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RESULTS OF A SPATIALLY INTENSIVE SURVEY FOR *Potamocorbula amurensis* IN THE UPPER SAN FRANCISCO BAY ESTUARY

Zachary P. Hymanson
California Department of Water Resources

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ABSTRACT

Abundance and distribution of the exotic Asian clam, *Potamocorbula amurensis*, have increased dramatically since it was first detected in December 1986 in several regions of the upper San Francisco Bay estuary. Results from a spatially intensive benthic survey conducted between August and September 1990 show the clam has achieved a ubiquitous distribution between San Pablo Bay and the confluence of the Sacramento and San Joaquin rivers. The immigration of *P. amurensis* into the Sacramento-San Joaquin Delta, however, has lagged behind its invasion of regions farther downstream. Distribution of *P. amurensis* in the western Delta was patchy, and no clams were found in the west-central Delta. Regional mean abundance estimates show *P. amurensis* has achieved high concentrations ($\geq$10,000 individuals/m^2) in many regions of the upper estuary. Clam abundances were generally greatest at sites where the substrate was mostly silt and clay, and this substrate type predominated over the survey area. Size frequency distribution results show the survey area was dominated by small ($\leq$10 mm) clams. Establishment of *P. amurensis* as a dominant benthic organism in the upper San Francisco Bay estuary may have significant ecological implications to both the benthic and pelagic communities.

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Chapter 1

INTRODUCTION

The Asian clam *Potamocorbula amurensis*, first detected in Suisun Bay in late 1986, is thought to have been introduced into Suisun Bay as larvae from ship ballast water (Carlton 1985; Carlton *et al* 1990). Since it was first detected, the abundance and distribution of *P. amurensis* has increased dramatically in the upper San Francisco Bay estuary (Carlton *et al* 1990), and it now occurs in a variety of substrates, depths, and salinities.

P. amurensis is suspected of contributing to the substantial and sustained reductions in surface chlorophyll *a* concentrations in Suisun Bay. *P. amurensis* is a suspension feeder capable of consuming phytoplankton, bacterioplankton, and other particulate organic matter in the water column (Hollibaugh and Werner 1991). This clam's ability to thrive at high concentrations ($\geq$10,000 individuals/m^2), combined with its feeding habits, suggests it has the potential of substantially altering the ecology of the upper San Francisco Bay estuary.

The Department of Water Resources, Bay-Delta Monitoring and Analysis Unit, has an ongoing benthic monitoring program that includes identification and enumeration of all macro-benthic organisms collected in monthly grab samples from five sites in Suisun Bay and the Sacramento-San Joaquin Delta. Markmann (1986) provided an in-depth review of this program, and summaries of results are presented in a series of annual reports (DWR, 1980 *et seq*). This monitoring program provides information about temporal variation of the benthos and the substrate composition at these sites, but yields limited information about spatial variation throughout the system.

Spatially intensive information is necessary to more fully understand the ecological implications of *P. amurensis*. This report describes results of a special study undertaken to determine the abundance, spatial distribution, and size class distribution of *P. amurensis* in the upper San Francisco Bay estuary.

METHODS

The benthic survey for *P. amurensis* was conducted in August and September 1990. The survey area included the subtidal portions of San Pablo and Suisun bays, the major sloughs of Suisun Marsh, and the major channels of the western and west-central Sacramento-San Joaquin Delta. Sampling sites were distributed uniformly among the channel and shoal regions of the survey area (Figure 1). In the shoals, sampling sites were uniformly spaced about 2 km apart. In the channels (arbitrarily defined as any region narrower than 2 km), sites were spaced about 1.5 km apart. Additionally, sites in the channels were alternated between the banks and the center channel. The longitude and latitude (coordinates) of each site were recorded at the time of sampling, using a LORAN navigating instrument. The coordinates of all sites sampled are listed in Appendix A.

Decisions on the sampling site distribution (*ie,* uniformly spacing sites in the shoals and alternating locations between the banks and the center of the channels) were based on both qualitative and quantitative information. A uniform site distribution pattern can provide accurate information regarding the spatial distribution of benthic organisms, but can greatly escalate data collection costs. Shoals predominate in San Pablo and Suisun bays, which qualitatively appear homogeneous, exhibiting relatively uniform substrate composition, water depth, and water quality. Channels such as sloughs and rivers appear more heterogeneous when compared to shoals, with greater substrate variability, steep cross-sectional depth contours, and stronger water currents that can vary across the channel. These differences can affect the distribution and abundance of benthic organisms (Nichols and Pamatmat 1988). Thus, the qualitative information suggested sites could be set farther apart in the shoals, where species abundance and distribution are presumably more uniform, and also suggested a stratified sampling strategy was needed to better describe the spatial distribution of benthic organisms in the channels.

Qualitative observations were supported by quantitative analysis of replicate benthic grab samples previously collected from various locations in the upper estuary. Data from San Pablo Bay and Carquinez Strait were provided by the U.S. Geological Survey and consist of five replicate grab samples collected bimonthly from each location during 1987 and 1988. Data from Suisun Bay, Sacramento River, and Sherman Island were provided by the Department of Water Resources and consist of three replicate grab samples collected monthly from each location between 1987 and 1989. Results show *P. amurensis* abundance varied more at channel sites than at shoal sites (Table 1), indicating the channels should be sampled more intensively than the shoals. This information helped to determine the distance between sites in the shoals and channels and the distribution pattern of channel sites as previously described.

All sites were sampled from a boat using a Ponar dredge (0.053 m^2 nominal sampling area) attached to a hydraulic winch. One grab sample was collected at each site, and 214 sites were sampled. After collection, the percentage of each material type (*eg,* sand, silt and clay, shell, or organic matter) was estimated to the nearest 5%. Texture, color, and odor of the substrate were also noted. The dominant substrate type, as estimated from the percent composition data, was plotted on a map of the survey area to indicate substrate distribution.

Photographs of each grab sample were taken before and after washing. All samples were washed over a screen with 0.5 mm^2 openings, and the material retained on the screen was preserved in 25% (V/V) formaldehyde to which Rose Bengal stain had been added.

Hydrozoology, Inc., of Newcastle, California, analyzed all but 10 of the samples. The analysis included separating whole organisms from the non-living debris and determining the total number and size of all *P. amurensis*.

