San Francisco Estuary
Invasive *Spartina* Project
Monitoring Report for 2003

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EXECUTIVE SUMMARY

The San Francisco Estuary Invasive *Spartina* Project's 2003 Monitoring Program was designed with the goal to provide (1) detailed updated information on new found populations of non-native *Spartina* in the San Francisco Estuary (Estuary); (2) information on the amount of spread since the 2001 by using a sub-sampling of sites Estuary-wide; (3) a review of the existing field and aerial photo interpretation mapping and monitoring methods; and (4) a summary of the 2002-2003 *Spartina* treatment sites and their control efficacy.

The change in area of non-native *Spartina* was mapped at 28 monitoring sites stratified across the Estuary by Subregion (latitude), Site Type, and Marsh Type. Non-native *Spartina* monitoring locations were mapped using field and aerial photo interpretation methods. In the field plants were mapped as points, lines or polygons with a given cover class. Aerial photo interpretation methods were applied at large infestation sites. Polygons were digitized around the areas classified as infested on the photographs and assigned to a percent cover class. Data from both field and aerial photo methods were summarized in GIS and presented as maps and summary graphs of change in area cover or percent change.

Surveys of possible new sites (including genetic testing of suspected non-native plants) found no new locations of non-native *Spartina*, just spread or newly found clones of non-native *Spartina* in some of the already known outlying sites such as Point Reyes, Bolinas Lagoon or in the area of San Rafael's Loch Lomond Marina. However, the 2003 survey was a sample not a census of the entire Estuary so some new sites may have been missed.

The average percent increase in area between 2000 and 2003 for all species of non-native *Spartina* in the Estuary was 244%. *S. alterniflora*-hybrids are spreading at the greatest rate of 317% increase. Based on the 317% spread for *S. alterniflora*-hybrids since 2001, the bay wide non-native *Spartina* acreage calculation from 2001 of 470 acres may now be as high as 1960 acres. Their rate of spread is greatest in the Central Bay, near the original introduction sites. Spread was greatest for marsh habitats, Site Types I (tidal, micro tidal, former diked baylands, and back barrier marshes) and II (Fringing Tidal Marsh, Mudflats and Estuarine Beaches), when compared to creeks or slough and urbanized habitat. *S. densiflora* spread to a lesser degree, 52% increase in area, which is likely the result of its growth habit. It is a cespitose species that forms dense clumps or tufts that spread less vegetatively and more by seed. *S. densiflora* spread the most in Site Type I where seed was likely deposited with the tide on the high marsh plane. *S. patens* was determined to have decreased in cover, however this is likely due to error associated with the monitoring techniques. (*S. anglica* was not mapped during the 2003 monitoring effort.) This Inventory Monitoring Program showed that the highly invasive non-native *Spartina* species are spreading exponentially in the Bay Estuary, especially *S. alterniflora*-hybrids. The spread is a threat to existing habitat and species assemblages in the San Francisco Estuary.

Field mapping calculations of area covered by non-native *Spartina* were compared to those made with remote sensing/aerial photo interpretation. The field mapped areas were on average 170% higher than the aerial photo mapped area however the two data types were not statistically correlated. The potential benefits of monitoring invasive *Spartina* by remote sensing, especially where it is in large stands or inaccessible areas, warrant further research to calibrate the method. The ability to assign a fine scale cover class to a digitized polygon on an aerial photo would improve the ability to detect a small change in cover. Another improvement can be made in mapping new, small areas of infestation by using sub-meter resolution GPS instead of the existing 3 meter resolution units, or by using tape measures or optical range finders to measure area instead of depending on the GPS in all cases. This is most important for mapping small populations or species such as *S. patens* or *S. densiflora* and may explain why a decrease in cover was observed in the *S. patens* at Southampton Marsh in Benecia or the *S. densiflora* at Pickleweed Park in San Rafael.

The Treatment Site Monitoring of the 2002 treatments indicates that manual methods of *Spartina* control, digging or covering with geo-textile fabric, are effective at removing or killing the smaller populations of *Spartina* species. However, care must be taken to ensure that the entire plant or plants are completely dug out or covered. Where divots remain after removal, native plantings could take place to reduce chance of continued invasion of susceptible habitat by non-natives. Large areas invaded by *S. alterniflora* and its hybrids will require large-scale eradication methods and follow-up to avoid re-growth and continued spread of hybrid *Spartina* by pollen.

The experience gained in 2003 resulted in several recommendations for future monitoring. Field mapping is preferable to aerial photo interpretation until the photo method is proven and calibrated. GPS mapping in the field should use points and lines instead of polygons because of the imprecision in area estimation found using polygons. Measure diameters and widths of points and lines in the field with tools such as tape measures or optical range finders. Upgrade to sub-meter GPS units if possible. Increase the number (decrease the size) of cover class intervals when making aerial photo interpretations or when mapping large areas in the field.

The 2003 monitoring program documented increased spread of non-native invasive *Spartina* in the San Francisco Bay Estuary and the relative efficacy of initial control efforts. Continued monitoring as well as accelerated control efforts need to be implemented to achieve the goals of the Invasive *Spartina* Project.

1.0 INTRODUCTION

1.1 INVASIVE *SPARTINA* PROJECT AND THE MONITORING PROGRAM

The San Francisco Bay Estuary (Estuary) supports the largest and most ecologically important expanses of tidal mudflats and salt marshes in the contiguous western United States. This environment supports a diverse array of native plants and animals. Over the years, many non-native species of plants and animals have been introduced to the Estuary, and some now threaten to cause fundamental changes in the structure, function, and value of the Estuary's tidal lands. Among these threatening invaders are several species of salt marsh cordgrass (genus *Spartina*). In recent decades, four species of non-native *Spartina* were introduced to the Estuary and began to spread rapidly. Though valuable in their native settings, these introduced *Spartina* species are highly aggressive in this new environment, and frequently become the dominant plant species in areas they invade. (e.g., Callaway and Josselyn, 1992; Cohen and Carleton, 1995; Daehler and Strong, 1996; Goals Project 1999; Ayres *et al.* 2003; California Coastal Conservancy 2003; Ayres *et al.* 2004)

The San Francisco Estuary Invasive *Spartina* Project (ISP) was established at the California Coastal Conservancy in 2000. The ISP is a regionally coordinated approach to controlling, or eradicating, populations of non-native *Spartina* in San Francisco Bay. The ISP includes a monitoring program to track and map the extent of non-native *Spartina* and to assess the effectiveness of the treatment methods. In 2000-2001 the ISP mapped the entire Estuary using the methods outlined in the Guidelines to Monitor the Distribution, Abundance, and Treatment of Non-indigenous Species of Cordgrass in the San Francisco Estuary (Collins *et al.* 2001).

This report presents the 2003 monitoring program results for The San Francisco Estuary Invasive *Spartina* Project (ISP). Included in the report is a comparison of different methods for monitoring invasive *Spartina* in the San Francisco Estuary.

1.1.1 Background/Problem Statement

Five species of *Spartina* are currently found in the San Francisco Estuary. Only one of these five species is native, *S. foliosa*. The four non-native species currently found in the Estuary are *S. alterniflora*, *S. densiflora*, *S. anglica*, and *S. patens*. One of the non-native *Spartina* species in particular, Atlantic smooth cordgrass or *S. alterniflora*, and its hybrids (formed when this species crosses with the native Pacific cordgrass, *S. foliosa*) are now threatening the ecological balance of the Estuary and are likely to eventually cause the extinction of native Pacific cordgrass, choke tidal creeks, dominate newly restored tidal marshes, and displace thousands of acres of existing shorebird habitat (e.g., Callaway and Josselyn, 1992; Cohen and Carleton, 1995; Daehler and Strong, 1996; Ayres *et al.* 2003; California Coastal Conservancy 2003; Ayres *et al.* 2004). Once established in this Estuary, invasive cordgrasses could rapidly spread to other estuaries along the California coast through seed dispersal on the tides (Ayres *et al.* 2003 and 2004). The results of the 2000-2001 Monitoring Program were published by Ayres *et al.* in 2004. At the time of the survey, a total of 483 net acres of non-native *Spartina* were found distributed throughout nearly 40,000 acres of tidal marsh and 29,000 acres of tidal flats of the Estuary; 470 acres of *S. alterniflora*-hybrids; 13 acres of *S. densiflora;* 0.58 acres of *S. patens;* and 0.09 acres of *S. anglica*. The ISP Control Program proposes to implement a coordinated, region-wide eradication program, comprising a number of on-the-ground treatment techniques to stave off this invasion. The ISP Monitoring Program will monitor the efficacy of the Control Program treatment as well as the abundance and distribution of non-native cordgrass within the Estuary.

1.1.1.1 Background: Non-native *Spartina* Distribution/Inventory

As stated above, 2000-2001 monitoring of the non-native *Spartina* in the San Francisco Estuary calculated that the extent of non-native *Spartina* equaled 483 net acres (ISP 2000-2001 data; Ayres *et al.* 2004). Net acres are the coverage if all non-native *Spartina* plants were contiguous. Gross acreage would be all the marsh areas that have some non-native *Spartina* plants. The *S. alterniflora*-hybrids have increased in area 100-fold since the 1970s, from a few acres of planted *S. alterniflora* in 1978 (Ayres *et al.* 2004). According to Ayres *et al.* 2004, the rate of expansion ranges from constant, yielding exponential increase in area, to increasing through time, yielding greater than exponential increase in area. This means that the proliferation of hybrids is accelerating the rate at which areas are covered. One explanation for an accelerating spread rate is natural selection acting on hybrids and favoring those plants capable of exceptional clonal expansion and sexual reproduction. Ayres *et al.* reported having observed such plants growing in nature. During a 1999-2000 study of an invaded marsh restoration site at Hayward Regional Shoreline, plants in the 70% hybrid category increased in area more than 2.5-fold, and a few hybrid clones increased in size more than 4-fold in area as *S. foliosa* (Zaremba 2001). Due to clonal expansion, hybrid cover at a marsh in San Lorenzo increased 8-fold in three years, from 5% in 1997 (Ayres and Strong 2001) to 42% in 2000. Among 54 plants in an invaded marsh, the highest annual output of fertile seed by a single plant was 4.9 million seeds and this exceptional individual was a hybrid (Zaremba 2001). Hybrids sire and/or set large numbers of hybrid seedlings, disproportionate to their cover in the marsh. Extrapolating from their area estimates, and assuming constant growth rates, leads to the prediction that all 3,729 gross acres currently invaded in the central and south Bay will be a solid sward of hybrid cordgrass in ca. 30 years. Oversimplifying invasion dynamics, the entire 69,432 gross acres of mud flat and marsh that currently exist in the estuary would be covered in two centuries. If growth rates are increasing, the time until virtually all tidal marshes and mud flats in San Francisco Bay are covered by hybrid cordgrass will be shorter.

1.1.1.2 Background: Non-native *Spartina* Genetics

In addition to the physical displacement of native marsh plants, the *S. alterniflora*-hybrid invasion threatens the genetic integrity of the native *Spartina foliosa*. According to Ayres *et al.* (2003), the native *S. foliosa* may be a "common species on the road to rarity". In another recent paper by Ayres *et al.* (2003) a model was run estimating *Spartina* species and hybrid fitness values from their data comparing hybrids with the parental species. In all their model simulations, a hybrid swarm replaced both species - *S. foliosa* and *S. alterniflora* - within six generations due to the superior fitness of hybrids. The local extinction and replacement by hybrids of *S. foliosa*, as well as *S. alterniflora*, was also predicted in a recently published theoretical analysis of the *Spartina* invasion of San Francisco Bay (Wolf *et al.* 2001). Their analysis predicted that *S. foliosa* would become extinct in an invaded population within three to 20 generations owing to low fertility and competitive ability relative to *S. alterniflora*.

1.1.1.2 Background: Non-native *Spartina* Treatment Efficacy

A variety of treatment methods have been proposed to control or eradicate non-native invasive species of cordgrass including manual, mechanical, and chemical. The methods proposed are described and reviewed in great detail in the ISP Control Program PEIS/R. Manual, mechanical and chemical methods have been applied to a few treatment sites in 2002 and 2003 and have been monitored by the ISP Monitoring Program. The manual methods include digging and covering with black geotextile fabric. Digging simply removes the unwanted non-native vegetation, including the associated root and rhizomes. Covering kills the plants by removing needed sunlight, and heating (solarizing) the plants to temperatures that they cannot withstand. Mechanical mowing and application of glyphosate herbicide were also used in some locations. Mowing simply reduced the above ground biomass, and would not kill the plant on its own. However, it is used to reduce above ground biomass in conjunction with a secondary treatment such as covering or chemical spraying. The plant is initially stressed by the mowing action, the plant is more easily covered with fabric or herbicide and less is required to get full effective coverage. All of these methods have be used in the San Francisco Estuary and other invaded west coast regions and shown to be effective treatment methods for cordgrass control (California State Coastal Conservancy 2003).

