Basic Regional Spatial Analysis of NIS *Spartina* Invasions in the San Francisco Estuary

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Introduction

The California Coastal Conservancy provided funds to the San Francisco Estuary Institute (SFEI) to produce protocols for regional mapping of Non-indigenous Invasive Species (NIS) of cordgrass (*Spartina* spp.), and for site-specific assessment of the efficacy of local efforts to control NIS *Spartina* (Collins et al 2001). As part of the process to develop the regional mapping protocols, SFEI has produced this report to show some of the ways that the regional mapping might be used to assess the stage, magnitude, and location of the invasions at local, subregional, and regional scales.

Methods

All data were collected in the field using the regional mapping protocols (Collins et al. 2001), as briefly summarized here. In the field, patches of NIS *Spartina* were assigned to size classes based on patch diameter. The locations of the patches were recorded using GPS. Groups of small, closely associated patches were mapped together as single points, line features, or polygons, depending on the shape and size of the group. In these cases, percent cover was estimated for the group as a whole. The field data support the analysis of these features as patches, using the following rules. Only data for *S. densiflora* and the *S. alterniflora* complex (*S. alterniflora* and its hybrids with the native *S. foliosa*) were included in this analysis.

Point features. When a point feature was used to represent more than one plant, the patch count for that feature was equal to the number of plants represented. The area for each patch was equal to the total area of the point feature divided by the number of plants represented.

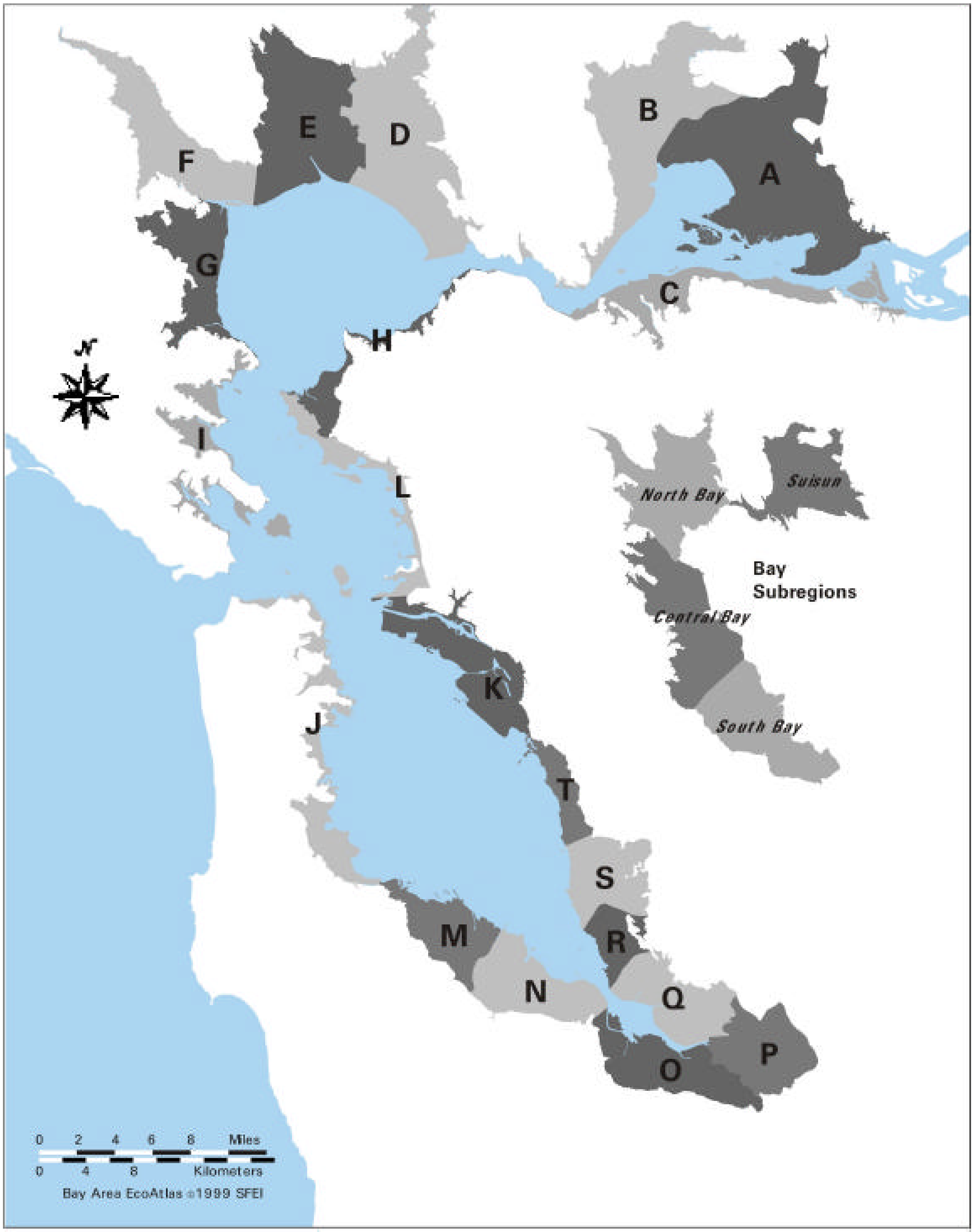
Line features. When a line feature (narrow band of patches) had more than 60% cover, it was considered a single patch, with an area equal to the value obtained as: line width x line length x percent cover. If the line had less than 60% cover, the number and area of patches was determined by dividing the total area of the line feature (adjusted by percent cover) by the area of the average clone size recorded for the line.

