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BIOMASS ESTIMATES OF PACIFIC HERRING, *CLUPEA PALLASI*, IN CALIFORNIA FROM THE 1990-91 SPAWNING-GROUND SURVEYS

by

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ABSTRACT

The spawning biomass of Pacific herring, *Clupea pallasi*, estimated from spawning-ground surveys in San Francisco Bay declined to 45,850 tons this season, following a peak of 71,000 tons in the 1989-90 season. This is the first major decline since the 1983-84 El Nino.

In Tomales Bay the 1990-91 spawning biomass more than doubled to 779 tons. The spawning biomass has increased the past two seasons, while the fishery has been closed.

There was no biomass estimate for Bodega Bay, but an additional 95 tons of herring were caught in Bodega Bay this season. The total herring biomass for the Tomales-Bodega area is a minimum of 874 tons.

Humboldt Bay was surveyed by the Department for the first time this season, and spawning biomass was estimated to be 400 tons.

January was the month of peak spawning activity in all spawning areas surveyed.

In San Francisco Bay, 62% of all spawning occurred along the San Francisco waterfront; for the first time there was no significant spawning in the northern part of the bay. Nearly 70% of the spawning activity in San Francisco Bay occurred on January 3-6, 1991.

A total of 3.5 million m^2 of eelgrass, *Zostera marina*, was measured in Tomales Bay this season. The change in eelgrass density this season varied from bed to bed, however the overall density of eelgrass in Tomales Bay declined.

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Patrick Collier, Northern Ocean Management Biologist at Eureka, assisted with spawning-ground surveys in Humboldt Bay. Herring biomass estimates in Humboldt Bay could not have been accomplished without the assistance of Ken Bates, commercial herring fisherman from Eureka.

INTRODUCTION

The California Department of Fish and Game (CDFG) has estimated the annual spawning biomass of Pacific herring, Clupea pallasi, in Tomales and San Francisco Bays since 1973. Spawning-ground surveys were expanded during the 1990-91 season to include Humboldt Bay. Biomass estimates were derived from estimates of herring eggs deposited during the spawning season. California's bays where herring spawn are relatively small and well suited for intensive spawning-ground surveys.

This report includes spawning biomass estimates for Tomales Bay, San Francisco Bay, and Humboldt Bay during the 1990-91 season, and continues the series of annual herring spawning biomass estimates from 1973-74.

DESCRIPTION OF STUDY AREA

Tomales Bay

Tomales Bay (Figure 1) lies in Marin County, north of San Francisco. It is 20 km (12.4 mi) long and averages 1.5 km (0.9 mi) wide. Hardwick (1973) determined that eelgrass, Zostera marina, was the predominant marine flora in the bay. The portion of the bay surveyed covers the known distribution of eelgrass (Figure 1). There are other species of marine flora in Tomales Bay, but eelgrass is the primary one used by herring as spawning substrate.

San Francisco Bay

The portion of San Francisco Bay surveyed included all shoreline and shallow subtidal areas to a depth of 4.6 m (15 ft) bounded by the Golden Gate Bridge on the west, the Richmond

Bridge on the north, Hunters Point on the south, and the east bay shoreline between Richmond and Alameda (Figure 2). Other areas of the bay were surveyed only when reports of spawning activity were received.

In San Francisco Bay, herring spawn both intertidally (partly exposed at low tide) and subtidally (never exposed at low tide). Herring spawn intertidally on all suitable substrates including bare rocks, sand, pier pilings, and marine flora. Subtidal spawns generally occur in areas of the bay shallower than 4.6 m (15 ft) within vegetated areas of eel grass, red algae Gracilaria sp., and sea lettuce Ulva sp.; but may also occur in shallow rocky or hard bottom areas. Broad, shallow mud flats without vegetation have not been utilized by herring as spawning areas.

Humboldt Bay

Humboldt Bay is California's northernmost embayment, 80 mi (129 km) south of the Oregon border. Humboldt Bay has an unusual shape, with the northern and southern ends broadened into shallow mud flats that are interspersed by tidal drainage channels. These mud flats, which are exposed on most minus tides, support vast areas of eelgrass covering an estimated 13 million m^2 (Harding and Butler 1979). The general distribution of eelgrass in north Humboldt Bay has not changed since 1979. Herring utilize both the north and south ends of the bay, but previous surveys found most spawning in the northern end (Rabin and Barnhart 1986). The 1990-91 spawning-ground surveys were confined to the eelgrass beds in the northern part of Humboldt Bay (Figure 3).

METHODS

Tomales Bay Sampling Techniques

Spawning-ground surveys were conducted from November 16, 1990 to March 18, 1991. The frequency of surveys was reduced from daily to three days per week (Mon., Wed., and Fri.), due to project budget restrictions. Eelgrass beds (Figure 1) were inspected as weather permitted from the project's 4.6 m (15 ft) boat. Spawn deposition area (m^2) and density were determined by dragging a vegetation sampler (rake) through the eelgrass beds at random locations. When the perimeter of the spawn deposition was found, the location was marked by dropping an anchored float as a reference point. Measuring between floats with an optical rangefinder provided linear measurements that were used to calculate spawning area.

Processing of spawn deposition samples was unchanged from previous seasons (Spratt 1981). Herring eggs were removed from the eelgrass blades, then counted or estimated by weighing to the nearest 0.1 g. The eelgrass was then weighed to the nearest 0.1 g to obtain the number of eggs per unit weight of eelgrass.

Density of eelgrass (kg/m^2) on spawning grounds was estimated using a multiple linear regression between density and eelgrass blade measurements (Spratt, 1989). The multiple regression model is represented by the following equation:

$$Y = a_l(\text{length}) + a_w(\text{width}) + B$$

where:

Y = kg eelgrass per m^2

a_l = slope of regression for length variable

a_w = slope of regression for width variable

B = Y intercept

During December and January, eelgrass blade length and width measurements were taken from eelgrass samples collected from the project's boat with a vegetation sampler. Between 6 and 15 sets of eelgrass blade lengths and widths were collected from 29 of the 37 eelgrass beds in the bay. The 1990-91 eelgrass density values were computed by substituting these eelgrass data in the regression formula.

The area (m^2) of 18 eelgrass beds was remeasured. The perimeter of smaller eelgrass beds was determined with a recording fathometer, then marked with anchored floats. An optical rangefinder was used to measure distance between floats, and these distance measurements were used to calculate area. Larger beds were measured by triangulation using known landmarks, plotting bed perimeters on navigation charts, then calculating the area directly from the chart.

San Francisco Bay Sampling Techniques

Spawn surveys in San Francisco Bay were also affected by project staff reduction. The season began with an emphasis on hydroacoustic surveys, with the intention of conducting spawn surveys only when herring were suspected to have spawned. This

procedure remained in effect until the end of December, when a key member of the hydroacoustic survey team suffered an off-duty injury that curtailed his field duties for the remainder of the season. Consequently, hydroacoustic surveys ceased because the expertise to conduct the field surveys was not available. On January 3, 1991 daily spawning-ground surveys were resumed and continued until March 15, 1991.

The techniques used to sample both subtidal and intertidal spawns in San Francisco Bay have remained unchanged since the 1983-84 season (Spratt 1984). A two stage random sampling plan was used to select sample sites for intertidal shoreline spawns. Three 100 cm^2 samples of eggs were removed at each sampling site and egg numbers were counted or estimate to determine density (eggs/m^2).

Spawnings on pier pilings were not sampled randomly; but, 100 cm^2 samples of eggs were collected at regular intervals 274 to 457 m (300 to 500 yards) apart throughout the entire linear length of a spawn.

Samples from subtidal spawns were collected randomly throughout the spawn area by towing a weighted rake. These samples provided the number of eggs to kg of vegetation ratio. To quantify the number of eggs, vegetation density estimates (kg/m^2) from pre-spawning SCUBA surveys were used. In areas of hard bottom or shell beds, the rake is effective in picking up pieces of shell or clusters of eggs. In these cases, the layers of eggs deposited are recorded (1 layer of eggs = 750,000 eggs/m^2).

Subtidal vegetation densities were determined prior to the spawning season by collecting samples with SCUBA from 1/4 m^2

quadrats from permanent stations at Kiel Cove and Angel Island (Figure 4). Belvedere Cove and Brooks Island stations were eliminated this season due to lack of spawning activity in those areas. New stations were added near Alameda and Oakland Airport (Figure 5) because herring are now spawning near these locations.

Humboldt Bay Sampling Techniques

The techniques used to sample herring spawning in Humboldt Bay eelgrass beds were similar to those used in Tomales Bay. Densities for eelgrass beds 1 through 5 in north Humboldt Bay (Figure 5) were determined on November 8, 1990, by measuring eelgrass blade lengths and widths and substituting them in the regression equation developed for Tomales Bay eelgrass.

Regular spawning-ground surveys were not conducted. The project relied on the voluntary assistance of Ken Bates, a local herring fisherman, to notify us of the time and place of spawning. Mr. Bates made daily trips across the Bay to hydroacoustically assess herring school movement. When he reported a suspected herring spawn, project personnel traveled to Eureka and conducted a spawn survey utilizing fathometer, vegetation sampler, and optical rangefinder. Spawn sampling and processing followed methods described for Tomales Bay.

