would a conservation based development organization EVER support the use of a chemical under ANY conditions? And why are some environmentalists so livid with us and our community at large for taking the position we have taken? Quite simply, we approach the world with a different understanding of how to get at community well being than do the more ideological environmentalists.

For community based, sustainable economic development to take place significant trust must be put in local stewardship and local processes that are based upon civil dialogue, community debate, and then consensus around conservation based development issues. This founded upon sound, a-political or non-politicized science. The science will no doubt be argued for some time as perhaps it should be.

For many of us in our community and those involved with the Willapa Alliance who consider themselves environmentalists and/or conservationists coming to the decision to support an IPM approach to control spartina was a highly charged and difficult decision. Some of those on my board and staff who support an IPM approach have been some of the primary flag carriers for environmental health in the Willapa for many years. The Nature Conservancy, the local chapters of the Audubon and Sierra Club have also supported an integrated pest management approach. Have they compromised? No, I think they, as I, analyzed the situation and came to a tough conclusion that if all weapons within reason with sound scientific safeguards were not utilized to control spartina the Willapa ecosystem would experience significant loss in biodiversity and productivity - devastatingly affecting wildlife, shellfish, economy, and human culture.

In drawing to a conclusion all of this doesn't mean we support a perfect solution. We do live in an imperfect world. However, we would contend we are holding to informed and longer lasting solutions because they have been hammered out on the anvil of local debate, have been tested in the fires of EISes, litigation, and permit processes, and are now embraced by majority of local people who possess a balanced mixture of science, local understanding, local values, and long term commitment to place. Top down legislated or litigated solutions while sometimes necessary are not as effective as locally produced and embraced stewardship values when those local solution have a credible science basis. My experience as a county commissioner in Pacific County in the 1980s, being then called the "environmental commissioner", taught me that unless environmental law is locally supported it has limited impact in the short term and most assuredly limited impact in the long term.

The more ideological environmentalists, who some at times could be aptly described as fundamentalist environmentalists, are often those who obstruct and deny the wisdom of community consensus because to them consensus is compromise when and if that local consensus wisdom and community collaboration disagrees with their position. They are fundamentalists not because they are bad people or are dumber than other people, but because they have positions/views/beliefs that are non-negotiable. I myself have certain non-negotiable positions, thus a fundamentalist on some issues. Holding to one's fundamental position is not wrong. The question is how we go about that; as to our own education, and as to how we act towards others and respond to them. Fundamentalist environmentalists may understand the complexities of ecosystems but many times they don't understand or they don't want to consider the complexities of human interactions, human values, community processes. They often loose credibility and the respect of local communities because as they hold to their unyielding position they are viewed as unnecessarily frustrating hard sought community solutions. They often offend well intentioned and honest people with accusations, rumors and unfounded conspiracy theories which has at times occurred Pacific County, Willapa Bay.

This is not to say that fundamentalist ideologues and fundamentalist ideological positions do not have an important role in community processes. Ancient Israel often had irritating prophets, most of whom where false prophets and false alarmists. But occasionally one of those irritating, ideological prophets was a true prophet with a true message that needed to be heeded. The body politic or "majority" can be wrong, sometimes terribly wrong.

It seems to me there are three key or "fundamental" issues that will take some time for differing parties and the public in general to sort out:

1) Is spartina counter productive, even destructive to estuaries like Willapa Bay?
2) If the answer to question #1 is yes, then can the bay be saved by non-chemical means alone?
3) If the answer to question #2 is no, then is the "proper" use of a chemical wrong to save the Bay from devastating impacts? The sort of "bay or hay" dilemma. Can society come to an answer as to what "proper" use is or is not? Or are chemicals wrong not matter what, under any circumstances?

Name calling and characterizations like "nozzleheads" and "chemophobes" are not helpful. Adhering to scare tactics on one hand and conspiracy theories on the other hand are extremely counterproductive. For example, I have been told that some of those in the Willapa who oppose an IPM approach have received threats of bodily harm. Fear makes a fertile bed for conspiracy thinking. On the other hand, because The Alliance supports an IPM approach and because a chemical company has taken out of context an interview of a member of my staff to further their advertising campaign, one of the more popular conspiracy theories is the Alliance is being paid by or controlled by industry. All this "rubbish" and negativity is so terribly counter productive and such a waste of time and resources. Additionally, it is ethically, and even at times morally wrong.

Furthermore quip five second sound bites that play to the press but don't play in Peoria (that is local communities), really don't get at resolving issues. It is truly unfortunate we are becoming a society in which winning becomes everything at the expense of genuine solutions; and that the tools of winning are not usually civil dialogue and debate, open minds and hearts, and thoughtfulness, but rather they are political schemes, shrewd attorneys, or the best spin doctors to win most effective headlines.

Allow me to propose Dan'l Markham's six rules for community based solutions to natural resource/environmental issues:

1. Be open and honest about what you are trying to accomplish and be flexible about the details.
2. Work through local people, local organizations, and local processes whenever possible, while humbly recognizing that local knowledge has its limitations.
3. Seek agreement on practical issues rather than on the theoretical issues.
4. Everything is negotiable; build reciprocity and mutual respect into the process while putting a premium on civil dialogue and your own education. Your own learning is an important part of the process, and if you haven't changed your mind recently you are probably not learning and not really a part of the civil process.
5. Work toward consensus as long as possible but never expect unanimous consensus. Their comes a point when you must take action regardless of how many people have or have not reached consensus. *By the way The Willapa Alliance doesn't have unanimous agreement on the best approach to control spartina but we have as an organization yielded to our agreement to continue to have civil dialogue around this and other environmental issues as we support the consensus process.*
6. Once you have taken a stand and action, then expect and accept criticism but do your best to not take it personally. Don't react. Rather, respond.

In a day when civil processes and civil dialogue are so pervasively ignored and even disdained that they even threaten the civility of society in general, it is assuring today that we have come together to not win but I hope learn as we honor civil dialogue.

ECOSYSTEM RISK ASSESSMENT

RISK EVALUATION THROUGH ESTUARINE MODELING

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Ecological Risk Assessment deals with the effect of anthropologically induced stresses in an ecosystem. In the case of Willapa Bay, there are a number of stresses evident operating simultaneously, not the least of which is the aggressive spread of the smooth cordgrass, ***Spartina alterniflora***. Other sources of stress include land-use management practices, such as clear-cutting, diked and drained high marsh, oyster mariculture and associated harvesting, shellfish and fish harvesting, tourism activities, real estate development, farming and so on.

The ecological risk assessment framework consists of a sequence of phases - problem formulation, analysis and risk characterization - refined by feedback. Careful characterization of assessment endpoints linked to a conceptual model yields an analysis plan. The analysis phase consists of characterization of exposure and ecological effects, and result in exposure and stressor-response profiles. The risk characterization phase describes and estimates the extent of the risk, yielding management options. Modeling ecosystems provides a means of evaluation of risk and prediction of ecological effects from environmental stresses.

Traditional ecological risk assessment has dealt with chemical pollutants that differ from biological entities such as ***Spartina*** in that they have no dynamic growth characteristic. For example, our risk assessment of DDT and dieldrin at an estuarine Superfund site in San Francisco Bay[i] involved extensive planning, preparation, site sampling, complex chemical analysis, bioaccumulation testing, bioassays, characterization of the benthic infauna and water-column species, statistical analysis and modeling. The resulting and historical site data were used to calibrate the model and make predictions about the fate and effects of the pollutants on the most sensitive species to be protected, fish-eating birds. At this site, from 1946 to 1967, DDT and dieldrin were milled and formulated into application powder at a rate of ~ 600 tons per month; by any measure, the operation lost a considerable amount of product. The sampling plan required replicate sediment grabs for chemistry, benthos, physical characterization, bioassays and bioaccumulation tests. Gradients of dispersion of this low-solubility pollutant were very evident.

