Title

Humboldt Bay Cooperative Eelgrass Project

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Humboldt Bay Cooperative Eelgrass Project

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Introduction

The detection of dwarf eelgrass (*Zostera japonica* Aschers and Graebn) in Humboldt Bay, California, in June 2002 represents the southern extent of its range in the Eastern Pacific and it is the first time this introduced species has been encountered in California. *Z. japonica* is capable of rapid expansion over non-vegetated mudflats, and the species has become well established in estuaries throughout Washington and Oregon (Baldwin and Lovvorn 1994, Bulthuis 1992, Dudoit 2006). The *Z. japonica* population in Humboldt Bay was monitored from June 2002 through April 2003, and the plants exhibited exponential growth (Schlosser et al, in prep).

Eradication efforts were initiated in April 2003 by a team of volunteers coordinated by U.C. Sea Grant Extension in collaboration with the California Department of Fish and Game (DFG). Since April 2004, on-going monitoring and eradication has been made possible through grant funding provided by the National Fish and Wildlife Foundation. Expenses covered by grant funds have included U.C. Sea Grant Extension staff time, student interns, and field supplies. Contributions to the project include DFG staff time and DFG boat use. This report documents the work accomplished for the period April 1, 2004 through November 30, 2007. A new grant provided by DFG will allow the project to continue starting December 1, 2007.

Project Background

Z. japonica was discovered at the southwest end of Indian Island in Humboldt Bay in June 2002 during annual surveys for the native eelgrass (*Zostera marina* L.) conducted by the Humboldt Bay Cooperative Eelgrass Project (U.C. Sea Grant; Humboldt Bay Harbor, Recreation and Conservation District; and DFG). Dr. Frank Shaughnessy (Humboldt State University Biology Department) and Gordon Leppig (DFG, Eureka office) were the first to identify the species, and the identification was subsequently confirmed by Dr. Paul G. Harrison (Associate Professor, Department of Botany, University of British Columbia), Dr. Douglas Bulthuis (Research Coordinator, Padilla Bay National Estuarine Research Reserve, State of Washington Department of Ecology), Dr. Barry Tomlinson (Professor of Biology, Harvard University), and Dr. Sandy Wyllie-Escheverria (University of Washington). Dr. Sandy Talbot (Geneticist, USGS Alaska Science Center) confirmed the identification with a genetic analysis. A voucher specimen of *Z. japonica* was deposited at the Humboldt State University (HSU) and the California Department of Food and Agriculture (CDFA) herbaria in summer 2002.

The *Z. japonica* found at Indian Island extended along a 272 m stretch of beach, and consisted of 27 patches covering approximately 156 m^2. *Z. japonica* was growing on sandy mudflats in the mid to upper intertidal, ranging from 0.9—1.2 m MLLW. *Z. marina* beds occurred nearby at lower elevations, and in some places the two species were intermixed. The site is adjacent to a dredged channel that drains approximately 75% of North Bay.

After this initial discovery, a bay-wide survey for *Z. japonica* was performed that covered over 47 km of shoreline. No additional areas containing *Z. japonica* were found. Boyd et.al (2002) surveyed 58 locations in Humboldt Bay for non-indigenous species and no *Z. japonica* was found.

The method of introduction into Humboldt Bay is unknown. The precise timing of the introduction is also unknown, but is believed to have occurred sometime between 1996 and 2002. Posey (1988) found that there is a significant decrease in particle size in the associated sediments in patches of *Z. japonica* that are six years or older. When we found *Z. japonica* here in 2002, we conducted a particle size analysis and found no significant difference, leading us to believe that the *Z. japonica* had been established for less than six years.

A team of scientists, including representatives from NOAA Fisheries, USFWS, CDFG, UC Sea Grant, HSU, and UC Davis, was assembled to assess the available information on *Z. japonica* and the extent of its introduction into Humboldt Bay. It was the consensus of the team, and additional marine scientists whom were consulted, that an eradication program should be undertaken. Because there appeared to be only a small isolated area in Humboldt Bay where *Z. japonica* was located, the prospects for complete eradication were considered to be good. No other previous attempts have been made to eradicate this species.

Before initiating eradication measures, we established a monitoring program of the *Z. japonica* population, gathering data on growth characteristics and phenology from June 2002 through April 2003. All patches monitored increased in size, particularly at +1.2 m MLLW tidal elevation. The plants exhibited a perennial habit, with highest biomass, shoot density, and number of flowering shoots occurring in the fall (Schlosser et al, in prep.). These characteristics are similar to those found in Oregon *Z. japonica* populations by Larned (2003), while Kaldy (2006) reported highest shoot density and biomass during summer months. Schlosser et al (in prep) also examined the effects of *Z. japonica* on benthic polychaetes. Polychaete species diversity was significantly higher within *Z. japonica* patches compared to unvegetated mudflat, and overall invertebrate species composition was different.

We tested several eradication methods including excavation, burning, covering, and hand weeding. Excavation was determined to be the most effective method for removal of patches. We gathered information on the biology of the species; we researched the policies regarding *Z. japonica* in Oregon and Washington; and then we developed an eradication proposal to excavate all plant material from the shoreline of Indian Island and deposit it at an upland location on the island, well above the extent of tidal action and protected by a man-made levee.

Initial removal of the plants took place during April 2003 under emergency authorization from California Coastal Commission, Humboldt Bay Harbor District, and Army Corp of Engineers. This initial effort resulted in the removal of 284 m^2 of *Z. japonica*. The task was completed with the assistance of 48 volunteers working a combined total of 259 hours over two days. Monitoring and removal efforts continued on a regular basis until mid October 2003 and then sporadically until April 2004 when National Fish and Wildlife Foundation funds became available to hire a U.C. Sea Grant Staff Research Associate to coordinate monitoring and eradication of *Z. japonica* in Humboldt Bay.

Study Area

Humboldt Bay (N 40° 46', W 124° 14') is a marine dominated embayment linked to the Pacific Ocean by a narrow (0.5 mile) entrance channel (figure 1). Humboldt Bay is one of California's largest estuaries, covering 62.4 km^2 (MHW), second only to San Francisco Bay, which is located 372 km to the south. Intertidal mudflat covers 65-70% of the total bay area and extends from MHW to MLLW over approximately 2.0 m relief (Barnhart et al. 1992). Humboldt Bay temperatures range from 9-20^{o}C. Salinities range from 25-34 ppt with true estuarine conditions occurring only near the mouth of the six tributaries entering Humboldt Bay.

The bay consists of three regions: North Bay, Central Bay, and South Bay. North Bay is farthest from the entrance channel resulting in a mud-dominated system. Central Bay links North