1.1.2 Overview of the ISP Monitoring Program Report for 2003 and Report Organization

This report presents the 2003 monitoring program results. The goals of the 2003 monitoring program were to provide (1) detailed updated information on new found populations of non-native *Spartina* in the San Francisco Estuary and outer coast marshes; (2) information on the amount of spread since the 2001 survey at 28 sampled sites bay-wide; (3) a review of the existing field and aerial photo interpretation monitoring methods; and (4) a summary of the 2002-2003 treatment sites and their control efficacy. The selected approach for the 2003 Monitoring Program and the organization of this report includes three parts: (1) Distribution/Inventory Monitoring (2) Genetic Survey Monitoring and (3) Treatment Site Monitoring: Efficacy of control.

2.0 METHODS

2.1 DISTRIBUTION/INVENTORY MONITORING

The 2003 Distribution/Inventory Monitoring Program mapped the distribution and abundance of non-native *Spartina* in the San Francisco Estuary at 28 sample sites and compared that to the distribution and abundance at those locations in 2001. The precision and accuracy of the monitoring methods being used in 2003 (modified from the Guidelines to Monitor the Distribution, Abundance, and Treatment of Non-indigenous Species of Cordgrass in the San Francisco Estuary (Collins *et al.* 2001)) were also reviewed. Sampling sites were selected to provide representative coverage for the entire bay shoreline. A stratified approach was developed using two major selection criteria, "Subregion" (latitude) and "Site Type". The subregions were North Bay (NB), Central Bay (CB), and South Bay (SB) (Figure 1). The site types were I. Tidal/micro-tidal/former diked bayland, back barrier marsh; II. Fringing tidal marsh, mud flats and estuarine beaches; III. Major tidal slough, creek or flood control channel; and IV. Urbanized rock, riprap, docks, boat ramps and marinas. Field sites were selected across the latitudinal extent of the non-native *Spartina spp*. invasion in the Estuary. At least two marshes of each site type were selected from each of the three subregions of the Bay. Within each site type 6-7 marshes were selected. Also, marsh type (e.g. mud flat) within each site type was considered, but it was not possible to sample each marsh type for each combination of subregion and site type. . At each of the 28 field locations data were collected for all non-native *Spartina* observed (Figure 3, Tables 1-4).

Table 1. Background on Site Type I Marshes (Tidal/Microtidal/Former Diked Bayland) Inventoried in 2003.

Site name	*Marsh Type*	*Subregion*	*Latitude*	*Longitude*	Spartina *Species Present*
Bunker Marsh	Tidal	Central Bay	37.67612	-122.165	*S. alt*-hybrids
Citation Marsh	Tidal	Central Bay	37.68537	-122.165	*S. alt*-hybrids
Cogswell Marsh (North Quad)	Tidal	Central Bay	37.64403	-122.050	*S. alt*-hybrids
Piper Park West	Tidal	Central Bay	37.94285	-122.528	*S. densiflora*
Southampton Marsh	Tidal	North Bay	38.07220	-122.191	*S. patens*
Point Pinole	Tidal	North Bay	38.00641	-122.358	*S. alt*-hybrids & *S. densiflora*
Palo Alto Baylands	Tidal	South Bay	37.45763	-122.104	*S. alt*-hybrids
Corte Madera Marsh Reserve	Former diked bayland	Central Bay	37.93430	-122.504	*S. alt*-hybrids & *S. densiflora*
Pickleweed Park, San Rafael	Former diked bayland	Central Bay	37.96920	-122.494	*S. densiflora*

Table 2. Background on Site Type II Marshes (Fringing Tidal Marsh, Mudflats and Estuarine Beaches) Inventoried in 2003.

Site name	*Marsh Type*	*Subregion*	*Latitude*	*Longitude*	Spartina *Species Present*
Emeryville West	Fringing tidal/Mudflats	Central Bay	37.82640	-122.304	*S. alt*-hybrids
Coyote Creek Marsh, Fremont	Fringing tidal/Mudflats	South Bay	37.46937	-122.036	*S. alt*-hybrids
Alameda Island – North Elsie Roemer	Fringing tidal/Mudflats	Central Bay	37.75167	-122.243	*S. alt*-hybrids
Blackie's Pasture	Fringing tidal/Mudflats	Central Bay	37.89500	-122.488	*S. alt*-hybrids & *S. densiflora*
Ideal Marsh	Fringing Tidal	South Bay	37.55718	-122.128	*S. alt*-hybrids
Richmond Inner Harbor-Steege Marsh	Fringing Tidal	Central Bay	37.90958	-121.334	*S. alt*-hybrids
Bayshore Park, San Mateo	Fringing tidal/Mudflats	Central Bay	37.60330	-122.370	*S. alt*-hybrids

Table 3. Background on Site Type III Marshes (Major Tidal Slough, Creek or Flood Control Channel) Inventoried in 2003.

Site name	*Marsh Type*	*Subregion*	*Latitude*	*Longitude*	Spartina *Species Present*
Blackie's Creek	Slough, creek, channel	Central Bay	37.89674	-122.487	*S. alt*-hybrids
Colma Creek	Slough, creek, channel	Central Bay	37.64278	-122.397	*S. alt*-hybrids
Corte Madera Creek	Slough, creek, channel	Central Bay	37.94166	-122.517	*S. densiflora*
San Leandro Creek	Slough, creek, channel	Central Bay	37.73894	-122.204	*S. alt*-hybrids
San Mateo Creek	Slough, creek, channel	South Bay	37.57483	-122.304	*S. alt*-hybrids

Table 4. Background on Site Type IV Marshes (Urbanized Rock, Rip-Rap, Docks, Ramps, Marinas) Inventoried in 2003.

Site name	*Marsh Type*	*Subregion*	*Latitude*	*Longitude*	Spartina *Species Present*
Coyote Point Marina	Urbanized	South Bay	37.58924	-122.315	*S. alt*-hybrids
Oakland Inner Harbor	Fringing Tidal Marsh	Central Bay	37.78558	-122.262	*S. alt*-hybrids
Yosemite Slough	Fringing Tidal Marsh	Central Bay	37.72318	-122.383	*S. alt*-hybrids
India Basin	Fringing Tidal Marsh	Central Bay	37.73299	-122.374	*S. alt*-hybrids
Pier 94	Fringing Tidal Marsh	Central Bay	37.74684	-122.374	*S. alt*-hybrids
Pier 98/Herons Head	Fringing Tidal Marsh	Central Bay	37.73676	-122.371	*S. alt*-hybrids
Loch Lomond Marina	Fringing Tidal Marsh	Central Bay	37.97294	-122.476	*S. alt*-hybrids

2.1.1 Field Methods

At each sampling site, observers mapped the location and aerial extent of non-native *Spartina* species using a Global Positioning System (GPS) handheld sensor and data entry unit (Trimble Geo-Explorer III). The plant data were entered into the unit as points, lines or polygons depending on the extent of the invasion. For example a single clone less that 5 meters was considered a data point. A linear array of clones, for example, along a creek bank, was mapped as a line. A cluster or meadow of clones was mapped as a polygon. Due to the limits of resolution for the Trimble Geo-Explorer III GPS unit (3 meters), points larger than 5 meters were mapped as lines or polygons. In some cases, a cluster of individual clones was mapped as a single point for efficiency. These points would have clone number greater than one and relatively larger area compared to the other single clone points.

The GPS units automatically collect data on date, time, location, area and perimeter (if polygon data), and length (if line data). Field staff manually entered additional data including site name, species identification, clone identification (if applicable), clone diameter (if point data), width (if line data), sample name (if applicable), percent cover class (if line of polygon data) and any other information from the monitoring staff in a "comments" field.

Three of the four non-native species of *Spartina* found in the San Francisco Estuary: *Spartina densiflora*, *S. patens*, *S. alterniflora* and its hybrids were mapped in 2003. *S. anglica* was found at one location in the San Francisco Bay, Creekside Park in Kentfield, during the 2001 survey. This marsh was not randomly selected site for the 2003 monitoring program. *Spartina* species were identified using plant morphology using the ISP Field Identification Guide (Zaremba 2001). To confirm field identification of *S. alterniflora* and hybrids, 3-5 leaf samples per site were collected for genetic testing.

GPS data were downloaded using Pathfinder software, exported to ArcView, differentially corrected, and reviewed for errors. The data were then exported to Excel and once again reviewed for data entry errors. Final data were summarized and mapped in ArcView and statistically analyzed using Systat. A complete Quality Assurance/Quality Control Plan of the Monitoring Program is included in Appendix 4.

2.1.2 Aerial Photo Interpretation Methods:

In addition to field-collected data, aerial photo interpretation was used. Aerial photo interpretation was only used for larger infestations, not single *Spartina* clones. In the aerial photo interpretation method, color infrared photos were taken at 1:6000 feet scale at low tide during the peak of the growing season (between August-October). The photos were taken at the same time of year as previous photos, in the late summer or early fall when the plants were at peak of growth and still green to allow for accurate yearly comparison. Photos were scanned at 1200 dpi and orthorectified. Photos were imported into ArcView 3.3 for review and analysis. Polygons were digitized around the *Spartina* meadows and polygons were given a cover class (<1% seedlings, <1% mature, 1-10%, 10-30%, 30-60%, 60-90%, 90-100%). Areas of the polygons were calculated using the ArcView Xtools extension. Area of the *Spartina* infestation of the polygon was then determined by creating a new area field based on a calculation of the total polygon area multiplied by the percent cover of non-native cordgrass. The total calculated non-native *Spartina* areas were compared over time to determine spread (percent change in area covered) between years. Field and aerial photo interpretation measurements were compared to assist in assessing the utility of the aerial photo interpretation methodology for efficient and accurate monitoring in the future.

2.2 GENETIC SURVEY MONITORING

Genetic analyses to confirm species identification were done at each of the 28 - 2003 inventory monitoring sites (Tables 1-4) and at the additional sites requested by concerned landowners, managers or stakeholders (Table 5). Genetic sampling and testing was done at a few sites along the coast north of the Golden Gate in Point Reyes National Seashore and Bolinas Lagoon (Table 5). In order to confirm species identification, leaves from ambiguous plants and at least 3-5 plants per monitoring site were collected according to standard methods used previously (Ayres *et al.* 2004) and conforming to recommendations in Collins *et al.* (2001). Where needed, transects were run the length of marshes sampling every 10 meters to determine (1) if there were any "hidden" *S. alterniflora*-hybrids, or (2) the percent invasion of a particular marsh. From each individual clone of unknown species identification and from each 10-meter sample along the transects, a single plant leaf was collected, labeled with indelible ink and placed in a labeled zip lock bag. Plant samples were kept refrigerated until mailed overnight to Dr. Debra Ayres at the UC Davis *Spartina* Laboratory. Plant samples were tested for species using RAPD (Randomly Amplified Polymorphic DNA) nuclear markers (Daehler and Strong 1997; Ayres *et al.* 1999).

Once genetic testing was complete, the *Spartina* Laboratory emailed the results as Excel spreadsheets to the ISP Field Biologist who coordinated the Monitoring Program. The genetic results were then incorporated into the GIS database for further GIS analysis and map production. Final genetic results were then passed on to the landowners, managers or stakeholders that may have requested the genetic survey.

Table 5. Background on Genetic Survey Sites.

Site name	*Sub Site*	*Marsh Type*	*Site Type*	*Subregion*	Spartina *Species Present*
Cooley Landing-Ravenswood Preserve, Palo Alto		Former diked bayland	I	South Bay	*S. alt*-hybrids
Plummer Creek Mitigation, Fremont		Former diked bayland	I	South Bay	*S. foliosa*
Richmond Inner Harbor – Steege Marsh	East/West Steege Marsh	Former diked bayland	I	Central Bay	*S. alt*-hybrids
	Outbound Steege Marsh	Fringing tidal marsh	I	Central Bay	*S. alt*-hybrids
	Meeker Slough	Former diked bayland	I	Central Bay	*S. alt*-hybrids
Petaluma Marsh	Woloki Creek	Tidal	I	North Bay	*S. foliosa*
	San Antonio Creek	Tidal	I	North Bay	*S. foliosa*
	Donahue Slough	Tidal	I	North Bay	*S. foliosa*
Coyote-Nayhan Creek, Mill Valley		Slough, creek, channel	III	Central Bay	*S. foliosa*
Beach Drive, San Rafael		Tidal	IV	Central Bay	*S. alt*-hybrids
Loch Lomond Marina, San Rafael		Former diked bayland	IV	Central Bay	*S. alt*-hybrids
Crissy Field, San Francisco		Former diked bayland	I	Central Bay	*S. alt*-hybrids seedlings
Limantour Estero, PRNS		Fringing tidal marsh	I	Outer Coast	*S. alt*-hybrids
Bolinas Lagoon South		Fringing tidal marsh	I	Outer Coast	*S. alt*-hybrids
Coyote Creek Marsh, Fremont		Fringing tidal marsh	III	South Bay	*S. alt*-hybrids
Yosemite Slough, San Francisco		Slough, creek, channel	IV	Central Bay	*S. alt*-hybrids

2.3 TREATMENT EFFICACY MONITORING

A variety of methods have been used or proposed for treating non-native *Spartina* (PEIS/EIR 2003 and other sources). During 2001, 2002 and 2003 three types of treatment were applied: manual (digging and covering), mechanical (mowing), and chemical (herbicide). The treatment sites were not stratified by subregions or site type across the entire Bay. The 2002-03 control treatment work and some effectiveness monitoring were implemented on an ad hoc basis by landowners or stewards, not by the ISP, because the PEIS/EIR had not been finalized as of the 2003 fieldwork season to allow the ISP to do work. Individual landowners and managers treated *Spartina* using their own resources with advice from the ISP. ISP staff monitored the treatment efficacy at sites as time and staff resources allowed. Table 6 lists all sites treated and mapped in 2002 and 2003. Some treatments were done in 2002 with assessment of efficacy in 2003, while some treatments took place in 2003 with assessments of efficacy to be done in 2004 (Table 6). A description of each site and the treatment implemented there are provided in Appendix 1.