Biomass Computation

In San Francisco Bay, the estimated number of herring eggs spawned was converted to tons of spawners by incorporating sex ratio estimates for each spawning run. The following formula was used to calculate the conversion factor:

$$\text{Conversion factor} = \frac{1}{F \times \frac{f}{P} \times \frac{\text{Grams}}{\text{pound}} \times \frac{\text{Pounds}}{\text{ton}}}$$

where:

F = fecundity (males and females combined)

f = percent females in a given spawning run.

P = percent females in population (assumed to be 50%)

Fecundity of herring (eggs/g of female) in San Francisco Bay ranged between 220 and 226 from 1984 to 1986. These differences were not significant (Reilly and Moore 1986). Fecundity was also not significantly different between Tomales Bay and San Francisco Bay herring. A fecundity value of 113 eggs /g of body weight (males and females combined) was used in calculating 1990-91 biomass estimates.

In Tomales Bay and Humboldt Bay sex ratio data was not available and a 50/50 sex ratio was assumed for conversion to tons of herring.

Combining Hydroacoustic and Spawn Survey Estimates

Starting with the 1989-90 season, the San Francisco Bay herring population estimate from spawning-ground surveys and hydroacoustic estimates have been merged to generate one biomass estimate which is used as a basis for setting herring catch quotas. The two surveys remain independent during the season, but results are combined at the end of the season to obtain the biomass estimate that most accurately reflects population size. If both methods yield acceptable results for a given spawning event, then they are averaged. If one method encounters problems

(weather, equipment failure, or unable to sample adequately etc.) then results from the other method were used. Because both surveys have strengths and weaknesses, a merged biomass estimate emphasizes the strengths of both methods. This procedure eliminates a conservative bias and probably more accurately reflects the actual spawning biomass.

RESULTS

Tomales Bay

There were 37 eelgrass beds in Tomales Bay. A new eelgrass bed was discovered this season, bed no. 10A near White Gulch (Figure 1). Spawning has also been found in two Gracilaria sp. beds, numbers 28B and 29 (Figure 1).

The total eelgrass area consistently ranged between 3.8 and 4.0 million m^2 annually until 1989-90 when the area declined to 3.5 million m^2. Only about half of the eelgrass beds were measured this season, but the total area remained about the same as last year (Table 1).

Eelgrass Density Estimates From Regression

Beginning with the 1987-88 season, eelgrass density was estimated from regression using eelgrass blade length and width measurements. Prior to that, eelgrass density was estimated subjectively by on-site visual inspections based on quantitative samples collected in 1976 (Spratt 1981).

During the 1990-91 season, eelgrass density was estimated from eelgrass data collected in December and January, and substituted in the regression formula:

$$\text{Density } kg/m^2 = .002177(l) + .0765(w) - 1.1810, \quad r=.78$$

The computed eelgrass density for each bed (Table 2) was compared with density estimates from the previous season. The majority of the beds declined in density. However, most 1990-91 herring spawning occurred in eelgrass beds that had increased in density.

Spawning Biomass

There were four distinct periods of spawning activity this season, the most in three years. The first spawning occurred January 8, 1991 at vegetation beds 1B, 28, and 28B (Figure 1 and Table 3).

The largest spawn this season on January 27, 1991 covered several vegetation beds (28, 28A, 28B, 1A, 1B, and 1C), and included an intertidal spawn near Marconi Cove (Figure 1 and Table 3). This season's spawning escapement estimate for Tomales Bay was 779 tons (Table 3). Tomales Bay has been closed to fishing the past two seasons, therefore spawning escapement equals spawning biomass (Table 4).

Hydroacoustic surveys were attempted in Bodega Bay after the curtailment of surveys in San Francisco Bay, but results were inconclusive. Consequently, only the 95 tons of herring landed commercially in Bodega Bay was included in the Tomales/Bodega area spawning biomass estimate (Table 5). Nevertheless, the 1990-91 minimal spawning biomass estimate of 874 tons in the Tomales-Bodega area was the highest in three seasons (Table 5).

Vegetation Density Estimates

Quantitative samples of subtidal vegetation were collected by Department divers on October 25, 1990. Subtidal vegetation decreased at Angel Island (Figure 4), when compared to 1989 densities (Spratt 1990). New stations in south San Francisco Bay (Figure 5) had very light to medium densities of eelgrass, with the densest beds found near Ballena Bay.

Vegetation densities in San Francisco Bay are low compared to Humboldt and Tomales Bays and no spawning occurred in known vegetation beds.

Spawning Biomass

There were seven periods of spawning activity during the 1990-91 season. Normally there are at least nine herring spawns each season. Some of the smaller early season spawns may have been undetected because of the reduced spawning-ground survey effort during the first part of the season. Additional spawning at Mare Island and Redwood City was reported to have occurred. These locations are outside of our regular survey area. Reports of spawning outside of the survey area occur frequently, but are usually received too late to survey and are not included in biomass estimates.

The first spawn of the season on November 24, 1990 at Tiburon and Belvedere Cove was the only spawn in the northern part of the bay (Table 6, Figure 6). The San Francisco water-front was again the major spawning area, accounting for about 62% of the spawning escapement (Table 6, Figure 7a and 7b). The largest single spawn ever recorded occurred from January 3-6,

1991, when over 26,000 tons of herring spawned in the vicinity of San Francisco, Oakland, Alameda, and Treasure Island (Figure 7b).

Only two subtidal spawnings were found: one in Belvedere Cove (Table 6 and Figure 6) on ulva sp., and another near Alameda (Table 6 and Figure 8) on hard sand and oyster shells with little vegetation.

The 1990-91 season spawn escapement estimate was 37,890 tons of herring (Table 6). Including the catch of prespawning herring from the roe fishery, the spawning biomass estimate for the 1990-91 season was 45,850 tons (Table 7).

The San Francisco Bay population estimate from spawning-ground surveys peaked in 1989-90 at 70,912 tons (Spratt 1990). This season's estimate represents a 35% decline in biomass and is the first significant decline in seven years.

Combined Acoustical and Spawn Survey Biomass Estimate

Hydroacoustical surveys were conducted until the end of December, fortunately encompassing the season's largest spawning aggregation. The hydroacoustic estimate for the January 3-6 spawn was 38,600 tons (Ken Oda, CDFG, pers comm.), about 12,000 tons greater than the spawn survey estimate. Averaging both survey estimates for the season's largest spawn and using spawning-ground survey results the remainder of the season, produced a combined 1990-91 season biomass estimate of 51,000 tons, a 21% decline from the 1989-90 combined estimate of 64,500 tons. The 1991-92 San Francisco Bay herring quotas will be based on a biomass of 51,000 tons.

Humboldt Bay

Vegetation Density Estimates

Eelgrass density was estimated for bed numbers 1 through 5 (Figure 3), where herring were expected to spawn. The multiple regression formula developed for Tomales Bay was used to estimate eelgrass density. Densities ranged from 0.2 kg/m^2 at bed number 5 to 1.04 kg/m^2 at bed number 1.

Rabin and Barnhart (1986) estimated herring biomass using eelgrass densities of about 0.5 kg/m^2. Harding and Butler (1979) reported winter eelgrass densities in Humboldt Bay ranging from 0.3 to 2.1 kg/m^2, but found the highest densities in the southern part of Humboldt Bay.

Spawning Biomass

A large school of herring entered Humboldt Bay about December 25, 1990. Herring spawning was first reported on January 20, 1991. Field surveys conducted on January 23, 1991 found spawn at eelgrass beds 1, 3, and 5 (Figure 3). Herring spawning escapement from this large spawn was estimated at 336 tons (Table 8); however, it is probable that other smaller spawns also took place. The 1990-91 spawning biomass including the catch of 63 tons, was 399 tons.

Confidence Limits

Tomales Bay

Confidence limits for herring spawning escapement estimates in Tomales Bay were calculated from variation in the density of egg deposits. Each spawning event usually encompassed several small spawning sites and total spawning escapement was the sum of the estimates for each site (Table 3). The confidence intervals were

also calculated for each spawn site individually except for the January 27 spawn at beds 1A, 1B, and 1C; samples from these three small spawns were combined. The 95% confidence intervals for 1990-91 season (Table 9) were broad for most sites due to the very light and patchy distribution of spawn. However, confidence intervals were narrower at two of the larger spawn sites which accounted for 73% of the biomass.

San Francisco Bay

Confidence limits for San Francisco Bay spawn estimates were also calculated for each spawn site from variation in the density of egg deposits. Eight of this season's spawning sites (86% of biomass) had 95% confidence intervals ranging between 17% and 43% of the estimate (Table 10).

Confidence limits for the January 9, 1991 spawn at Alcatraz were more than twice the estimate due to inadequate sampling. Alcatraz is a very difficult area to sample due to the rocky exposed shoreline. In addition spawn deposition ranged from very light to heavy, resulting in high between sample variance.