To characterize the results briefly, I'll illustrate with a couple of examples of how the data were used. Predictions of fish-eating bird exposure to DDT and dieldrin as a function of time spent feeding in each sample location were accomplished by calculating a yearly average DDT residue in their fish prey (residue = # days feeding x average fish residue in ppb / 365 days). Plotting the data, we demonstrated that birds feeding exclusively in the areas remote from the spill would not exceed the National Academy of Science exposure criteria (50 μg/kg) no matter how long they fed; birds feeding adjacent to the site would exceed the criteria after 56 days, whereas birds feeding at the spill site would exceed the criteria after feeding for about 28 hours.

Based on these and benthic survey data, Swartz *et al*. (1993)[ii] demonstrated that the dominant ecotoxicological factor from these sediments for amphipods was due to ΣDDT (9.4 toxic units) and not to dieldrin (0.018 toxic units) in the sediment, although many other stressors were present (PAHs, PCBs, heavy metals). Declining abundance of sensitive species along sediment gradients approaching the highest contamination, verified by bioassays, provided the evidence.

The next example involves different kinds of stressors, without "traditional" pollutants. Staff at our laboratory[iii] modeled Yaquina Bay, starting with a bathymetric plot of the estuary, scaling the intertidal area. Incorporating a modified tide model allowed determination of the total time of exposure during daylight for increments of area of mudflat. A modification of the Green model (Miller, 1995)[iv] of ultra-violet-B radiation (UV-B) component of solar radiation allowed calculation of UV-B dose and dessication stress during those exposure periods. Using GIS techniques, estuarine habitat maps were overlain to combine the layers, helping to reveal the degree to which the organisms were vulnerable to the studied stress(es).

Again using amphipods as an example, two species of ***Corophium***, ***C. salmonis*** and ***C. insidiosum*** compete for territory in the Yaquina. ***C. salmonis***, the native species has historically been an important food for juvenile salmonids. Behavioral differences of ***C. salmonis*** and the non-indigenous ***C. insidiosum*** may affect preferential feeding patterns and prey selection by juvenile salmonids (Magnhagen, 1985,[v] 1986[vi]; Schlacher and Wooldridge, 1996[vii]), leading to heavy predation pressure on ***C. salmonis***, leaving ***C. insidiosum*** the relative freedom to exploit the site. The fact that ***C. insidiosum*** is sensitive to salinity and indifferent to temperature fluctuation, and that ***C. salmonis*** is sensitive to elevated temperature and indifferent to salinity fluctuation provides a way to model outcomes from differing climate scenarios. Using habitat overlays, we can then construct scenarios of the introduction of non-indigenous species via discharge of shipping ballast water.

The third example is drawn from Proposed Guidelines for Ecological Risk Assessment (EPA, 1996)[viii], which examines the threat of insects and fungi introduced by the import of sawlogs from Chile to the Pacific Northwest. The model clearly allows for consideration of the population dynamics of the stressor, but does not consider the secondary side effects of control measures. For instance, the description of distribution in the environment of the stressor considers colonization potential, spread potential, survival and reproduction; characterization of effects considers potential for ecosystem destabilization, reduction in biodiversity and loss of keystone or endangered species.

Control of ***Spartina*** in Willapa Bay may prove difficult, considering the history of non-indigenous species invasions such as ***Hydrilla***, water hyacinth, the infamous zebra mussel, fire ants and ***Melanoleuca*** in the Everglades. Control efforts have been expensive, time consuming, and in most cases, clearly a losing battle, sometimes with unforeseen side effects.

For example, attempts at control of fire ants by the pesticide Mirex® has had a long and troubled history of ineffectiveness; mass application resulted in the decimation of native ant populations,[ix] which were the only apparent effective deterrent to these opportunistic invaders, not to speak of the "downstream" effect of Mirex® on sediment-dwelling crustacea.

Cohen and Carlton (1995)[x] cite the experience of Cal Fish and Game in eliminating ***Spartina alterniflora*** in Humboldt Bay, consuming about five years of diking and smothering with black plastic, at a reported cost of $30,000 to $40,000, for a clump "the size of a house." A number of tests of control techniques for ***Spartina*** are underway in California, Washington, New Zealand, Australia and Great Britain; clearly some of these efforts will contain valuable lessons about effectiveness, costs and problems.

Consideration of these examples allows one to construct a scenario where the trade-offs involved in attempts to control invasions of species such as ***Spartina alterniflora*** may be modeled to a degree useful to management decision makers. For example, is it acceptable to allow ***Spartina*** to simply expand to a point of equilibrium, and learn to live with its effects? If not acceptable, to what degree would an assortment of control measures, *i.e.*, physical manipulation (mowing, covering with black plastic, *etc.*), biological or chemical control or outright removal be tolerable to the community of owners, resource managers and users?

The continual evolvement of the Ecological Risk Assessment Procedure, combining the relevant parts of these modeling procedures will accommodate such scenarios, and provide useful guidance to managers.

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CONTROL OF *SPARTINA ALTERNIFLORA* IN WILLAPA BAY, WASHINGTON: EFFICACY OF MECHANICAL AND CHEMICAL CONTROL TECHNIQUES, AND THEIR OFF TARGET IMPACTS ON EELGRASS (*Z. JAPONICA*)

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A report submitted to the Washington Department of Natural Resources by the Washington Cooperative Fish and Wildlife Research Unit, School of Fisheries, University of Washington, Seattle, 98195 (206)-543-6475

METHODS

Study Areas

In order to best determine the effectiveness of a treatment type within a particular substrate, four study sites were chosen at various locations within Willapa Bay: Lewis Unit, N. River, Nemah Beach, and Kaffee Meadow on Long Island.

The Lewis Unit is located at the southernmost part of the bay on the Willapa National Wildlife Refuge (WNWR) at approximately 46,20 N-124,00 W and is characterized by a deep, soft muddy substrate. Spartina currently exists in both meadows and clones in this area and a very heavy seed set over the last 2 yr. is rapidly expanding the total Spartina coverage. Where Spartina is absent approximately 55% (visual interpretation) of the mudflat supports eelgrass. The site is cut by several channels, up to 1.5 m deep, that drain south to north from the meadow out to the bay. Research here was limited to treatment of clones only.

The Nemah Beach site is located mid bay at approximately 46,35 N-123,55 W and is characterized by a hard packed sand substrate with an underlying clay layer at higher tidal elevations. There are no channels within this site, but a number of pools of standing water were present during low tide. Spartina coverage is limited to clones only. The study site extended approximately 1.2 km north and south along the beach. Where Spartina was absent, approximately 65% of the substrate contained eelgrass.

The North River site is located at the north end of the bay at 46,45 N-124,00 W and approximately 0.5 km SW of the confluence of Smith Creek and the N. River. The substrate is a mixture of sand and mud. Spartina coverage is limited to clones only with 55% of the uninfested areas containing eelgrass. There are a few small channels draining the site, with none more than 0.5 m deep.

Kaffee Meadow is located on the NE side of Long Island at approximately 46,30 N-123,55 W between the Kaffee and Lewis Sloughs. The meadow covers nearly 66 ha with greater than 90% being fully mature, homogenous Spartina meadow. The substrate is soft mud and a number of deep (1-2 m) channels drain the site. Eelgrass is limited to the eastern edge of the meadow where it shares mudflat with a natural set of oysters. Research was conducted within two, 2 ha plots and one 600 m transect, all including the mudflat (eastern) edge of the meadow. The tidal range on the two 2 ha plots was less than 1 m while the transect had a range of approximately 1.3 m. No clones occur at this site.