The methods for collecting monitoring data were consistent with the approach suggested in the "Guidelines to Monitor the Distribution, Abundance and Treatment of Non-indigenous Species of Cordgrass in the San Francisco Estuary" (Collin *et al.* 2001). At each treatment site, prior to treatment, the extent of non-native *Spartina* was mapped according to the Inventory Monitoring Methods to determine the total area of non-native *Spartina* prior to treatment. For large treatment sites (sites mapped as a polygon with a percent cover of non-native *Spartina*) the sampling scheme described by Collin *et al.* 2001 was modified from GIS based sampling approach to a field based approach. A stratified random sub-sampling method was applied. Transects were run across the length of the treatment area parallel to the shoreline. Random points were selected across the length of the transects. Perpendicular transects extended down to the low intertidal. For smaller treatment sites (individual clones mapped as points), all the mapped plants (up to a maximum of 30 plants per site) were monitored. If more than 30 plants were mapped, 30 were randomly selected to monitor pre-treatment and post-treatment to determine the treatment efficacy. Treatment efficacy data (measurements of overall plant vigor including plant height, density per 0.25 meter, plant vigor (high/medium/low), tide wash (yes/no) plant species percent cover (native and non-native plant species) per 0.25 meter, percent flower *Spartina* per 0.25 meter, sediment type, high/medium/low marsh, burn (yes/no) (as outlined in Collins *et al.* 2001) were collected from each of these sampling locations. One year post treatment, in addition to collecting treatment efficacy data at treatment sites, the entire treatment area was mapped again according to the Inventory Monitoring Methods to determine the area of non-native *Spartina* cover after treatment.

2.4 DATA MANAGEMENT AND STATISTICAL METHODS

Data collection was similar to methods used in 2001 corresponding to guidelines presented in Collins *et al.* (2001). The ISP Field Biologist and Monitoring Coordinator, K. Zaremba trained all field biologists for uniformity and consistency in field methods. Data on species, location, and area covered were entered into handheld GPS units in the field. Supplemental notes were added as needed. Once in the office, data were downloaded to Pathfinder software, differentially corrected, and reviewed by the ISP Biologist and Monitoring Coordinator. After review, the data files were exported to ArcView. All files were backed up regularly to CDs. Once all data files were collected for the season, the individual site files were merged into a single data set. Files were sorted by data collector and exported to Excel for another round of review by the data collectors. Files were

Table 6. Sites Treated and Mapped 2001, 2002 and 2003.

Site name	*Marsh Type*	*Site Type*	*Treatment Type*	*Date Mapped*					
				2001		*2002*		*2003*	
				Treated	*Monitored*	*Treated*	*Monitored*	*Treated*	*Monitored*
Piper Park	Tidal	I	Digging		5/03/01	12/03/02	12/27/02	1/10/03, 1/11/03, 1/25/03	1/24/03, 9/12/03, 9/15/03, 09/24/03, 11/05/03, 11/12/03
PRNS-Drakes/Limantour Estero-	Fringing Tidal Marsh/ Mudflats	II	Trampling Covering			Summer 2002	6/22/02, 6/28/02, 10/06/03		7/20/03, 11/04/03
PRNS-Drakes Estero	Fringing Tidal Marsh/ Mudflats	II	Trampling Covering			Summer 2002			11/4/03
Bolinas Lagoon North	Fringing Tidal Marsh/ Mudflats	II	Digging		11/23/01	Winter 2002			
Bolinas Lagoon South	Fringing Tidal Marsh/ Mudflats	II	Trampling Covering					7/08/03	7/08/03
Emeryville	Fringing Tidal Marsh/ Mudflats	II	Mow '02 Mow/Cov '03			Summer 2002		Summer 2003	9/03/03, 9/04/03
Richmond Inner Harbor – Steege Marsh	Fringing Tidal Marsh/ Mudflats	II	Trampling Covering					9/29/03, 10/29/03, 10/30/03	9/02/03
Alameda Island – North Elsie Roemer	Fringing Tidal Marsh/ Mudflats	II	Mowing Spraying					9/03, 10/03	8/28/03, 9/02/03
Pier 94	Fringing Tidal Marsh	IV	Digging Trampling Covering					8/03/03, 12/05/03	6/30/03
Pier 98	Fringing Tidal Marsh	IV	Digging Covering					Summer 2003	6/18/03

Site and Marsh Types:
Type I. Former Diked Bayland /Microtidal /Tidal / Back Barrier Marsh
Type II. Fringing Tidal Marsh /Mudflats /Estuarine Beaches
Type IV. Urbanized rock, riprap, dock, ramp, marina.

edited as necessary and then combined and imported into ArcView for preliminary GIS analysis and imported into Systat for further statistical analyses.

The first statistical analysis was a cross-tabulation of categorical names to check for typographical errors and duplications. Summary statistics were then calculated for quantitative variables to check for unreasonable ranges and outliers. A few errors were detected in the Systat screening tests and these were corrected in the GIS database and the Excel spreadsheets. GIS plots and statistical comparisons were performed on the final edited files.

We tested the hypothesis that there was an increase in area covered by non-native *Spartina* using a T-test between area covered in 2001 and 2001. The hypothesis that a particular species, site type or bay region (latitude) had an influence on the change in area covered between 2001 and 2003 was tested with an Analysis of Variance (ANOVA). We tested the hypothesis that site latitude had a signification effect on change in area covered between 2001 and 2003 by using an Analysis of Covariance (ANCOVA). The accuracy and precision of the field ID of species compared to the verification by genetic testing was tested using a Chi-square test of frequencies.

Quality control was provided by having all data collected by the same method, direct entry in the field, by trained field biologists who had all been instructed and mentored by the project manager. Handwritten notes were taken if needed to supplement the machine-entered data.

Quality assurance was provided by multiple editing checks of the data and frequent back-ups to CD of intermediate and final data files. A complete Quality Assurance Statement is provided in Appendix 4.

3.0 RESULTS

3.1 DISTRIBUTION/INVENTORY MONITORING

A total of 31 estimates of area covered by three species of non-native *Spartina* at 28 separate sampling areas were inventoried in 2003 (Tables 1-4). Area covered was expressed in square meters. The three species of *Spartina* were *S. patens*, *S. densiflora*, and *S. alterniflora*. The *S. alterniflora* category included hybrids of *S. alterniflora* with the native *S. foliosa* and was described as a single type, *S. alterniflora*-hybrid. The 28 sampling areas were distributed across the latitudinal extent of the non-native *Spartina spp.* invasion in three bay regions (as defined by the Wetlands Goals Project (Goals Project 1999)). By subregion, two sites were inventoried in the North Bay, 21 sites were inventoried in the Central Bay, and five sites were inventoried in the South Bay. The distribution of effort by site type was nine Type I (tidal marshes and formerly diked baylands), seven Type II (strip marshes and mudflats), five Type III (channels and sloughs), and seven Type IV (urbanized habitat). The three non-native species differed in their distributions among the three bay regions. *S. patens* occurred at one location, Southampton, in the North Bay where no other non-native species occurred. *S. densiflora* occurred at seven locations: one in the North Bay and six in the Central Bay. At three of the Central Bay sites *S. densiflora* and *S. alterniflora*-hybrids both occurred. Two of these three sites are adjacent to each other, that is, Blackie's Creek runs through Blackie's Pasture. *S. alterniflora*-hybrids occurred at 23 separate sites from the Central Bay and the South Bay. It was not possible to sample equal numbers of sites within each type and subregion due to the unequal frequencies of appropriate sites, the requirement to avoid clapper rails in some locations, to sample particular sites at particular tide heights, and limited numbers of trained field staff and GPS units. Nevertheless, as noted above, the sampling in 2003 encompassed the full known regional extent of non-native *Spartina* species distribution.

Area covered by non-native *Spartina* was quantitatively summarized using descriptive statistics. Summary descriptive statistics and analyses were performed using the statistical package SYSTAT 10 (SPSS 2000) (Appendix 2, Tables 5 & 6). See Appendix 2 for the complete descriptive statistics. Hypotheses about changes over time and among species and regions were tested with parametric and non-parametric statistics. The data for area covered (square meters) at each of the locations by non-native *Spartina* were not normally distributed so statistical analyses were performed on log-transformed values.

In order to make comparisons between 2001 and 2003 among all 31 sites, it was necessary to convert aerial photo-based data for five sites in 2001 to equivalent "field estimates" based on empirical relationships in the data. The relationship of aerial photo measurements of area to field measurements of area was tested using a t-test and linear regression (on log-transformed data) of field estimates on photo estimates for five sites in 2003. No difference in mean area covered was found between methods (t-test, $p = 0.616$). However, no regression relationship was found ($p = 0.797$). Due to high variability among the small sample size of aerial photo measurements, it was not possible to predict field observations statistically from aerial photo interpretations for the five sites where both kinds of data were collected in 2003.

The next attempt was to predict field measurements in 2001 from field measurements in 2003 using log-transformed values for area covered by *S. alterniflora*-hybrids at all 18 marshes where they occurred. This relationship was highly significant ($p<.001$) with 71% of the variability in 2001 explained by the 2003 observations (R-squared = 0.709). Based on this relationship it was possible to estimate the five missing "field estimates" for 2001 using the regression equation Log(2001 area) = 0.091 + 0.828 Log(2003 area). The values thus obtained were anti-logged to obtain a value in square meters and these values were then used to calculate percent change in area of *S. alterniflora*-hybrids from 2001 to 2003 (Appendix 2, Table 7). Note that values estimated by the regression equation for sites without field data are assumed to follow general patterns in the data and not be dramatically different in some way from the values for sites where field measurements were made. Additional calibrations of photo-based and field-based estimates of coverage are warranted.

3.1.1 Inventory Results by Individual Site

3.1.1.1 Site Type I Tidal/Back Barrier/Former Diked Marsh

"Site Type I" sampling sites include tidal, back barrier and former diked marshes. There were 9 sites of this site type. Their results are described below and summarized in Table 7.

Bunker Marsh - Central Bay

In 2003, both field and aerial photo interpretation methods were used to map Bunker Marsh (Figure 4), resulting in measurements of 5665.59 m^2 (1.40 acres) and 8501.62 m^2 (2.10 acres) of *S. alterniflora*-hybrids respectfully. In 2001, the site was mapped using only the aerial photo interpretation mapping method, which measured 5100.86 m^2 (1.26 acres) of *S. alterniflora*-hybrids at the site. Using the regression equation for the log-transformed values of the existing 2001 field measurements of area covered, the 2001 field measurement was estimated to be 1580.11 m^2 (0.39

Table 7. Change in Area Covered Between 2001 and 2003 Using Field Measurements (and Field Estimates*) for Ten Site Type I Locations

Site Name (Site Type I)	*Species*	*Area in 2001 (acres)*	*Area in 2003 (acres)*	*Area in 2001 (square meters)*	*Area in 2003 (square meters)*	*Change in Area 2001 to 2003*
Bunker Marsh*	*S. alt*-hyb	0.39	1.40	1580.11	5665.59	259%
Citation Marsh*	*S. alt*-hyb	0.51	1.93	2059.735	7803.41	279%
Cogswell Marsh (North Quadrant) *	*S. alt*-hyb	0.37	1.32	1503.16	5334.08	255%
Piper Park West	*S. densiflora*	0.02	0.08	99.92	318.40	219%
Southampton Marsh	*S. patens*	0.31	0.05	1244.49	196.99	-84%
Point Pinole	*S. densiflora*	0.00	0.00	2.99	6.39	114%
Palo Alto Baylands	*S. alt*-hyb	0.12	0.15	478.26	618.49	29%
Corte Madera Marsh Reserve 1	*S. densiflora*	0.011	0.014	44.95	60.75	35%
Corte Madera Marsh Reserve 2	*S. alt*-hyb	0.01	0.05	26.46	214.92	712%
Pickleweed Park	*S. densiflora*	0.49	0.03	1964.07	118.73	-94%

*No field measurement collected in 2001. 2001 field estimate was calculated using a regression curve based on a correlation between the existing 2001 and 2003 field measurements.

acres). A comparison of the 2001 field estimate based on the regression curve and the 2003 field measurement shows an increase of 4085.48 m^2 (1.08 acres, 259%). A comparison of the aerial photo interpretation based results for the two years shows an increase of 3400.76 m^2 (0.84 acre, 67%) of the *S. alterniflora*/hybrids at the site. Comparing the 2003 methods, the field method estimated 33% less area (-2836.03 m^2, -0.70 acres) than the aerial photo interpretation method. (Sec. 3.1.2).