Humboldt Bay

In Humboldt Bay attempts to reduce the confidence intervals of spawn estimates were made by combining samples from adjacent spawn sites. However, the attempts did not improved confidence intervals over treating each spawn site separately (Table 11).

The spawn on bed number 5 accounted for more than 90% of the spawn estimate and was not sampled adequately. Seven samples were collected, but after processing it was apparent that samples would have to be stratified by area. Only three samples were collected from the area of heaviest egg deposits, which resulted

in confidence limits that were more than the estimate (Table 11). Combining all seven samples from bed No. 5 yielded a biomass estimate of only 200 tons ± 260 tons.

DISCUSSION

Tomales Bay and Bodega Bay

Spawning escapement estimates have more than doubled in Tomales Bay each of the past two seasons (Table 4). The bay has been closed to herring fishing during this time, and the increase in biomass estimates could be linked to reduced fishing pressure.

Due to mortality, there are few herring remaining from the last good season of 1986-87. The spawning escapement estimate for that season was nearly 6,000 tons. Those herring presumably had a genetic link to Tomales Bay. It was thought that these fish could return to Tomales Bay, however this is no longer a possibility. The recovery of the Tomales Bay herring spawning stock will be dependent either on rebuilding the small population that remains or on attracting herring to Tomales Bay that have not previously spawned there. We assume that the reduced spawning biomass in Tomales Bay is attributed to reduced freshwater inflow because of the 1987-91 drought. Although the California drought has not ended, this season's major spawning event coincided with a large winter storm.

Herring biomass estimates in Bodega Bay have been difficult to obtain. Open ocean conditions limit acoustical and spawn escapement surveys. Conducting acoustical surveys from small vessels when weather conditions permit has proven of limited benefit. It is doubtful that acoustical surveys will be

effective in Bodega Bay except on rare occasions when good weather and concentrations of herring coincide. Intermittent surveys will not be adequate to estimate total biomass or manage the herring fishery.

The Bodega Bay fishery remains open, with a 200 ton quota. The age composition of this catch indicates a stable healthy stock (Spratt 1991). The relatively small Bodega Bay herring quota of 200 tons has not been taken the past two seasons, suggesting that the biomass is either relatively small or of limited availablity. The relationship between herring caught in Bodega Bay and herring that spawn in Tomales Bay is also unknown. There has been no verified herring spawning in Bodega Bay except that which occurs on herring gillnets used in the fishery. These are considered to be artificial spawns caused by fishing activity. The probability remains that herring caught in Bodega Bay may be bound for the spawning grounds in Tomales Bay.

Spawning by Area 1973 to 1989

Annual spawning-ground surveys have been conducted in Tomales Bay since 1973-74, with the exception of the 1978-79 and 1985-86 seasons. The 1985-86 season biomass was estimated by cohort analysis (Spratt 1986).

The distribution of herring spawn within Tomales Bay has changed over the past three years. Spawning is now centralized in the upper part of the bay at vegetation beds 1, 1A, 1B, 1C, 28, 28A, and 28B (Table 12). The herring that still spawn in the bay no longer spawn in the large lush eelgrass beds near Walker Creek (Figure 1). This change in the spawn distribution in Tomales Bay is probably related to the drought. Herring spawning has been

concentrated in the upper bay near Lagunitas Creek, which is the major source of freshwater inflow into Tomales Bay.

San Francisco Bay

Results from past spawning-ground surveys indicate that the San Francisco Bay herring population has peaked twice in the past 10 years (1981-82 and 1989-90). In both cases, the population declined 35-40% the following season (Table 7). However, the decline following the 1981-82 peak was associated with the 1982-83 El Nino and continued for two seasons. Ultimately the population declined by 60% before rebuilding began in the 1983-84 season. The Tomales Bay population still has not recovered from the effects of the 1982-83 El Nino.

Environmental conditions during 1990 were similar to those in 1982-83 in that ocean temperatures were above normal and upwelling of nutrient rich sea water was below normal. These conditions are unfavorable for herring growth and survival. The 1990 oceanographic conditions were not as severe as those found during 1982-83; however, if conditions remain unfavorable for herring in 1991 the San Francisco population may decline further.

Spawning Escapement by Area 1973 to 1991

Spawning-ground surveys have been conducted in San Francisco Bay for 18 seasons. During this time, there has been a major change in the distribution of herring spawning in the bay. From the 1973-74 to 1981-82 seasons, Richardson Bay, Sausalito, and Richmond were the major spawning areas. Since the 1982-83

season, the San Francisco waterfront has accounted for 61% of all spawning escapement (Table 13).

Humboldt Bay

The first herring survey of Humboldt Bay in 15 years estimated a herring biomass of at least 400 tons for the 1990-91 season. It is suspected that more spawning occurred than our surveys detected. However, due to broad confidence limits of the biomass estimate this data should be used cautiously. The Department recommends further studies in Humboldt Bay before any management changes are considered.

CONCLUSION

Tomales Bay

The Tomales Bay herring fishery has been closed since the 1989-90 because of low spawning escapement. During the closure, spawning escapement has increased to nearly 800 tons. However, the biomass is still well below the long term mean of 5,000 to 6,000 tons prior to the present depressed state. The closure should continue until spawning escapement in Tomales Bay increases to at least 2,000 tons.

San Francisco Bay

The San Francisco Bay herring population declined significantly for the first time in seven years. Unfavorable environmental conditions during 1990 may be responsible for the decline. This season's combined spawn escapement and hydroacoustic biomass estimate of 51,000 tons is about 15 % below the 10 year population mean of 60,000 tons, and herring quotas will

be reduced next season. If a declining trend develops, further restrictions on the fishery will be necessary.

Humboldt Bay

The Humboldt Bay herring population is sufficiently large to support the existing small fishery.

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TABLE 1. Tomales Bay Eelgrass Bed Measurements, 1990-91 Season.

Bed number	Area m^2	Season last surveyed	Bed number	Area m^2	Season last surveyed
1	5,000		12	1,700	1989-90
1A	43,400		13	0	1989-90
1B	5,400		14	700	1989-90
1C	2,700		15	0	1989-90
2	9,500		16	4,500	
2A	0		16A	7,800	1989-90
3	4,300		17	2,000	1989-90
3A	0		18	0	1989-90
4	2,500		19	38,000	1989-90
5	6,500	1989-90	20	135,500	1989-90
6	8,300	1989-90	20A	33,400	1989-90
7	9,500	1989-90	21	1,488,000	
8	4,000	1989-90	22	140,000	
9 North	14,400	1988-89	23	1,209,000	
9 South	17,900	1988-89	24	45,500	1989-90
10	1.500		25	102,000	1989-90
10A	3,000		26	120,000	1989-90
11 North	10,500		27	27,800	
11 Middle	3,800		28	65,000	
11 South	1,750		28A	5,900	

Total area = 3,546,550 m^2

TABLE 2. Eelgrass Density Estimates (kg/m^2) for Most Tomales Bay Eelgrass Beds, Calculated from Multiple Regression.

Bed no.	89-90 Density	90-91 Density	Percent change
1	1.67	.88	- 47
1A	1.44	1.99	+ 38
1B	2.03	2.10	+ 3
1C	1.41	1.61	+ 14
2	1.61	1.46	- 9
3	1.23	1.11	- 10
3A	no data	0.77	--
4	0.93	1.22	+ 31
5	1.24	0.69	- 44
6	1.04	1.08	+ 4
7	1.24	1.13	- 9
8	1.33	no data	--
9S	1.46	0.83	- 43
9N	1.18	0.83	- 30
10	2.06	1.45	- 30
10A	no data	0.94	--
11	1.19	1.07	- 10
12	1.16	no data	--
13	no data	"	--
14	0.68	"	--
15	no data	"	--
16	1.76	1.09	- 38
16A	2.03	no data	--
17	1.59	1.17	- 27
18	0	no data	--
19	1.79	"	--
20	1.14	0.42	- 63
20A	0.86	0.43	- 50
21	2.78	0.96	- 64
22	1.98	1.99	0
23	1.75	0.98	- 44
24	1.28	1.83	+ 43
25	1.55	no data	--
26	1.47	0.63	- 57
27	1.11	2.07	+ 86
28	1.35	1.91	+ 41
28A	1.83	2.08	+ 14

TABLE 3. Tomales Bay Herring Spawn Data, 1990-91 season.

Date	Location *	Area m^2	Eggs per m^2	Millions of eggs	Conversion factor $X\ 10^{-8}$	Tons
8 Jan 91	1B	700	304,500	210	1.20	3
8 Jan 91	28	65,000	60,000	3,900	"	50
8 Jan 91	28B	300,000	392	118	"	1
27 Jan 91	**	4,600	430,000	1,978	.97	20
27 Jan 91	28	65,000	823,000	53,476	"	520
27 Jan 91	28A	5,900	1,848,000	10,900	"	105
27 Jan 91	28B	418,000	3,680	1,538	"	15
27 Jan 91	1A	8,000	124,000	992	"	10
27 Jan 91	1B	5,400	25,830	140	"	1
27 Jan 91	1C	2,700	11,000	48	"	Trace
21 Feb 91	1A	9,000	554,000	4,986	"	50
8 Mar 91	1	5,000	55,000	275	"	3
Total		889,300		78,491		779

* See Figure 1.