Sampling Design

Clones

Three study sites were chosen: Lewis Unit, Nemah Beach and N. River. Within each study site, Spartina clones were selected with diameters of 5-10 m and were marked for standardized sampling of stem density, stem height and yearly change in overall clone diameter. The surrounding mudflat was also incorporated within the sampling design in order to assess the non-target impacts of treatment on eelgrass. To accomplish this, each clone was marked with a center stake that was numbered and color coded to treatment type. Each clone was divided by four transects extending onto the mudflat for 5 m. Each transect contained a sampling point for Spartina located 1 m in from the clone edge, and two points for eelgrass outside the clone located 2 m and 6 m from the Spartina sampling point. A single entry point to each clone was established and these remained consistent in their directional approach over a given site. Travel within and around a clone during sampling was limited, and when necessary was contained to the inside edge of the perimeter where no sampling occurred.

Treatment

Mechanical treatment (mowing) of clones was carried out by technicians from the WNWR (Lewis Unit) and Washington Department of Fish and Wildlife (WDFW; N. River, Nemah Beach). Mowing was accomplished using various hand-held brush cutters. Depending on the substrate and Spartina density a variety of cutting attachments were utilized on the cutters including steel and plastic blades, and heavy duty plastic line. All mowing was done to within 10 cm of the substrate and any remaining culms were hand pulled or broken off at the base.

Herbicide application to clones was accomplished using hovercraft or back pack sprayers. At the Lewis Unit spraying was done using a hovercraft equipped with a Model 60-Spotlyte® agricultural sprayer with a hand-held wand and adjustable brass nozzle. The Nemah Beach, and N. River sites were sprayed using solo, 4 gallon back pack sprayers.

Both types of hand spray application used Rodeo® at 5% solution with the surfactant LI-700 @ 2% solution, following label directions of "spray to wet". Prespray calibrations of equipment provided approximate application rates of 42.1 L active ingredient/ha.

The combination treatment of mowing and spraying was accomplished using the two separate techniques listed above in combination. Clones were first mowed, then allowed to rejuvenate for approximately 6 weeks before being chemically treated.

All chemical treatments were made at low tides allowing 5-6 h of exposure before inundation of at least 50% of the plant. Weather conditions were optimal with air temperatures ranging between 19º and 29 ºC and wind speeds of 0-8 kmph (occasional gusts to 16 kmph at one site).

Treatment by hand application of herbicide occurred on July 19, 27, and 28 (Lewis Unit), July 18, and 19 (Nemah Beach), and July 20 (N. River).

Mechanical treatment by mowing occurred first on June 2,9, or 12 and again on August 8, or 9 (Lewis Unit), first on June 8, second on July 24, and last on August 24 (Nemah Beach), and first on June 13, second on July 28, and last on August 23 (N. River).

Sampling Design

Meadow Array

Monitoring for the aerial application of Rodeo at Kaffee Meadow was done within a treatment plot 400 m long by 50 m wide and included the adjacent mudflat along one length. Within this treatment plot, a buffer zone was created 5 m in from the edges from which 25 points were randomly selected for sampling. Random selection was accomplished by treating the plot as an x/y grid and generating random coordinates by computer. At each point a PVC pole was placed to mark it for continuous use as a sampling point . On the meadow sides adjacent to the core area, three 10 m transects were established at equal distances along each side. The adjacent mudflat perimeter contained five 10 m transects also spaced at equal distances

along the side. Sampling points along each transect (meadow and mudflat) were marked with PVC poles at 0, 3, and 10 m from the edge of the core treatment plot.
A control plot was also established for the aerial treatment and was located 400 m north of the treatment plot. It's design was consistent with that of the treatment plot with the exclusion of any adjacent meadow transects. Mudflat transects were established. Additionally, five points were evenly spaced and marked with a PVC pole on the southern edge of the control plot. These points were used for the attachment of filter papers during the spray to monitor for possible long range drift of the chemical.

Treatment

Herbicide application was accomplished by a Soloy Bell® helicopter with a 9.1 m toe-mounted boom on August 13, 1996 at 0915. Volume application rate included Rodeo® at 8.77L active ingredient/ha with X-77 ® Spreader, a non-ionic surfactant at 1.2 L/ha.

Application occurred 1 h before low tide on that date, allowing for maximum exposure time before inundation. Weather conditions for the spray were optimal with winds ranging from 0-8 kmph from the south, and an ambient air temperature of 14.5º C at time of spray.

Efficacy Data Collection

Measurement of treatment efficacy was conducted on the three different treatments (mow, hand spray, and mow/hand spray) for Spartina clones and the aerial spray on the Kaffee Meadow. Measurements included stem heights, and stem densities for meadows and clones as well as yearly diameter measurements of the clones. Off-target impacts were assessed by recording changes in shoot densities and percent cover of eelgrass (Z. japonica) proximate to the treatment areas.

Clones: Lewis Unit, Nemah Beach, N. River

To determine Spartina stem densities and stem heights at each location along the four transects, a 0.25 m^2 hoop was centered around the PVC marker and the number of individual culms was counted. Height was measured on the tallest shoot within the hoop. The four sampling points were averaged for each clone.

Percent cover and shoot density of eelgrass were measured at each clone along the two points of the four established transects; one adjacent to the clone, and one 5 m from the clone's edge. These points were located for each sampling period by a pre-marked cord that was stretched in a straight line from the center pole, over the Spartina shoot density stake, and out onto the adjacent mudflat. Sampling points were kept 'blind' during treatment to avoid any bias by operational personnel. Percent cover and shoot density were determined at a given point by centering a 0.25m2 frame subdivided into 25 100 cm2 squares over the spot marked in the cord. Percent cover was determined by counting the number of times eelgrass shoots intersected the 36 corners of the frames' subdivided squares. Shoot density was calculated by counting all shoots within the 25 squares. For every clone, percent cover of eelgrass was determined at both sampling points on all four transects with the adjacent and outer points being averaged for the entire clone. Shoot density was recorded at both points along only one randomly chosen transect in each clone.

All pre spray efficacy data collection occurred within 3-weeks prior to treatment. All pre mow and pre mow/spray efficacy data collection occurred within three weeks prior to any site's first treatment (mow). One year post efficacy data collection for all three treatments occurred within two weeks of true one year post with the exception of the mow and mow spray treatments at the N. River sites. This data was collected approximately three weeks beyond true one year post.

After averaging the values for Spartina shoot density and stem height, and eelgrass percent cover and shoot density for each clone, the values were then averaged over each treatment type per site and the % change was calculated between pre treatment (T1) and 'one year post' sampling (T2) with the formula:
{(T2-T1)/T1} X100.

Meadow: Kaffee Meadow on Long Island

At sampling points within the 2 ha core treatment plot, along the adjacent meadow transects, within the control plot and along the elevation gradient transect, Spartina shoot density and stem height were determined using the protocol for the clones described above. In addition, water height at one high tide was recorded at each of the 25 points of the treatment core area and the 14 elevation gradient transect sampling points in order to determine exposure time post treatment. To do this, a simple device was placed at each sample point at one time during the season and allowed to remain through a high tide at which time it was retrieved at the following low. On the adjacent mudflat (treatment and control) transect points, eelgrass shoot density and percent cover were determined using the same frames as the clone sites. For this meadow site the frames were centered against the pole and aligned on a compass bearing of 148º SE.

Pre spray efficacy data collection occurred within two weeks prior to treatment and 'one year post' data was collected approximately six weeks prior to true one year post. Data collection times were concurrent for treatment and control sites.