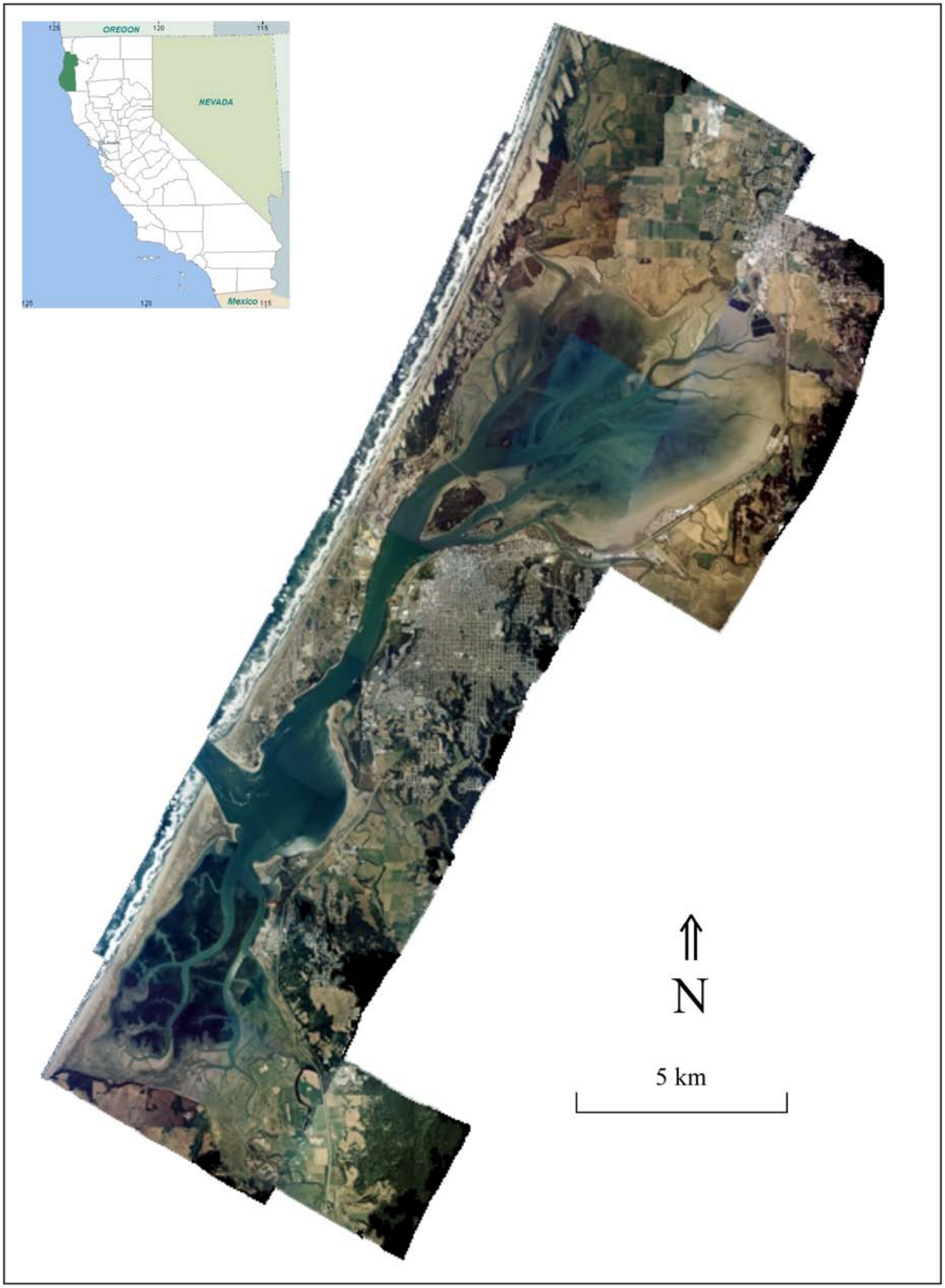

Figure 1. Aerial photo of Humboldt Bay. (Inset: map of California, highlighting Humboldt County).

Bay to the entrance and contains two islands, Indian Island and Woodley Island (figure 1). Tidal currents are strongest in the Central Bay where current velocity is between 0.75 to 1.2 cm/sec (Barnhart et al. 1992). South Bay receives significant sediment from ocean currents resulting in sand and silty substrates in the western portion and with soft, mud substrates in the east. *Z. marina* forms extensive meadows in North and South Bay, whereas in Central Bay, narrow fringing beds occupy the edges of dredged channels with steeply sloping walls. Oyster mariculture activities are concentrated in North Bay. Shipping is concentrated in Central Bay and to a lesser extent in South Bay.

The open mudflats of Humboldt Bay are vital feeding grounds for important resident and migrating shorebirds such as whimbrel, long-billed curlews, willets, and marbled godwits (Long and Ralph 2001, Danufsky and Colwell 2003, Leeman and Colwell 2005). Around the perimeter of Humboldt Bay are remnant salt marshes.

Zostera japonica--Species Profile

Z. japonica is similar in appearance to the native eelgrass *Z. marina*, but the leaves are shorter (15 to 40 cm) and narrower (1 to 2 mm) (Lee and Lee 2004). *Z. japonica* has an open leaf sheath and *Z. marina* has a closed leaf sheath (Harrison and Bigley 1982).

Z. japonica was first detected in Washington in 1957 (Hitchcock 1969), in British Colombia in 1969 (Harrison and Bigley 1982), and in Oregon in 1975 (Posey 1988). *Z. japonica* likely arrived coincident with the introduction of oysters from Japan as packing material or as seed on oyster shell (Harrison and Bigley 1982). Although 1957 marks the date of first collection, the exact date of introduction to the Pacific Northwest coast is not known and may have occurred much earlier (Harrison and Bigley 1982). The introduction of *Z japonica* to Humboldt Bay was NOT likely associated with oyster culture, as oyster larvae imported here come from hatcheries.

In its native range *Z. japonica* forms dense, monospecific beds in shallow littoral areas from subtropical Vietnam to cold temperate Kamchatka Peninsula (den Hartog 1970, Mukai et al. 1980). In the Pacific Northwest, *Z. japonica* colonizes intertidal mud and sand flats that lack permanent macrophyte cover (Harrison and Bigley 1982, Posey 1988, Thom 1990, Larned 2003), and Bando (2006) reported that in Washington, *Z. japonica* is also invading vegetated flats historically dominated by *Z. marina*. *Z. japonica* generally occurs higher in the intertidal than the native eelgrass *Z. marina*, but the two are sometimes intermixed with each other and/or various algal species (Harrison 1982b, Thom 1990, Baldwin and Lovvorn 1994, Bulthuis 1995). Expansion of *Z. japonica* is characterized by rapid growth and spread during spring and summer (Harrison 1982b). In British Columbia, *Z. japonica* increased its coverage 17-fold between 1970 and 1991 (Baldwin and Lovorn 1994). Oregon and Washington each have well-established *Z. japonica* populations that cover thousands of acres. In Willapa Bay, WA, Harrison and Bigley (1982) reported that all substrates except those with excessive clay or gravel supported dense populations of *Z. japonica*.

Z. japonica has a variable life cycle, possibly in response to the variability of its mid-intertidal habitat. In Hong Kong (N 22° 20', E 114° 11'), *Z. japonica* populations achieve their highest biomass in the spring and flower in the spring (Mukai et al. 1980, Lee 1997, Fong et al. 1998) and then decline when the water temperature rises in the summer (Fong et al. 1998). In northern Vietnam (N 20° 49', E 106° 4'), populations reach their highest biomass and density in the fall and flower primarily in the spring (Huong et al. 2003) and in the Pacific Northwest of North America populations achieve their highest biomass and reproductive effort in the fall

(Nomme and Harrison 1991, Larned 2003). Annual populations of *Z. japonica* have been reported in British Columbia (N 49° 12', W 124° 11') (Harrison and Bigley 1982, Baldwin and Lovvorn 1994) where severe winter storms and ice cause the turions to die back (Harrison 1982b), while perennial populations have been reported in Oregon (N 44° 38', W 124° 3') (Larned 2003) and Hong Kong (Fong et al. 1998) where the winters are milder. Subtidal populations of *Z. japonica* are also perennial (Harrison 1982b). *Z. japonica* reproduces vegetatively through rhizomatous cloning and sexually through seed production (Phillips 1984). In the Pacific Northwest, flowering occurs in the summer and seeds are released in the fall. The seeds overwinter in the sediment and germinate in early spring (Dumbauld and Wyllie-Echeverria 2003).