** Intertidal spawn near Marconi Cove.

TABLE 4. Tomales Bay Herring Biomass Estimates 1973-74 Through 1990-91 seasons.

Season	Spawn escapement (tons)	Catch (tons)	Spawning biomass (tons)
1973-74	6,041	521	6,562
1974-75	4,210	518	4,728
1975-76	7,769	144	7,913
1976-77	4,739	344	5,083
1977-78	21,513	646	22,163
1978-79	--	448	--
1979-80	5,420	603	6,023
1980-81	5,128	448	5,576
1981-82	6,298	851	7,149
1982-83	10,218	822	11,040
1983-84	1,170	110	1,280
1984-85	6,156	430	6,586
1985-86	435	771	6,000 *
1986-87	4,931	867	5,798
1987-88	1,311	750	2,061
1988-89	167	213	380
1989-90	345	--	345
1990-91	779	--	779

* Biomass estimated by cohort analysis; for all other years biomass was estimated from spawning-ground surveys.

TABLE 5. Tomales/Bodega Bay Area Herring Biomass Estimates. [1/]

Season	Tomales Bay	Bodega Bay	Catch [2/] in tons	Total tons
1988-89	167	NO SURVEY	213	380
1989-90	345	350	95	790
1990-91	779	NO SURVEY	95	874

1/ Biomass estimates are from spawning ground surveys in Tomales Bay and hydroacoustic surveys in Bodega Bay.

2/ Herring catch is from Bodega Bay.

TABLE 6. San Francisco Bay Herring Spawn Data, 1990-91 season.

Date	Location	Area m^2	Eggs per m^2	Millions of eggs	Conversion factor X 10^{-8}	tons
11/24/90	Tiburon	6,700	800,000	5,360	1.2	65
11/24/90	Belvedere Cove	20,000	220,000	4,400	"	55
12/6-10/90	San Francisco	250,000	1,680,000	420,000	0.107	4,500
1/3-6/91	San Francisco	570,000	2,360,000	1,345,200	"	14,400
1/3-6/91	Treasure Island	70,000	5,740,000	401,800	"	4,300
1/3-6/91	Oakland-Alameda	152,000	4,510,000	685,520	"	7,350
1/9-10/91	Alcatraz	23,000	2,500,000	57,500	"	620
1/21-24/91	San Francisco	30,000	500,000	15,000	"	160
1/21-24/91	San Francisco	210,000	1,300,000	273,000	"	2,900
1/21-24/91	Hunters Pt.	70,000	1,000,000	70,000	"	750
2/4-7/91	Oakland-Alameda	45,000	3,210,000	144,450	0.8	1,150
2/4-7/91	Alameda	200,000	550,000	110,000	"	900
3/4-7/91	San Francisco	70,000	1,320,000	92,400	"	740
Total		1,716,700		3,629,630		37,890

TABLE 7. San Francisco Bay Herring Biomass Estimates from Spawning-Ground Surveys 1973-74 Through 1990-91 Seasons.

Season	Spawn escapement (tons)	Catch (tons)	Spawning biomass (tons)
1973-74	4,300	1,938	6,238
1974-75	26,730	514	27,244
1975-76	25,360	1,719	27,079
1976-77	22,670	4,201	26,871
1977-78	3,750	4,987	8,737
1978-79	32,590	4,121	36,711*
1979-80	46,590	6,430	53,020
1980-81	59,615	5,826	65,441
1981-82	89,220	10,415	99,635
1982-83	49,518	9,695	59,213
1983-84	37,987	2,838	40,825
1984-85	39,130	7,740	46,870
1985-86	41,770	7,298	49,068
1986-87	48,721	8,098	56,819
1987-88	60,155	8,726	68,881
1988-89	56,308	9,736	66,044
1989-90	61,950**	8,962	70,912
1990-91	37,890	7,960	45,850

*Subtidal spawning areas were discovered in 1979. Biomass prior to 1979 was probably underestimated.

**Includes hydroacoustical estimates totaling 7,800 tons.

TABLE 8. Humboldt Bay Herring Spawn Data, 1990-91 season.

Date	Location *	Area m^2	Eggs per m^2	Millions of eggs	Conversion factor X 10^{-8}	Tons
20-21 Jan 91	1	200,000	11,000	2,200	.97	21
20-21 Jan 91	3	21,000	635	13	"	Trace
20-21 Jan 91	5	200,000	161,000	32,200	"	310
20-21 Jan 91	5	84,000	29,000	478	"	5
Total		505,000		34,891		336

* See Figure .

TABLE 9. Confidence Limits of the Tomales Bay Herring Spawn Estimates During the 1990-91 Season.

Spawn date	Location	S. E. eggs per m	D. F. N-1	Estimated tons	95% Conf.int.
1/8	1B	--	0	3	--
1/8	28	20,000	3	50	±50
1/8	28B	--	0	1	--
1/27	*	115,000	3	20	±18
1/27	28	218,000	4	520	±350
1/27	28A	1,640,000	1	105	±1,200
1/27	28B	1,400	3	15	±18
1/27	1A,B,C	25,000	3	12	±12
2/21	1A	165,000	4	50	±14
3/8	1	24,000	2	3	±5
	Total			779	

* Intertidal spawn near Marconi Cove, not on eelgrass.

TABLE 10. Confidence Limits of the San Francisco Bay Herring Spawn Estimates During the 1990-91 Season.

Spawn starting date	Location	S. E. eggs per m	D. F. N-1	Estimated tons	95% Conf. int.
11/24	Belvedere Cove	57,000	3	55	±45
11/24	Tiburon	120,000	5	65	±20
12/6	San Francisco	148,000	7	4,500	±930
1/3	San Francisco	321,000	13	14,400	±3,800
1/3	Treasure Island	977,000	10	4,300	±1,600
1/3	Oakland-Alameda	656,000	8	7,350	±2,450
1/9	Alcatraz	1,258,000	2	620	±1,300
1/21	San Francisco	0	2	160	±0
1/21	San Francisco	300,000	7	2,900	±1,600
1/21	Hunters Point	70,000	1	750	±450
2/4	Oakland-Alameda	550,000	5	1,150	±500
2/4	Alameda	175,000	2	900	±700
3/4	San Francisco	106,000	9	740	±130
	Total			37,890	

TABLE 11. Confidence Limits of the Humboldt Bay Herring Spawn Estimates During the 1990-91 Season.

Spawn date	* Location	S. E. eggs per m	D. F. N-1	Estimated tons	95% Conf.int.
1/21	1	4,000	5	21	±19
1/21	3	36	1	0.12	±0.09
1/21	5	1,350	3	5	±3
1/21	5	61,000	2	310	±500
	Total			336	

* See Figure 3.

TABLE 12. Average Herring Spawning Escapement by Area for Tomales Bay, Expressed as % of Season Total.

Vegetation bed no.	Season 1973-74 to 1982-83	1983-84 to 1987-88	1988-89 to 1990-91
1	0.84	0.98	1.17
1A	1.93	7.69	8.20
1B	--	0.50	0.47
1C	--	--	--
2	3.97	4.05	--
2A	--	0.29	--
3	1.14	0.62	--
3A	--	0.15	--
4	0.04	--	--
5	0.32	1.63	--
6	0.54	2.96	--
7	1.06	1.95	--
8	0.53	3.54	--
9	11.00	4.49	--
10	0.81	--	--
10A	--	--	--
11	3.41	2.96	--
12	0.10	0.06	--
13	--	--	--
14	0.01	0.06	--
15	--	--	--
16	2.83	0.20	--
16A	0.30	1.24	--
17	--	--	--
18	--	--	--
19	1.17	--	--
20	2.42	1.92	--
20A	0.50	--	--
21	23.22	15.97	--
22	19.24	24.10	--
23	16.16	3.84	--
24	0.81	--	--
25	3.36	6.86	--
26	3.68	5.17	--
27	0.13	2.99	--
28	0.32	--	47.54
28A	0.05	2.13	21.08
28B	--	--	20.14
29	--	0.59	--
Intertidal	--	2.96	1.40
Total	100.00	100.00	100.00
Tons average escapement *	7,926	3,382	427

* No spawn surveys were conducted in 1978-79 or1985-86.

TABLE 13. Herring Spawning Escapement by Area for San Francisco Bay.