Again, all measurements were averaged within their location (treatment core area, mudflat perimeter, meadow perimeter and control) and represented as percent change from pretreatment to 'one year post' (Tables 5-6).

In order to determine the exposure time of the top 50% of the plant to the herbicide post application, the tidal inundation rate and height at each sampling point for the core treatment area was calculated. By using the ' Tides and Currents for Windows™' (Microsoft Inc., Redmond WA, 98052), we compared our on-site high tide measurements and site elevation to those given in the program for Paradise Point--the closest location to the study site. This gave us the difference between our site and Paradise Point, allowing us to convert Paradise Point information to our study location. Combining this with the Spartina stem heights taken at each sample point, we were able to determine the amount of time, post spray, that 50% of the plant was exposed prior to inundation.

RESULTS

All results of treatment efficacy, non-target impacts to eelgrass and chemical persistence are regarded as preliminary and will not be conclusive until 1 yr. post data is completely analyzed for statistical significance. The following results are based entirely on the summary statistics.

Efficacy

One year post treatment efficacy and non-target impacts to eelgrass are presented in Tables 3-6 for the three clone sites and the aerial spray (meadow) site.

Clone

For the clone sites, Spartina stem density and stem height showed a decrease in all treatment types at one year post. For eelgrass, all treatments at Lewis and Nemah showed a decrease in shoot density while N. River showed decreases for all treatments at the adjacent sampling point and increases at the five meter point. Percent cover of eelgrass was reduced at Lewis for all treatment types and all sampling points while Nemah and N. River showed decreases for mow and mow spray treatments and increases for the spray treatment at all sampling points.

Meadow

Efficacy measurements for the aerial spray treatment site showed increases in stem density and reductions in stem height from pre treatment to 'one year post'. These measurements were *very* similar to the data collected on the control site. Eelgrass measurements at the treatment site also showed reductions to both shoot density and percent cover. Again all measurements appear to be very consistent with the data collected simultaneously at the control site.

Table 3. Percent change in Spartina stem densities and stem heights within clones between pre-treatment and 'one year post' data collection.

	Lewis		Nemah		N. River	
	Stem Density	Stem Height	Stem Density	Stem Height	Stem Density	Stem Height
Mow Spray	-93.4	-77.8	-89.5	-87.3	-89.4	-87.3
Spray	-81.1	-72.9	-90.1	-87.7	-90.1	-87.7
Mow	-46.7	-29.2	-68.5	-61.6	-68.5	-61.6

Table 4. Percent change in eelgrass stem density and percent cover on mudflats among clones between pre treatment and 'one year post' data collection.

	Lewis		Nemah		N. River	
	Stem Density	% Cover	Stem Density	% Cover	Stem Density	% Cover
Mow Spray						
adjacent	-81.1	-85.2	-66.72	-54.01	-53.47	-63.79
5m	-74.5	-88.9	-29.77	-39.01	27.27	-36.58
Spray						
adjacent	-86	-90.9	-36.62	10.37	-32.71	67.07
5m	-91.8	-88.9	-25.83	6.11	35.22	198.65
Mow						
adjacent	-84.2	-86.8	-39.28	-44.67	-63.06	-81.28
5m	-70.9	-89.4	-49.92	-54.13	30.44	-38.5

Table 5. Percent change in Spartina shoot densities and stem heights between pre-treatment and 'one Yard post' collection at Kaffee Meadow--Aerial Spray Site.

	Stem Density	Stem Height
Treatment--Core Area	30.7	-41.2
Control	34.1	-41.2

Table 6. Percent change in stem densities and percent cover in eelgrass between pre-treatment and 'one year post' data collection at Kaffee Meadow--Aerial Spray Site.

	Stem Density	% Cover
Treatment--Adjacent Mudflat		
0meter	-54.5	-50
3meter	-25.6	-28.8
10meter	-62	-66.2
Control--Adjacent Mudflat*		
0meter	-52	-67.1
3meter	-43.4	-49.7
10meter	-61.5	-66.7

IMPROVING EFFICACY OF CONTROL TECHNIQUES AND NEW APPROACHES ON THE HORIZON

SPARTINA MANAGEMENT IN WASHINGTON STATE: APPLYING INNOVATION TO NOXIOUS WEED CONTROL

Cindy Moore, Washington State Department of Agriculture

By the mid 1990s *Spartina* control in Washington State was ready for a new approach. For years, federal, state and local government along with private landowners had been battling the aggressive, exotic cordgrass *Spartina*. Environmental concerns, extensive permit requirements and a lack of coordination and resources had hampered control efforts. In 1995, the Washington State Legislature declared and ecological emergency and directed the Washington State Department of Agriculture (WSDA) to take the lead in controlling and eradicating *Spartina*. Just over a year old, the state *Spartina* control and eradication program is significant in several ways. This paper addresses the specifics of the WSDA *Spartina* Control and Eradication Program in Washington State and discusses why some of the approaches that WSDA employs are considered innovative.

Spartina in Washington State

Since *Spartina* was first introduced into Washington State in the early 1900s, three species of *Spartina* have invaded approximately 17,000 acres of shoreline. Ten counties in western Washington are infested with either *Spartina alterniflora*, *Spartina anglica* or *Spartina patens*. These include San Juan, Skagit, Snohomish, Island, King, Kitsap, Clallam, Jefferson, Grays Harbor, and Pacific Counties. The majority of *Spartina* in our state, *Spartina alterniflora*, resides in Willapa Bay. County infestations range from one *Spartina* colony (or clone) measuring 50 feet in diameter in Clallam County, to a meadow measuring more than 400 acres in Pacific County. These infestations can be found primarily in four waterbodies including Willapa Bay, Grays Harbor, Hood Canal and the Puget Sound.

Program Components

Due to the fact that WSDA does not own any property, the program focuses on helping private landowners manage their infestations while coordinating control efforts on both public and private property. To achieve this, WSDA recognizes that boundary disputes need to be minimized, and that all tools for control need to be made available to landowners; the newest tool of which is herbicide control. These guidelines were used to develop the four main components of the WSDA *Spartina* control and eradication program: the state management plans, the 50/50 cost share program, the water quality permits, and public/private coordination efforts.

Management Plans

WSDA in cooperation with several county noxious weed control boards, wrote six management plans which cover western Washington. These areawide management plans are unique in that they address all known *Spartina* infestations, regardless of ownership. This allows control efforts to be prioritized geographically. The management plans document information for each infestation including when it was first discovered, property ownership, previous treatment methods, infestation size, the species, and possible threats it may pose. The management plans describe the eradication strategy for the coming year, listing the preferred method of treatment by the landowner. It is important to note that WSDA advocates Integrated Pest Management (IPM) in the management plans. WSDA staff asks landowners to carefully consider each of the control options before deciding on a control method.

These six management plans serve a variety of purposes. First, they document all known infestations in a given waterbody. This helps government agencies, tribal members, non-profit organizations, and private landowners plan their control efforts. Second, the management plans are an educational tool for landowners who live near an infested waterbody but know little about *Spartina*. Third, the management plans serve as an historical document which grows as new information is obtained. Due to the fact that *Spartina* eradication is a multi-year process, careful documentation of historical information is crucial. Next, the plans correspond with the waterbodies covered by each of the water quality permits which allow the herbicide Rodeo® to be used during the control season. Finally, the area management plans are used to draft the Statewide *Spartina* Management Plan.