Area features. Since "average clone size" for area features was rarely recorded, the approach used for lines could not be taken. Instead, each area feature was considered a single patch, with area for the patch equal to the area of the feature, times its cover class.

When adjusting any area by cover class, the multiplier used was the mid-range for the cover class (e.g., for a cover class of "3060%", the multiplier was 0.45).

As requested by the Coastal Conservancy, the patch data were partitioned among Segments of the baylands ecosystem of the San Francisco Estuary (Figure 1), as defined by the San Francisco Bay Area Wetland Ecosystem Goals Project (Goals Project 1999). Any feature (i.e., point, line, or area) that crossed a Segment boundary was assigned to the Segment within which most of the feature occurred. No patches were counted partly or more than once.

Figure 1: Subregions and Segments of the San Francisco Estuary, downstream of the Delta, according to the San Francisco Bay Area Wetland Ecosystem Goals Project (Goals Project 1999). The 20 Segments are labeled A-T.



Results

Patch size-frequency and total number of patches relate to invasion stage (see analysis on page 11. The data for *S. densiflora* and *S. alterniflora* (including *S. alterniflora x S. foliosa* hybrids, henceforth called the *S. alterniflora* complex) are summarized in Tables 1 and 2 below.

Table 1: Distribution of *Spartina densiflora* among patch size classes and estuarine segments (see Figure 1).

Densiflora	Patch size class (diameter in meters)					Total patches
	1	2	3	4	5	
Estuarine Segment (see Fig 1)	0-1 m	1-3 m	3-10 m	10-30 m	>30 m	
D	0	1	0	0	0	1
H	58	0	0	0	0	58
I	5687	838	11	15	3	6554
J	2	0	0	0	0	2
						6615

Table 2: Distribution of *Spartina alterniflora* (including *S. alterniflora x S. foliosa* hybrids) among patch size classes and estuarine segments (see Figure 1).

Alterniflora	Patch size class (diameter in meters)					Total patches
	1	2	3	4	5	
Estuarine Segment (see Fig. 1)	0-1 m	1-3 m	3-10 m	10-30 m	>30 m	
H	0	13	6	4	0	23
I	3	8	8	0	0	19
J	15	77	59	46	37	234
K	31	2350	495	98	19	2993
L	7	12	8	1	0	28
M	12	378	114	48	8	560
N	15	190	333	106	8	652
O	4	5	24	9	0	42
Q	0	1	5	1	7	14
R	0	2	2705	4	11	2722
S	0	271	42	7	28	348
T	0	0	42	34	15	91
						7726

The distributions of individual patches of NIS *Spartina* among the patch size classes for each estuarine Segment are shown below in Figures 2 and 3. The distributions of patch area among the size classes and Segments are shown in Figures 4 and 5. It should be noted that the graphs of patch size frequency (Figures 2 and 3) reflect decisions made in the field about measuring patches as points, lines, or polygons. Some patches that could have been measured as polygon were instead subdivided into their component lines. This provided more detailed measurements, but increased the total number of patches.

Figure 2: Distribution of *Spartina densiflora* among patch size classes for estuarine Segments D, H, I, and J. Values above the bars are the numbers of patches.