Citation Marsh - Central Bay

In 2003, both field and aerial photo interpretation methods were used to map Citation Marsh (Figure 5), resulting in measurements of 7803.41 m^2 (1.92 acres) and 2448.35 m^2 (0.61 acre) of *S. alterniflora*-hybrids respectfully. In 2001, the site was mapped using only the aerial photo interpretation mapping method, which measured 244.83 m^2 (0.06 acre) of *S. alterniflora*-hybrids at the site. Using the regression equation for the log-transformed values of the existing 2001 field measurements of area covered, the 2001 field measurement was estimated to be 2059.74 m^2 (0.51 acres). A comparison of the 2001 field estimate based on the regression curve and the 2003 field measurement shows an increase of 5743.67 m^2 (1.42 acres, 279%). A comparison of the aerial photo interpretation results for the two years shows an increase of 2203.52 m^2 (0.54 acres, 900%) of the *S. alterniflora*/hybrids at the site. Comparing the 2003 methods, the field method estimated 219% greater area (5355.06 m^2, 1.32 acres) than the aerial photo interpretation method. (Sec. 3.1.2).

Cogswell Marsh (North Quadrant) - Central Bay

In 2003, both field and aerial photo interpretation methods were used to map the North Quadrant of Cogswell Marsh (Figure 6), resulting in measurements of 5334.08 m^2 (1.32 acres) and 700.12 m^2 (0.17 acres) of *S. alterniflora*-hybrids respectfully. In 2001, the site was mapped using only the aerial photo interpretation mapping method, which again measured 700.12 m^2 (0.17 acre) of *S. alterniflora*-hybrids at the site. Using the regression equation for the log-transformed values of the existing 2001 field measurements of area covered, the 2001 field measurement was estimated to be 1503.16 m^2 (0.37 acres). A comparison of the 2001 field estimate based on the regression curve and the 2003 field measurement shows an increase of 3830.92 m^2 (0.95 acres, 255%). A comparison of the aerial photo interpretation results for the two years shows no change in area of the *S. alterniflora*/hybrids at the site. Comparing the 2003 methods, the field method estimated 662% greater area (4633.96 m^2, 1.15 acres) than the aerial photo interpretation method. (Sec. 3.1.2).

Piper Park West- North Bay

The West side of Piper Park (Figure 7) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.02 acre of *S. densiflora*, while in 2003 the site was determined to have 0.08 acre, an increase of 219%.

Southampton Marsh- North Bay

Southampton Marsh (Figure 8) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.31 acre of *S. patens*, while in 2003 the site was determined to have only 0.05 acre, a marked decrease of 84%.

Pt. Pinole - North Bay

Pt. Pinole's marshes (Figure 9) were mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.0007 acre of *S. densiflora*, while in 2003 the site was determined to have 0.0016 acres, an increase of 114%.

Palo Alto Baylands - South Bay

Palo Alto Baylands' marshes (Figure 10) were mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.12 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.15 acre, an increase of 29%.

Corte Madera Marsh Reserve (1. S. alterniflora-hybrids & 2 S. densiflora) - North Bay

The Corte Madera Marsh Reserve (Figure 11) was mapped using field methods in 2001 and 2003 for both *S. alterniflora*-hybrids and *S. densiflora*. In 2001 the site was determined to have 0.01 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.05 acres, an increase of 712%. In 2001 the site was determined to have 0.011 acre of *S. densiflora*, while in 2003 the site was determined to have 0.014 acre, an increase of 35%.

Pickleweed Park - North Bay

Pickleweed Park's marshes (Figure 12) were mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.49 acre of *S. densiflora*, while in 2003 the site was determined to have only 0.03 acre, a marked decrease of 94%.

3.1.1.2 Site Type II Fringing Tidal Marsh/Mudflats/Estuarine Beaches

"Site Type II" sampling sites include fringing tidal, mudflats and estuarine beaches. There were seven sites of this site type. Their results are described below and summarized in Table 8.

Emeryville West - Central Bay

Emeryville West's marshes (Figure 13) were mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.07 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 1.59 acres, a marked increase of 2175%.

Table 8. Change in Area Covered Between 2001 and 2003 Using Field Measurements (and Field Estimates*) for Eight Site Type II Locations

Site Name (Site Type II)	*Species*	*Area in 2001 (acres)*	*Area in 2003 (acres)*	*Area in 2001 (square meters)*	*Area in 2003 (square meters)*	*Change in Area 2001 to 2003*
Emeryville West	*S. alt*-hyb	0.07	1.59	282.60	6430.15	2175%
Coyote Creek Marsh	*S. alt*-hyb	0.09	0.06	353.25	233.15	-34%
Alameda Island - North Elsie Roemer*	*S. alt*-hyb	0.29	0.98	1171.89	3948.94	237%
Blackie's Pasture 1	*S. densiflora*	0.021	0.020	84.12	82.66	-2%
Blackie's Pasture 2	*S. alt*-hyb	0.01	0.08	41.37	330.90	700%
Ideal Marsh*	*S. alt*-hyb	0.26	0.88	1070.72	3541.00	231%
Richmond Inner Harbor – Steege Marsh	*S. alt*-hyb	0.01	0.02	32.19	100.46	212%
Bayshore Park	*S. alt*-hyb	0.05	0.25	168.19	1018.84	506%

*No field measurement collected in 2001. 2001 field estimate was calculated using a regression curve based on a correlation between the existing 2001 and 2003 field measurements.

Coyote Creek Marsh - South Bay

The marshes along Coyote Creek (Figure 14) were mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.09 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.06 acre, a decrease of 34%.

Alameda Island/Elsie Roemer North - Central Bay

In 2003, both field and aerial photo interpretation methods were used at north end of Elsie Roemer Bird Sanctuary at Alameda Island (Figure 15), resulting in measurements of 3948.94 m^2 (0.98 acres) and 2882.37 m^2 (0.89 acres) of *S. alterniflora*-hybrids respectfully. In 2001, the site was mapped using only the aerial photo interpretation method, which measured 2882.37 m^2 (0.71 acre) of *S. alterniflora*-hybrids at the site. Using the regression equation for the log-transformed values of the existing 2001 field measurements of area covered, the 2001 field measurement was estimated to be 1171.89 m^2 (0.29 acres). A comparison of the 2001 field estimate based on the regression curve and the 2003 field measurement shows an increase of 2777.05 m^2 (0.69 acres, 237%). A comparison of the aerial photo interpretation results for the two years shows an increase of 727.63 m^2 (0.18 acre, 25%) of the *S. alterniflora*/hybrids at the site. Comparing the 2003 methods, the field method estimated 9% greater area (338.94 m^2, 0.8 acres) than the aerial photo interpretation method (Sec. 3.1.2).

Blackie's Pasture - North Bay

The marsh at Blackie's Pasture (Figure 16) was mapped using field methods in 2001 and 2003 for both *S. alterniflora*-hybrids and *S. densiflora*. In 2001 the site was determined to have 0.01 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.08 acre, an increase of 700%. In 2001 the site was determined to have 0.021 acre of *S. densiflora*, while in 2003 the site was determined to have 0.020 acre, a decrease of 2%.

Ideal Marsh - South Bay

In 2003, both field and aerial photo interpretation methods were used to map the north end of Ideal Marsh (Figure 17), resulting in measurements of 3541.00 m^2 (0.88 acre) and 3863.62 m^2 (0.95 acre) of *S. alterniflora*-hybrids respectfully. In 2001, the site was mapped using only the aerial photo interpretation method, which measured 2229.01 m^2 (0.55 acre) of *S. alterniflora*-hybrids at the site. Using the regression equation for the log-transformed values of the existing 2001 field measurements of area covered, the 2001 field measurement was estimated to be 1070.72 m^2 (0.26 acres). A comparison of the 2001 field estimate based on the regression curve and the 2003 field measurement shows an increase of 2470.28 m^2 (0.61 acres, 231%). A comparison of the aerial photo interpretation results for the two years shows an increase of 1634.61 m^2 (0.4 acre, 73%) of the *S. alterniflora*/hybrids at the site. Comparing the 2003 methods, the field method estimated 8% less area (-322.62 m^2, -0.08 acres) than the aerial photo interpretation method. (Sec. 3.1.2).

The north end of Ideal Marsh (Figure 17) was mapped using field methods as well as with aerial photo interpretation methods in 2003. The site was determined to have 0.55 acre in 2001 and 0.95 acre in 2003 of *S. alterniflora*-hybrids, an increase of 73%. In 2003, the field survey determined to site to have 0.88 acre, 8% less than the aerial photo interpretation calculation.

Richmond Inner Harbor - Central Bay

Steege Marsh within the area of Richmond Inner Harbor (Figure 18) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.01 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.02 acre, a decrease of 212%.

Bayshore Park - South Bay

The marsh along Bayshore Park (Figure 19) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.05 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.25 acre, an increase of 506%.

3.1.1.3 Site Type III Major/Minor Tidal Sloughs/Channels/Creeks

"Site Type III" sampling sites include major and minor tidal sloughs, channels and creeks. There were 7 sites of this site type. Their results are described below and summarized in Table 9.

Blackie's Creek - North Bay

The creek at Blackie's Pasture (Figure 16) was mapped using field methods in 2001 and 2003 for both *S. alterniflora*-hybrids and *S. densiflora*. In 2001 the site was determined to have 0.03 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.02 acre, a decrease of 13%. In 2001 the site was determined to have 0.003 acre of *S. densiflora*, while in 2003 the site was determined to have 0.002 acre, a decrease of 30%.

Colma Creek - Central Bay

The marsh along Colma Creek (Figure 20) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 2.36 acres of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 7.16 acres, an increase of 203%.

Corte Madera Creek -North Bay

The marsh along Corte Madera Creek (Figure 21) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 1.19 acres of *S. densiflora*, while in 2003 the site was determined to have 2.70 acres, an increase of 128%.

San Leandro Creek - Central Bay

The marsh along San Leandro Creek (Figure 22) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 2.16 acres of *S. alterniflora*-hybrids, while in 2003

Table 9. Change in Area Covered Between 2001 and 2003 Using Field Measurements for Six Site Type III Locations

Site Name (Site Type III)	*Species*	*Area in 2001 (acres)*	*Area in 2003 (acres)*	*Area in 2001 (square meters)*	*Area in 2003 (square meters)*	*Change in Area 2001 to 2003*
Blackie's Creek 1	*S. alt*-hyb	0.03	0.02	108.33	93.97	-13%
Blackie's Creek 2	*S. densiflora*	0.00	0.00	12.06	8.46	-30%
Colma Creek	*S. alt*-hyb	2.36	7.16	9551.11	28957.46	203%
Corte Madera Creek	*S. densiflora*	1.19	2.70	4802.16	10948.30	128%
San Leandro Creek	*S. alt*-hyb	2.16	3.83	8760.60	15481.79	77%
San Mateo Creek	*S. alt*-hyb	68.10	0.78	825.41	3172.16	284%

the site was determined to have 3.83 acres, an increase of 77%.

San Mateo Creek - South Bay

The marsh along San Mateo Creek (Figure 23) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.20 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.78 acre, an increase of 284%.

3.1.1.4 Site Type IV Urbanized Marsh/Rock, Rip-Rap, Docks, and Marinas

"Site Type IV" sampling sites include urbanized marsh/rock, rip-rap, docks, and marinas. There were 5 sites of this site type. Their results are described below and summarized in Table 10.

Coyote Point Marina - South Bay

The marsh habitat in and around the Coyote Point Marina (Figure 24) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.35 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.74 acre, an increase of 113%.

Oakland Inner Harbor - Central Bay

The marsh habitat in and around the Oakland Inner Harbor (Figure 25) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 2.74 acres of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 5.40 acres, an increase of 96%.

Yosemite Slough - Central Bay

The marsh habitat within Yosemite Slough (Figure 26) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.02 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.12 acre, an increase of 530%.

India Basin - Central Bay

The marsh habitat within India Basin (Figure 28) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.10 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.01 acre, a decrease of 90%.