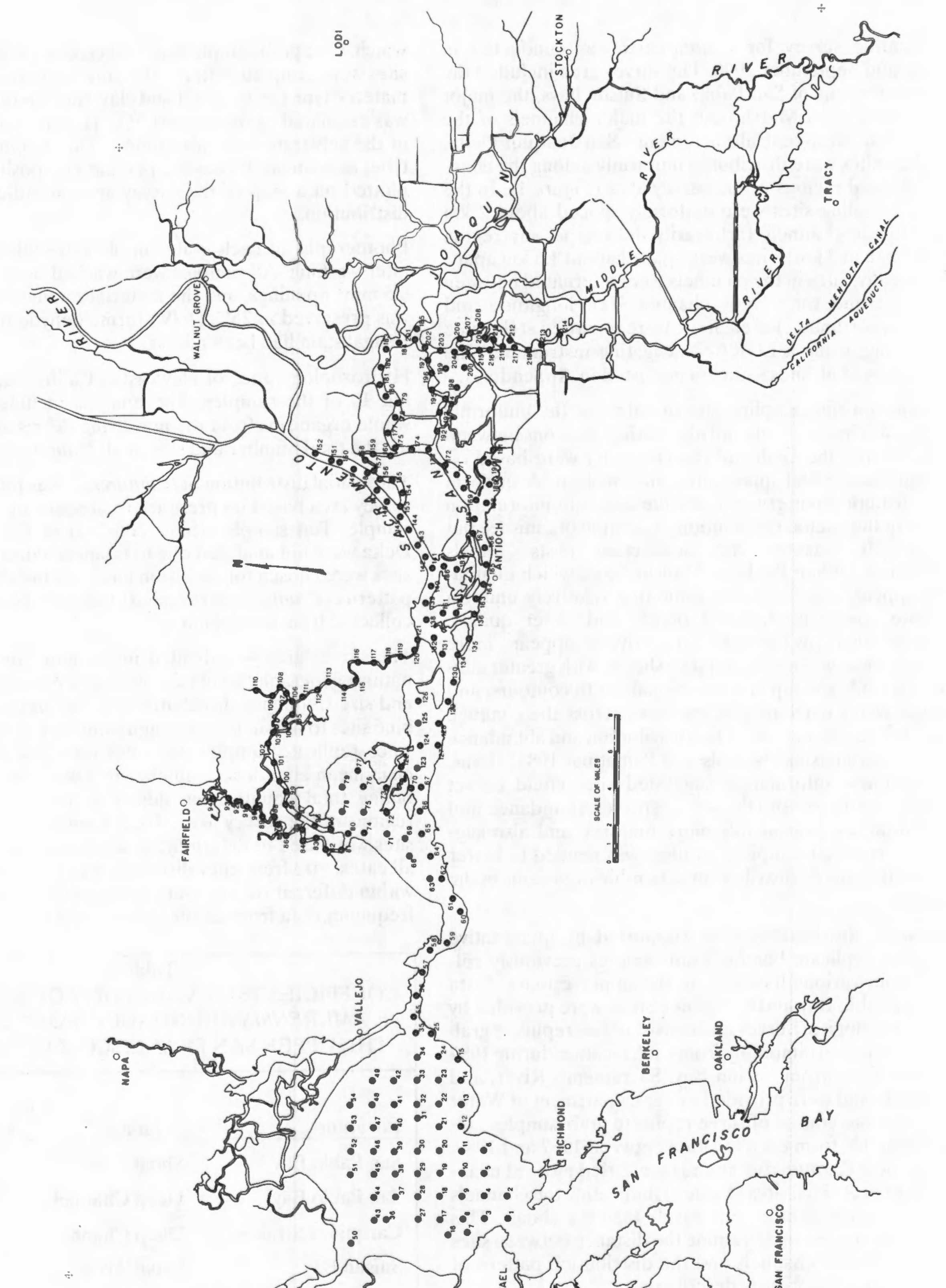
The spatial distribution of *P. amurensis* was plotted over the survey area based on presence or absence of clams in each sample. Ten samples (Sites 206-215) in the west-central Delta were not analyzed due to financial constraints. These sites were chosen for exclusion based on the obvious spatial pattern of *P. amurensis* revealed by analysis of other samples collected from this region.

The survey area was divided into regions on the basis of natural geography to obtain estimates of mean abundance and size frequency distributions. It was necessary to combine sites to obtain large enough samples for these analyses, since replicate samples were not collected. Estimates of clam mean abundance (number/m^2) were derived by combining total counts from adjacent sites within different regions of the survey area. Total counts from at least four sites were used to determine mean abundance estimates in all cases. Size frequency distributions of all clams collected within different regions were generated by pooling the size frequency data from all sites within each region.

Table 1
COEFFICIENTS OF VARIATION OF REPLICATE *P. AMURENSIS* ABUNDANCE SAMPLES FROM THE UPPER SAN FRANCISCO BAY ESTUARY

Location	Habitat	Coefficient of Variation
San Pablo Bay	Shoal Area	118
San Pablo Bay	Deep Channel	168
Carquinez Strait	Deep Channel	296
Suisun Bay	Shoal Area	32
Sacramento River	Deep Channel	147
Sherman Island	Shoal Area	82

Figure 1
SAMPLING SITE NUMBERS AND APPROXIMATE LOCATIONS
(See Appendix A for site coordinates.)



RESULTS

A map of the dominant substrate type encountered at each site shows the survey area was dominated by silt and clay (fines) (Figure 2). Channel regions showed greater variability with regard to substrate type, due in part to the sites being alternated between banks and center channel. The conclusion that fines comprise most of the substrate throughout the upper estuary is corroborated by monthly substrate data collected in the DWR benthic monitoring program, which show increases in the percentage of silt and clay at several locations beginning in 1981 (DWR 1991). At all of the sites where fines predominated, the substrate was grey to black and had a metallic or sulfuric odor. These characteristics are typical of permanently wet sediments containing relatively high amounts of reduced iron (Fe^{2+}) or sulfur (Bohn *et al* 1985).

P. amurensis were found at every site sampled between San Pablo Bay and the confluence of the Sacramento and San Joaquin rivers, with the exception of eight center channel sites in Carquinez Strait and San Pablo Bay and one shoal site in San Pablo Bay (Figure 3). *P. amurensis* had a patchy distribution in the western Delta. Clams were found at 6 out of 7 sites sampled in the lower 10 km of the Sacramento River, but were absent at every site upstream. In the San Joaquin River, clams were found at 3 out of 14 sites sampled in the lower 14 km, but were absent at every site upstream. No clams were found in the west-central Delta.

P. amurensis was first detected in Suisun Bay in late 1986. Between 1987 and 1990, mean surface salinity levels have varied from 11.2 ppt *(parts/thousand)* in lower Suisun Bay to 2.8 ppt in the western Delta (Figure 4). Surface salinity levels were generally higher downstream of Suisun Bay and lower upstream of the western Delta.

The highest concentration of *P. amurensis* was in the Suisun Marsh region, where mean concentrations up to 19,200 clams/m^2 were measured near the mouth of Suisun Slough (Figure 5). Consistently high abundances were found in both San Pablo and Suisun bays. Clam abundance declined rapidly in the western Delta, where the distribution was patchy. Overall, the highest abundances were at sites where fines predominated.

The size frequency distribution of all *P. amurensis* collected from San Pablo Bay (Sites 1-35) (Figure 1) shows a somewhat bimodal distribution that is skewed toward the larger size classes (Figure 6). However, the majority of individuals collected in this region were less than half the maximum size observed, with a median size of 10-11 mm.