Still in draft form, the Statewide *Spartina* Management Plan will eventually become the main document for *Spartina* control. It incorporates past, present and future plans for control in a waterbody, tracks control efforts by most public and private entities, and contains a brief description of all the key agencies and organizations involved in *Spartina* control. In addition, general information on distribution, control techniques, education efforts, research requirements, and a bibliography of published and unpublished reports collected over the years will be added to this plan. Due to the immense amount of information that this document will eventually contain, the statewide plan is being produced in stages.

Cost Share Program

There was substantial support for a 50/50 cost share program to aid private landowners. However, it was not clear how it should be structured. WSDA staff felt that *Spartina* cost share should deviate from the norm, allowing landowners a variety of options to work off their portion of the match. In an attempt to accomplish this and incorporate IPM, all control methods were considered and included. Table 1, *1996 WSDA Cost Share Options*, describes the cost share options that were available to landowners in 1996.

Table 1, 1996 WSDA Cost Share Options

Method	WSDA Pays	Landowner Pays	Cost-Share Terms
Mowing -Landowner	50% of rental fee, or 100% of maintenance fees	100% labor and 50% of rental fee	All eradication work must occur in '96 season
Mowing - County Crews	WSDA grants County funds to treat twice in '96 control season	Must meet cost-share term requirements	Must treat once more during '96 for eradication
Herbicide Applicat.- Landowner	100% herbicide and adjuvant	100% labor & equipment	All eradication work must occur in '96 season
Herbicide Application - County Crews	WSDA shares cost with County	Must meet cost-share term requirements	Eradicate uncontrolled areas & pull seedlings in '96
Cover - Landowner	100% of pre-approved material, stakes and cable	100% labor	All eradication work must occur in '96 season
Dig up - Landowner	50% of rental fee	100% labor and 50% of rental fee	All eradication work must occur in '96 season
Hire Contractor (for above methods)	50% of contract	50% of contract	All eradication work must occur in '96 season

For the 1996 control season, WSDA set aside approximately $150,000 for county work crews (an option on the cost share matrix), and another $100,000 for landowner cost share requests. Given that this was the first year a cost share program was implemented, WSDA was pleased with the results. The county crew option was almost exclusively used, indicating that landowners need not only monetary aide but also physical help. These lessons will be factored into the cost share plans for 1997.

Water Quality Permits

As a result of the 1995 legislation, *Spartina* control was exempted from all permits except for a "water quality permit" that was to be created and issued by the Washington State Department of Ecology (WDOE). This new permit was negotiated between WDOE and WSDA, and was the first of its kind. These permits are unique in that they allow the herbicide Rodeo® to be used with specified surfactants (spreaders) for five months beginning June 1, and ending October 31 of each year. The permit also covers an entire waterbody instead of limiting an applicant to a site-specific area within that waterbody.

The most significant change is that these permits are applied for and issued to WSDA, and in turn WSDA grants coverage under these permits to any landowner who qualifies for coverage. This means that landowners can avoid the traditional bureaucratic permitting process. Anyone who holds a valid pesticide license, has taken and passed the WSDA aquatic pest control exam, applies to WSDA, and agrees to the permit terms is granted coverage under the WSDA water quality permits. The application process requires individuals to fill out a one-page form, show proper licensure and send the form to either their county noxious weed control board or WSDA. Anyone granted coverage receives a copy of the applicable permit(s), a *Spartina*-specific pesticide application record to be filled out after each herbicide application, and a list of WSDA herbicide application recommendations.

The water quality permits mandate extensive public notification requirements. WSDA fulfills all public notification requirements, sending informational letters to all residents who could potentially be affected by Rodeo® applications in their neighborhood. In 1996, WSDA met those requirements by conducting a mass mailing to more than 44,500 residents in western Washington. WSDA staff also posted public accesses along selected shorelines, and published legal notices in newspapers of affected counties each month during the control season.

Public/Private Coordination

One of the key goals of the WSDA *Spartina* Control and Eradication Program is to coordinate public and private control efforts. Logic dictates that pulling together both public and private resources, coordinating control efforts geographically, and sharing knowledge will increase control effort results. This coordination is conducted in several different ways. First, planning sessions are carried out prior to each season which allows everyone to learn who is planning control work. Private landowners have a chance to speak about their needs and make suggestions. County control crew members make recommendations based on their knowledge of a given area and discuss problems. Second, WSDA coordinates equipment demonstrations so that landowners and control crews have a chance to test new equipment. Third, WSDA conducts two aquatic pest control licensing workshops annually for anyone interested in treating their *Spartina* with Rodeo®. Next, WSDA holds public information meetings prior to each control season in an effort to educate the general public about *Spartina* control in their area.

In addition, WSDA submits progress reports to the Legislature every six months, and conducts educational presentations when needed. Finally, in 1996 WSDA helped organize a *Spartina* Bash at The Evergreen State College in Olympia, Washington. This one-day conference assembled all individuals associated with *Spartina* into one room so that information and experiences could be shared. Due to the success of this Bash, it will become an annual event.

1996 Results and 1997 Plans

In 1996, a significant effort took place in western Washington to not only control *Spartina*, but also to eradicate it where possible. WSDA funded three county work crews in northern Puget Sound and two work crews in Pacific County. WSDA staff worked with Adopt-A-Beach, a non-profit organization contracted to do survey work, and private citizens to control or eliminate infestations in those counties without an active weed board. As a result of these control efforts and those made by other agencies and tribes in 1996, the extent of the *Spartina* infestation in our state was captured, further spread in most areas was prevented, and the work conducted this year gained on the *Spartina* infestation as a whole in Washington.

To put the 1996 WSDA-related control efforts into perspective, county and WSDA staff worked with approximately 100 landowners, controlling many *Spartina* infestations in nine of the ten counties. This is roughly translated to 870 acres of *Spartina* controlled during the control season. In addition, a large-scale aerial was carried out for the first time encompassing 405 acres in Willapa Bay. While this effort prevented seed set, information on efficacy will not be known until the spring of 1997. In addition Adopt-A-Beach, surveyed 246 miles of shoreline in the Puget Sound.

The 1997 program plan is to build on the efforts conducted in 1996. Due to the fact that much more is known about the *Spartina* infestation in Washington State, statewide priorities can be established. In keeping with weed science, the priorities will be to eradicate the outliers, eliminate the *Spartina* colonies northward in northern Puget Sound and southward on the coast, and then eradicate the *Spartina* meadows in northern Puget Sound and in Willapa Bay. All ten counties will be targeted for control during the 1997 control season, and cost share will once again be available to private landowners. However, the cost share program will be reconfigured in an effort to maximize resources. WSDA is also working with other government agencies and private organizations to explore alternative funding options. WSDA will once again contract with Adopt-A-Beach for survey work, and Skagit, Snohomish , Island, and Pacific Counties for county control crews.

Conclusion

It is understood that the war on *Spartina* is far from over. However, a great deal of public input and a little creativity has resulted in a new approach that focuses on the needs of private landowners, while coordinating *Spartina* control as a whole in our state. Probably the two greatest achievements of the WSDA *Spartina* control program are the simplification of government permit process for private landowners, and that fact that collective control efforts actually gained on the state *Spartina* infestation in 1996.

There is a great deal of work still to be done in Washington State. Obstacles ahead include finding large-scale machinery effective for mowing *Spartina* meadows, applying sophisticated mapping equipment to keep track of infestations and control priorities, and obtaining sufficient funding to adequately meet the challenge. It is clear that each player involved in *Spartina* control from the private landowner to key legislators plays a significant role in *Spartina* eradication. Therefore, WSDA staff will continue to push the parameters of traditional government approaches, initiate forums for public/private coordination, and charge ahead to eliminate *Spartina* before it is no longer possible.