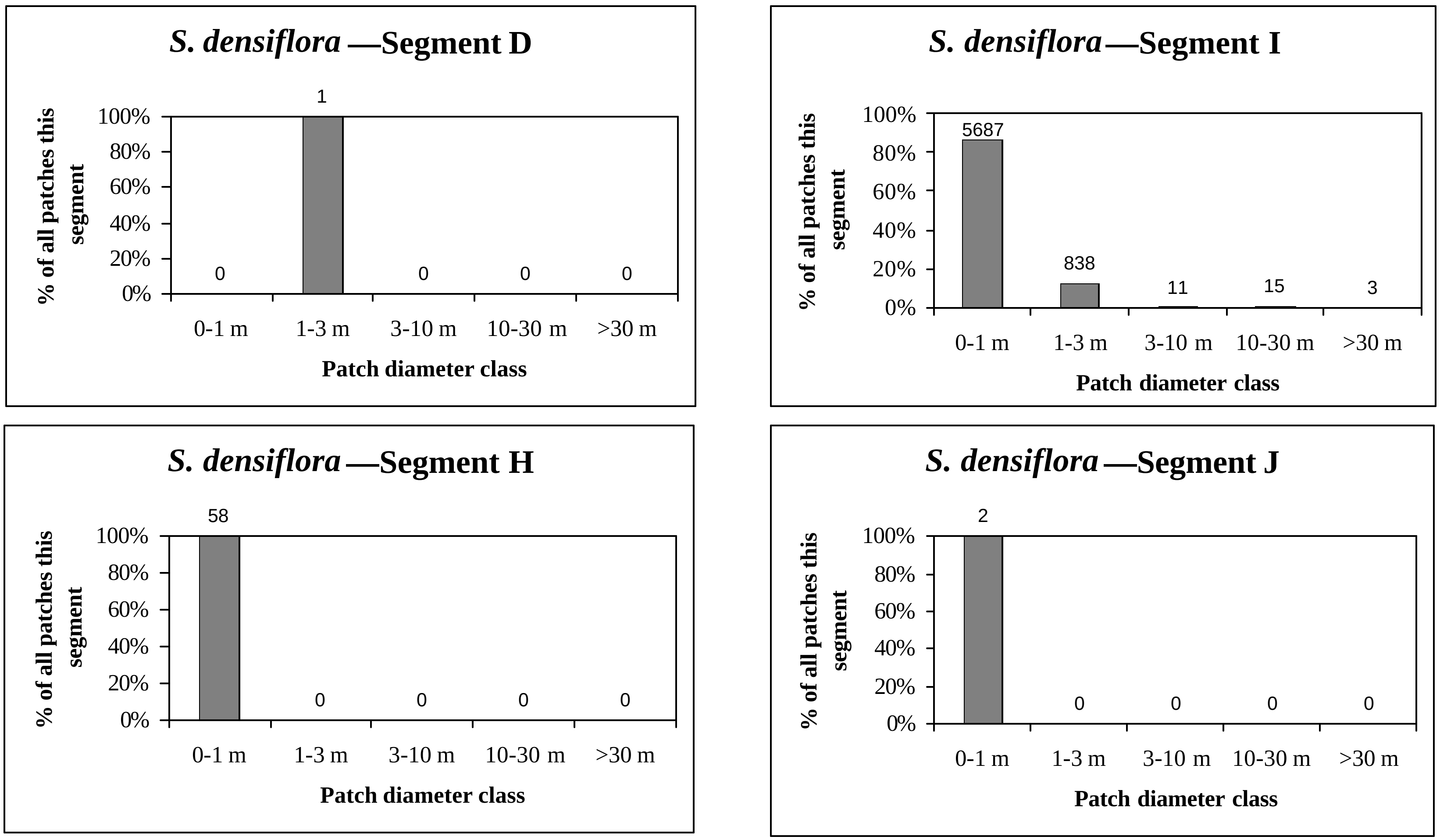


Figure 3: Distribution of *Spartina alterniflora* complex among patch size classes for estuarine Segments H, I, K, and L. Values above the bars are the numbers of patches.