The size frequency distribution of *P. amurensis* from the Suisun Bay shoals is based on data from the shoal regions of Suisun Bay (Sites 63, 68-80, and 122-126) and excludes all channel sites on the south side of the bay. Results show a size frequency distribution that is skewed toward the smaller size classes, with a median size of 5-6 mm (Figure 6). Few clams from the larger size classes (20 + mm) were collected.

The size frequency distribution of *P. amurensis* from the Suisun Bay channel region includes all the channel sites along the south side of Suisun Bay (Sites 61, 62, 64-67, 127-138, 161, 162) and all sites in Carquinez Strait (Sites 55-60) (Figure 2). As with the Suisun Bay Shoal region, the resulting size frequency distribution is skewed toward the smaller size classes (Figure 6), but the median size (8-9 mm) differed significantly from the Suisun Bay shoal median size (5-6) mm ($X^2 = 61.68; P < 0.001$). Few clams from the larger size classes were collected, although the largest individuals (up to 26 mm) were found in this region.

The size frequency distribution of *P. amurensis* from the Suisun Marsh region (Sites 81-121) was heavily skewed toward the smaller size classes, with a median size of 2-3 mm (Figure 6). Overall, the greatest number of clams was collected from this region, although most were smaller than 6 mm.

The size frequency distribution of *P. amurensis* from the western and west-central Delta (Sites 139-160 and 163-205) was also skewed toward the smaller size classes, with a median size of 2-3 mm (Figure 6). The fewest clams were collected from this region, even though it contained the most sites.