COST-EFFICACY OF INTEGRATED SPARTINA CONTROL PRACTICES IN WILLAPA BAY, WASHINGTON

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Abstract. The cost-effectiveness of hand-pulling, mowing, combined mowing/Rodeo® (glyphosate), and lone Rodeo® treatments were determined. There were 174 treatments evaluated from 1993 through 1996. Hand-pulling newly established seedlings in May, June, or July 1995, eradicated Spartina at a cost ranging from 4 to 12¢/stem. The most cost-effective treatment is presented for each control option. A June 19 and August 10, 1995, mowing of Spartina to the mudline caused 95% necrosis. The cost was $312/acre. Mowing on May 31 and July 6, 1995, followed by a August 25, 1995, Rodeo/LI 700® hand wiper application provided 98% control at a cost of $431/acre. A June 9, 1994, Rodeo/LI 700 hand wiper application resulted in 91% necrosis. The cost was $310/acre. A July 28, 1995, Rodeo/LI 700 backpack treatment caused 81% kill at a cost of $585/acre. Simulated aerial treatments were applied with on the ground equipment but conformed to Rodeo label specifications. For simulated aerial treatments applied on July 2 and July 25, 1996, the absorption period was, respectively, 6 and 11 hrs. The degree of "browndown" 4 weeks after treatment was 30 and 71%, respectively, for the 6 and 11 hr. absorption periods. Treatments reduced seed-set to 0 or 1%. The cost of an actual aerial treatment would be $162/acre. The cost-efficacy of control measures should be considered when developing an integrated Spartina management plan.

INTRODUCTION

Spartina alterniflora (hereafter referred to as Spartina), an exotic, perennial, noxious weed is aggressively colonizing the intertidal mudflats of Willapa Bay, Washington. The infestation is growing geometrically and threatens to convert this productive, biodiverse, estuarine habitat into a monotypic Spartina saltmarsh. To date, Spartina has colonized 5000 acres of Willapa Bay mudflat.

The objective of this study was to determine the cost-effectiveness of the Spartina control options outlined in the Integrated Spartina (*Spartina alterniflora* Loisel.) Management Plan adopted by the Pacific County Noxious Weed Board (1, 2, 3). Control efforts evaluated included hand-pulling, mowing, combined mowing/herbicide treatments, and various herbicide applications. There were 174 treatments evaluated from 1993 to 1996. Only the most cost-effective treatments were reported herein (Tables 1-7).

MATERIALS AND METHODS

Hand-pulling. Hand-pulling of newly established Spartina clones was conducted in May, June, and July, 1995 (Table 1). Spartina leaves and roots were removed from each plot. The time required to hand-pull Spartina leaves and roots was recorded. Harvested biomass was rinsed, blotted dry, weighed and the number of stems determined. The cost of hand-pulling was determined on a per weight ($/kg) and per stem ($/stem) basis using a working wage of $7.50/hr. Efficacy was determined by counting the number of live stems in plots on September 15, 1995 and April 27, 1996. Percent control ratings were derived using the formula; [100 * (1 - (stem number observed Sept.'95 or Apr. '96/ stem number pulled))].

Mowing and mowing followed herbicide treatments. Spartina was mowed with a hand-held weed whacker to the mudline whenever possible. Wiping treatments were applied with a hand-held wiper. The height of the Spartina canopy prior to mowing or herbicide application was determined (Table 2). Spartina heights were significantly and progressively higher prior to the initial early-, mid-, and late-season mowing. All follow-up mowings were done when 1) growth suppression was 80% or less and 2) when regrowth reached a height of 12 to 15 inches. Continuous mowing regimes consisted of two, three, or four mowings (Table 3). Continuous mowing regimes followed by a herbicide treatment consisted of one, two, or three mowings followed by an August 25, 1995 wiping herbicide treatment (Table 4). The costs of implementing the various control measures were determined by monitoring labor ($7.50/hour), fuel

($1.50/gal.), and herbicide (Rodeo, $97). The long-term efficacy of treatments was determined by counting the live stems (regrowth) in a 1.0 ft^2 quadrat. The stems in one or two quadrats were counted for each plot. Percent kill ratings derived by using the formula; [100 * (1 - (stem number / stem number in untreated check))].

Herbicide treatments. The application methods evaluated included simulated aerial, hand-held backpack, and hand-held wiping. Backpack and simulated aerial treatments were applied with a CO_2 pressurized, hand-held, two-person, hooded, boom sprayer. Carrier volume was 10 gpa for simulated aerial treatments. The degree of seed-set in each plot was determined by visually estimating the percentage of stems that terminated in a seed-head.

Statistical analysis. A randomized complete block was used for all treatments except for hand-pulling plots which were arranged in a completely random design. All treatments were replicated 4 to 7 times. Treatment means were separated using Fisher's protected LSD ($Pr < 0.05$) or by standard error of the mean.

RESULTS AND DISCUSSION

Hand-pulling. Hand-pulling of one to three year old clones in May and July 1995, provided 97% to 100% control of Spartina based on April 1996, estimates of regrowth (Table 1). The cost ranged from $0.07 to $0.12/stem.

Mowing and mowing followed by herbicide treatments. The most cost-effective continuous mowing treatment involved a June 19 and August 10, 1994, mowing (Table 3). Based on April 1996 stem counts of regrowth, 95% of the Spartina was killed at a cost of $312/A. The most cost-effective combined mowing and Rodeo adjuvant treatments was a May 31 and July 6, 1995, mowing followed by an August 25, 1995, wiping treatment (Table 4). This treatment provided 98% control at a cost of $431/A.

Herbicide treatments. Simulated aerial, backpack, and wiping herbicide treatments were evaluated (Tables 5 and 6). The most cost-effective backpack and wiping treatment provided 91 and 81% kill at a cost, respectively, of $310 and $585/A (Table 5).

The adjuvants evaluated for simulated aerial applications were LI 700, R 11, Silwet L 77, Rhodameen OA-910, Alcodet MC-2000, Nu-Film-IR, and AgRho DR 2000 (Table 6). The period when applications are made until tidal waters inundate the treated portion of the Spartina canopy is referred to as absorption period. Identical sets of treatments were compared on July 2 and July 25 to determine the influence of drying time (Table 6). Increasing the absorption period from 6 to 11 hrs increased the degree of browndown from 30 to 70%. Both sets of treatments reduced seed-set from 68 to 0%. The cost-effectiveness of treatments are summarized in Table 7. The cost-efficacy of control measures should be considered when developing an integrated Spartina management plan.

Table 1. Cost-efficacy of hand-pulling Spartina.

		- - - % Kill - - -	
Month '95	¢/stem	Sep '95	Apr '96
May	4	99	97
June	7	100	
July	12	100	100
LSD, Pr < 0.05	nsd		

Table 2. Height of Spartina canopy at the time mowing.

Mowing	Early '95	Mid '95	Late '95
	Canopy height, inches		
1st	16*	23*	30*
2nd	13	14	15
3rd	13	14	
4th	12		

*LSD, Pr < 0.05 = 3 inches

Table 3. Cost-efficacy of continuous mowing treatments.

Mow Regime	Mowings	% Kill Apr '96	$/Acre
Control	0	0	0
Early '95	4	92	469
Mid '95	3	99	346
Late '95	2	95	312
LSD, Pr < 0.05		nsd	

Table 4. Cost-efficacy of combined mowing and Rodeo adjuvant treatments.

Mow Regime	Mowings	Rodeo* Qt/A	% Kill Apr '96	$/Acre
Control	0	0	0	0
Early '95	3	6.5	100	637
Mid '95	2	3.5	98	431
Late '95	1	4.8	97	456
LSD, Pr < 0.05			nsd	

*Wiping appl'n with 5% LI 700

Table 5. Cost-efficacy of hand-held wiping and back-pack Rodeo adjuvant treatments.