Pier 94 - Central Bay

The marsh habitat at Pier 94 (Figure 26) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.04 acre of *S. alterniflora*-hybrids, while in 2003 the site

Table 10. Change in Area Covered Between 2001 and 2003 Using Field Measurements for Seven Site Type IV Locations

Site Name (Site Type IV)	*Species*	*Area in 2001 (acres)*	*Area in 2003 (acres)*	*Area in 2001 (square meters)*	*Area in 2003 (square meters)*	*Change in Area 2001 to 2003*
Coyote Point Marina	*S. alt*-hyb	0.35	0.74	1408.81	3004.87	113%
Oakland Inner Harbor	*S. alt*-hyb	2.74	5.40	11087.72	21685.73	96%
Yosemite Slough	*S. alt*-hyb	0.02	0.12	75.47	476.02	531%
India Basin	*S. alt*-hyb	0.10	0.01	408.20	41.47	-90%
Pier 94	*S. alt*-hyb	0.04	0.03	171.72	129.50	-25%
Pier 98/Heron's Head (treat took place in 2002)	*S. alt*-hyb	0.002	0.009	8.83	37.40	324%
Loch Lomond Marina	*S. alt*-hyb	0.005	0.016	19.63	64.98	231%

was determined to have 0.03 acre, a decrease of 25%.

Pier 98/Heron's Head - Central Bay

The marsh habitat at Pier 98/Heron's Head (Figure 26) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.002 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.009 acre, an increase of 323%.

Loch Lomond Marina - Central Bay

The marsh habitat within and around the Loch Lomond Marina (Figure 12) was mapped using field methods in both 2001 and 2003. In 2001 the site was determined to have 0.005 acre of *S. alterniflora*-hybrids, while in 2003 the site was determined to have 0.016 acre, an increase of 231%.

3.1.2 Change in Area Covered by Non-native *Spartina* averaged by Species (2001 - 2003)

Field surveys methods (measurements plus estimates) showed that when data is averaged over all species and all sites sampled, the non-native species of *Spartina* increased area (paired sample t-test, p = 0.003) covered by 244% between 2001 and 2003 (Table 11). *S. patens* occurred at only one site in the North Bay, a Site Type I. It decreased in area covered by 84%. *S. densiflora* occurred at six sites, one in the North Bay and five in the Central Bay. *S. densiflora* occurred at three site types: I, II, and III. *S. densiflora* decreased in nearly as many sites (3) as it increased (4).

Statistical comparisons were not possible for this species because of low sample sizes but the average percent change in area covered by *S. densiflora* was 53% with a range from -94% to +219%. *S. alterniflora*-hybrids make up most of the non-native coverage and their proportion among the non-natives increased in 2003 compared to 2001. *S. alterniflora*-hybrids accounted for 83% of the

Table 11. Change in Area Covered by Non-native Spartina species between 2001 and 2003 Averaged over All Sites Surveyed Comparing Aerial Photo Interpretation Measurement (APIM), Field Estimate and Field Measurement Measurements.

Species	*Change in Area from 2001-2003*		
	Field Survey Methods		*APIM (N=5)**
	*Field Measurement (N=23)***	*Field Measurement + Field Estimates (N=28)****	
***S. alt*-hyb**	335.06%	317.00%	213.05%
S. densiflora	52.83%	52.83%	n/a
S. patens	-84.2%	-84.2%	n/a
Average	242.95%	244.41%	213.1%

See Table 7-11 for the methods used at the individual sites.
* Five of the 28 sites had only aerial photo interpretation measurements for 2001. For these five sites, a 2001 field estimate was calculated using a regression curve based on a correlation between the existing 2001 and 2003 field measurements. This 2001 field estimate was used in the place of the 2001 field survey data to calculate the change in area from 2001-2003.
** Change in area with five sites removed. Only 23 sites are used to calculate the change in area from 2001-2003
*** For five sites of the 28 sites, 2001 aerial photo interpretation measurement was used in the place of the 2001 field survey data to calculate the change in area from 2001-2003.

non-native *Spartina* coverage in 2001 and had increased their proportion to 90% in 2003 (calculated from Appendix 2, Tables 1 and 2). The average percent difference in area covered by *S. alterniflora*-hybrids was 317% with a range from -90% to +2175%. The five sites where aerial photo interpretation methods were used to measure change in area covered between 2001 and 2003 by *S. alterniflora* and its hybrids had an average increase of 213%. The aerial photo interpretation measurements of area covered by *S. alterniflora* and its hybrids were on average 170% less than, or approximately half the field measurements. However, both methods still recorded an approximate doubling of area invaded in two years.

3.1.3 Area Covered by Non-native *Spartina* averaged by Subregion (2001 - 2003)

Field surveys (field measurement plus estimates) showed an increase of non-native *Spartina* of 15% in the North Bay, 292% in the Central Bay and 177% in the South Bay from 2001 to 2003 (Table 12).

As noted above, *S. patens* was at only one site in the North Bay where it apparently decrease by 84%. *S. densiflora* was mapped at only one sample location in the North Bay at Pt. Pinole, where they increase by 114%. *S. densiflora* increased by 43% in the Central Bay, while *S. alterniflora*-hybrids

Table 12. Change in Area Covered by Non-native Spartina species between 2001 and 2003 Averaged by Region Comparing Aerial Photo Interpretation Measurement (APIM), Field Estimate and Field Measurement Methods.

Subregion	*Species*	*Change in Area from 2001-2003*		
		Field Surveys		*APIM (N=5)**
		*Field Measurement (N=23)***	*Field Measurement + Field Estimates (N=28)****	
Central Bay	All	294.72%	291.97%	9.39%
North Bay	All	14.69%	14.69%	n/a
South Bay	All	98.23%	177.00%	109.56%
Central Bay	*S. alterniflora*-hybrids	402.73%	391.68%	9.39%
South Bay	*S. alterniflora*-hybrids	98.23%	177.00%	209.73%
Central Bay	*S. densiflora*	42.7%	42.7%	n/a
North Bay	*S. densiflora*	113.5%	113.5%	n/a
North Bay	*S. patens*	-84.2%	-84.2%	n/a

See Table 7-11 for the methods used at the individual sites.
* Five of the 28 sites had only aerial photo interpretation measurements for 2001. For these five sites, a 2001 field estimate was calculated using a regression curve based on a correlation between the existing 2001 and 2003 field measurements. This 2001 field estimate was used in the place of the 2001 field survey data to calculate the change in area from 2001-2003.
** Change in area with five sites removed. Only 23 sites are used to calculate the change in area from 2001-2003
*** For five sites of the 28 sites, 2001 aerial photo interpretation measurement was used in the place of the 2001 field survey data to calculate the change in area from 2001-2003.

increased 392% accounting for the majority of the spread in the region. Only *S. alterniflora* hybrids were documented in the South Bay where they were responsible for the 177% increase in non-native invasive *Spartina* between 2001-2003 (Table 12). *S. alterniflora*-hybrids had higher mean and total area covered in Central Bay than in South Bay in both 2001 and 2003 (Appendix 2, Tables 5,6). The slight trend of percent change in *S. alterniflora*-hybrid area covered with latitude (south to north trend) was not statistically significant, $p = 0.18$ (Appendix 2, Figure 2) (Tables 1-4).

3.1.4 Area Covered by Non-native *Spartina* averaged by Site Type (2001 - 2003)

Field survey (field measurements plus estimates) data showed that non-native *Spartina* (all species) increased from 2001-2003 by 172% at Type I sites, by 504% at Type II sites, by 108% at Type III sites, and by 169% at Type IV sites (Table 13). *S. patens* apparently decreased at the single Type I site where it was found (Table 13). *S. densiflora* increased in Type I and Type III sites but apparently decreased slightly at Type II sites. No *S. densiflora* were noted at Type IV sites. While *S. alterniflora*-hybrid acreage increased greatly from 2001 to 2003 across all Site Types, the percent change in area covered by *S. alterniflora*-hybrids did not differ significantly among the Site Types (ANOVA $p = 0.254$). However, Site Types I and II did have higher percent increases, on average, than site types III and IV (Appendix 2, Figure 1). Analysis of the area covered by *S. alterniflora* hybrids (log transformed square meters) in 2003 found no statistical difference among site types (ANOVA $p = 0.377$). A large area in each of the Site Types was covered by the non-native *S. alterniflora*-hybrids. The difference in mean area covered increased highly significantly in 2003 over 2001 (paired sample t-test, $p < 0.001$), and this area increased in 19 of 23 marshes sampled, a statistically significant proportion of the sites (non-parametric sign test, $p =0.003$).

3.1.5 Aerial Photo Interpretation: Change in area covered between 2001 and 2003. Comparison of 2003 aerial photo interpretation results to the 2003 field monitoring results.

The estimates of the area covered of non-native *Spartina* hybrids differed between the two methods of estimation using either aerial photo interpretation area data or field measurement data. The aerial photo interpretation measurements indicated that the *S. alterniflora*-hybrids increased 322% at Site Type I, and 49% at Site Type II. Field data-derived measurements were on average 170% greater than the aerial photo interpretation measurements (Tables 14). This discrepancy affects the estimates of total acreage involved but does not substantially change the estimates of rate of increase of the invasion between 2001 and 2003, which is approximately doubled or more, whether averaged by Subregion or by Site Type. The relationship of aerial photo measurements of area to field measurements of area was tested statistically using a t-test and linear regression (on log-transformed data) of field estimates on photo estimates for five sites in 2003. No difference in mean area covered was found between methods (t-test, $p = 0.616$). However, no regression relationship was found ($p = 0.797$). This was likely due to high variability among the small sample size of aerial photo measurements. Thus, aerial photo interpretation measurement can not be used to estimate field measurement.

Table 13. Change in Area Covered by Non-native Spartina Species Averaged by Site Type I-IV Comparing Aerial Photo Interpretation Measurement (APIM), Field Estimate and Field Measurement Methods.

Site Type	*Species*	*Change in Area from 2001-2003*		
		Field Surveys		*APIM* *(N=5)
		Field Measurement ** (N=23)	*Field Measurement + Field Estimation** (N=28)	
Site Type I	All	132.95%	172.29%	322.23%
Site Type II:	All	592.89%	503.89%	49.29%
Site Type III:	All	108.16%	108.16%	n/a
Site Type IV:	All	168.54%	168.54%	n/a
Site Type I	*S. alterniflora* hybrids	306.74%	370.72%	322.23%
Site Type II:	*S. alterniflora* hybrids	711.82%	267.97%	49.29%
Site Type III:	*S. alterniflora* hybrids	137.70%	137.70%	n/a
Site Type IV:	*S. alterniflora* hybrids	383.14%	383.14%	n/a
Site Type I	*S. densiflora*	68.34%	68.34%	n/a
Site Type II:	*S. densiflora*	-1.73%	-1.73%	n/a
Site Type III:	*S. densiflora*	49.08%	49.08%	n/a
Site Type IV:	*S. densiflora*	n/a	n/a	n/a
Site Type I	*S. patens*	-84.2%	-84.2%	n/a

Site and Marsh Types:
Type I. Former Diked Bayland/Microtidal /Tidal/Back Barrier Marsh
Type II. Fringing Tidal Marsh /Mudflats/Estuarine Beaches
Type III. Major Tidal Slough, Creek or Flood Control Channel
Type IV. Urbanized rock, riprap, dock, ramp, marina.

See Table 7-11 for the methods used at the individual sites.
* Five of the 28 sites had only aerial photo interpretation measurements for 2001. For these five sites, a 2001 field estimate was calculated using a regression curve based on a correlation between the existing 2001 and 2003 field measurements. This 2001 field estimate was used in the place of the 2001 field survey data to calculate the change in area from 2001-2003.
** Change in area with five sites removed. Only 23 sites are used to calculate the change in area from 2001-2003

***For five sites of the 28 sites, 2001 aerial photo interpretation measurement was used in the place of the 2001 field survey data to calculate the change in area from 2001-2003.

Table 14 Change in Area Covered by Non-native Spartina between 2001 and 2003 for Five Sites Comparing Aerial Photo Interpretation Measurements (APIM), Field Estimate and Field Measurement Measurements.

Site Name	*Site Type*	*Species*	*Area in 2001 (square meters)*		*Area in 2003 (square meters)*		*Change in Area 2001 to 2003*		*Difference Between Methods of Estimating Areas*
			APIM	Field Estimate*	APIM	Field Measurement	APIM 2001 vs APIM 2003	Field Estimate 2001 vs Field Measurement 2003	Field Measurement 2003 vs APIM 2003
Bunker Marsh	I	*S. alt-hybrids*	5100.86	1580.11	8501.62	5665.59	67%	259%	-33%
Citation Marsh	I	*S. alt-hybrids*	244.83	2059.735	2448.35	7803.41	900%	279%	219%
Cogswell Marsh (North Quadrant)	I	*S. alt-hybrids*	700.12	1503.16	700.12	5334.08	0%	255%	662%
Alameda Island - North Elsie Roemer	II	*S. alt-hyb*	2882.37	1171.89	3610.10	3948.94	25%	237%	9%
Ideal Marsh	II	*S. alt-hyb*	2229.01	1070.72	3863.62	3541.00	73%	231%	-8%
Average	Avg	*Avg*	2231.43	1477.12	3824.74	5258.60	213%	252%	170%

*No field measurement collected in 2001. 2001 field estimate was calculated using a regression curve based on a correlation between the existing 2001 and 2003 field measurements.