Figure 2
DISTRIBUTION OF DOMINANT SUBSTRATE TYPES OVER THE SURVEY AREA

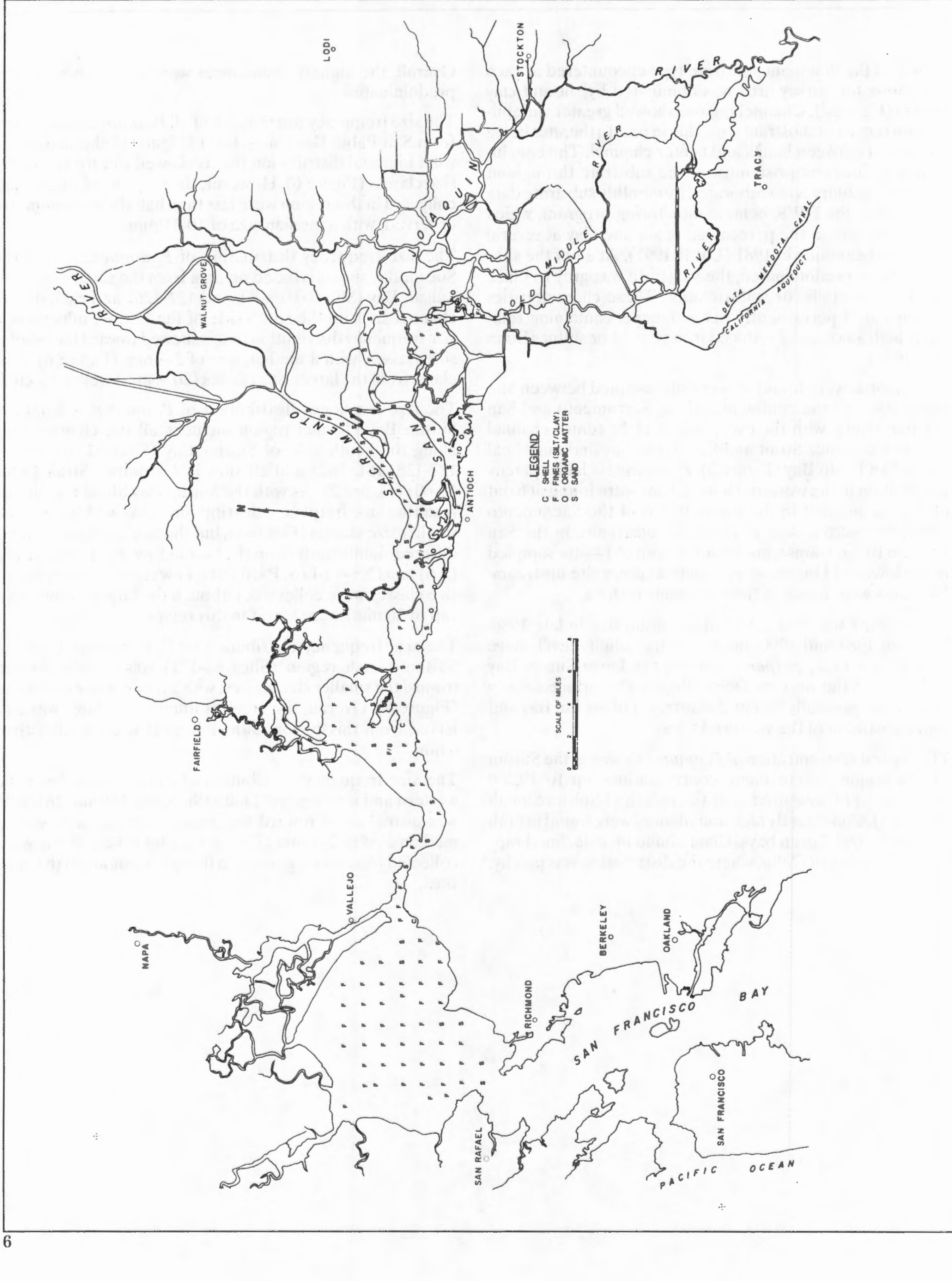


Figure 3

DISTRIBUTION OF *P. AMURENSIS* OVER THE SURVEY AREA

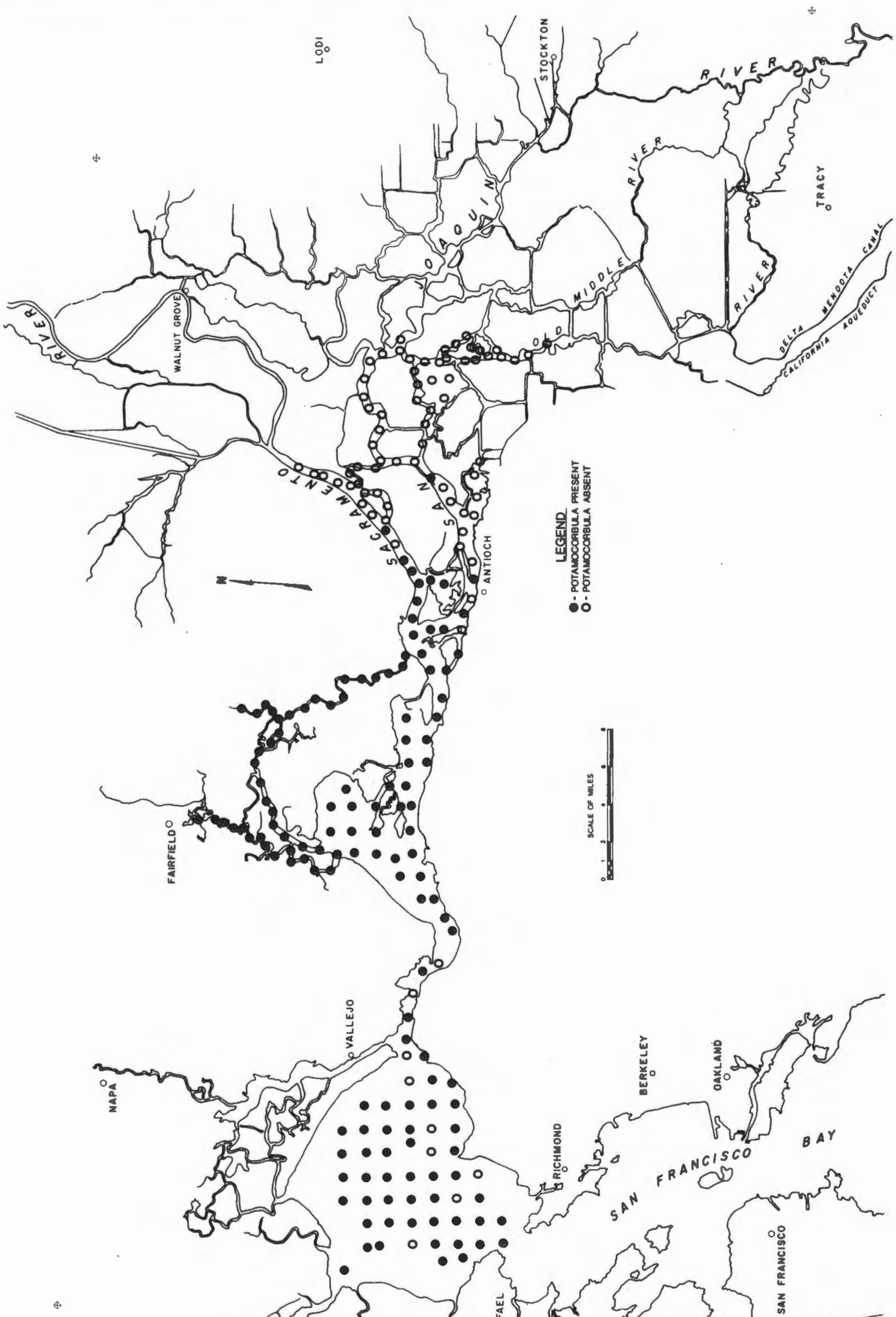


Figure 4
MEAN SALINITY (±C.I.) AT SIX LOCATIONS IN THE UPPER SAN FRANCISCO BAY ESTUARY, 1987-1990

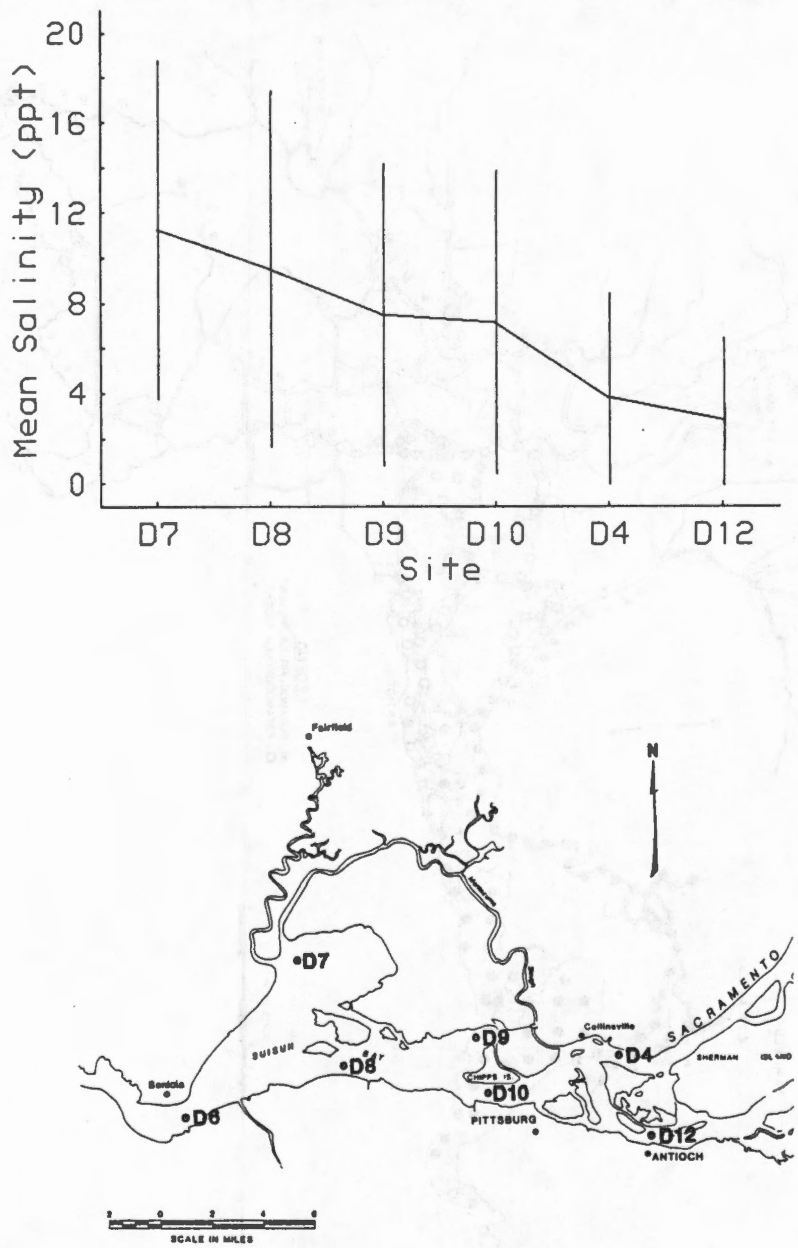


Figure 5
REGIONAL MEAN ABUNDANCE ESTIMATES OF *P. AMURENSIS* OVER THE SURVEY AREA

Data from at least four sites (n≥4) were combined to calculate relative mean abundances at different locations within regions.