1973-74 to 1981-82

Spawning area	Average % of seasonal biomass	Average escapement (tons)
Richardson Bay	38.6	13,334
Sausalito	16.3	5,616
Richmond	12.7	4,393
Tiburon	9.8	3,389
Angel Island	6.8	2,344
Treasure Island	3.7	1,275
Kiel Cove	3.5	1,205
Belvedere-Tiburon	3.0	1,038
Belvedere	1.9	655
San Francisco	1.5	533
South Bay	0.8	288
Belvedere Cove	0.7	244
Berkeley	0.6	211
Coyote Point	<0.1	11
Oakland-Alameda	0.0	- -
Total	100.0	34,536

1982-83 to 1990-91

Spawning area	Average % of seasonal biomass	Average escapement (tons)
San Francisco	61.6	29,638
Oakland-Alameda	11.0	5,293
Sausalito	8.6	4,140
Belvedere-Tiburon	3.8	1,830
Angel Island	3.6	1,732
Treasure Island	3.6	1,732
South Bay	2.6	1,250
Tiburon	2.3	1,110
Belvedere Cove	0.9	433
Kiel Cove	0.8	385
Richardson Bay	0.4	192
Richmond	0.4	192
Belvedere	0.2	96
Alcatraz	0.1	70
Coyote Point	<0.1	21
Berkeley	0.0	- -
Total	100.0	48,114

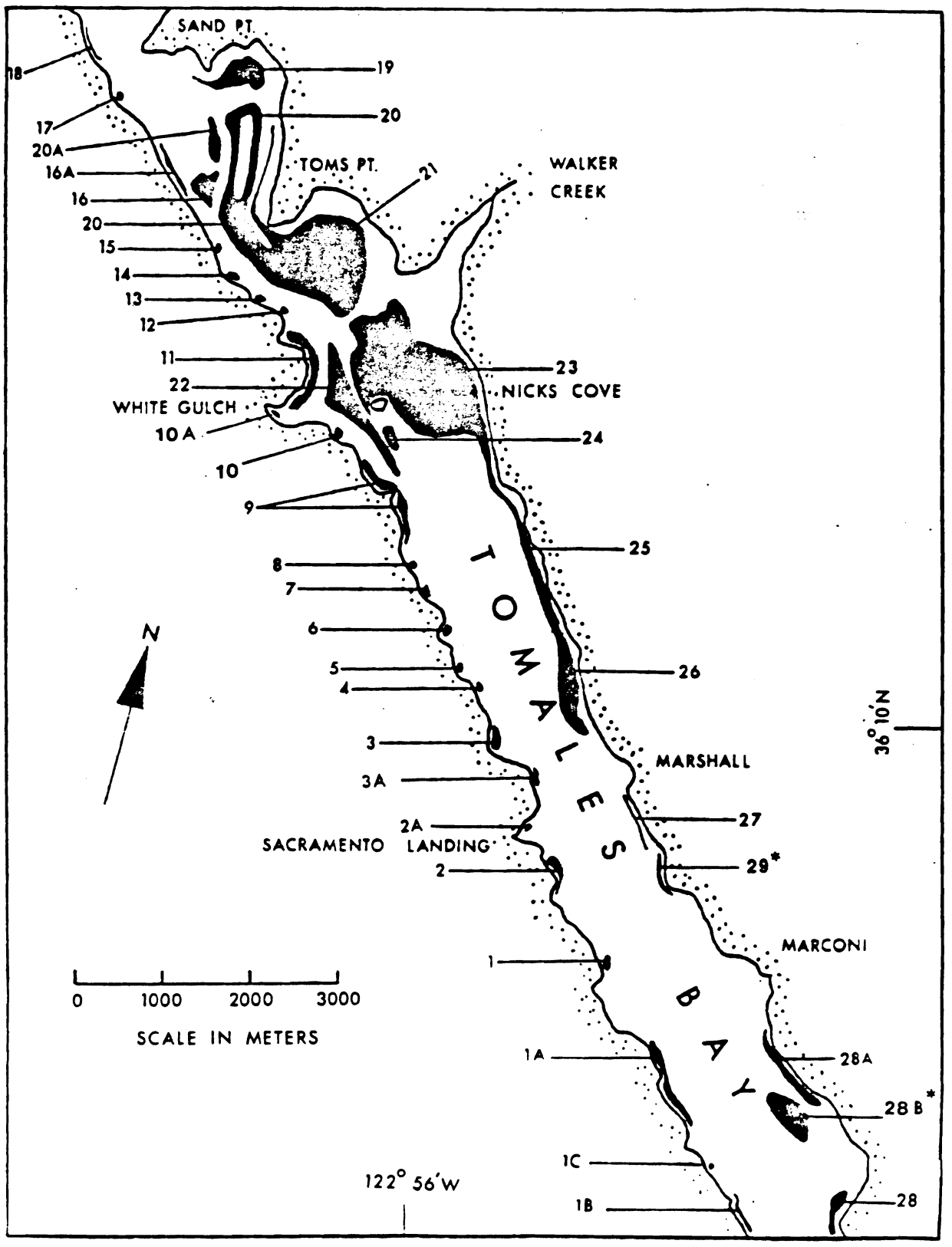

FIGURE 1. Tomales Bay with numbered vegetation beds. All beds are eelgrass except where (*) indicates Gracilaria sp.

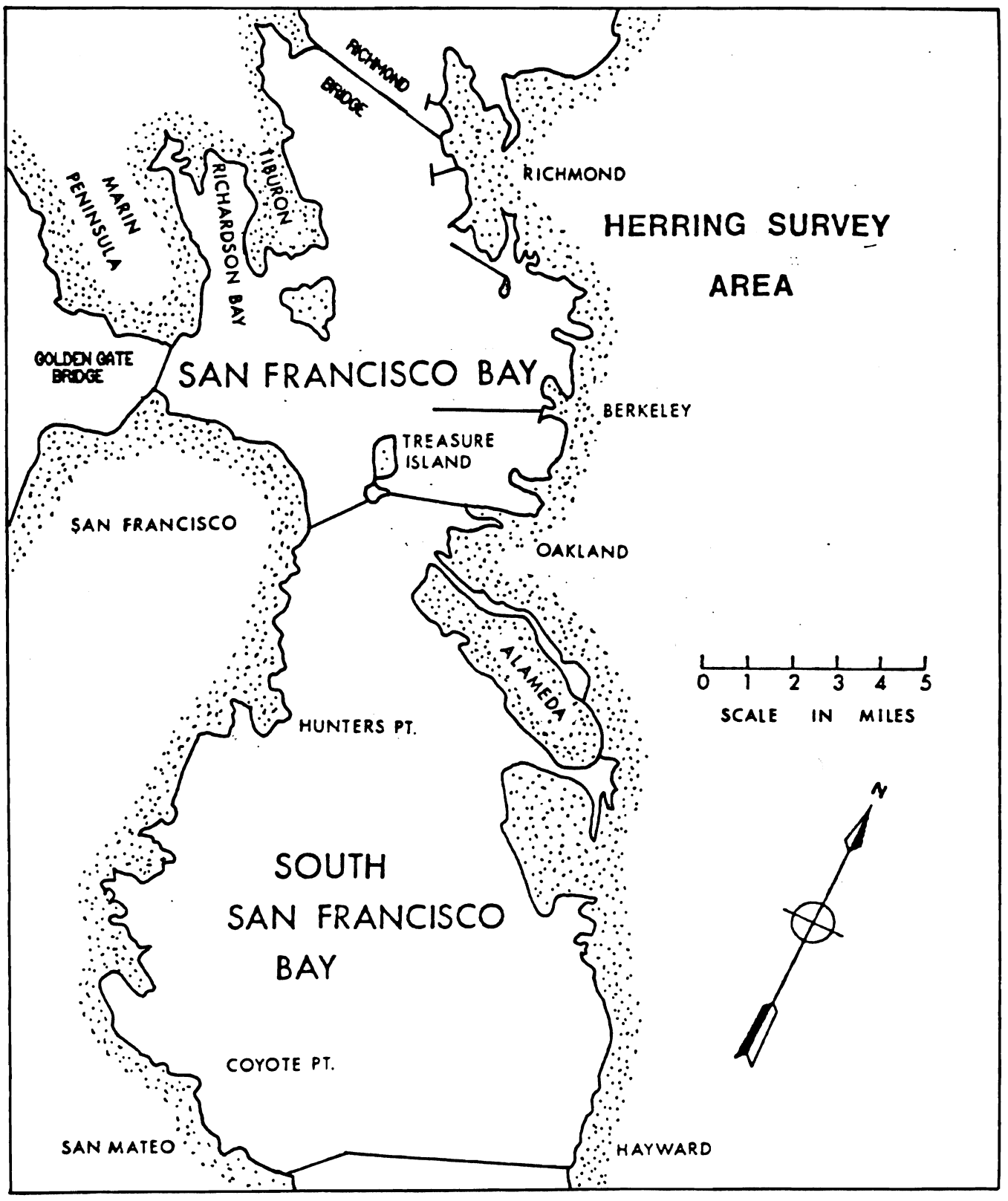

FIGURE 2. San Francisco Bay survey area.