3.2 GENETIC SURVEY MONITORING

The purpose of the genetic survey component of the ISP Monitoring Program was to provide genetic surveys of *Spartina* in marshes requested by landowners or managers, and to confirm field identifications. (Table 15. See Appendix 3 for a list of all *Spartina* leaf samples tested in the lab.)

3.2.1 Surveys of Marshes Requested by Landowners

Over the course of the 2003 monitoring season, 12 landowners, managers or concerned stakeholders requested surveys for the presence of non-native *Spartina* (Table 15).

The marsh at Beach Drive in San Rafael has been accreting sediment and an increasing amount of *Spartina* habitat. Two clones were easily identified as *S. alterniflora*-hybrids. They were confirmed genetically and account for the two non-natives of the 17 point samples collected.

Table 15. Genetic Testing Results at 12 Locations Where Landowners Requested Surveys.

Site Name	Point (P)/Transect (T) Samples (randomly sub sample)	County	Date Collected	Percent Non-native	Survey Requested by
Beach Drive 1	T	Marin	6/6/03	0%	Private landowner
Beach Drive 2	P	Marin	6/6/03	18%	Private landowner
Bolinas Lagoon South	T	Marin	7/8/03	13%	Marin County Open Space, land manager
Cooley Landing-Ravenswood Preserve - established vegetation	T	San Mateo	7/29/03	19%	Wetland Research Assoc., restoration site consultants
Cooley Landing-Ravenswood Preserve - seedlings	T	San Mateo	9/16/03	0%	Wetland Research Assoc., restoration site consultants
Coyote Creek	P	Alameda/ Santa Clara	7/15/03	38%	Don Edwards National Wildlife Refuge, USFWS, land owner
Crissy Field	P	San Francisco	5/6/03	21%	Golden Gate National Recreation Area (GGNRA), land owner
Limantour Estero	T	Marin	7/21/03	0%	Point Reyes National Seashore, National Park Service, land owner
Loch Lomond Marina	P	Marin	6/6/03	40%	Private landowner
Coyote Creek-Nahyan Creek	T	Marin	10/13/03	0%	Jane Valerious, restoration consultant/botanist
Petaluma Marsh - Donahue Slough	T	Marin	8/11/03	0%	Petaluma River Keeper, stakeholder
Petaluma Marsh - San Antonio Creek/Mud Slough	T	Marin	8/11/03	0%	Petaluma River Keeper, stakeholder
Petaluma Marsh - Wiloki Creek	T	Marin	8/11/03	0%	Petaluma River Keeper, stakeholder
Plummer Creek Mitigation	T	Alameda	9/3/03	0%	Jane Valerious, restoration consultant/botanist
Richmond Inner Harbor - East Steege Marsh	T	Contra Costa	4/22/03	0%	Aquatic Outreach Institute, stakeholder
Richmond Inner Harbor - Meeker Slough	T	Alameda	9/3/03	0%	Aquatic Outreach Institute, stakeholder
Richmond Inner Harbor - Outbound Steege Marsh	P	Alameda	9/3/03	33%	Aquatic Outreach Institute, stakeholder
Richmond Inner Harbor - West Steege Marsh	T	Contra Costa	4/22/03	0%	Aquatic Outreach Institute, stakeholder
Richmond Inner Harbor - West Steege Marsh	P	Contra Costa	12/15/03	n/a	Aquatic Outreach Institute, stakeholder
Yosemite Slough	P	San Francisco	6/18/03	89%	California State Parks, land owner/manager
Yosemite Slough - transect 1	T	San Francisco	6/18/03	84%	California State Parks, land owner/manager

The marsh adjacent to the found and treated *S. alterniflora*-hybrid clone in the south end of the Bolinas Lagoon was sampled and came back as pure native *S. foliosa*.

The Cooley Landing/Ravenswood Preserve Restoration Project site was surveyed for mature as well as seedling *S. alterniflora*-hybrids. The transect results from the mature stand of *Spartina* indicated that the established plants in this restored marsh are 19% *S. alterniflora*-hybrid, while the seedling that are recruiting at this stage are native.

Of the 16 point samples randomly collected along Coyote Creek in Newark, six (38%) came back as non-native.

Six of the 14 plants samples collected at Crissy Field, which were mostly seedlings, were determined to be non-native. (All non-native seedlings were pulled.)

The marsh in the area of the found and treated non-native *Spartina* in Limantour Estero was surveyed and test results indicated the marsh had no more non-native (0% non-native).

Two of the five plants sampled in Loch Lomond Marina were determined to be non-native *Spartina*.

Transect samples taken along Coyote-Nahyan Creek in Mill Valley were determined to be 100% native, as were the samples from Petaluma Marsh, East-West Steege Marshes and Meeker Slough of Richmond, and Plummer Creek Mitigation in Fremont.

Outbound Steege Marsh had two easily identifiable clones that were confirmed to be non-native.

The transect samples tested from Yosemite Slough in San Francisco were determined to be 84% non-native, as were 56 of the 63 random point samples collected.

3.2.2 Confirmation of Field Identifications

Genetic tests were performed to confirm species identification by field staff at each of the Inventory Monitoring Sites (Table 16). Three to five samples were taken for genetic testing to confirm the field identification at each site, and a single sample was also taken for each plant with unknown field identification. The accuracy of field Identification of S. alterniflora, S. foliosa and their hybrids were tested statistically with a Chi square test of frequencies of correct field identification of *S. alterniflora*, *S. alterniflora*-hybrids, and *S. foliosa*. This test used the genetic analysis as the true (or theoretical expected frequencies) and the field observations as the observed frequencies. A total of 68 plant samples were identified to species in the field using plant morphology, leaf samples were collected from each plant, and analyzed using genetic tools (Daehler and Strong 1997; Ayres *et al.* 1999). Fifty-five of the plants were field identified as *S. alterniflora*-hybrids, and 13 as *S. foliosa*. Forty-nine of the plants were confirmed genetically to be *S. alterniflora*-hybrids, and 18 were confirmed to be *S. foliosa*. The Chi square value for these four frequencies was 2.629. The critical value for $p = 0.05$ is 3.84. Therefore there was not a statistically significant difference between field classification and subsequent genetic (or true) identification at the 0.05 level. The p value for the Chi square value was $p > 0.10$ and less than $p = 0.20$. The errors in field identification of the *Spartina* species were conservative. More native *S. foliosa* were

Table 16. Genetic Confirmation of Species Field Identification

Field Identification	*# of Samples*	*Lost or no data*	*# Analyzed*	*# Confirmed S. alterniflora*	*# Confirmed Hybrid*	*Percent Confirmed Hybrid or S. alterniflora*	*# Confirmed S. foliosa*	*Percent Confirmed S. foliosa*
S. alt-hyb	62	7	55	18	31	89%	6	11%
S.foliosa	13	0	13	0	0	0%	13	100%
Unknown	163	9	154	20	64	55%	70	45%

called *S. alterniflora*-hybrid than vice versa. 89% of the *S.alterniflora*-hybrids and 100% of the *S. foliosa* were correctly identified. However, there is still justification for genetic testing in the future.

3.3 TREATMENT EFFICACY MONITORING

Table 17. Background on Pre- and Post-treatment Sites Monitored in 2003.

Site name	*Marsh Type*	*Site Type*	*Region*	*Pre-Post Treat Monitoring*	*Treatment*
Piper Park (Including East Strip Marsh)	Tidal	I	North Bay	Post	Dig Winter 2003
Piper Park (w/out East Strip Marsh)	Tidal	I	North Bay	Post	Dig Winter 2003
PRNS-Drakes/Limantour Estero-2002	Fringing Tidal Marsh/ Mudflats	II	Outer Coast	Post	Trample & Cover Summer 2002
PRNS-Drakes Estero-2003	Fringing Tidal Marsh/ Mudflats	II	Outer Coast	Pre	Trample & Cover Fall 2003
Bolinas Lagoon North-2002 Treat	Fringing Tidal Marsh/ Mudflats	II	Outer Coast	Post	Dig Winter 2002
Bolinas Lagoon South-2003 Treat	Fringing Tidal Marsh/ Mudflats	II	Outer Coast	Pre	Trample & Cover Summer 2003
Emeryville Crescent	Fringing Tidal Marsh/ Mudflats	II	Central Bay	Pre & Post	Mow & Cover Summer 2003
Emeryville Crescent –Mowed Portion	Fringing Tidal Marsh/ Mudflats	II	Central Bay	Pre & Post	Mow 2003
Emeryville Crescent – Mowed & Covered Portion	Fringing Tidal Marsh/ Mudflats	II	Central Bay	Pre & Post	Mow & Cover Summer 2003
Emeryville Crescent – Untreated Portion	Fringing Tidal Marsh/ Mudflats	II	Central Bay	Pre & Post	None
Richmond Inner Harbor	Fringing Tidal Marsh/ Mudflats	II	Central Bay	Pre	Trample & Cover Fall 2003
Alameda Island – North Elsie Roemer	Fringing Tidal Marsh/ Mudflats	II	Central Bay	Pre & Post	Mow/Mow & Spray 2002/Fall 2003
Pier 94	Fringing Tidal Marsh/ Mudflats	IV	Central Bay	Pre	Dig, Trample & Cover Summer 2003

Site and Marsh Types:
Type I. Former Diked Bayland/Microtidal /Tidal/Back Barrier Marsh
Type II. Fringing Tidal Marsh /Mudflats/Estuarine Beaches
Type IV. Urbanized rock, riprap, dock, ramp, marina.

The purpose of the monitoring of treatment sites was to determine the efficacy of treatment and to document any ongoing Bay-wide *Spartina* treatment efforts, whether performed by the ISP or not.

Table 18. Change in Acreage of Non-native Spartina at Pre- and Post-treatment Sites Monitored in 2003.

Site name	*Treat-ment Year(s)*	*Pre-Post Treat-ment*	*Area*			*% Change 2002-2003*	*% Change 2001-2003*	*Comment*
			2001 Acres/m^2	2002 Acres/m^2	2003 Acres/m^2			
Piper Park (entire treatment area including east strip marsh)	2002	Post	0.03/ 123.0	0.02/ 97.12	0.01/ 50.47	-48.0%	-59.0%	2002-3 treatment, volunteers did not finish the entire treatment area. Nor did they dig every plant in the primary treatment area thus not 100% kill.
Piper Park (primary treatment area w/out east strip marsh)	2002	Post	0.03/ 122.17	0.02/ 85.92	0.01/ 23.00	-73.2%	-81.2%	2002-3 treatment, primary treatment area, however volunteers did not dig every plant thus not 100% kill.
PRNS-Drakes/Limantour Estero	2002	Post	n/a	0.06/ 233.53	0.00005/ 0.20	-99.9%	n/a	One clone at Creamery Bay had a patch that grew out from under the tarp.
PRNS-Drakes Estero	2003	Pre	n/a	n/a	0.005/ 19.63	n/a	n/a	Pre-treatment data
Bolinas Lagoon North	2002	Post	n/a	0.002/ 7.07	0.00001/ 0.03	-99.6%	n/a	Return visits found occasional new sprouts.
Bolinas Lagoon South	2003	Pre	n/a	n/a	38.47/ 0.01	n/a	n/a	Pre-treatment data
Emeryville Crescent	2002 2003	Pre & Post	0.05/ 215.68	n/a	0.63/ 2547.52	n/a	1081.2%	Small scale 2002 mowing treatment had no effect thus mostly seeing spread.
Emeryville Crescent –Mowed Portion	2002 2003	Pre & Post	0.05/ 205.2775	n/a	0.38/ 1539.58	n/a	650.0%	Pre-treatment data.
Emeryville Crescent – Mowed & Covered Portion	2002 2003	Pre & Post	0.00/ 3.53	n/a	0.08/ 306.15	n/a	8566.7%	Pre-treatment data.
Emeryville Crescent – Untreated Portion	2002 2003	Pre & Post	n/a	n/a	0.02/ 66.73	n/a	n/a	
Richmond Inner Harbor – Steege Marsh	2003	Pre	0.01/ 32.19	n/a	0.02/ 100.46	n/a	n/a	Pre-treatment data.
Alameda Island – North Elsie Roemer	2003	Pre & Post	0.53/ 2143.97	n/a	0.53/ 2125.05	n/a	n/a	GIS based area calc 2003. Area calculations may be "imperfect".
Pier 94	2003	Pre	0.04/ 171.72	n/a	0.08/ 318.94	n/a	n/a	Pre-treatment data.

The following are the results for the 2002 treatment sites that were monitored in 2003 (Tables 17-19) and limited results for the few sites that were treated in 2003 (Tables 20-21).

3.3.1 Piper Park City of Larkspur

ISP staff monitored the Piper Park treatment site in the fall of 2003, approximately 9 months post treatment, and remapped existing *S. densiflora* and monitored 30 randomly selected treatment clones (Table 21). In summary the treatment effort resulted in an 81.2% reduction in overall coverage of *S. densiflora* in the main treatment area, and 59% including the East strip marsh that wasn't completed. On average, the *S. densiflora* was reduced to 0.27, less than a percent, at each treated clone. Native plants including *Salicornia virginica, Frankenia grandiflora, Distichilis spicata*, and *S. foliosa* were found establishing covering at an average of 24% of the clone areas treated. However, divots (holes) remained where digging took place at 26 of the 30, or 87%, clones treated. The average divot size was 0.47 meters in diameter.