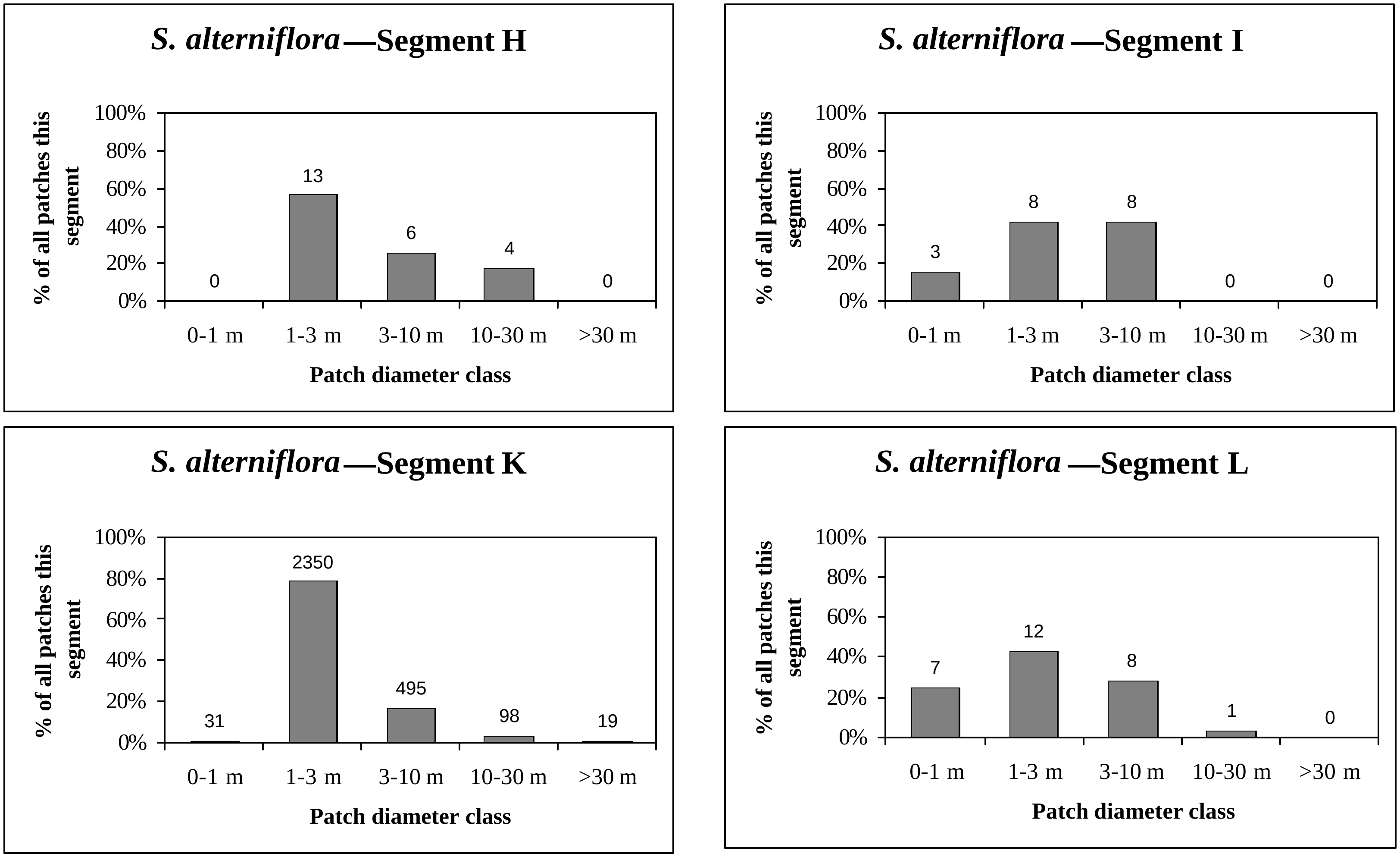
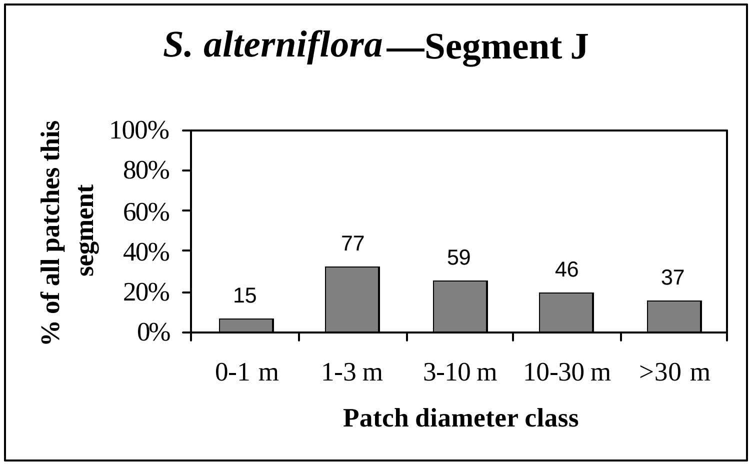
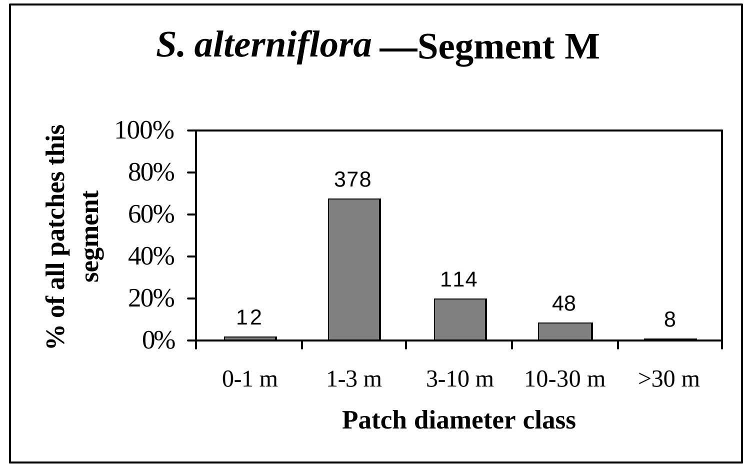
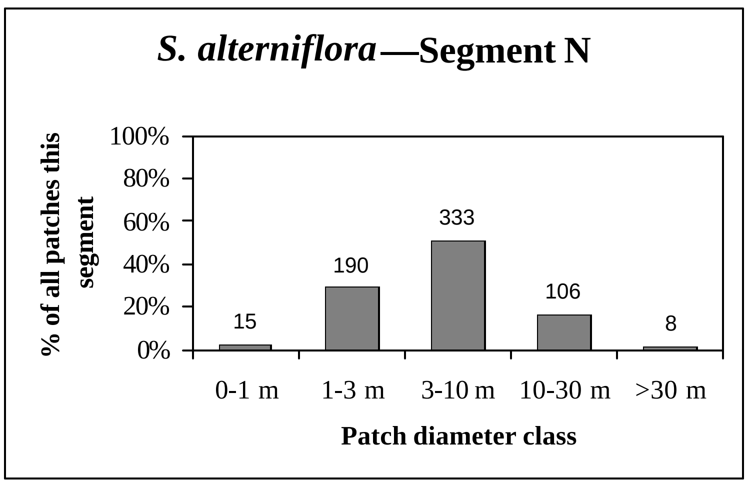


Figure 3 (continued): Distribution of *Spartina alterniflora* complex among patch size classes for Segments J, M, N, and O. Values above the bars are the numbers of patches.