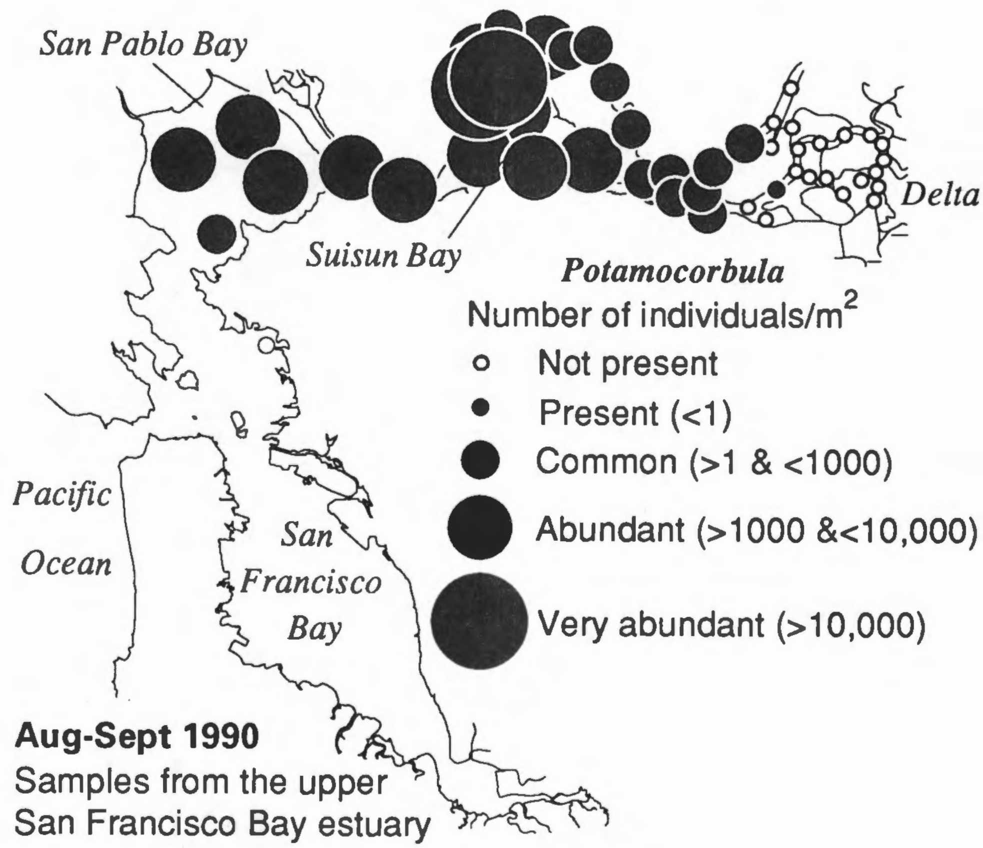
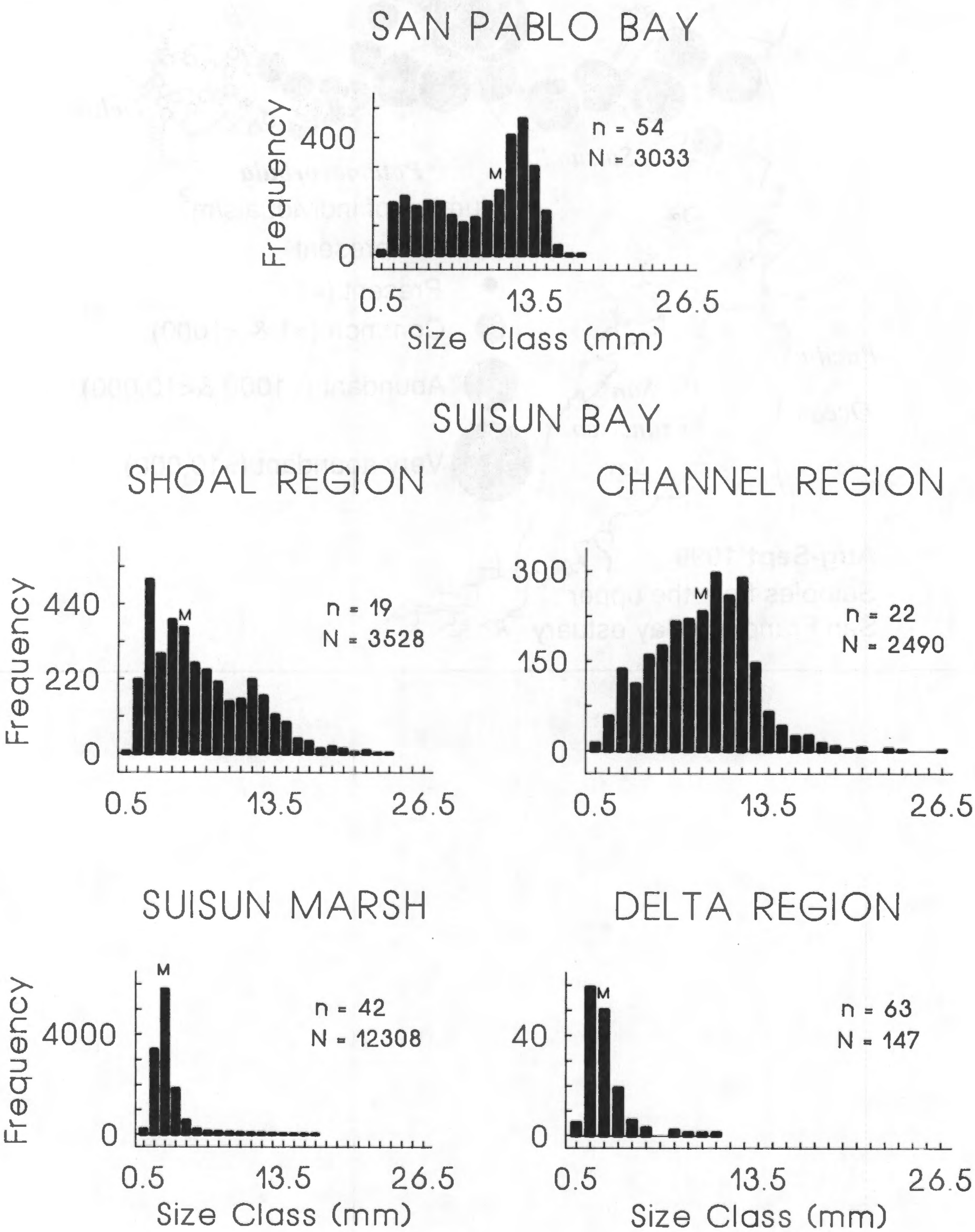


Figure 6

REGIONAL SIZE FREQUENCY DISTRIBUTIONS OF *P. AMURENSIS*

(See text for sites included in each region.)

For all plots: n = Number of sites in the region
N = Total number of clams collected from the region
M = Median size class.



DISCUSSION

P. amurensis quickly spread throughout San Pablo and Suisun bays after it was first detected in Suisun Bay in late 1986. By late 1987, the clam was well established throughout both bays, commonly at concentrations greater than 1,000 individuals/m^2 (Carlton, *et al* 1990). Clam abundance in both San Pablo and Suisun bays continued to increase in 1988, although the distribution remained patchy (Jan Thompson, USGS, unpublished data). By the completion of this survey in September 1990, *P. amurensis* was ubiquitous throughout both bays.