Potential Impacts

The physical structure of the mid to upper intertidal zones is altered where *Z. japonica* occurs, often forming a dense, sod-like root matrix that may completely cover the substrate surface (Posey 1988). The narrow blades trap fine sediments. Posey (1988) documented that particle size was significantly smaller in *Z. japonica* patches after six years. Substrate particle size affects which invertebrates can inhabit the sediment and this change in invertebrate community structure can impact shorebird populations that feed on invertebrates (Quammen 1984; Baldwin and Lovvorn 1994, Danufsky and Colwell 2003). Although studies have shown an overall increase of invertebrate species diversity and biomass in areas colonized by *Z. japonica* (Fong et al 1998, Lee et al 2001), a decrease in the burrowing ghost shrimp (*Neotrypaea californiensis*) and other large epifauna was also found (Posey 1988, Harrison 1987). *N. californiensis* is a favored prey for the long-billed curlew and found in the diets of the marbled godwit and willet (Dr. Nils Wornock, pers. comm., Point Reyes Bird Observatory). Additionally, the sediment accretion associated with *Z. japonica* could enhance extension of the invasive dense-flowered cordgrass *Spartina densiflora* in Humboldt Bay salt marshes, further reducing mudflat habitat and foraging area for shorebirds.

In Yaquina Bay, Oregon, Larned (2003) demonstrated that *Z. japonica* altered the balance of nutrient flux between the sediment and the water column and suggested that this could negatively impact pelagic productivity. *Z. japonica* is a net sink for NH_4+ and PO4 -3 during the summer and for NO_3- during the spring, while nearby unvegetated mudflat act as an NH_4+ source in both seasons. By removing nutrients from the system, *Z. japonica* may be reducing the abundance of phytoplankton and so reducing the productivity of the estuary. *Z. japonica* also decomposes faster than *Z. marina*, thereby changing the microbial community and further altering the sediment chemistry (Hahn 2003).

Management Policies

Eelgrass management policies in Washington and Oregon were investigated at the onset of our project through internet research and direct correspondence with managers. In Oregon, there are no formal policies regarding either *Z. marina* or *Z. japonica*. The managers contacted acknowledged that eelgrass *Z. marina* is important and beneficial, and they believed that *Z. japonica* likely bestowed the same ecological benefits. In most places, both species are afforded protection through estuary zoning and mitigation requirements. In Washington, regulations are in place that provide for a no-net loss of eelgrass habitat, and in practice these regulations apply to both *Z. marina* and *Z. japonica*. Since 2002, there has been increased research in Oregon, Washington, and British Columbia to examine the effects of *Z. japonica* on native communities, and management policies regarding the species are being questioned. Based on the results of controlled experiments that show *Z. japonica* to have a competitive advantage over *Z. marina* under disturbed conditions, Bando (2006) recommended a change in Washington eelgrass policies to recognize *Z. japonica* as an invasive species and to rescind the protection it is currently afforded. Recently, Dudoit et al (2006) set up a small-scale *Z. japonica* eradication experiment in a high marsh in the Coquille estuary in Oregon.

In California, there are regulations that protect *Z. marina*. The presence of *Z. japonica* was previously undocumented in California. Dean et al (2007) included *Z. japonica* in list of non-native species that have recently invaded California and characterized it as a species with a high potential for being an invasive pest. We petitioned CDFA to assign a pest rating for *Z. japonica*. In response, *Z. japonica* has been assigned a "Q" rating, a temporary designation used until determination of a permanent rating (S. Schoenig, pers. comm., 02/02/2007).

Permits

Initial removal of *Z. japonica* took place during April 2003 under emergency authorization from the California Coastal Commission, Humboldt Bay Harbor, Recreation, and Conservation District (HBHRCD), and the U.S. Army Corp of Engineers (COE). On October 21, 2003, HBHRCD Permit No. 03-03 was issued to allow continued eradication work for one year, and since then, one-year extensions for the permit have been issued annually. Annual progress reports were submitted to the HBHRCD 2004-2007.

Additional permits have been obtained from the Coastal Commission, COE, DFG, the U.S. Fish and Wildlife Service, the City of Eureka, the City of Arcata, and the Wiyot Tribe to allow access for shore surveys and to remove *Z. japonica* where found.

Objectives

The objectives of the Humboldt Bay Cooperative Eelgrass Project include:

1. Detect new occurrences of *Z. japonica* in Humboldt Bay as early as possible.
2. Eradicate all *Z. japonica* found as quickly as possible.
3. Gather data that will further our understanding of the species and help assess the effectiveness of our eradication methods.
4. Restore affected areas to pre-invasion conditions.

Methods

An overview of work conducted from April 2004 through November 2007 is provided as figure 2. Indian Island remained the only known location of *Z. japonica* until November 2006 when a small patch was found on the northeast shoreline of North Bay. Subsequently, two additional populations were found in North Bay during surveys conducted spring/summer 2007 (figure 3).

Each spring, the shoreline of Indian Island was intensively surveyed and all new occurrences of *Z. japonica* were recorded, sampled, and removed. To detect new locations of infestation, the shoreline of Humboldt Bay was stratified into 1000-m sections using ArcView3, and a random survey point for each section was generated, resulting in 104 random survey points around the bay perimeter (figure 4). At each point location, if suitable intertidal mudflat habitat was present, we surveyed 200 m of shoreline from the upper edge of mudflat extending out 50 m (or less where the area of exposed mudflat was narrower). All surveys were conducted at low tides of 0.6 m MLLW or lower. Survey tracks were recorded using GPS. In addition to searching

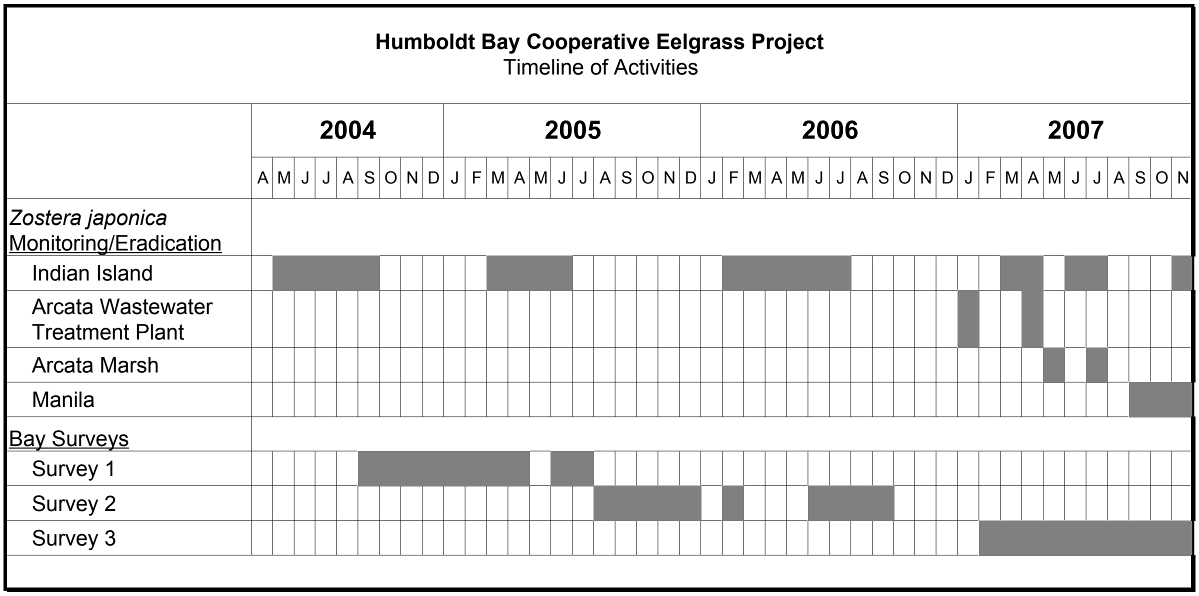

Figure 2. Overview of work conducted between April 2004 and November 2007 including bay-wide surveys for *Zostera japonica,* eradication efforts, and monitoring of infested sites.

for *Z. japonica*, we recorded the substrate type, level of human disturbance, dominant mudflat vegetation, and the presence/abundance of *Z. marina* within each survey area.

The first such survey was conducted 09/04/2004 to 07/09/2005. Then a new random point was selected within each section and the survey was repeated. The second survey was conducted 08/18/2005 to 09/11/2006. No new *Z. japonica* was found during these two surveys.