Method	Appl'n Date	Rodeo* Qt/A	% Kill Apr'95/'96	$/Acre
Control	na	0	0	0
Wipe	Jun '94	8.3	91	310
Spray	Jul '95	18.0	81	585
LSD, Pr < 0.05			26	

*Plus 5% LI 700 for wipe and 2% for spray

Table 6. Preliminary data from simulated aerial applications (3.75 Qt/A Rodeo, average of 7 adjuvants).

Appl’n	Absorp	4 WAT*	Oct '96

Date ‘96	Period	% Browndown	% Seed set	$/Acre
Control	0	0	68	0
Jul 2	6	30	0	162
Jul 25	11	71	0	162

*Four weeks after treatment.

Table 7. Summary of the most cost-effective, integrated Spartina management practices.

Method	% Kill	Acreage	$/Acre
Mow only	95	low	312
Mow + Rodeo	98	low	431
Rodeo hand wipe	91	low	310
Rodeo hand spray	81	low	585
Rodeo aerial spray	?	high	165

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WHY ARE THERE 5,000 ACRES OF *SPARTINA* IN WILLAPA BAY???

Wendy Sue Bishop, Pacific County Weed Board

Three species of *Spartina* are invading Washington saltwater estuaries, turning the biologically rich beaches and intertidal flats into high marshy meadows. *Spartina* is native to the East Coast, where estuaries have extensive intertidal meadows instead of beaches, eelgrass, and clam and oyster beds. If we allow change in this direction to continue, migrating shorebirds will lose an important food source, waterfront owners will lose their beaches, many fish will lose their nursery areas, and clams and oysters will lose their habitat. If left uncontrolled, these areas will ultimately consist of broad high marsh flats cut by narrow, deep channels. The result is massive habitat alteration with ramifications to wildlife, fisheries, geology and hydrology.

How did the infestation in Willapa Bay get so out of hand?

Back in the 1980's when there was approximately 500 acres of *Spartina* in Willapa Bay, it was being decide at a state level how to proceed forward in dealing with *Spartina*. *It was illegal at that time to even remove a seedling from your property in Willapa Bay.* In the early 1990's when the infestation had expanded to 3,000 acres; an environmental assessment had been completed, permits were still being argued over and...the grass still grew.

In 1991 at the State level the Legislature allocated $450,000.00 for research, an Environmental Impact Statement (EIS), public education, and an eradication plan. Thus funding 23 agencies (state, federal, local, tribal, business-related, and volunteer) to study the issue.

A group of approximately fourteen people that represented several state and federal agencies and local landowners and business people, were assembled in October, 1993 by the Pacific County Commissioners who had declared *Spartina* an emergency issue. Their assigned goal was to develop a practical *Spartina* Management Plan for the approximate 450 private tideland owners of Willapa Bay. This Pacific County *Spartina* Task Force completed a draft of a SMP in February of 1994. The Management Plan itself outlines an Integrated Pest Management (IPM) approach that applies available and legal management methods to situations actually found in Willapa Bay. This approach follows the IPM strategy identified in the Aquatic Plant Environmental Impact Statement where location specific treatments based on specific site conditions are preferred over a generic area-wide treatment. The plan is a living, breathing document and is updated annually with control season information.

Early in 1994 the county, state and federal agencies applied for permits to initiate control efforts. These applications were immediately challenged by three entities. After lengthy negotiations, the parties reached agreement in 1995 initiating a comprehensive IPM approach to *very limited* infested acres in Willapa Bay.

When permitting process for the following spring became bogged down in legal complexities, state Senator Sid Snyder from Pacific County introduced legislation in the Washington State Senate to streamline the permitting process. There was great support for this step and the legislation passed both the house and the senate with only one descending vote that was changed, and was signed into law by the Governor in May, 1995.

The Pacific County Noxious Weed Control Board is the mechanism by which private landowners are contacted, trained and kept informed of the ongoing status of the program. The Washington State Department of Agriculture (WSDA) is the entity to which required annual permits are granted. There are over 470 private landowners with intertidal and saltmarsh land in Willapa Bay. The PCNWCB coordinates inventory, management, and evaluation processes with other agencies.

In order to manage the over 5,000 acres of *Spartina* in Willapa Bay, the *Spartina* Management Plan addressed this issue by geographic considerations. The Willapa Bay estuary specific *Spartina*

Management Plan is driven by three major geographic considerations: land ownership, surface conditions, and the distribution of target populations within each estuary. Therefore the Willapa Bay estuary was divided into 37 smaller manageable units, by: substrate, access, and topography. The units have been defined between 1,000 and 3,000 acres each, or around five miles of shoreline.

Prioritization has been key in the eradication strategy. The immediate target populations (Priority One) include: areas of highly viable seed producers (hot clones) in sites that allow for wide dispersal. *Lack of control in these areas will result in in-effective control in other units due to the re-seeding potential of these high seed production areas*, riverine populations, extensive meadows, areas of seedlings and small clumps on mostly open tidelands, and intertidal regions that are free of *Spartina* at this time, but will require annual inventory. Other populations (Priority Two) include: groups of medium to large clumps, scattered clumps in native salt marshes, fringing meadows less than 200 feet wide, and, outliers.

1997 Control Efforts. Full scale control efforts of *Spartina* in Willapa Bay have been initiated. *Interagency coordination has been key in this process.* There are four prominent areas were private tideland owners of Willapa Bay can find assistance for *Spartina* eradication on their property. These include: Pacific County Control Crews, Washington State Department of Agriculture Cost Share, Farm Service Agency Cost Share, and the United States Fish and Wildlife Service Challenge Grant.

Pacific County Control Crews consist of *Spartina* control crews, hired by Pacific County Noxious Weed Control Board and funded through the Washington State Department of Agriculture, will be available to aid the private landowners with control efforts on individual properties.

Washington State Department of Agriculture Cost Share. The Washington State Department of Agriculture will be implementing a cost share program for the private tideland owners of Willapa Bay.

Farm Service Agency Cost Share. The United States Department of Agriculture's Agricultural Conservation Program is implementing a Spartina Control Cost Sharing Program for commercial agriculture and aquaculture producers through the Grays Harbor and Pacific County Farm Service Agency.

United States Fish and Wildlife Service Challenge Grant. Through grants and in-kind supplies, labor, materials and equipment the County will raise $50,000.00 toward the completion of Spartina control projects in the southern end of the Bay adjacent to the United State Fish and Wildlife Service's Infestations.

With the help and coordinated efforts of State, Federal, Local, and Tribal governments, and private tideland owners of Willapa Bay ,and the state, we will win back the territory, the habitat, the unique character of our estuaries. We can reclaim the thousands of acres already displaced. And in doing so, secure the future health of our estuaries, our economic and ecological heritage. *By working together, we can defeat this opportunistic intruder called Spartina.*

MANAGING *SPARTINA* IN VICTORIA AND TASMANIA, AUSTRALIA

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1. Introduction

The problems associated with the spread of *Spartina* in Australia have long been recognised. During the 1970s and 1980s government agencies and community groups expressed their concerns for ecological and social impacts associated with *Spartina* encroachment. During this period, concerns and actions relating to the spread of rice grass were limited to sectoral discussion and ad hoc decision making. More recently, the aquaculture industry has voiced concern over the likely economic impacts associated with expanding *Spartina* infestations, particularly with regard to the culture of the intertidal oyster *Crassostrea gigas*.