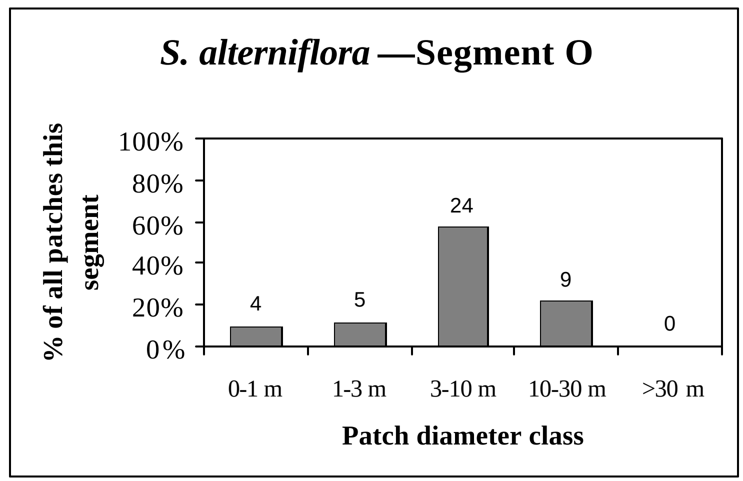
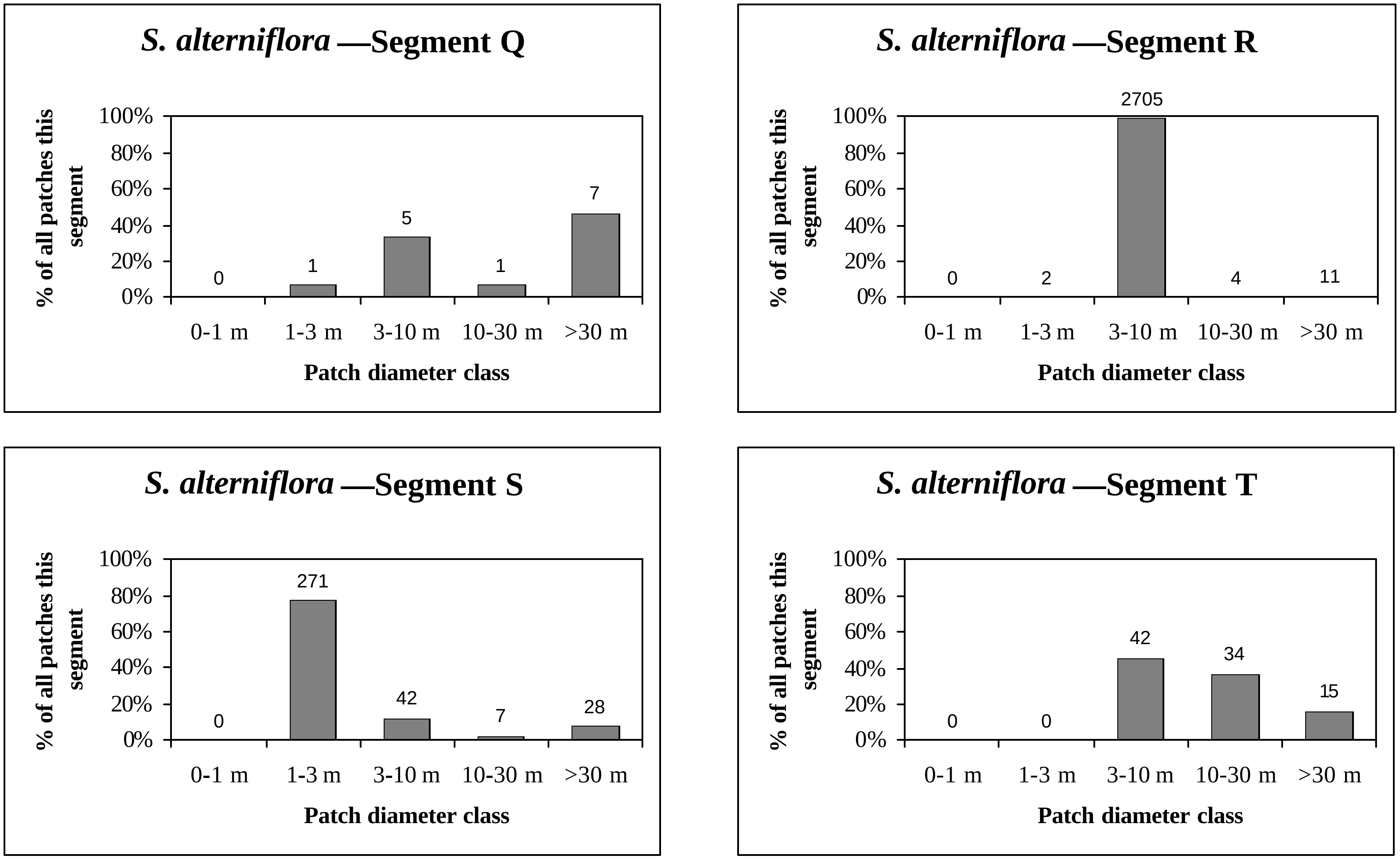


Figure 3 (continued): Distribution of *Spartina alterniflora* complex among patch size classes for Segments Q, R, S, and T. Values above the bars are the numbers of patches.