In November 2006, a City of Arcata employee found and reported to us a small patch of *Z. japonica* growing near the Arcata Wastewater Treatment Plant (AWTP) in North Humboldt Bay. We collected data on the new patch and then removed the material in January 2007. In March 2007, at the start of the active growing season for *Z. japonica*, we began intensive mudflat surveys radiating out from the North Bay location. We found a fairly substantial population of *Z. japonica* at the Arcata Marsh, near the boat ramp at the foot of I Street in Arcata. Both the AWTP and Arcata Marsh sites had easy access, so we used the opportunity to teach people how to recognize the invasive eelgrass, including biologists, HSU students, oyster farmers, and interested community members. The Arcata Marsh material was removed in May 2007.

In August 2007, our field crew found a third new occurrence of *Z. japonica* growing on intertidal mudflats in Manila. This material was removed September-November 2007. At this site, some *Z. japonica* was growing in association with a patch of bulrush, *Scirpus pungens*, the first time that we have seen this growth habit. Typically, we have found *Z. japonica* growing on open mudflats or together with small amounts of the native eelgrass *Z. marina* and/or various species of algae. Where the *Z. japonica* was growing with *S. pungens*, we tried to keep the bulrush intact while we selectively weeded out the *Z. japonica*, which has shallower rhizomes.

The locations where we have encountered and removed *Z. japonica* are shown in figure 3. To date, no *Z. japonica* has been found in south Humboldt Bay. At each location where *Z. japonica* was found, data was collected prior to removal of the plants. The location of each *Z. japonica* patch detected was staked and recorded using GPS. At the new locations detected in 2007, plant material was collected for genetic analysis to improve our understanding of how the populations are related to one another and how the plant is spreading.

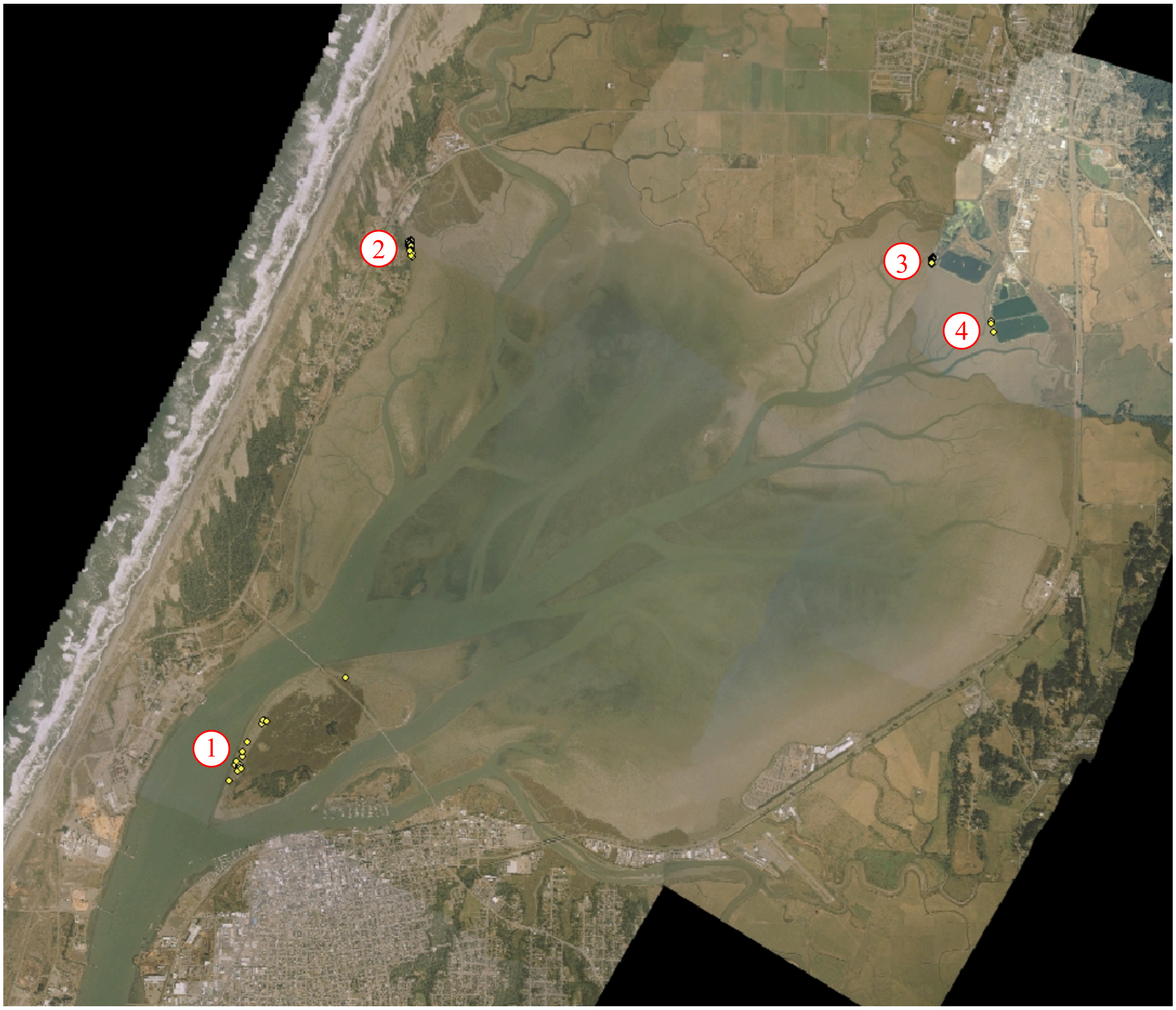

Figure 3. Four locations in North Humboldt Bay where *Zostera japonica* was removed in 2007. 1) Indian Island; 2) Manila; 3) Arcata Marsh; and 4) Arcata Wastewater Treatment Plant.

Data were collected for each *Z. japonica* patch, including diameter (based on the longest measurement of the patch) and percent cover (based on an ocular estimate of cover within a circle defined by the diameter). A core sample was collected from each patch (4 cm deep) to determine the density of vegetative and reproductive shoots and the biomass. In the laboratory, core samples were rinsed, and plant material was separated. Vegetative shoots and reproductive shoots were counted and weighed to determine aboveground biomass (AGB). Rhizomes plus roots were weighed to determine belowground biomass (BGB). The material was then dried at 50^{o}C for approximately 7 days and re-weighed to calculate % dry matter.

All *Z. japonica* was excavated by hand using shovels. Plant material, together with mud, was placed in heavy-gauge plastic bags and transported off-site for disposal at a landfill. The Indian Island and Manila sites required hauling the material out by boat; the Arcata Marsh and AWTP sites were accessible by vehicle. The location of all *Z. japonica* removed was mapped using GIS, contributing to the existing spatial database. The amount of material removed was quantified and compared to previous years.