Results of this survey show *P. amurensis* is not well established in the western Delta and was not found in the west-central Delta. At least two hypotheses could explain why this clam has not spread into the Sacramento-San Joaquin Delta at the same rate it has spread into the lower bays.

- *P. amurensis* may be adversely affected by the relatively low salinity levels in the Delta. Preliminary laboratory observations show adult clams placed in containers of fresh water are able to survive for an extended time (Jan Thompson, USGS, personal communication). However, fresh water could still stress the clams, although not to the point of death in a controlled environment. In natural situations, where conditions are more variable, the additional stress of low salinity water may reduce the ability of *P. amurensis* to compete for resources such as food or space. Additionally, the lower salinity waters may preclude the existence of clam larvae. In this survey, the distribution of *P. amurensis* became patchy at locations where mean surface salinities have been less than 5 ppt since January 1987.
- Competition with another introduced clam, *Corbicula fluminea*, may prevent the upstream progression of *P. amurensis*. *C. fluminea* is a freshwater clam often found in high abundance throughout the Sacramento-San Joaquin Delta (Markmann 1986; Nichols and Pamatmat 1988). *P. amurensis* may be a less successful competitor for space or food in the Delta, where conditions are favorable for *C. fluminea*.

Other water quality factors could limit the upstream migration of *P. amurensis* as well. Longitudinal variations in water temperature could play a role, but this is not likely given the clam's broad distribution in its native habitat (Carlton, *et al* 1990). Pollutants from agriculture and other human activities could also affect the migration of *P. amurensis*. However, *P. amurensis* rapidly colonized regions downstream of the Delta that receive relatively large amounts of wastes, suggesting pollutants have not substantially inhibited the invasion of this clam.

Substrate composition in the upper estuary does not appear to limit the occurrence of *P. amurensis*. Clams were found in all of the predominant substrate types, although clam presence and abundance were more variable in the channels, where substrate composition was also more variable. The distribution data suggest *P. amurensis* is unable to persist at high concentrations in the center of major channels such as Carquinez Strait or the San Pablo Bay ship channel. The substrate in the central portions of these channels was dominated by coarse, unconsolidated material that readily shifts in response to water movement. However, the lack of clams in these channels may be due to the high current velocities, rather than the substrate composition itself. In contrast, the slower water velocities typically found in the shoals may have facilitated the spread of this clam.

The predominance of fines in the upper estuary reduces the ability to determine if substrate composition limits the occurrence of *P. amurensis*. This clam is clearly not inhibited by the presence of silt or clay, since individuals were most abundant at sites where fines predominated. Large quantities of fines at a site suggest slow water currents (Nichols and Pamatmat 1988). The high proportion of sites in the upper estuary with fines is probably due, at least in part, to the persistent drought-associated low flows.

Field observations of grab samples showed the majority of clams were partially exposed at the substrate surface, and this behavior is corroborated by laboratory observations (Carlton *et al* 1990). The anatomy of *P. amurensis*, a relatively small clam with short siphons and thin shells, combined with its observed behavior, suggests clams can thrive in areas of reduced water motion and fine sediments.

With the exception of San Pablo Bay, the size frequency distributions of clams from the 5 survey regions were similar. All regions had a large number of small (≤10 mm) clams, suggesting something is limiting their growth, predators are removing the larger size classes, or the settlement of a new cohort.

The absence of the larger size classes, however, may actually result in increased filtering of the overlying water. Hollibaugh and Werner (1991) found the clearance rate of 10-mm clams was over three times greater than that of 20-mm clams on a wet weight basis.

It is apparent from this and other studies that *P. amurensis* has fully invaded the upper San Francisco Bay estuary. In little more than 4 years after it was first detected, this clam has become the most abundant benthic organism in several regions of the upper estuary and is among the most widely distributed. Trophic dynamics could be altered with the addition of a new and abundant food source for bottom feeding birds, fish, and crabs, while competition between other benthic organisms for space and food and other pelagic organisms for food may have increased (Carlton *et al* 1990; Nichols *et al* 1990). Establishment of *P. amurensis* has the potential to alter many of the fundamental ecological processes in the San Francisco Bay estuary.

RECOMMENDATIONS

There is a need for policies and procedures to prevent further introductions of organisms into San Francisco Bay. *P. amurensis* is one of numerous exotic organisms detected in the estuary during the 1980s. Several are thought to have been transported into San Francisco Bay via ship ballast water (Carlton 1979, 1985). The amount of foreign ship traffic in San Francisco Bay continues to grow, increasing the potential for further introductions.

A special study should be conducted to determine factors responsible for the lack of *P. amurensis* in the Sacramento-San Joaquin Delta. Such a study could provide key information as to what factors, if any, limit the occurrence of *P. amurensis*. Two hypotheses (low salinity and competition with *C. fluminea*) were discussed in Chapter 4.

A special study should be conducted to determine factors responsible for the low numbers of large *P. amurensis* in the upper estuary. This study should, at a minimum, include experiments to evaluate effects of predation. Such a study could provide information relating to the trophic interactions of *P. amurensis*.

At least two sites should be added to the DWR Benthic Monitoring Program. It is suggested they be located at two previous USGS Regional Effects Monitoring Program stations in San Pablo Bay (Station 10) and Suisun Bay (Station 12) (Schemel *et al* 1990).

This study should be repeated after a high flow (wet) year. Such a comparative study could provide information as to how seasonally high flows might affect the distribution of *P. amurensis* in the upper estuary.

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Appendix A

REFERENCE LOCATIONS OF SITES SAMPLED IN THE SPATIAL BENTHIC SURVEY

Site numbers correspond to those used in Figure 1.
Latitude/longitude = Coordinates determined by LORAN at each sampling site.
Channel position = Location in channel when facing downstream: right bank, left bank, or center channel.
7.5-minute USGS Quad = Name of the 7.5-minute USGS quadrangle map on which the site occurs.