The area covered by an invasion relates to its magnitude. Note that the pie charts in the following Figures 4 and 5 represent the area actually covered by NIS *Spartina* plants, based on patch size and percent plant cover (see rules on page 1). For example, a 100-acre patch with 50% cover is represented as a 50 acre patch of 100% cover. Very small pie charts are magnified as indicated so that they are visible on the map.

Figure 4. Relative acreages of *Spartina alterniflora* complex and patch size distributions
Pie chart size is proportional to acreage of *Spartina*. Pie divisions indicate relative area of each patch size class.

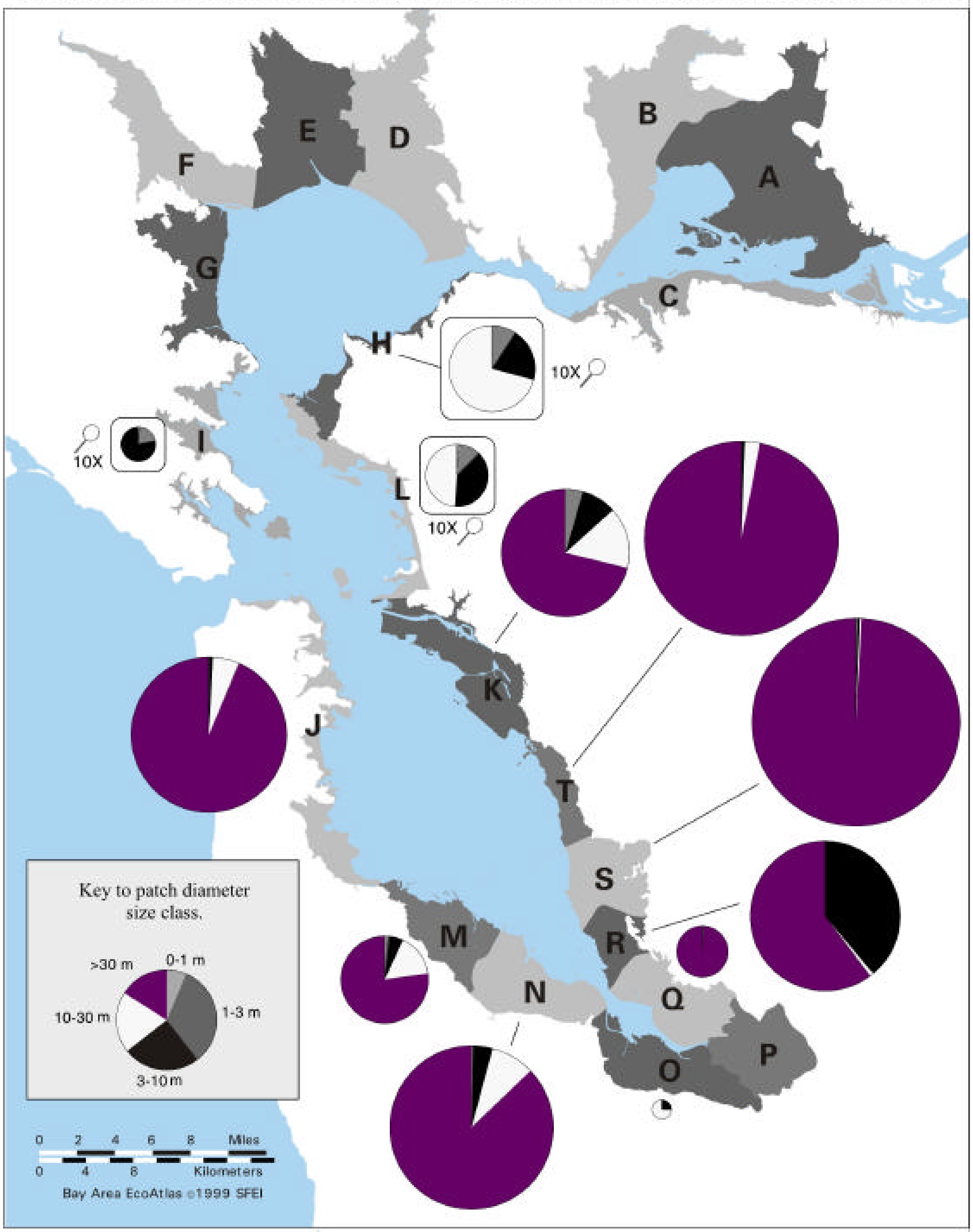
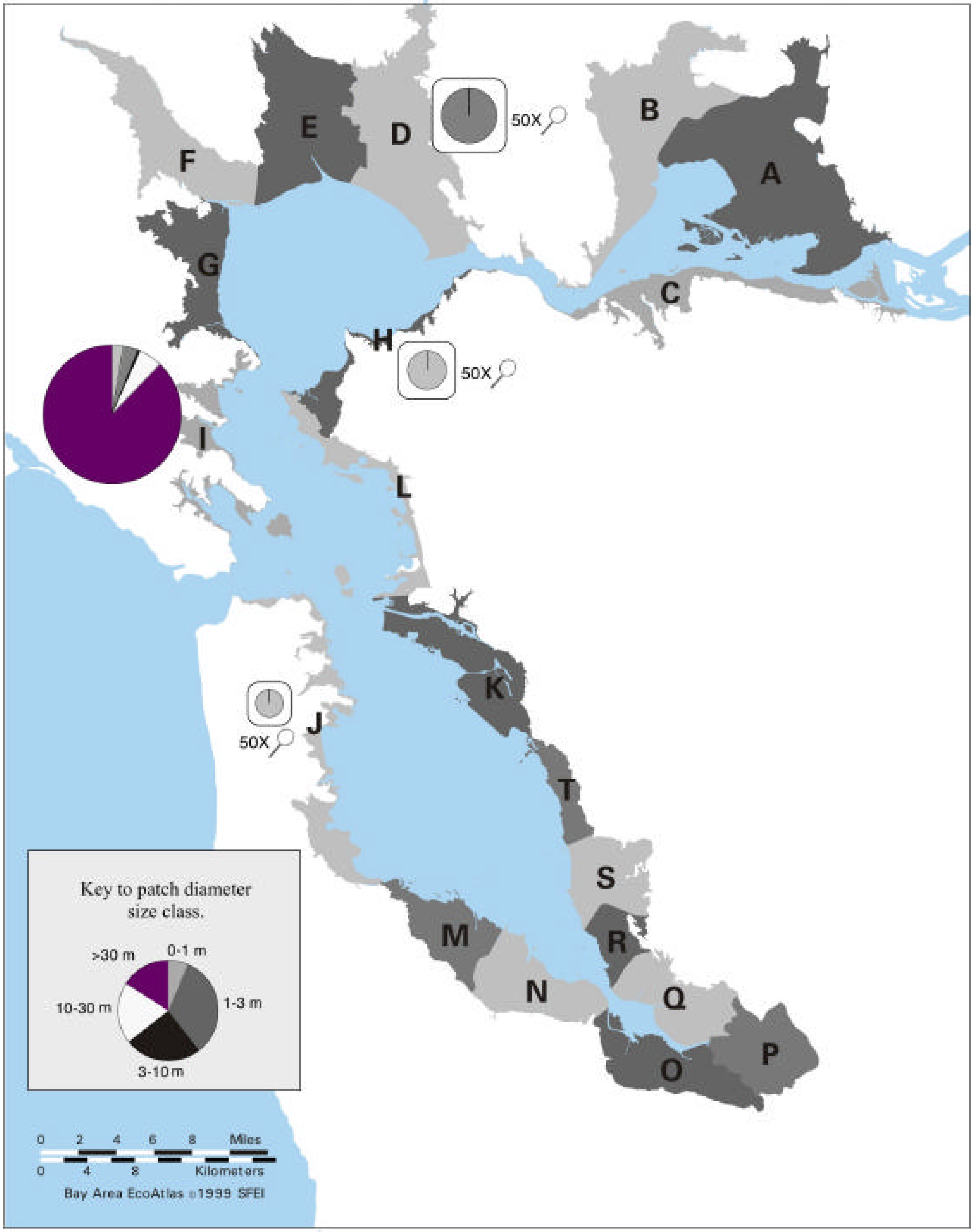