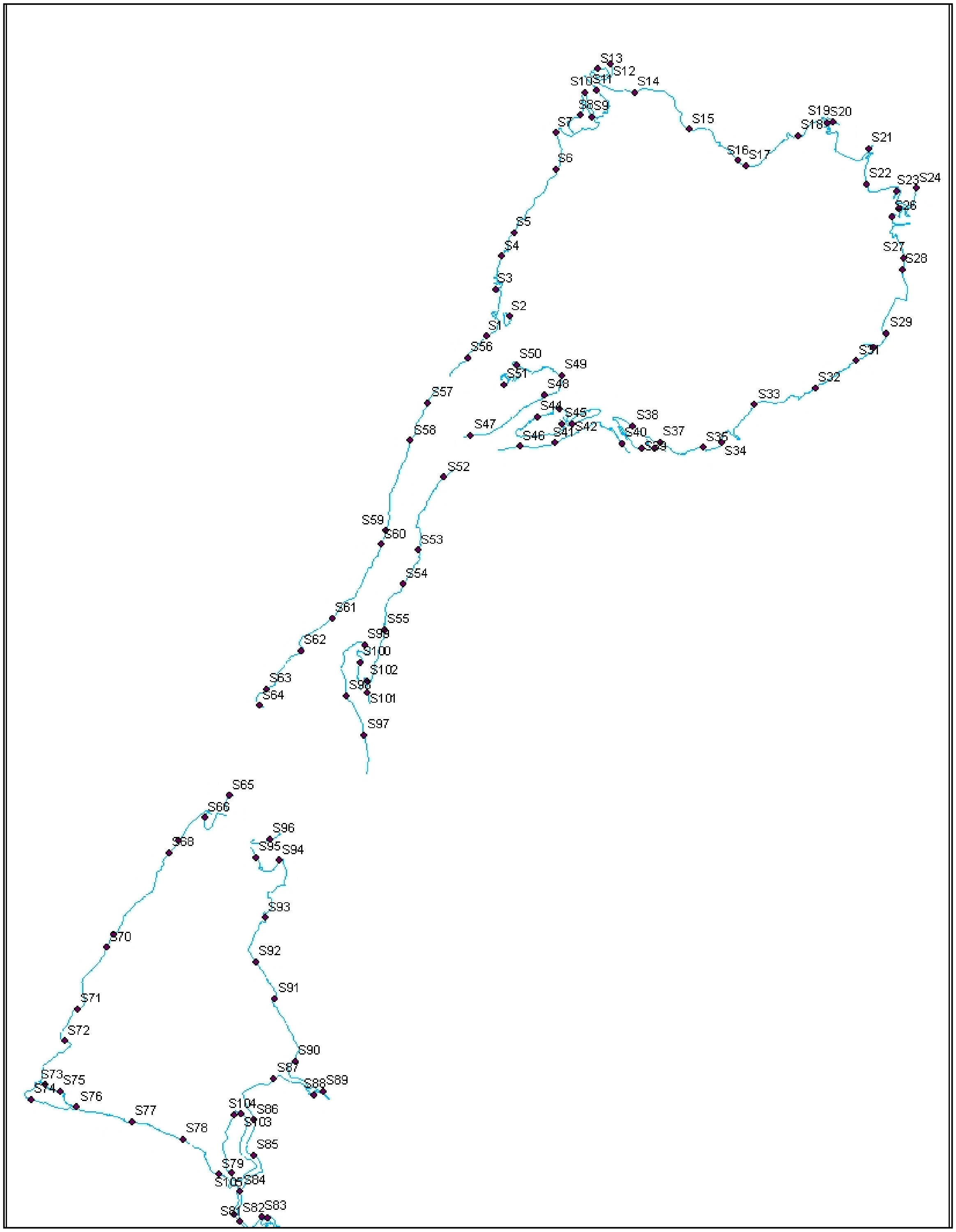

Figure 4. Location of Humboldt Bay shoreline surveys.

Results

The primary use of NFWF funds was for salary to hire a U.C. Sea Grant Extension Staff Research Associate (SRA) to coordinate work on monitoring and eradication of *Z. japonica*. Under the supervision of Sea Grant Marine Advisor Susan Schlosser, Neil Kalson worked as a SRA fulltime from April 2004 through March 2006, then Annie Eicher worked fulltime April 2006 through July 2006, halftime August 2006 through June 2007, and fulltime July 2007 through November 2007. Humboldt State University Student interns were also funded by the NFWF grant to assist with field and lab work. Work was performed in collaboration with DFG staff John Mello, Vicki Frey, and Kirsten Ramey. Monthly progress reports were prepared April 2006 through November 2007.

Survey work, including reconnaissance, baywide shoreline surveys, and intensive surveys, required approximately 350 hours labor per year. Removal efforts, including data/sample collection, excavation, and hauling required approximately 275 hours per year, and laboratory work, including biomass cores, and specimen examination about 150 hours per year. Other tasks not included in these tallies include transportation, project management; field scheduling; intern supervision; permits; recordkeeping; data entry; data analysis; GPS data management; literature review; reports; cleanup; boat maintenance, and outreach.

The amount of plant material requiring removal at Indian Island declined dramatically following 2004. In 2005, the number of patches found was still fairly high, but the patches were smaller (presumably younger), such that the area covered and the amount of biomass was much less (table 1, figure 5). The amount of material removed in 2007 is similar to that removed in 2006. The current level may represent a maintenance "plateau" that will hopefully someday decline to zero. The three new populations of *Z. japonica* found in North Bay this year all were relatively small (table 1, figure 6)—much smaller than the population first found on Indian Island in 2002.

Table 1. Quantitative summary of the amount of *Zostera japonica* removed from Humboldt Bay from 2004 to 2007.

	Number of Patches	Area (m^2)	Dry Weight of Aboveground Biomass, Vegetative (kg)	Dry Weight of Aboveground Biomass, Reproductive (kg)	Dry Weight of Belowground Biomass (kg)	Total Biomass Dry Weight (kg)
Indian Island						
2004	188	186.86	5.24	4.13	8.50	17.87
2005	149	25.26	1.89	0.19	2.34	4.42
2006	23	6.62	0.23	0.12	0.23	0.58
2007	16	5.63	0.33	0.11	0.15	0.60
AWTP 2007	4	1.02	0.02	0.00	0.03	0.05
Arcata Marsh 2007	36	10.85	0.34	< 0.01	0.14	0.49
Manila 2007	60	6.73	*data analysis in progress*			

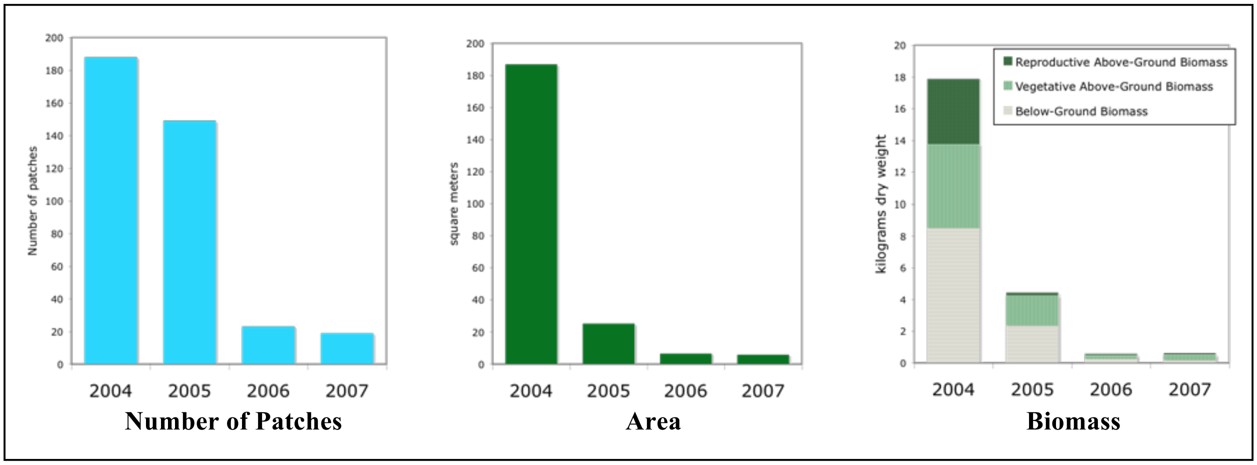

Figure 5. Abundance of *Zostera japonica* Removed from Indian Island, Humboldt Bay.