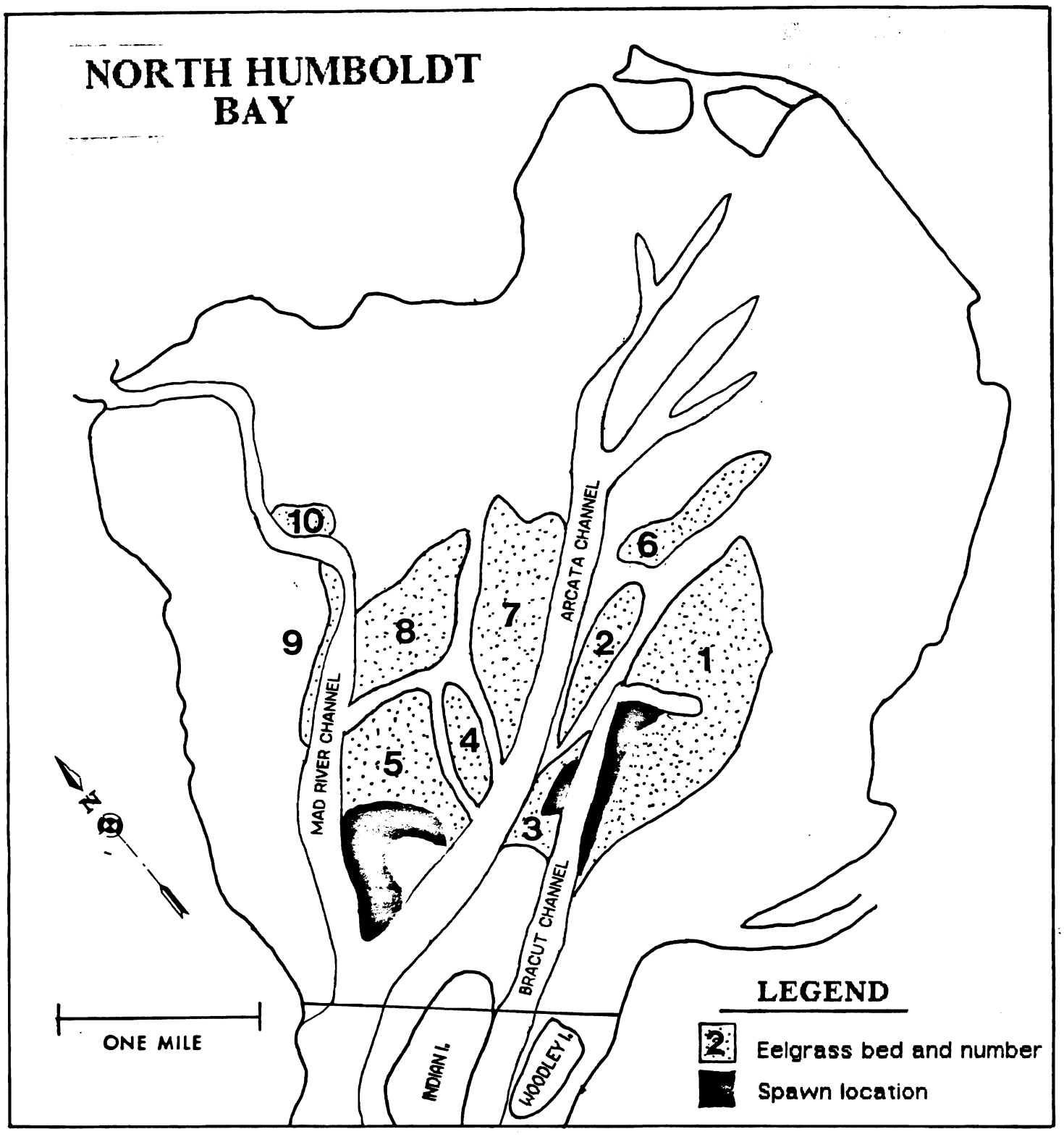

FIGURE 3. North Humboldt Bay with herring spawn locations and general location of eelgrass beds.

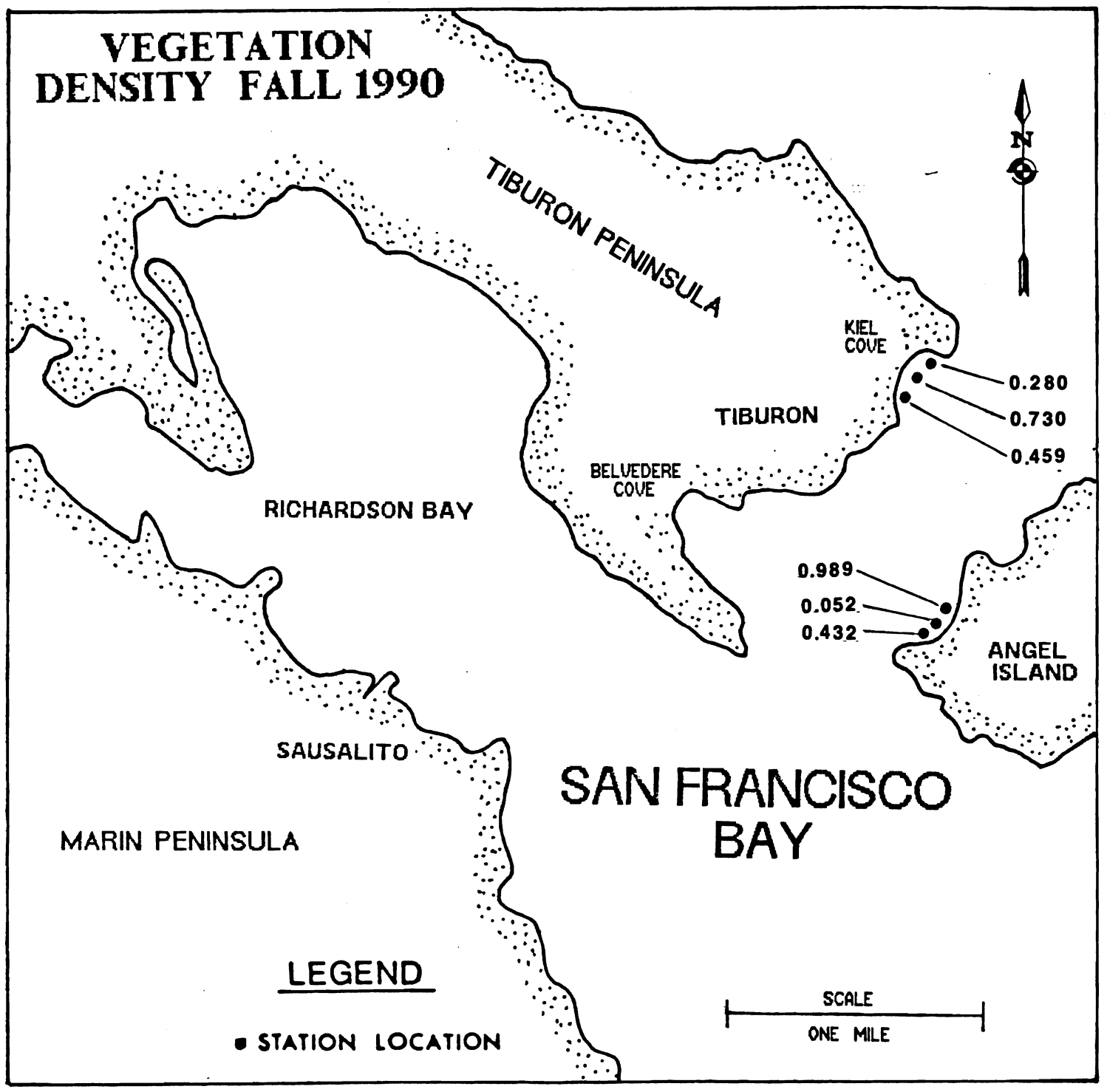

FIGURE 4. Vegetation densities kg/m^2 near Angel Island San Francisco Bay in the fall of 1990.