Figure 5. Relative acreages of *Spartina densiflora* and patch size distributions
Pie chart size is proportional to acreage of *Spartina*. Pie divisions indicate relative area of each patch size class.



Analysis

The size-frequency distribution of NIS *Spartina* populations can indicate the stage and magnitude of their invasions, help forecast changes in the location of invasion fronts and population centers, and help prioritize places for control.

A distribution that is characterized by very small patches probably indicates recent invasion, although the invasion may be older and arrested. A distribution with medium-large patches with few small ones suggests that the invasion is well established and that its expansion is due to the growth of existing colonies, rather than new colonization. A distribution with a broad range of patch sizes suggests that the invasion is both well established and subject to recruitment by new colonies.

The total number of patches and their total area of coverage indicate the magnitude of the invasions, regardless of its stage of development. In this case, area is calculated as the amount of intertidal substrate actually covered by NIS *Spartina*. In essence, the acreage values represent the amount of substrate below live NIS *Spartina* foliage, when the minimum spatial unit of measurement is an NIS *Spartina* seedling.

The regional mapping should be repeated in a standard way every few years to track changes in the overall distribution and abundance of the invaders. Comparisons between the previous regional map (Grossinger et al. 1998) and the current map are problematic because the previous map ignores patch size or cover density within patches.