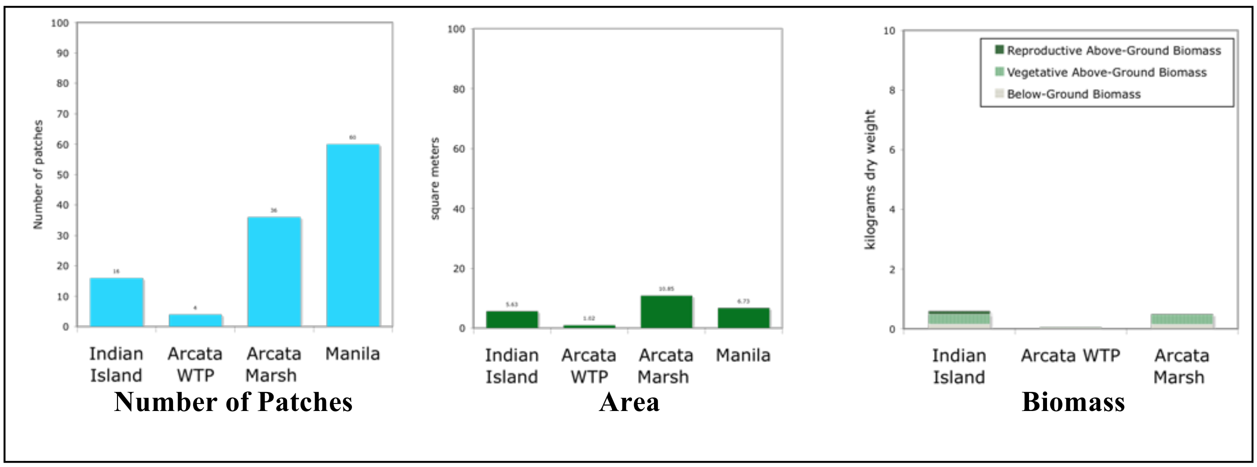

Figure 6. Abundance of *Zostera japonica* Removed from Humboldt Bay in 2007.

Data was collected on patch meristics for all *Z. japonica* removed. At Indian Island, the average patch size declined following 2004 (table 2, figure 7). Patch size was similar at all sites in 2007 (table 2, figure 8).

At Indian Island, the ratio of aboveground biomass to belowground biomass (AGB:BGB) increased since 2004, presumably because we are finding and removing the plants at a younger age before the development of extensive root systems. At the Arcata Marsh, the AGB:BGB was similar to Indian Island in 2007. At the Arcata Wastewater Treatment Plant, the AGB:BGB ratio was lower; most of these plants were sampled and removed in winter/early spring when vegetative growth is low, and also the plants had apparently been grazed by waterfowl (S. Schlosser, personal observation). Lab data for the Manila site is still being processed (table 2, figure 9).

The range of vegetative shoot density was highly variable at all sites in all years, while the average density was relatively similar (table 2, figures 11 and 12). Reproductive potential was assessed by looking at the number of reproductive shoots compared to total shoots. At Indian Island, the percent of reproductive shoots declined between 2004 and 2006, then rose in

2007 to a similar level as 2004 (table 2, figure 13). At the Arcata Wastewater Treatment Plant, there were no reproductive plants in the material we collected, but in March we found *Z. japonica* seedlings germinating (some with seed coat still attached) at the site. At the Arcata Marsh, there was evidence of flowering, but the number of reproductive shoots was low (table 2, figure 14), and data analysis is in progress for the Manila site.

Table 2. Growth Characteristics of *Zostera japonica* removed from Humboldt Bay 2004 to 2007.

	Mean Patch Size (m^2)	**Ratio of Aboveground Biomass: Belowground Biomass**	**Mean Density of Vegetative Shoots ($\#/m^2$)**	**Reproductive Potential (% reproductive shoots/ total shoots)**
Indian Island				
2004	1.01 ± 1.61	1.10	2,460 ±1,384	14.9%
2005	0.18 ± 0.32	0.89	1,572 ± 1,102	7.1%
2006	0.31 ± 0.34	1.54	2,570 ± 2,770	3.4%
2007	0.35 ± 0.31	2.81	3,313 ± 2,167	14.5%
AWTP 2007	0.26 ± 0.31	0.70	2,974 ± 4,036	0%
Arcata Marsh 2007	0.30 ± 0.48	2.44	2,239 ± 1,626	0.9%
Manila 2007	0.10 ± 0.10	*data analysis in progress*		

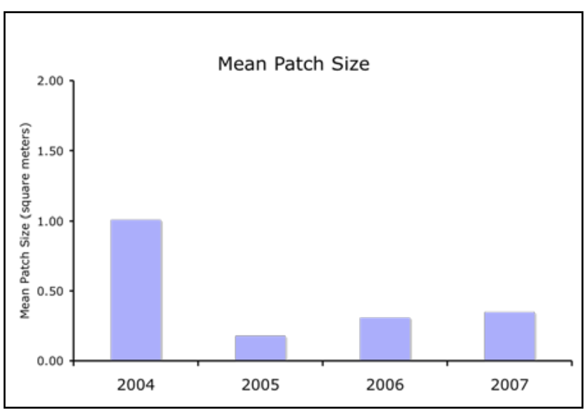

Figure 7. Mean patch size for *Zostera japonica* removed from Indian Island 2004-2007.

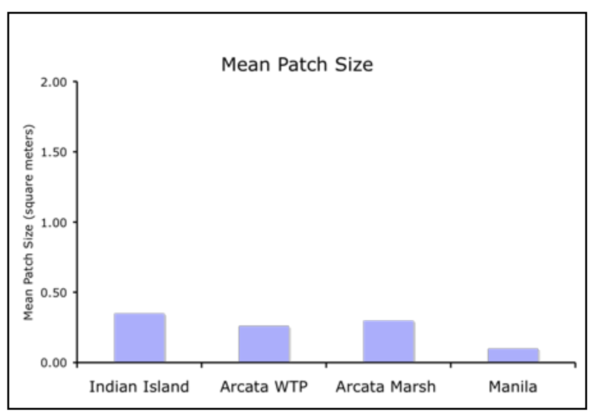

Figure 8. Mean patch size of *Zostera japonica* removed from all sites in 2007.

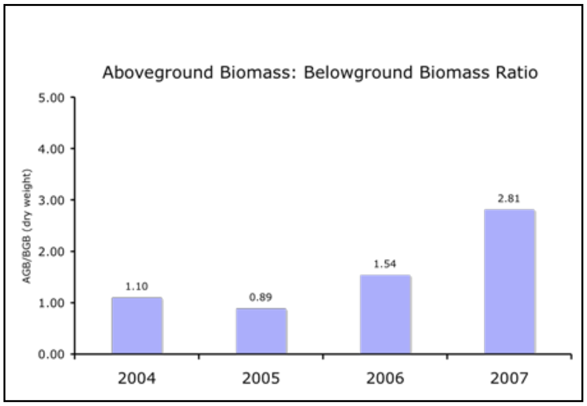

Figure 9. AGB:BGB Ratio for *Zostera japonica* removed at Indian Island 2004-2007.

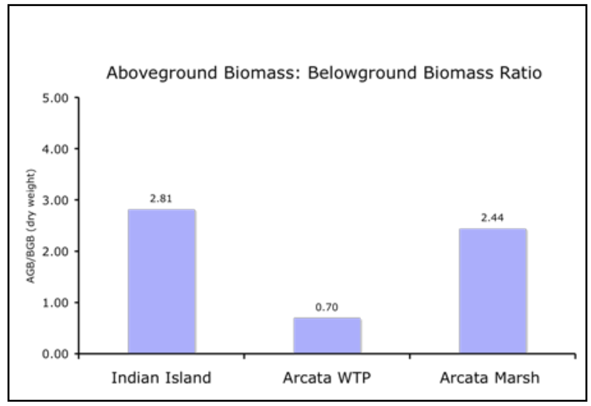

Figure 10. AGB:BGB Ratio for *Zostera japonica* removed in 2007.