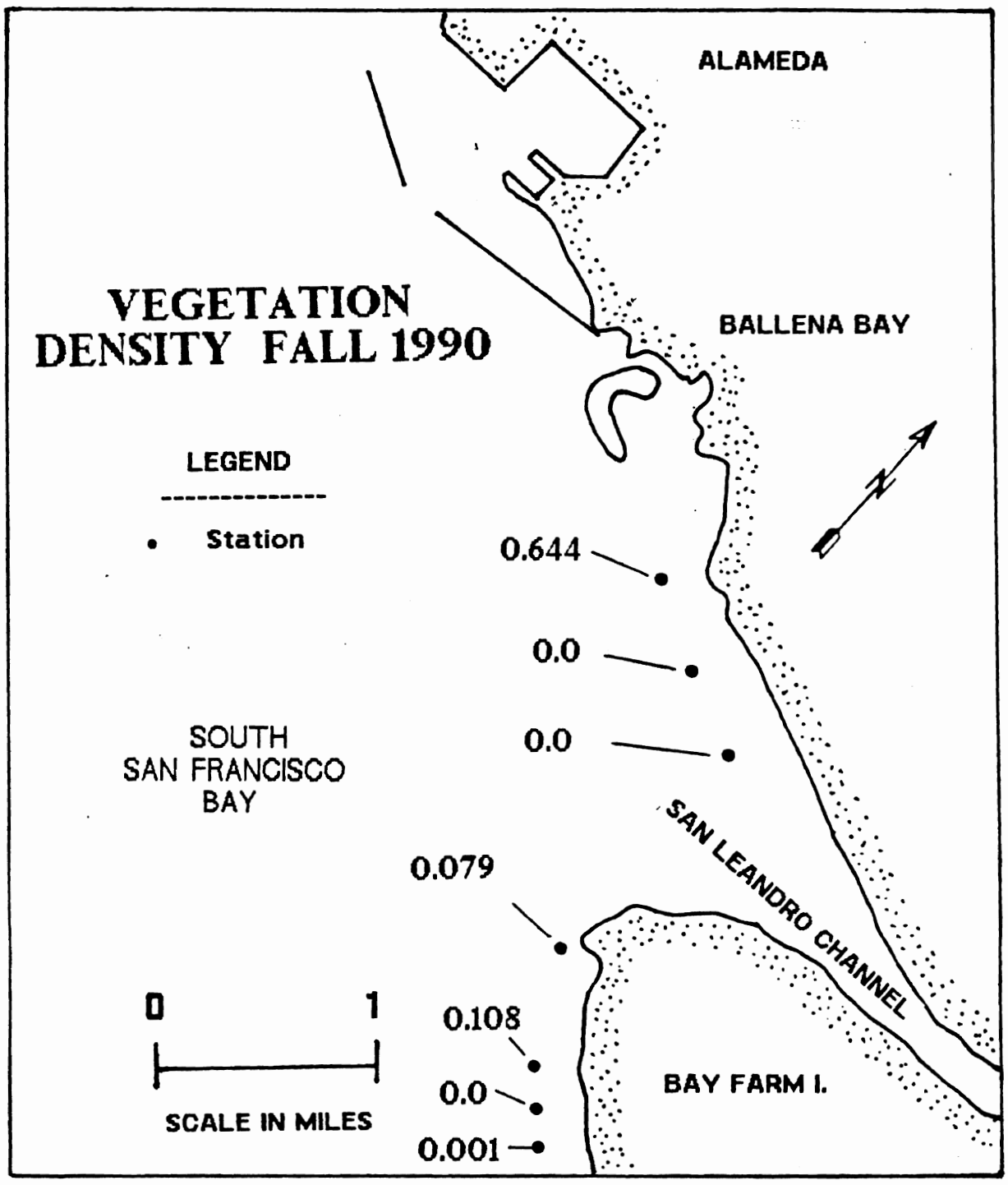

FIGURE 5. Vegetation densities kg/m^2 in south San Francisco Bay in the fall of 1990.

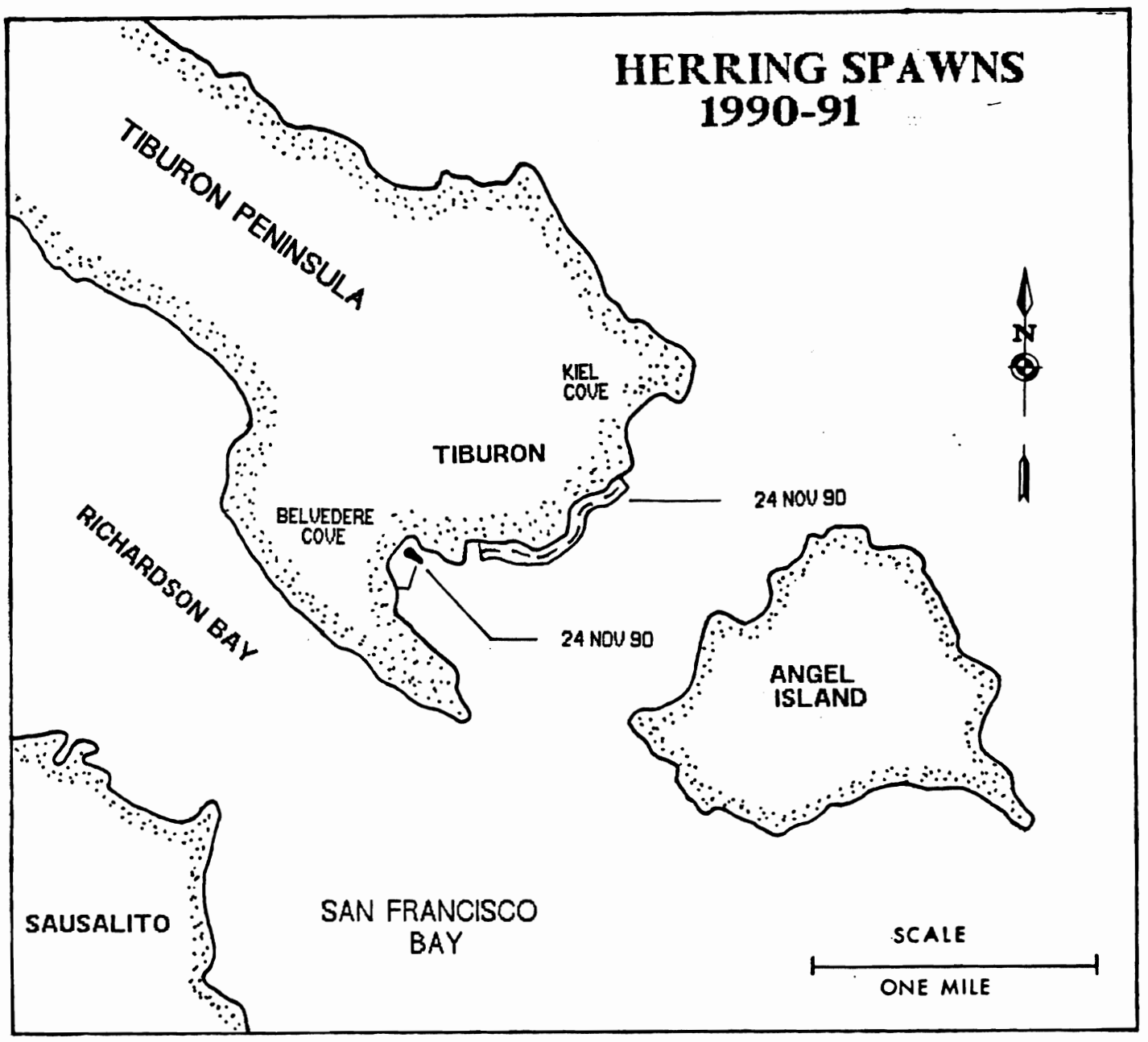

FIGURE 6. Herring spawns and starting dates in the north part of San Francisco Bay during the 1990-91 season.

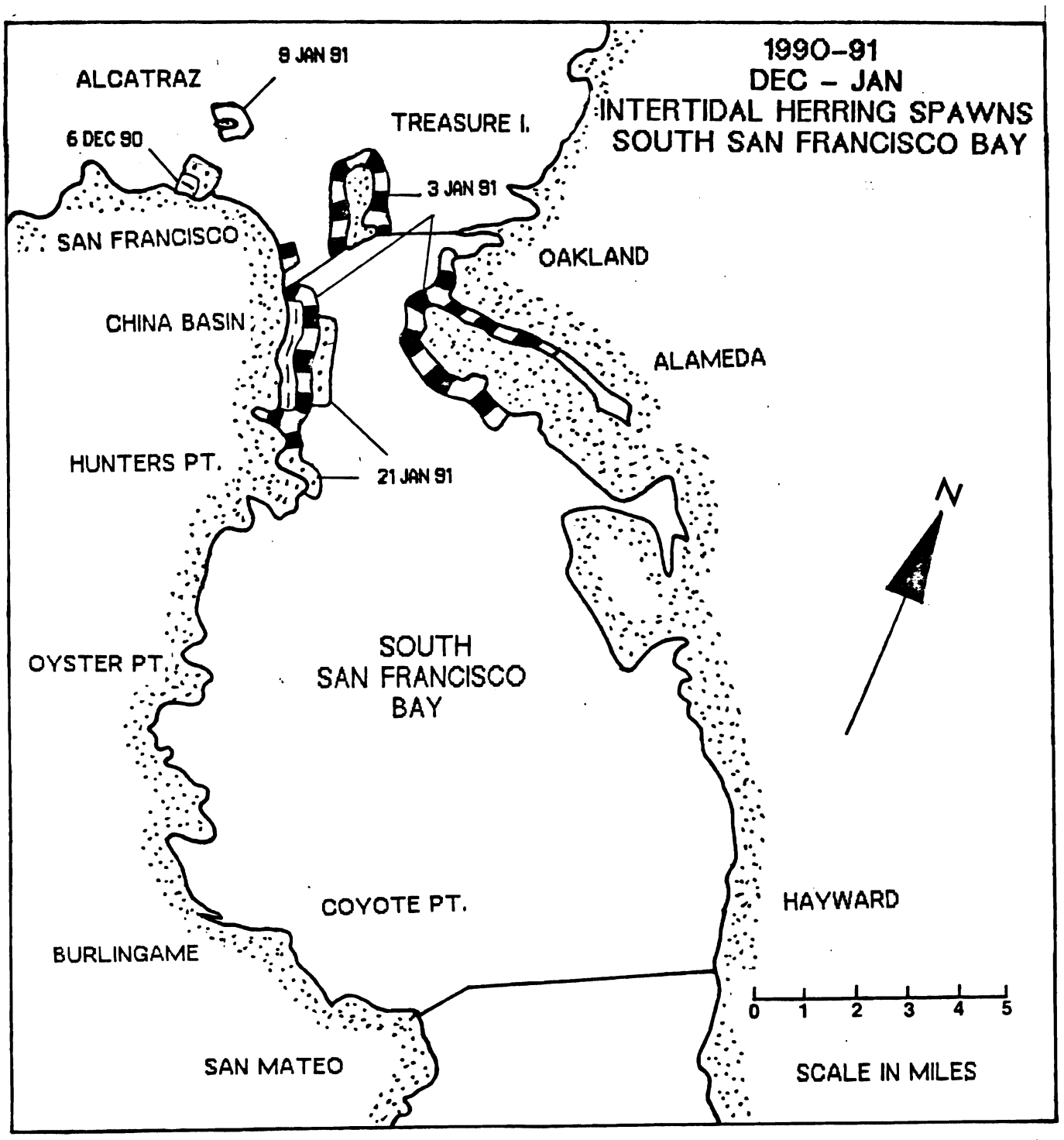

FIGURE 7a. South San Francisco Bay intertidal herring spawns and spawn starting dates during December 1990 and January 1991.