SAN PABLO BAY

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
1	37° 59.2'/122° 25.8'		San Quentin
2	37° 59.0'/122° 24.5'		San Quentin
3	38° 00.1'/122° 27.2'		Petaluma Point
4	38° 00.1'/122° 25.8'		Petaluma Point
5	38° 00.1'/122° 24.5'		Petaluma Point
6	38° 00.1'/122° 24.2'		Petaluma Point
7	38° 01.1'/122° 28.0'		Petaluma Point
8	38° 01.2'/122° 27.2'		Petaluma Point
9	38° 01.2'/122° 25.8'		Petaluma Point
10	38° 01.2'/122° 24.5'		Petaluma Point
11	38° 01.2'/122° 23.2'		Petaluma Point
12	38° 01.3'/122° 21.7'		Mare Island
13	38° 01.2'/122° 20.3'		Mare Island
14	38° 01.2'/122° 18.9'		Mare Island
15	38° 01.3'/122° 17.7'		Petaluma Point
16	38° 01.9'/122° 28.1'		Petaluma Point
17	38° 02.3'/122° 27.3'		Petaluma Point
18	38° 02.3'/122° 25.8'		Petaluma Point
19	38° 02.3'/122° 24.5'		Petaluma Point
20	38° 02.3'/122° 23.1'		Petaluma Point
21	38° 02.4'/122° 21.8'		Mare Island
22	38° 02.3'/122° 20.5'		Mare Island
23	38° 02.3'/122° 19.0'		Mare Island
24	38° 02.3'/122° 17.6'		Mare Island
25	38° 02.5'/122° 16.2'		Mare Island
26	DELETED		
27	38° 03.4'/122° 27.2'		Mare Island
28	38° 03.4'/122° 25.8'		Mare Island
29	38° 03.4'/122° 24.4'		Mare Island
30	38° 03.4'/122° 23.1'		Mare Island
31	38° 03.4'/122° 21.1'		Mare Island
32	38° 03.4'/122° 20.3'		Mare Island
33	38° 03.3'/122° 19.0'		Mare Island
34	38° 03.3'/122° 17.6'		Mare Island
35	38° 03.3'/122° 16.2'		Mare Island
36	38° 04.8'/122° 27.1'		Petaluma Point
37	38° 04.5'/122° 25.8'		Petaluma Point
38	38° 04.4'/122° 24.4'		Petaluma Point
39	38° 04.4'/122° 23.1'		Petaluma Point
40	38° 04.4'/122° 21.7'		Mare Island
41	38° 04.4'/122° 20.3'		Mare Island
42	38° 04.4'/122° 19.0'		Mare Island
43	38° 05.5'/122° 27.2'		Petaluma Point
44	38° 05.5'/122° 25.8'		Petaluma Point
45	38° 05.5'/122° 24.4'		Petaluma Point
46	38° 05.5'/122° 23.1'		Petaluma Point
47	38° 05.5'/122° 21.7'		Mare Island
48	38° 05.5'/122° 20.2'		Mare Island
49	38° 05.5'/122° 19.0'		Mare Island
50	38° 06.5'/122° 28.6'		Petaluma Point
51	38° 06.6'/122° 24.4'		Petaluma Point
52	38° 06.6'/122° 23.0'		Petaluma Point
53	38° 06.6'/122° 21.8'		Mare Island
54	38° 06.6'/122° 20.3'		Mare Island

CARQUINEZ STRAIT

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
55	38° 03.8'/122° 15.0'	Center	Benecia
56	38° 03.5'/122° 13.6'	Left	Benecia
57	38° 03.6'/122° 12.3'	Center	Benecia
58	38° 03.2'/122° 10.8'	Right	Benecia
59	38° 02.3'/122° 10.0'	Center	Benecia
60	38° 01.5'/122° 08.6'	Left	Benecia
61	38° 02.3'/122° 07.5'	Center	Vine Hill

SUISUN BAY

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
62	38° 02.4'/122° 06.7'		Vine Hill
63	38° 03.3'/122° 06.6'		Vine Hill
64	38° 03.2'/122° 05.3'		Vine Hill
65	38° 03.6'/122° 03.9'		Vine Hill
66	38° 03.9'/122° 02.6'		Vine Hill
67	38° 03.7'/122° 01.2'		Vine Hill
68	38° 04.3'/122° 05.4'		Vine Hill
69	38° 04.5'/122° 04.2'		Vine Hill
70	38° 04.4'/122° 01.2'		Vine Hill

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
71	38° 05.4'/122° 03.9'		Vine Hill
72	38° 05.5'/122° 02.6'		Vine Hill
73	38° 05.1'/122° 01.1'		Vine Hill
74	38° 06.2'/122° 03.9'		Vine Hill
75	38° 06.5'/122° 02.5'		Vine Hill
76	38° 06.4'/122° 01.1'		Vine Hill
77	38° 06.6'/122° 00.3'		Vine Hill
78	38° 07.4'/122° 02.5'		Fairfield South
79	38° 07.5'/122° 01.1'		Fairfield South

SUISUN MARSH

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
80	38° 07.1'/122° 03.8'	Center	Vine Hill
81	38° 07.5'/122° 04.9'	Left	Vine Hill
82	38° 08.2'/122° 04.9'	Center	Fairfield South
83	38° 08.6'/122° 04.2'	Center	Fairfield South
84	38° 09.3'/122° 04.3'	Right	Fairfield South
85	38° 09.4'/122° 03.6'	Center	Fairfield South
86	38° 10.1'/122° 04.1'	Left	Fairfield South
87	38° 10.4'/122° 03.4'	Center	Fairfield South
88	38° 10.7'/122° 03.0'	Right	Fairfield South
89	38° 11.2'/122° 03.0'	Center	Fairfield South
90	38° 11.5'/122° 02.4'	Left	Fairfield South
91	38° 12.2'/122° 02.3'	Center	Fairfield South
92	38° 12.6'/122° 02.1'	Right	Fairfield South
93	38° 13.3'/122° 02.0'	Center	Fairfield South
94	38° 14.1'/122° 02.3'	Left	Fairfield South
95	38° 08.0'/122° 03.8'	Right	Fairfield South
96	38° 08.8'/122° 03.4'	Center	Fairfield South
97	38° 09.4'/122° 02.8'	Left	Fairfield South
98	38° 10.2'/122° 02.3'	Center	Fairfield South
99	38° 10.1'/122° 01.4'	Right	Fairfield South
100	38° 10.6'/122° 00.5'	Center	Fairfield South
101	38° 10.8'/121° 59.5'	Left	Denverton
102	38° 11.2'/121° 58.6'	Center	Denverton
103	38° 11.0'/121° 57.8'	Center	Denverton
104	38° 10.3'/121° 57.2'	Left	Denverton
105	38° 10.1'/121° 56.5'	Center	Denverton
106	38° 10.1'/121° 56.1'	Center	Denverton
107	38° 10.6'/121° 55.1'	Left	Denverton
108	38° 10.8'/121° 55.0'	Ctr of Bay	Denverton
109	38° 11.2'/121° 55.5'	Center	Denverton
110	38° 11.8'/121° 55.2'	Center	Denverton
111	38° 09.8'/121° 55.7'	Right	Denverton
112	38° 09.1'/121° 55.1'	Center	Denverton
113	38° 08.5'/121° 54.5'	Left	Denverton
114	38° 07.9'/121° 54.9'	Center	Denverton
115	38° 07.1'/121° 54.3'	Right	Honker Bay
116	38° 07.1'/121° 53.2'	Center	Honker Bay
117	38° 06.2'/121° 53.2'	Left	Honker Bay
118	38° 05.7'/121° 53.3'	Center	Honker Bay

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
119	38° 05.1'/121° 52.7'	Right	Honker Bay
120	38° 04.4'/121° 52.5'	Center	Honker Bay
121	38° 04.3'/121° 51.7'		Antioch North