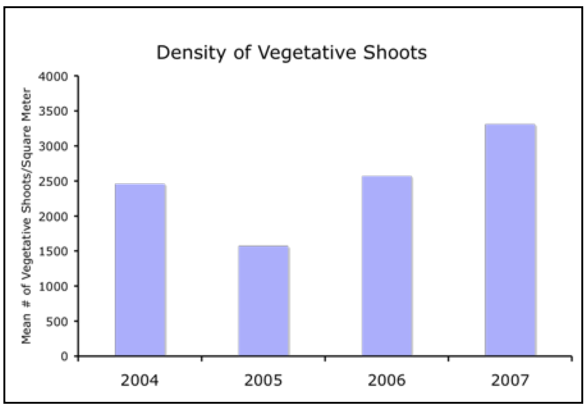

Figure 11. Mean density of *Zostera japonica* removed from Indian Island 2004-2007.

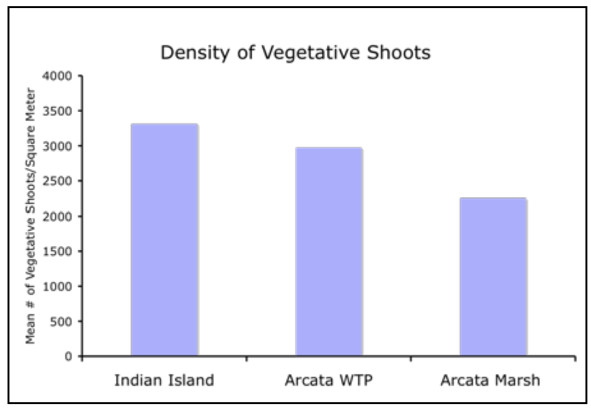

Figure 12. Mean density of vegetative shoots for *Zostera japonica* removed in 2007.

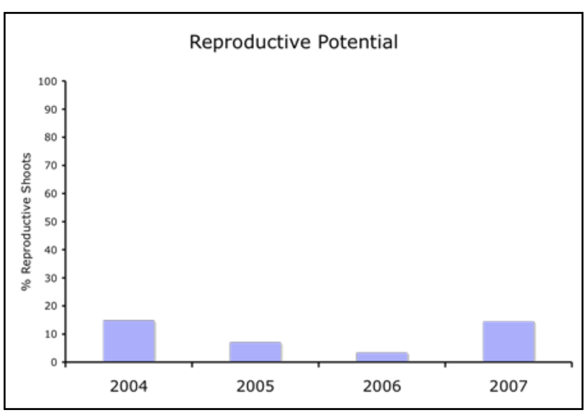

Figure 13. Percent of total shoots that were reproductive in *Zostera japonica* removed from Indian Island 2004-2007.

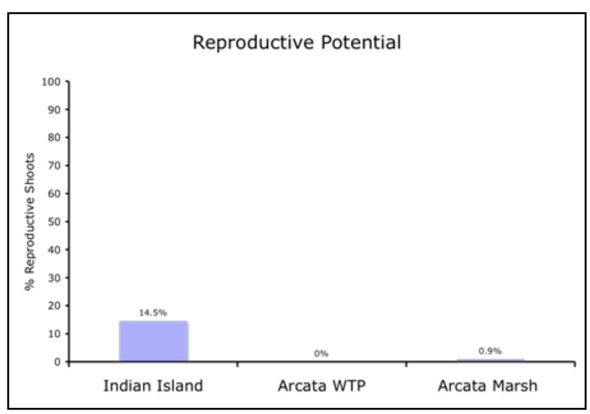

Figure 14. Percent of total shoots that were reproductive for *Zostera japonica* removed in 2007.

Funding

We submitted several grant proposals to acquire funding for on-going monitoring and eradication of *Z. japonica.* In addition, we think it would be valuable to expand the scope of our shoreline surveys to address multiple species. Towards that end, we drafted a proposal to first develop a target list of invasive species that are either known to occur here or that have the potential to occur here, and then to design a multi-species survey protocol. We submitted a proposal to the Western Region Panel on Aquatic Nuisance Species on 08/08/2006, to National Sea Grant Foundation on 08/16/2006, to the California Department of Food and Agriculture as part of a Humboldt/Del Norte Weed Management Area proposal on 10/13/2006, and to the U.S Fish and Wildlife Service on 03/14/2007. These proposals were not funded. On 01/22/2007, our collaborator John Mello at DFG submitted a proposal internally for DFG funds to keep the project going. This grant was approved and will go into effect 12/01/2007 to fund a U.C. SRA at half-time and three student interns for one year.

Outreach

Outreach in 2004 and 2005 included presentations to local advisory and regulatory committees and the Humboldt Bay Harbor Recreation and Conservation District Commission. Presentations were given to the Mariculture Monitoring Committee, the Shellfish Technical Advisory Committee, Friends of the Arcata Marsh, and the local chapter of the California Native Plant Society. Numerous presentations were given to Humboldt State University biology and fishery courses as part of the Eureka Sea Grant Program.

A local newspaper, the Eureka Times-Standard, interviewed S. Schlosser and J. Mello about *Z. japonica* and published a front-page article about the project. The project was also presented to the Pacific Estuarine Research Society (February 2005), the Western Society of Naturalists (November 2005), and at Humboldt Bay Symposia (October 2003, March 2006).

Public outreach was conducted to educate people about the threat that invasive species can pose to native communities, to alert people about the presence of *Z. japonica* in Humboldt Bay, and to teach people who might encounter *Z. japonica* how to recognize the species. We have taken small groups of people to view the plants before removing them. These included biologists, HSU students, oyster farmers, Arcata Wastewater Treatment Plant staff and interested community members.

In May 2007, we co-led an interpretive walk at the Arcata Marsh on the topic of "Marsh Invaders." We took *Z. japonica* specimens to the Phycology class at Humboldt State University, and we worked with student interns to prepare a Powerpoint on the taxonomy of *Z. japonica/Z. marina.* The Powerpoint presentation is used for training new student assistants and volunteers. We prepared an interpretive brochure with information on the species and our monitoring/eradication project, and we are in the process of developing a field guide for plant identification.

Discussion

Severe ecological and economic impacts caused by the invasion and spread of invasive species are now widely recognized and well documented (Cohen and Carlton 1995, California California Department of Fish and Game 2006, National Invasive Species Council 2001). An "early detection, rapid response" strategy is becoming widely recognized as the most effective way to combat invasive species in these plans and studies. The California Aquatic Invasive Species Management Plan states that species that may invade California in the future due to globalization of the economy and rapid movement of people will likely increase and may represent a greater threat than aquatic invasive species already here. One major objective of the California plan is to develop and maintain programs that ensure early detection of new aquatic invasive species and to monitor existing invasive populations. The National Invasive Species Management Plan also includes an objective to collaborate with states to coordinate a rapid response to invasions. This project represents an example of an early detection, monitoring and eradication response. Our successes and challenges may offer methods or considerations for other aquatic invasive species programs.

Our project benefited from the rapid response to the invasive marine alga *Caulerpa taxifolia*, detected in subtidal Southern California in July 2000. In this case a collaborative task force of local, state and federal agencies, local stakeholders, and experts met within days to determine how to manage the invasion. Permits for eradication work were expedited and *C. taxifolia* was officially declared eradicated in July 2006. The total eradication effort cost $7.7 million dollars, including planning, fieldwork, monitoring, and reports (Anderson 2005).

So far, our project has been a much less costly effort. The rapid response to detection of *Z. japonica* was expedited by advice from many of collaborators involved in the *C. taxifolia* project. Our project also benefited from early taxonomic identification of *Z. japonica*, successful collaboration with local, state and federal agencies, the City of Eureka, the Humboldt Bay Harbor Recreation and Conservation District, the Wiyot Tribe, and University researchers. We were encouraged to begin working on a plan, methods, and eradication. We have not been as successful as the *C. taxifolia* project yet, but are continuing our efforts to eradicate *Z. japonica*.