Spartina densiflora

The distribution of *Spartina densiflora* is concentrated along the upper tidal reaches of Corte Madera Creek in Segment I, very near to where it was first introduced into the San Francisco Estuary in 1976. However, the *S. densiflora* in this Segment is almost completely represented by small patches of individual plants (Figure 2). These small patches apparently grow slowly. But *S. densiflora* is beginning to expand its regional distribution with a few small pioneering patches in other saline-brackish Segments of Central Bay and North Bay. There are no known patches of *S. densiflora* in South Bay. Eradication of *S. densiflora* may be possible at this time, given its very limited distribution and small patch size.

Spartina alterniflora complex

The distribution of *Spartina alterniflora* and its hybrids (i.e., the *S. alterniflora* complex) extends from far South Bay (Segment O), through Central Bay (Segments I-L), and into the southeastern portion of North Bay (Segment H). It covers the most acreage in Segments S and T. Large patches of *Sp. alterniflora* are abundant in Segments J, K, S and T, which include the sites of earliest introduction of this species into the Estuary (USCOE undated, D. Smith personal communication, P. Baye personal communication). The size-frequency distribution for these Segments suggests that the *S. alterniflora* complex can achieve very large patches within a few decades. Large patches account for almost all the area of *S. alterniflora* complex in Segments S and T.

The *S. alterniflora* complex is beginning to expand into Central Bay in Segments L, H, and I. There is a broad range of patch sizes in these Segments, but the small-medium patches account for most of the area of the invasion.

The *S. alterniflora* complex seems well established along the southwest margins of the Estuary from Segment J through Segment N, with some very large patches in each of these Segments. The large coverage in Segment J may be due in part to its location directly across the Estuary from the site of a very early introduction of *S. alterniflora* in Segment K, although purposeful transplants of *Sp. alterniflora* into Segment J might also have happened very early. The *S. alterniflora* complex seems to be expanding southward into Segment O, which has a moderate number of patches, mostly in the middle size classes. According to the previous mapping effort (Grossinger et al. 1998), the *S. alterniflora* complex had reached the southeastern limits of the Estuary in Segment P as a few small pioneer plants. These patches were not observed during the more recent mapping effort. There is some uncertainty, however, about these particular previous sightings. The scarcity of small patches and the abundance of medium-large patches in Segments Q and R suggest that the invasion in these Segments is expanding due to the growth of existing patches, rather than new colonization. The distribution in Segment R is characterized by a large number of medium size patches along large sloughs. In Segment S, however, the distribution is characterized by a large number of small patches as well as large patches, which suggests that this Segment is still being subjected to colonization.

The main invasion fronts that appear at the regional scale are between Central Bay and North Bay at Segments H and I, and in the far South Bay at the boundaries of Segment P. There are apparently numerous invasion fronts within and between most of the South Bay and Central Bay Segments, however, where existing colonies are either expanding or the areas between them are being colonization by new recruits. The *S. alterniflora* complex is apparently very well established in South Bay, and is expanding rapidly through Central Bay and into North Bay, even as spaces between patches in South Bay become colonized.

Possible Large Scale Controlling Factors

The regional view of the NIS *Spartina* invasions reveals possible relationships between landscape processes and the distribution, abundance, and dispersal patterns of the invaders. For example, the invasion by *Sp alterniflora* seems to have been restricted, until recently, to the South Bay. The lack of tidal exchange between South Bay and North Bay may have contributed to this restriction, given that estuarine currents are an important means of *Spartina* dispersal. The *S. alterniflora* complex has recently found its way into Central Bay and the southern extent of the North Bay, especially along the eastern shoreline, which is consistent with the pattern of flood tide excursion into North Bay from the locations of Central Bay colonies. It is assumed that none of the recent colonizations in any Segment are the result of purposeful plantings.

The primary sites of colonization by the *S. alterniflora* complex appear to be intertidal mudflats along the bayshores, along large tidal marsh sloughs, and along the tidal reaches of local rivers and streams. Whether the invaders prefer rivers and streams with fluvial input or sloughs that lack direct upland runoff is unknown at this time. The *S.*

alterniflora complex tends to be very abundant as medium-large size patches along the large sloughs and tidal reaches of many South Bay creeks, where seeds and root parts can be well distributed within and between local patches of tidal flat by the ebb and flood of the tide. All of these channels convey material to and from the open bays. The sloughs and creeks may therefore be important sources for continued bayshore invasions.

Local gaps in habitat do not seem to have interrupted the invasions. For example, colonies of NIS *Spartina* exist on either side of long stretches of bayshore that lack intertidal mudflat. However, it is not known to what extent the occurrence of the species across habitat gaps represents natural colonization phenomena or unrecorded or incidental transplantings. It is possible, for example, that the movement of floating dredges among job sites in the Estuary helped to distribute the invaders. Unfortunately, there is no conclusive history of local introductions.

The potential for invasion by the *S. alterniflora* complex throughout the San Francisco Estuary, including its freshwater reaches, needs further investigated. No NIS *Spartina* patches have been found in non-tidal habitats, although there have been a few sitings in places with muted tidal action (i.e., Lake Merrit and Whittel March, Smith personal communication). In general the invading *Spartina* species seem to prefer full tidal action. But the role of aqueous salinity, soil salinity, sediment chemistry and soil grain size remain to be discovered.

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