The low profile of *Spartina* in Australia was addressed in 1991 at 'The Sea has Weeds Too!' conference in Inverloch, Victoria. The relatively low priority status and the need to share information and develop a National Strategy for the control of *Spartina* in Australia was discussed at the 1995 'How Green is Your Mudflat?' Australasian conference in Yarram, Victoria. The success of both conferences and continuing concern for ecological, social and economic impacts associated with *Spartina* encroachment in Victoria and Tasmania, has produced separate approaches to *Spartina* management in both states. This paper will outline the development and direction of both state strategies to control the spread of *Spartina*.

2. A Strategy to Control the Spread of *Spartina* in Victoria

During the late 1980s, the spread of *Spartina* in Victoria's inlets and estuaries attracted genuine concern from a variety of conservation groups and local individuals. In 1991 the Department of Natural Resources and Environment (DNRE), Yarram, was prompted to become involved in the *Spartina* issue in South Gippsland. The Department, in conjunction with conservation groups and local individuals, decided to approach the problem by:

- mapping *Spartina* infestations in the South Gippsland region;
- organising community workshops to raise the profile of the problem;
- participating in a joint project coordinated by the Royal Australasian Ornithologists Union (RAOU) to assess the effect of *Spartina* on migratory wader birds; and
- assessing methods used to control *Spartina* (Williamson, 1995).

The mapping exercise provided the Department with information that identified the location of known infestations, the extent of infestations and the magnitude of the problem. Community workshops provided conservation groups and individuals with the opportunity to ask questions, raise concerns and better understand the nature of the *Spartina* problem. Monitoring of migratory waders in Anderson's Inlet is continuing. Although meaningful data is not yet available, it appears that the spread of *Spartina* may be related to population decline in some migratory wader birds.

The Department assessed a variety of techniques used to control *Spartina*, including slashing, burning, sluicing, digging, smothering and herbicides. All control techniques, with the exception of herbicides, were considered ineffective or only suitable for small infestations. The search for a suitable herbicide to control *Spartina* was conducted by Graeme Pritchard at the Keith Turnbull Research Institute (KTRI). Preliminary trials with 13 herbicides investigating efficacy, toxicological properties, environmental persistence and post-spraying analysis of residues indicated that Fusilade (Fluazifop-P) was the most appropriate herbicide to control Victoria's *Spartina* infestations (Williamson, 1995).

Although Fusilade is not a registered herbicide for use in aquatic environments, the Department obtained an 'off-label' permit from the National Registration Authority for Agricultural and Veterinary Chemicals (NRA) after discussions with the Australian Commonwealth Environmental Protection Agency and Agriculture Victoria. The decision to grant an 'off-label' permit was strongly influenced by a report prepared by the KTRI and the Victorian Fisheries Research Institute (VFRI) investigating the toxicity of Fusilade to seagrass and near-shore marine fauna. The report showed that ecological impacts associated with Fusilade were acceptable and could be minimised with Best Management Practice (Palmer *et al.*, 1995).

In February 1995 a regional *Spartina* Control Project for South Gippsland (containing approximately 98% of Victoria's *Spartina* infestations) using Fusilade was proposed by the DNRE. The program is proposed to run in two phases:

- a five year control program for Corner Inlet (45 ha) and Shallow Inlet (<1 ha) and containment in Anderson's Inlet (130 ha); and

- a control program for Anderson's Inlet (130 ha) to be developed after refinement of control techniques in Phase 1.

The DNRE have committed a total of A$125,000 to the 5 year program ($25,000/year). The project has just entered the second year of phase 1. A recent assessment of the projects' first year showed that during the spraying period (February to April), Fusilade was particularly effective for controlling *Spartina* in Victoria (98 - 100 % efficacy). The use of hovercraft has proven to be particularly effective for traversing mudflats and has been the key to a successful control program.

3. The Establishment of the Rice Grass Advisory Group in Tasmania

A plethora of legislation, sectoral interest, ad hoc decision making and a general lack of integration in coastal zone issues has made the task of managing *Spartina* in Tasmania very difficult (OECD, 1990; Hedge, 1996). Until recently, efforts to control *Spartina* in Tasmania have been uncoordinated and sporadic. Under Tasmania's new Resource Management and Planning System, however, a Tasmanian State Coastal Policy has been developed. The policy mentions exotic weeds of the coastal zone and is designed to enforce sustainable development and management practices in the coastal zone and to include government, industry and the community in the decision making process relating to coastal zone management and planning issues (Tasmanian State Coastal Policy, 1996). Weedplan, a Tasmanian weed management strategy, has also been developed recently, addressing the State's weed problem by facilitating integration and cooperation between government agencies, industry and the community. The most important development for managing *Spartina* in Tasmania, however, is the establishment of the Rice Grass Advisory Group (RGAG).

The RGAG was established in early 1996 after mounting concern from government agencies, the aquaculture industry and the community over the spread of *Spartina* in Tasmania's estuaries and inlets. The RGAG is under the auspices of the Tasmania's Department of Primary Industries and Fisheries, the State's fisheries and weed management agency, and is made up of 12 individuals representing the major stakeholder groups including: State and local government, industry (fisheries), the Commonwealth Scientific and Industrial Research Organisation (CSIRO) the University of Tasmania; and the community. The overall objective of the RGAG is to coordinate management for the control of rice grass. To achieve this objective the RGAG will:

- determine the extent and impact of *Spartina* infestations in Tasmania;

- develop a strategy for managing *Spartina* in Tasmania including all stakeholders; and

- pursue funding options suitable for the control of *Spartina*.

In less than a year the RGAG has secured funding for two projects:

- Coastcare funded project: Coordinated Management Strategy for the Control of Rice Grass (A$16,500 + A$11,500 in-kind contribution). This project includes a brief outline of *Spartina* in Tasmania (positive and negative impacts), mapping all known infestations (using a hovercraft where necessary), evaluation of available control techniques and recommendations for future management direction.

- Fishcare funded project: This pilot project examines the impact of *Spartina* on fish habitat and biological diversity of Little Swanport Estuary, the efficacy and practicality of control techniques and the impact of Fusilade on fish habitat and biological diversity (A$7,500 + A$30,000 in-kind contribution)

The projects are being conducted concurrently. Results and findings are expected to be released in mid 1997. Information contained in the reports will help the RGAG to make informed decisions regarding steps toward *Spartina* control and eradication in Tasmania. At this stage, herbicides appear to be the only effective and practical way to control *Spartina* infestations in Tasmania. Early discussions indicate that a control program may be headed by a small team of specially trained field workers. The team would be responsible for planning, mapping, spraying and assessment of the control program. Funding options to support the implementation of a Statewide control program for *Spartina* are currently being explored. One may be the recently announced Federal Green Corps Program, set up to mitigate environmental degradation and encourage youth training in environmental issues and natural resource management. Another option is the National Heritage Trust which is Federal funding for the long-term conservation and sustainable management of the environment.

4. Managing *Spartina* Beyond 2000

Managing *Spartina* requires significant financial input to cover the cost of herbicide, travel and labour, particularly during the early stages of a control program. If funding for *Spartina* research and control is to continue in Australia, policy makers will want to see results for money (i.e. is the control program working and has it achieved its objectives?). To ensure a commitment to funding, it is therefore vitally important that funding priorities are carefully selected. Control programs should have realistic time frames, receive ongoing and adequate assessment; and the community should be informed on its progress.

Given adequate funding, and the sustained effectiveness of current control techniques, Australia's *Spartina* infestations can be controlled, however, this will not be a short term goal. Some waterways, such as the Tamar River, Rubicon Estuary and Anderson's Inlet, due to the magnitude of the problem and the social and economic consequences of total eradication, may never be totally free from *Spartina*.

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