SUISUN BAY

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
122	38° 05.0'/121° 59.6'		Honker Bay
123	38° 04.2'/121° 59.6'		Honker Bay
124	38° 04.2'/121° 58.3'		Honker Bay
125	38° 04.3'/121° 57.0'		Honker Bay
126	38° 04.0'/121° 55.6'		Honker Bay
127	38° 03.1'/121° 58.5'		Honker Bay
128	38° 03.1'/121° 57.0'		Honker Bay
129	38° 02.8'/121° 55.6'		Honker Bay
130	38° 02.4'/121° 54.4'		Honker Bay
131	38° 03.1'/121° 52.9'		Honker Bay
132	38° 03.2'/121° 52.0'		Antioch North
133	DELETED		
134	38° 02.5'/121° 53.0'		Honker Bay
135	38° 01.9'/121° 51.9'	Center	Antioch North
136	38° 01.6'/121° 50.6'	Left	Antioch North
137	DELETED		

SACRAMENTO RIVER

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
138	38° 03.7'/121° 51.0'		Antioch North
139	38° 03.9'/121° 49.9'	Center	Antioch North
140	38° 03.5'/121° 49.1'	Left	Antioch North
141	38° 03.6'/121° 48.0'	Center	Antioch North
142	38° 04.1'/121° 46.8'	Right	Antioch North
143	38° 04.4'/121° 46.1'	Center	Antioch North
144	38° 04.5'/121° 45.1'	Left	Antioch North
145	38° 05.1'/121° 44.7'	Center	Jersey Island
146	38° 05.7'/121° 44.0'	Right	Jersey Island
147	38° 06.1'/121° 43.1'	Center	Jersey Island
148	38° 06.5'/121° 42.0'	Left	Jersey Island
149	38° 07.4'/121° 41.7'	Center	Jersey Island
150	38° 08.1'/121° 41.6'	Right	Rio Vista
151	38° 08.5'/121° 41.2'	Center	Rio Vista
152	38° 09.1'/121° 40.9'	Left	Rio Vista
153	38° 05.0'/121° 44.1'	Center	Jersey Island

HORSESHOE BEND

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
154	38° 04.9'/121° 43.1'	Left	Jersey Island
155	38° 05.4'/121° 42.4'	Center	Jersey Island
156	38° 06.2'/121° 42.4'	Right	Jersey Island

THREEMILE SLOUGH

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
157	38° 06.3'/121° 41.8'	Center	Jersey Island
158	38° 06.7'/121° 41.2'	Left (West)	Jersey Island
159	38° 06.6'/121° 40.9'	Center	Jersey Island
160	38° 05.5'/121° 41.0'	Right (East)	Jersey Island

Site No.	Latitude/Longitude	Channel Position	7.5-Minute USGS Quad
	SAN JOAQUIN RIVER		
161	38° 03.2'/121° 50.3'	Center	Antioch North
162	38° 02.5'/121° 50.5'	Left	Antioch North
163	38° 01.8'/121° 49.6'	Center	Antioch North
164	38° 01.4'/121° 48.8'	Right	Antioch North
165	38° 01.2'/121° 47.6'	Center	Antioch North
166	38° 01.0'/121° 46.7'	Left	Antioch North
167	38° 01.8'/121° 45.9'	Right	Antioch North
168	38° 01.4'/121° 44.8'	Center	Jersey Island
169	38° 01.4'/121° 43.7'	Left	Jersey Island
170	38° 02.1'/121° 42.8'	Center	Jersey Island
171	38° 02.7'/121° 42.1'	Right	Jersey Island
172	38° 03.2'/121° 41.2'	Center	Jersey Island
173	38° 03.7'/121° 40.5'	Left	Jersey Island
174	38° 04.4'/121° 40.6'	Center	Jersey Island
175	38° 05.4'/121° 40.7'	Right	Jersey Island
176	DELETED		
177	38° 05.7'/121° 39.9'	Center	Jersey Island
178	38° 05.3'/121° 39.1'	Left	Jersey Island
179	38° 05.2'/121° 38.1'	Center	Jersey Island
180	38° 06.0'/121° 37.8'	Right	Jersey Island
181	38° 06.1'/121° 36.7'	Center	Bouldin Island
182	38° 05.9'/121° 35.8'	Left	Bouldin Island
183	38° 05.8'/121° 34.8'	Center	Bouldin Island
184	38° 05.1'/121° 34.1'	Right	Bouldin Island
185	38° 04.4'/121° 33.8'	Center	Bouldin Island
	SHERMAN LAKE		
186	38° 03.0'/121° 47.7'		Antioch North
187	38° 02.5'/121° 47.6'		Antioch North
	BIG BREAK		
188	38° 01.1'/121° 44.2'		Jersey Island
189	38° 01.1'/121° 42.6'		Jersey Island
190	38° 01.4'/121° 41.3'	Center	Jersey Island
191	38° 00.8'/121° 40.9'	Center	Jersey Island
	FALSE RIVER		
192	38° 03.3'/121° 39.6'	Center	Jersey Island
193	38° 03.2'/121° 38.6'	Left	Jersey Island
194	38° 02.9'/121o 37.7'	Center	Jersey Island
195	38° 03.6'/121° 37.3'	Right	Bouldin Island
196	38° 03.5'/121° 36.3'	Center	Bouldin Island
197	38° 03.7'/121° 35.5'	Left	Bouldin Island
	FRANKS TRACT		
198	38° 02.3'/121° 37.3'		Bouldin Island
199	38° 03.0'/121° 35.9'		Bouldin Island
200	38° 01.7'/121° 35.9'		Bouldin Island
	OLD RIVER		
201	38° 04.3'/121° 34.2'	Center	Bouldin Island
202	38° 03.8'/121° 34.8'	Left	Bouldin Island
203	38° 02.9'/121° 34.8'	Center	Bouldin Island
204	38° 02.4'/121° 34.9'	Right	Bouldin Island
205	38° 02.2'/121° 34.7'	Center	Bouldin Island
206	38° 02.3'/121° 34.2'	Left	Bouldin Island
207	38° 01.8'/121° 33.8'	Center	Bouldin Island
208	38° 01.1'/121° 33.3'	Right	Bouldin Island
209	38° 01.1'/121° 34.1'	Center	Bouldin Island
210	38° 00.6'/121° 34.1'	Left	Bouldin Island
211	38° 00.2'/121° 34.6'	Left	Bouldin Island
212	37° 59.9'/121° 34.1'	Right	Woodward Island
213	37° 58.2'/121° 34.4'	Center	Woodward Island
214	37° 57.5'/121° 33.8'	Left	Woodward Island
	HOLLAND CUT		
215	38° 01.4'/121° 34.9'	Center	Bouldin Island
216	38° 00.5'/121° 34.8'	Left	Bouldin Island
217	37° 59.8'/121° 34.7'	Center	Woodward Island
218	37° 58.9'/121° 34.7'	Right	Woodward Island