Table 19. Change in Number of Clones of Non-native Spartina at Pre- and Post-Treatment Sites Monitored in 2003.

Site name	*Treat-ment Year(s)*	*Pre/Post Treat-ment*	*Number of Clones*			*Comment*
			2001	*2002*	*2003*	
Piper Park (including East strip marsh)	2002	Post	246	274	151	2002 treatment, volunteers did dig every plant thus not 100% kill.
Piper Park (w/out East strip marsh)	2002	Post	226	239	109	2003 treatment, volunteers did dig every plant thus not 100% kill.
PRNS-Drakes/Limantour Estero	2002	Post	n/a	5	1	
PRNS-Drakes Estero	2003	Pre	n/a	n/a	n/a	Pre- treatment only
Bolinas Lagoon North	2002	Post	n/a	n/a	n/a	
Bolinas Lagoon South	2003	Pre	n/a	n/a	n/a	Pre-treatment only
Emeryville Crescent	2002 2003	Pre & Post	22+ 3clusters	n/a	23	Small scale 2003 treatment, thus mostly seeing spread
Emeryville Crescent – Mowed Portion	2002 2003	Pre & Post	n/a	n/a	15	
Emeryville Crescent – Mowed & Covered Portion	2002 2003	Pre & Post	n/a	n/a	4	
Emeryville Crescent – Untreated Portion	2002 2003	Pre & Post	n/a	n/a	4	
Richmond Inner Harbor	2003	Pre	2	n/a	3	Pre- treatment only
Alameda Island – North Elsie Roemer	2002 2003	Pre & Post	n/a	n/a	n/a	GIS based area calc 2003. Area calculations may be "imperfect". Mowing treatment 2002 may have reduced the overall spread.
Pier 94	2003	Pre	n/a	n/a	n/a	Pre- treatment only

Table 20. Results of Treatment by digging for S. densiflora at Piper Park. Site is an established Tidal Marsh. (All measurements were replicated three times at each of 30 randomly selected sampling plots).

	Non-native Spartina				*% Cover Natives (per 0.25 m^2)*									
	Vigor (High/Med/Low)	*% Cover (per 0.25 m2)*	*Average Density*	*Average Height (cm)*	Salicornia	Distichilis	Frankenia	Jaumea	S. foliosa	*Total Natives*	*% Cov Other Non-natives*	*Sediment Type*	*% of Sampling Plots with Divots*	*Divot Size (m)*
Average	Low	0.27	0	0	5.47	12.03	0.17	6.10	0.03	23.8	0	Mud	86.67	0.475

3.3.2 Point Reyes National Seashore

ISP staff monitored the Point Reyes treatment site in the summer of 2003 and inspected each clone treated in the summer of 2002 (Table 21). The plants were visually confirmed to be dead under the tarps. ISP and PRNS staff removed the covers of two clones, the Drakes Estero and Creamery Bay clones, in fall of 2003. The Drakes clone above ground had 0% cover. The Creamery Bay had 0% cover, except for a small area at the tarp edge that was not randomly selected to monitor (fell out side the randomly tossed quadrat). Overall, the clone was estimated to be 5% cover, thus reduced by 95%. The area of shoots that remained was dug out. Theses clones will be monitored for re-growth early in the 2004-growing season to confirm that the plants are dead. Core samples of these two clones were collected March 2004 and are being grown out in a greenhouse to speed up the confirmation of the plants death underground. Once their death is confirmed, the remaining 3 clones will be uncovered, possibly in the early summer of 2004.

Table 21. Results of Treatment by Trampling and Covering at Creamery Bay and Drakes Estero in Point Reyes National Seashore. Sites are established Fringing Marsh. (All measurements were replicated three times at each of the two sampling plots).

				Non-native Spartina										
Site Name	*Date*	*Sample #*	*Plant ID*	*% Cover (0.25 m^2)*	*Average Density (0.25 m^2)*	*Average Height (cm)*	*Vigor (High/Med/Low)*	*Average % Flowers*	*% Cover Other Natives*	*% Cover Other Non-natives*	*Sediment Type*	*Burn (Y/N)*	*Tidal Wash (Y/N)*	*Patch Diameter (cm)*
Creamery Bay	11/4/03	1	CB-02-1	0	0	0	L	0	0	0	Mud	N	Y	0
Drakes Estero	10/7/03	2	DE-02-1	0	0	0	L	0	0	0	Mud	N	Y	0

3.3.4 Bolinas Lagoon

ISP and Marin Open Space staff revisited the treatment area in Summer 2002, Winter 2003, and Summer 2003 and new shoots were found and removed by hand pulling on each occasion. The site will continue to be monitored until no new shoots are found.

3.3.5 Emeryville Crescent – mowing proposed

The mowing treatment at Emeryville Crescent was meant to have a follow up herbicide treatment, which didn't occur due to lack of an NPDES permit. The mowing had no beneficial effect, other that perhaps reducing spread by seed or pollen. In fact the area that was mowed in 2002 had an apparent increase in cover of more than 1000%.

3.3.6 Pier 98 – Heron's Head – digging and covering proposed

The partial digging and covering of a single clone at Pier P8 was partially effective. This site requires more thorough follow up treatment.

3.3.7 Bolinas Lagoon South – covering proposed

Monitoring in 2004 will determine the efficacy of the 2003 covering treatment.

3.3.8 Emeryville Crescent – mow and cover proposed

The treatment at Emeryville Crescent was meant to have a follow up herbicide treatment in 2003, which didn't occur again due to lack of an NPDES permit. Caltrans followed up the mowing treatment in 2003 with a covering treatment. Monitoring in 2004 will determine the efficacy of the 2003 covering treatment.

3.3.9 Alameda Island South – mow and spray proposed

Monitoring in 2004 will determine the efficacy of the 2003 treatment. Preliminary observations of the site indicated poor herbicide effect, perhaps due to application error.

3.3.10 Steege Marsh – covering proposed

Monitoring in 2004 will determine the efficacy of the 2003 treatment.

3.3.11 Pier 94 – dig and cover proposed

Monitoring in 2004 will determine the efficacy of the 2003 treatment.

4.0 DISCUSSION

4.1 DISTRIBUTION/INVENTORY MONITORING

Based on the ISP's 2003 survey results, the average increase in area covered by all non-native *Spartina* species and by *Spartina alterniflora* hybrids was 244% and 317%, respectively, over a period of two years. Daehler and Strong (1996) analyzed the spread over time of *Spartina* spp. in different regions of the Pacific Coast Estuaries. In Willapa Bay, Washington, *S. alterniflora* spread from 800 hectares (ha) to 1,000 ha between 1988 and 1999, an increase of 25% in 11 years, this would correspond to a 2% annual increase and a 6% increase in three years. In Humboldt Bay, California, a single patch of *S. densiflora* discovered circa 1980 spread to 100 patches over the Bay's marsh habitat by 1989, a 100-fold (9,900%) increase in nine years. This would correspond to a 70% annual increase, or 390% increase in three years. Callaway and Josselyn (1992) reported the 650 circular clones of *S. alterniflora* in the Bay in 1990. Daehler and Strong reported that the 650 clones had increased to 1000 by 1993. Ayres *et al.* (2004) estimated that the 650 clones in reported in 1990 and the 1000 clones in reported in 1993 would have correlated to an approximate increase in area of 5 ha to 10ha, or 100%. Ayres *et al.* (2004) further hypothesized that, given the discovery of "hidden" hybrids since 1992, the patch estimates by Callaway and Josselyn (1992) were likely low, and the change in area covered may have been more like 25 ha in 1990 to 50 ha in 1993. According to Ayres *et al.* the formation of hybrids between *S. alterniflora* and *S. foliosa* greatly increased the rate of spread of non-native *Spartina*. The expansion of hybrids in Cogswell Marsh, Hayward, California between 1999 and 2000 was reported to be 2.5-fold, or 150% and some hybrids increased in area 4-fold, or 300% (Zaremba, 2001). Additionally, Ayres and Strong (2000) reported a remarkable 8-fold, or 740% increase of *S. alterniflora*-hybrids of 5% to 42% at San Lorenzo Marsh between 1997 and 2000. Based on simplified invasion dynamics, extrapolation of their area estimates and assuming constant growth rates, Ayres *et al.* (2004) estimated that non-native *Spartina* would cover the 69,432acres of San Francisco Bay intertidal flat and tidal marsh habitat in approximately 200 years. Of the three Pacific-Coast locations reviewed, the current average rate of spread of all non-native *Spartina* species in the San Francisco Bay is most similar to the rapid to the recent reports of *S. alterniflora*-hybrid spread in San Francisco Bay, and least similar to the extremely slow rate of spread of *S. alterniflora* in Willapa Bay, Washington in the late 1990s. This is likely because hybrids were not involved in the Willapa and Humboldt invasions, and not yet a significant portion of the San Francisco Bay *Spartina* population in the 1980s, and the primary method of spread was clonal expansion. According to Ayres *et al.* (2004) the current extremely high rate of spread may be the result of natural selection acting on hybrids that favor exponential clonal growth over sexual reproductions.

In the following sections, the spread of non-native *Spartina* in the San Francisco Bay is further evaluated by site type, species, and Bay region.

4.1.1 Increased Acreage of Non-native *Spartina* by Site Type

Considerable variation in the rate of change of *Spartina* coverage was discernable when the data were evaluated by the type of site colonized. Coverage of invasive *Spartina* (all species) increased by 172% (field measurement plus fields estimate) 133% (field measurement) in Site Type I (tidal and microtidal marshes, former diked baylands, and back barrier marshes), and by 504(field measurement plus field estimate, 593% field) in Site Type II (fringing tidal marshes, mudflats, and estuarine beaches). Site Type III (tidal sloughs, creeks, and flood control channels) and Site Type IV (urbanized shoreline, e.g., rip-rap, docks, and ramps) had relatively less increase in coverage, 108% and 169%, respectively. The difference among site types appears to be related to successional processes that are linked to sedimentation. This is consistent with observation of *S. alterniflora* and *S. townsendii* invasions in New Zealand and *S. anglica* in England summarized by Daehler and Strong (1996) and predictions by Callaway and Josselyn (1992). Site Type I includes tidal marshes and formerly diked baylands (restoration sites). Established *S. foliosa* marshes and open mudflats of a newly opened restoration site are highly susceptible to invasion by pollen and by seed respectively. For example, the formerly diked bayland Citation Marsh experienced 900% increase in non-native *S. alterniflora*-hybrid cover in three years. Site Type II includes fringing marsh and beach habitat which likely experiences an initial high rate of spread until the lower elevation limit with respect to tidal inundation of the *Spartina* is reached. After the initial rapid colonization of suitable, "empty-niche" habitat, then the rate of spread will slow to match the rate at which the *Spartina* augments sedimentation and creates additional shallow habitat to invade. For example, Alameda Island may have experienced relative little spread over time because the majority of susceptible mud flat habitat, habitat within the elevational limits of *S. alterniflora*-hybrids, may already have been invaded prior to our observations. This is consistent with a pattern where invasion rates of susceptible habitat are initially high and then slow until more susceptible habitat is created by sediment accretion. Site Type III is initially slower to colonize because it includes deeper channels and creeks, which must accrete sediment before they are at suitable elevation for more extensive colonization. Once the channel beds have sufficiently accreted, colonization of remaining channel banks and bottoms is rapid, with clonal colonies quickly coalescing into meadows.

4.1.2 Increased Acreage of Non-native *Spartina* by Species

Among the three non-native *Spartina* species that were monitored (*S. alterniflora*-hybrids, *S. densiflora*, and *S. patens*) *S. alterniflora*-hybrids spread the most rapidly (317% field measurement plus field estimate/335% field measurement in three years). *S. alterniflora* and hybrids have high rates of vegetative spread, produce large quantities of pollen (called pollen "swamping"), have successful seed set, and readily hybridize with the native *S. foliosa*. Once native *S. foliosa* is exposed to pollen from non-native *S. alterniflora* or hybrid plants, it begins to produce hybrid seeds, further accelerating the hybrid invasion. The rate of colonization is particularly rapid in the early stages of invasion. For example, Emeryville West showed an increase in cover of and 2,175%, between 2001 and 2003. Citation Marsh, as noted above, likely experience a similarly high invasion due to hybrid pollen swamping of established *S. foliosa* by as well as by hybrid seedling establishment. These two sites are also of Site Types II and I, respectively, which were found to be the most rapidly colonized site types, as discussed above. It is also possible that small seedlings may have been present in 2002 but overlooked during early surveys. This error due to hidden hybrids or unseen seedlings, suggests that early cover estimates may be low. They may in fact be even higher. The high rate of spread during the early stage of invasion is consistent with the predictions of Ayres *et al.* (2003 and 2004) and Antilla *et al.* (1998 and 2000).