The Humboldt Bay Cooperative Eelgrass Project began native eelgrass, *Z. marina* surveys in July 2001. This collaborative project surveys 15 random sites for *Z. marina* plant characteristics each summer. The detection of *Z. japonica* resulted directly from *Z. marina* surveys. One of our random sites in June 2002 was the site of *Z. japonica* detection. Outreach to other programs throughout California that are sampling coastal and marine habitats to train them in identification of aquatic invasive species would increase early detection of invasive species. A need that remains is a central entity to report such findings so that a rapid response can take place. Our *Z. japonica* project outreach was successful in that the second known population, detected in November 2006, was reported to us by an individual who had attended presentations about the project.

Early detection of *Z. japonica* at new sites is challenging because the habitat it occupies is only exposed at tides of 0.6 m MLLW or lower, these intertidal mudflats are not easily traversed, and the very narrow blades of the eelgrass make it easy to miss. The surveys are therefore quite labor-intensive. Excavation is also labor-intensive, as the heavy bags of mud and plant material must be hauled off-site. These challenges represent the main cost of the *Z. japonica* project: the personnel needed to complete the eradication and shore surveys. This may be one of the main costs for other aquatic invasive species projects.

Our early detection of *Z. japonica* resulted in a quick, coordinated response. From the known aquatic invasive species projects in California, it appears this is less expensive than long-term control projects. We will propose in future work development of multi-species survey methods so that our shore surveys encompass more than searching for *Z. japonica*. We think development of this method, training local volunteers or others working coastal habitats will result in other early detections.

It is important to note that since April 2003, our primary focus has been eradication of what we perceive to be a noxious weed. Towards that end, it has been important to collect quantitative data on the amount of *Z. japonica* removed as a way of measuring the success of our eradication efforts. Secondarily, we have collected additional data on growth characteristics in an effort to better understand the autecology of *Z. japonica* in Humboldt Bay. Towards this end, however, we are presented with somewhat of a conflict. For example, our desire to remove plants before they set seed is greater than our interest in knowing the peak flowering period or true reproductive potential of our populations. It is interesting ancillary information to note that the patches found and removed at Indian Island from 03/13/2007 to 04/06/2007 contained no flowering shoots and that the patches found and removed from 04/20/2007 to 07/20/2007 contained (immature) flowering shoots in increasing number, however, if it were our primary focus we would sample this parameter is a less biased manner. We make this point as a cautionary note in reviewing the data on growth characteristics presented here. We do have nearly one year's worth of data collected prior to removal (June 2002 through April 2003), in which we found peak shoot density, biomass, and flowering to occur in the fall (Schlosser et al, in prep).

With regard to the quantitative assessment of *Z. japonica* removed each year, this represents the size of the population for that year in its entirety (at least to the best of our knowledge, notwithstanding any patches we may miss). There has clearly been a dramatic decline in the size of the *Z. japonica* population at Indian Island since 2004, as evidenced by lower plant cover and lower total biomass (table 1, figure 5), which we attribute to our eradication efforts. When we look at the size of the population at each of the new sites detected in 2007, we see that they are relatively small; i.e., none approached the size of the Indian Island population in 2004 (table 1, figures 5 and 6). The Manila population had a fairly high number of patches, but most of the patches were small, and cumulatively they did not result in a large amount of plant cover or large biomass. We believe that all the new populations detected in 2007 were relatively young and that they had not had the time to attain the exponential growth that was exhibited at Indian Island before initial eradication efforts there. We conducted a particle size analysis in and out of *Z. japonica* vegetated areas at the Arcata Wastewater Treatment Plant, and found no significant difference, consistent with Posey's (1988) finding that sediment particle size is reduced only after six years of *Z. japonica* growth. Additionally, none of these populations were detected during shoreline surveys conducted 2002-2006.

In addition to total abundance, the average patch size has also decreased at Indian Island since 2004 (table 2, figure 7), presumably because we are detecting and removing patches at a younger age. The average patch size at all of the new locations was similar to post-2004 Indian Island (table 2, figures 7 and 8), also supporting our theory that these represent young populations.

In Yaquina Bay, Oregon, Kaldy (2006) found strong seasonal variation in biomass and growth of *Z. japonica* in relation to seasonal changes in light and temperature. He found that belowground biomass remained relatively constant all year, and that aboveground biomass was highest in the summer. The ratio of aboveground biomass to belowground biomass was approximately equal in summer months, while belowground biomass was up to six times greater than aboveground biomass in the winter. The data presented here were not collected in a manner to assess seasonal variation, but rather at the time we removed the plants. Generally, removal occurred during spring and summer; refer to figure 2 for the months during which plants were removed at each site. In 2007, we found aboveground biomass to be up to 2.8 times that of belowground biomass (table 2, figures 9 and 10). We suggest that in young populations, the plants have not had the time to amass as extensive a root system as seen in the established *Z. japonica* populations studied by Kaldy (2006).

Kaldy reported densities of (1,500) 4,000-11,000 shoots/m^2, with highest densities occurring in the summer. With most of our data collected in spring-summer, we found densities of 1,500 to 3,300 shoots/m^2 (table 2, figures 11 and 12), with high variability at all sites in all years, and no clear pattern of change over time. In his two-year study, Kaldy (2006) noted a large interannual variation in reproductive effort, with reproductive shoots representing 10% total shoots in 2001 and only 2% in 2002. In British Columbia, Harrison (1976, 1982a) found up to 70% shoots were reproductive at peak flowering. At Indian Island, we found an average of 14.9% of total shoots that were reproductive in 2004, 7.1% and 3.4% in 2005 and 2006 respectively, and 14.5% in 2007 (table 2, figure 13). It appears that this pattern may represent interannual variation, although within-season variation compounds our analysis. There is not a clear response in reproductive effort in response to eradication efforts. In controlled experiments, Bando (2006) found that disturbance resulted in a 19-fold increase in *Z. japonica* shoot production.

The benefits of our work include removal of an introduced, intertidal eelgrass, passive restoration of native eelgrass habitat, detailed mapping of *Z. japonica* removed, and monitoring of revegetation in affected areas. After our first eradication on Indian Island, over 300 square meters of native eelgrass, *Z. marina*, recolonized the area. This population of *Z. marina* on Indian Island has persisted and now occupies the area of the intensive 2004 eradication area. The mud and sand flats that we are restoring are important feeding grounds for resident and migrating shorebirds such as whimbrel, long-billed curlews, willets, and marbled godwits. We plan to continue to monitor the shoreline of Humboldt Bay to enable early detection of any new occurrences of *Z. japonica* should they arise. The project will be determined successful when no *Z. japonica* can be found anywhere in Humboldt Bay.

A major challenge to our work is the unknown pathway or vector of *Z. japonica* arrival in Humboldt Bay. We do not know if *Z. japonica* continues to invade or if the Humboldt Bay population is the source of the Arcata and Manila populations. One way to address this unknown would be through genetic analysis of the Humboldt Bay populations and compare them to *Z. japonica* populations from Oregon and Washington. One of our long-term goals is to have this analysis completed.

Humboldt Bay has its own example of an early detection and rapid response to another intertidal plant. Eradication of smooth cordgrass (*Spartina alterniflora* Loisel) from Humboldt Bay in 1989-1990 resulted from the swift action taken by the California Department of Fish and Game. Early detection of and response to smooth cordgrass in one location was successful in eradicating the species from Humboldt Bay (K. Kovacs, DFG, pers. comm.). We hope to repeat this success with rapid response to the detection of new aquatic invasive species in Humboldt Bay. While disheartening to know that *Z. japonica* has successively spread in Humboldt Bay, we are encouraged by the fact that we detected the new occurrences at a stage in which eradication is still a reasonable goal. We finish this season having removed all material that we are aware of, and ready to resume monitoring at the start of the next growing season.

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