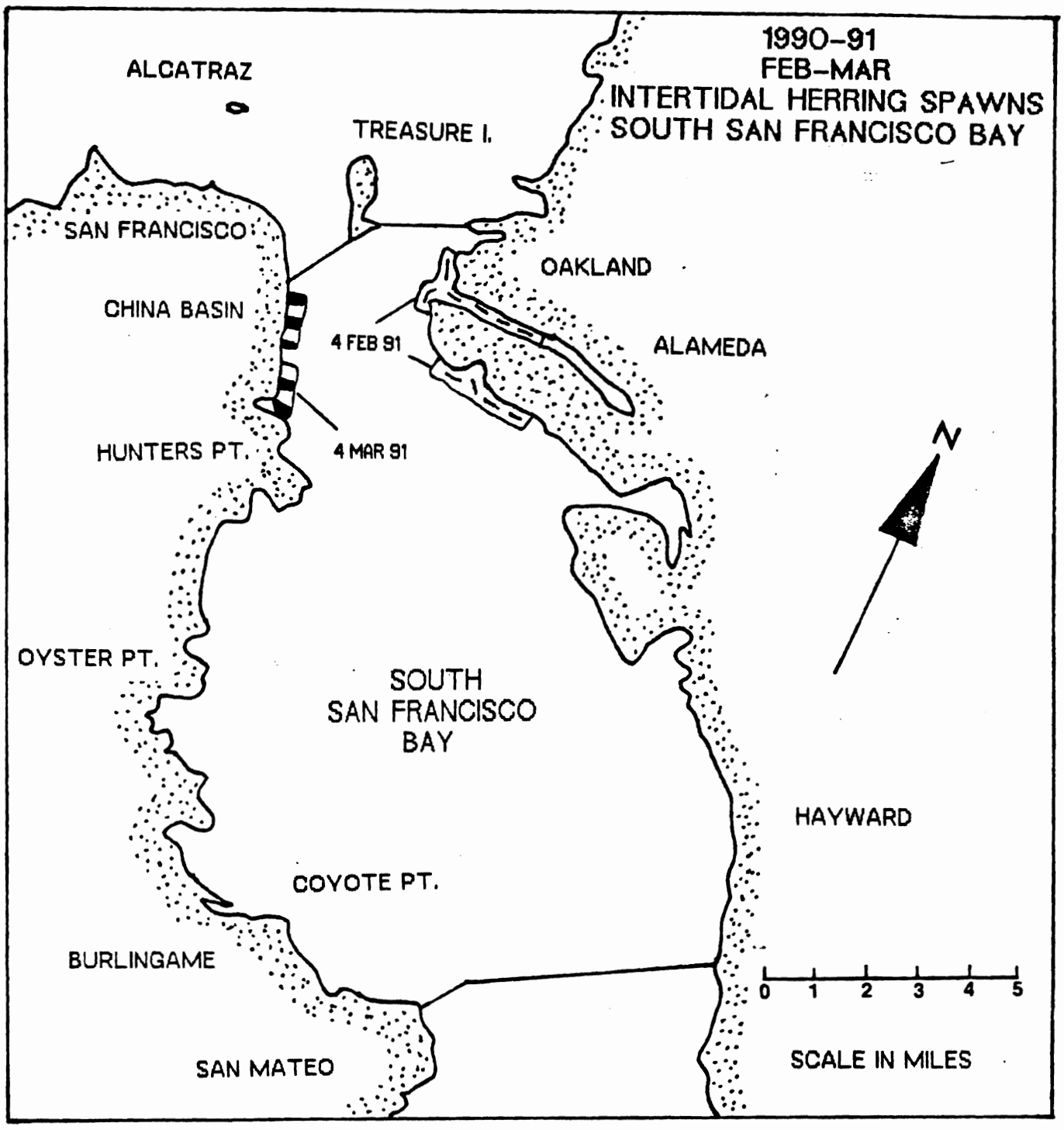

FIGURE 7b. South San Francisco Bay intertidal herring spawns and spawn starting dates during February, and March 1991.

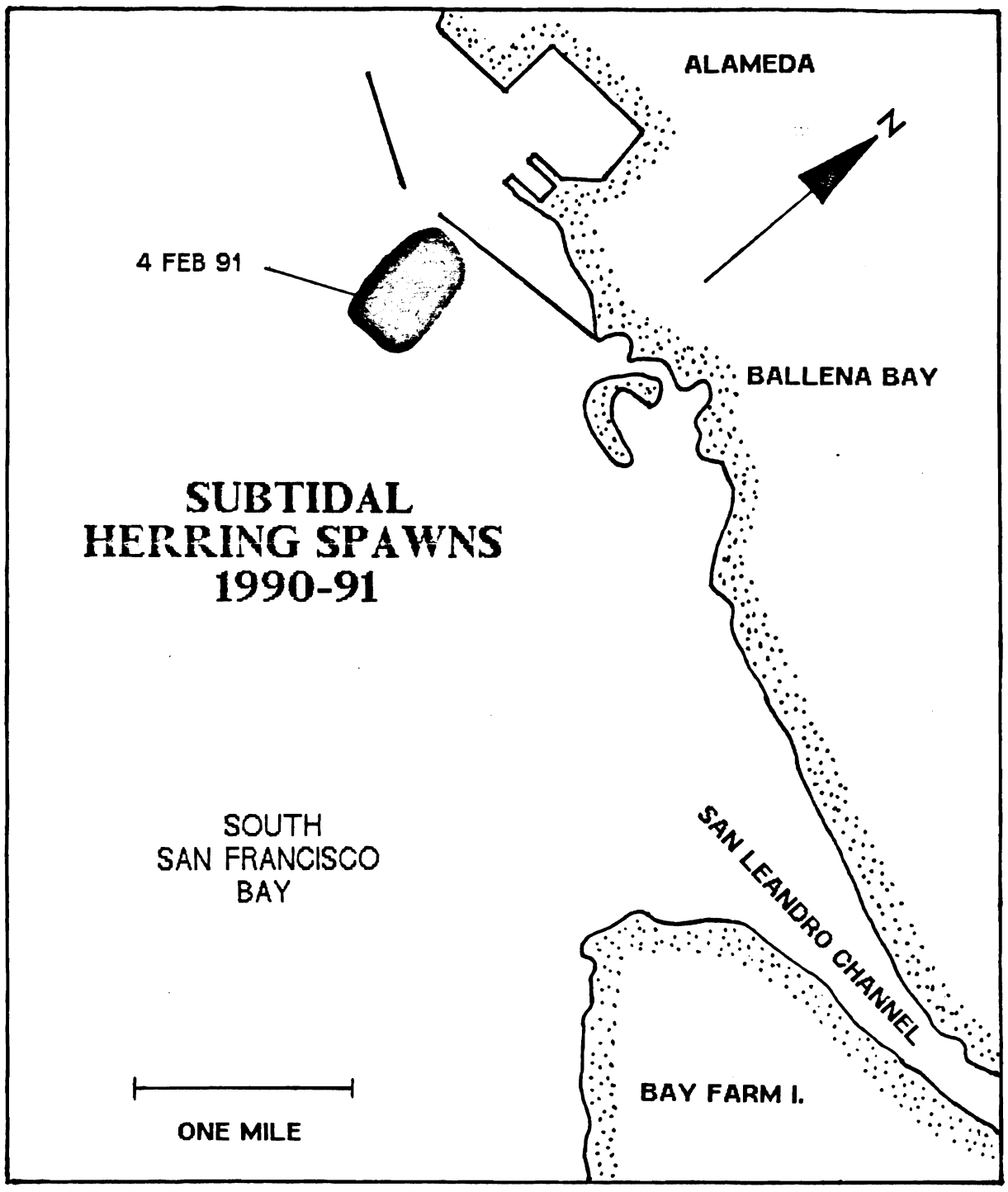

FIGURE 8. Subtidal herring spawns and spawn starting dates in South San Francisco Bay during the 1990-91 season.