The spread of *S. alterniflora*-hybrids was greatest within Site Type I, 371%, with Site Type II experiencing slightly less spread at 268%. Site Type III (creeks and sloughs) were invaded slightly less than Site Type IV (urbanized habitat), which experienced a 138% and 388% increase respectively. These results confirmed predictions by Ayres et al. (2004) that all habitats in the Bay are susceptible to invasion by this species.

S. densiflora didn't spread to the same degree as *S. alterniflora*-hybrid. On average across all Site Types it spread 52%. This is not surprising as it has a different growth form—a ceaspitose or clumping form such as a bunch grass. This species invests more energy in seed production rather that vegetative spread. Consistent with this hypothesis, Site Type III, creek and slough habitat, which act as the conduits of water and propagules where seeds may be initially deposited with the incoming tides. However, the tidal waters and seed they carry finally reach the established marshes, Site Type I, which in fact experienced the greatest increase in cover of *S. densiflora* (68%). During the 2003 monitoring season, the *S. densiflora* was not mapped in any habitat that was classified as Site Type IV, urban habitat. However, it has been observed growing in and around riprap and docks along Corte Madera Creek. Site Type II, fringing marsh and beach habitat, experienced an apparent decrease in *S. densiflora* cover (-2%). This may have been an artifact of sampling because only one site of this habitat type was surveyed.

S. patens apparently decreased in cover, a remarkable 84% decrease in area. *S. patens* is found only at one site in the Estuary, Southampton Marsh, where there is less than an acre of total cover. The apparent decrease is likely due to mapping error, rather than being a true decrease in cover.

4.1.3 Increased Acreage of Non-native *Spartina* by Bay Region-Latitude

Of the three Bay subregions, the Central Bay had a largest increase in cover, 292% . *S. alterniflora*-hybrids, the fastest spreading species (392%), dominate this region of the Bay. *S. densiflora* spread was greatest in the North Bay (113%).*S. patens* was only mapped in the North Bay, where it apparently decreased in cover (-84%). Clearly, the *S. alterniflora*-hybrids are the dominant invasive *Spartina* species and are well established and spreading the most in the heart of the Bay, nearest to the original introduction sites in the Freemont and San Bruno marshes.

4.1.4 Critique of the Monitoring Methods Used to Estimate Cover

It is to be expected that different monitoring methods will have different strengths and weaknesses. The strengths should be considered when selecting methods for monitoring. The strengths and weaknesses need to be considered when evaluating the estimated area coverage or the rate of expansion by non-native *Spartina.* Three difficulties identified during the 2003 monitoring are discussed here: imprecision of measuring small clonal species or small areas of invasion due to the limits of accuracy of the GPS units, differences between aerial photo interpretation estimates and ground-truth data, and low precision of net change of area coverage estimates because of broad cover class intervals.

The monitoring methods used in this survey were designed initially for *S. alterniflora*, which forms large expanses of cordgrass. These can be mapped as polygons with handheld GPS units. Polygons inherently have area, however the GPS units used to date (Trimble GeoExplorer III) have 3-meter error. Thus, the length of one side of a polygon could be measured as much as 6m too long or 6m too short. An overestimate of area one year followed by an underestimate the following year could result in an apparent decrease in area due to this imprecision in the measurements. This may have been the case for India Basin and Pier 98, two sites that had supposed decreases in cover (-90% and -25%).

The intrinsic error in the GPS may hinder accurate measurements of the smaller species, *S. densiflora* and *S. patens* at their present state of invasion. *S. patens* establishes as very small seedlings that spread vegetatively, forming large mounding clones that are mapped using GPS units as either polygons, points or lines. When large enough to be mapped as polygons, the +/- 6m per side error applies. This could account for the supposed decrease in cover of *S. densiflora* at Pickleweed Park (-94%) or Blackie's Pasture and Creek (-2% and -30%).

Small areas of invasive cordgrass can also be mapped as points or lines. If a plant is mapped as a point, the field staff input an estimate of clone diameter that is later used to calculate clone area. If a population is linear in form, it may be mapped as a line with an estimated width, which is used to calculate line area. For a small species, or populations of small size, the imprecision associated with these mapping techniques may be quite high. Two solutions to the problems of imprecise mapping are to use GPS units with sub-meter accuracy and to make precise field measurements of diameter (points) and length and width (lines) with these GPS units or with tape measure or laser range-finder or other survey technique.

Remote sensing using aerial infra-red photography has great potential for synoptic mapping of the spread of invasive *Spartina* compared to the labor-intensive field mapping. In 2003, we digitized photographs of large meadows of *S. alterniflora*-hybrid at five sites (Table 14) and used GIS to compare the areas estimated by both methods. Over all five sites, the field measurements were 170% greater than the aerial photo measurements. For two of the sites, Bunker and Ideal Marshes, the area calculated from aerial photos was less than that calculated with the field method (-33% and -8%). For the three sites where the aerial photo interpretation-method estimated a greater area than the field method, there were very different changes in percent cover: Alameda Island had an increase of 9%, Citation Marsh increased 219%, and the North Quadrant of Cogswell Marsh increased 661% (as calculated by the aerial photo interpretation method). The examples of both higher and lower aerial photo interpretation cover estimates indicate that the current method of digitizing polygons around the marsh or *Spartina* patch with a cover class may be too coarse to determine accurate estimated of cover.

Additional potential sources of imprecision in monitoring include the breadth of the cover class interval into which estimated percentages are grouped (i.e., <10%, 10-30%, or >30%) and the method for assigning the classes. If a polygon area is within a cover class, e.g., 10-30%, then it is assigned the midpoint of the class, 15%, in this example. In both 2001 and 2003, according the aerial photo interpretation method, Cogswell Marsh was determined to fall within the same cover class, 10-30%. This indicates that either there was no change in cover between 2001 and 2003 or that the difference was not large enough for 2003 to be assigned to <10% or >30%. Using the current methods, it is not possible to make estimates of percent cover more precise than the existing classes Thus, only gross changes in cover will be reflected in monitoring results for sequential years. If a trend of expansion or contraction continues for several years, then it will be detected when it crosses a cover class boundary. The cover classes are useful for determining an approximate infestation level and can be used to prioritize removal efforts.

4.2 GENETIC SURVEY MONITORING

Genetic surveys were conducted for several landowners, managers and stakeholders to determine whether suspect *Spartina* plants were non-native. No new non-native *Spartina* populations were found in the surveyed sites in North Bay (Petaluma Marsh and Coyote/Nahyan Creek in Mill Valley), nor in the outer coast marshes (Bolinas Lagoon and Limantour Estero). In the South Bay, a survey of the Plummer Creek Mitigation Site found only native *Spartina*. Seedlings from a *Spartina spp.* population at the Cooley Landing/Ravenswood Preserve Restoration Project were tested and determined to be 19% hybrids, but were predominantly native. Both of these sites are near extensive *S. alterniflora*-hybrid populations, and considered to be at risk. Genetic surveys were performed at a few small sites in the Central Bay (Crissy Field, Steege Marsh and Beach Drive) as part of a management regime to identify and remove newly established non-natives. The Golden Gate National Recreation Area actively manages Crissy Field, and GGNRA staff removed all non-native plants, mostly seedlings, that they discovered. Aquatic Outreach Institute, a stakeholder group, acquired the appropriate permits and manually treated the found non-natives at Steege Marsh. Two clones found at Beach Drive have not yet been treated because the private citizen who requested the survey does not have the authority to control the plants without a number of permits. The ISP staff will work with the landowner to get the necessary permits so that these few plants can be treated in 2004. (Table 6a).

Genetic tests were also performed to confirm species identification by field staff at each of the Inventory Monitoring Sites. The genetic tests confirmed that field staff were accurately identifying both *S. alterniflora*-hybrids (89%) and *S. foliosa* (100%). The samples labeled as "unknown" or "unidentifiable" by field staff were found by the genetic tests to be just as likely *S. alterniflora* as *S. foliosa* (55%-45%). This confirms that distinguishing between the native and hybrid species is quite challenging, and genetic surveys will continue to be necessary for future monitoring efforts (Figure 36).

4.3 TREATMENT EFFICACY MONITORING

Little *Spartina* treatment took place in 2002 and 2003, so there were few opportunities to monitor treatment efficacy. Post-treatment monitoring was done at 5 sites (sites that were treated in 2002), and pre-treatment monitoring was done at 7 sites. All of these sites will be monitored again and evaluated after the 2004 treatment season.

Post-treatment monitoring of the *S. densiflora* treatment site in Piper Park showed good efficacy of the manual removal method (digging). However, it was noted that a number of divots remained visible in the marsh plain several months after the clones were removed. It is uncertain how long these features may remain in the marsh, and it is unclear what effect they may have on the quality of the marsh habitat. We observed that volunteer removal efforts are excellent for public outreach. However, the commitment of volunteers to complete tedious treatment projects was tenuous, and it was frequently necessary for organizers and ISP staff to complete and/or follow-up on volunteer labor.

Surveys of clones in Bolinas Lagoon and Point Reyes that had been manually treated (dug or trampled and covered) showed vegetative cover reduced by 95%, however, the clone that was dug out in Bolinas Lagoon continues to produce some shoots around the clone edge that requiring pulling. Of the five clones treated in Point Reyes, two were uncovered and sediment core samples were collected for grow out tests. Once the roots and rhizomes are confirmed dead, the remaining covered plants will be uncovered. One of the Point

Reyes clones had no living vegetation above ground, while one had some remnant shoots that emerged from the clone edge. These results demonstrate that it is very important that the clones be entirely covered for the treatment to be effective. These two clones will be monitored again in the 2004 growing season for new shoots.

Preliminary post-treatment monitoring of the Emeryville treatment site (mowed in 2002) indicated no noticeable treatment effect, and further monitoring was cancelled. A single clone at Pier 98, which had been partially dug out and covered by volunteers, had a number of remaining shoots that required further control. This site will be monitored in more detail once treatment is completed in 2004.

5.0 CONCLUSIONS AND RECOMMENDATIONS

Inventory monitory of a subset of 28 sites in the San Francisco Bay Estuary indicates that non-native *Spartina* species are spreading rapidly in the San Francisco Bay Estuary. Between 2000 and 2003, the average percent increase in area for covered by all non-native *Spartina* species of *Spartina* in the Estuary was 244%, and by *S. alterniflora*-hybrids, 317%. Some locations experienced an increase of several thousand percent. According to the statistical analyses, both the changes in percent cover of all *Spartina* species and *S. alterniflora*-hybrids increased significant amounts over time. The *S. alterniflora*-hybrids increased in area at each site type and spread was greatest for Site Type I and II. However, the percent change in area did not differ significantly among Site Types. While there was a slight trend in increase of *S. alterniflora*-hybrids cover with latitude (south to north trend), it was not statistically significant. The relationship of aerial photo measurements of area to field measurements of area were tested statistically and no difference was found, thus the tow methods produce comparable results. However no regression relationship was found and thus aerial photo interpretation measurements cannot be used to estimate field measurement. Neither *S. densiflora* nor *S. patens* had adequate sample size for statistical analysis. The increasingly rapid rate of spread of *Spartina,* in particular *S. alterniflora*-hybrids, continues to pose a great threat to existing habitat and species assemblages and potentially threatens the success of ongoing and planned restoration projects within the San Francisco Estuary and outer coast marshes.

Monitoring by both field and aerial photo interpretation based methods are both useful to document and to evaluate the spread of non-native *Spartina*. However, except for grossly invaded areas, aerial photo interpretation mapping is not precise enough to map less than grossly invaded marshes without field truthing except for grossly invaded areas. Field mapping with three-meter-resolution GPS units is imprecise for small areas such as new invasion sites with smaller populations and physically smaller *Spartina* species. While trained field biologists can accurately identify the majority of non-native *Spartina* plants, genetic testing of ambiguous *S. alterniflora*-hybrid specimens will continue to be necessary to reduce the risk of overlooking non-natives and their hybrids.

Species specific patterns of invasion and spread, e.g., seeds, clones, hybrids, will require species specific control and eradication methods. The manual treatment methods applied in 2002 have been effective at controlling the physically smaller species and smaller scale invasions of *Spartina* in the Bay. Smaller, individual, vegetatively spreading plant patches, seedlings, and flowers can be effectively removed with manual techniques. Divots that remain after the removal of *Spartina* spp. by digging leaves "divots" in the marsh surface that persist for six months or more. These features should be more carefully evaluated to determine the overall effect on the quality of the marsh habitat. If necessary, the divots could be filled with sediment and planted with native species from the same plant community and elevation level, e.g., gumplant, (*Grindelia*, from native plant nurseries. *stricta* var. *angustifolia*), saltgrass (*Distichlis spicata*), and pickleweed (*Salicornia virginica*). Large areas invaded by *S. alterniflora* and its hybrids will require larger-scale eradication methods and follow-up to avoid re-growth and continued spread of hybrid *Spartina* by pollen. Successful control will only be achieved with dedication of adequate resources, attention to following protocols completely, and follow-up monitoring and periodic re-treatment as needed.

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