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BIOMASS ESTIMATES OF PACIFIC HERRING, *CLUPEA PALLASI*, IN CALIFORNIA FROM THE 1991-92 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 41,000 tons this season. This was the second consecutive year that the San Francisco Bay herring population estimate has declined.

In Tomales Bay, the 1991-92 season spawning biomass estimate, including the catch of 24 tons from Bodega Bay, was 1,238 tons. This was the third consecutive season that the Tomales-Bodega area herring population has increased.

The 1991-92 Humboldt Bay herring spawning biomass estimate of 225 tons, was nearly half of last season's estimate of 400 tons.

December and January were the peak months of spawning activity in all areas surveyed.

In San Francisco Bay, the first major spawn since the 1981-82 season occurred in the Sausalito area, and the Oakland-Alameda area accounted for 50% of all spawning activity.

A total of 3.5 million m^2 of eelgrass, *Zostera marina*, was measured in Tomales Bay this season. The eelgrass density declined in most beds this season.

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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 1991-92 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 surveyed portion of the bay covered 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. Herring also spawn intertidally and subtidally on other suitable substrates including bare rocks, sand, and pier pilings.

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 eelgrass, 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, 129 km (80 mi) 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 1991-92 spawning-ground surveys were confined to the northern part of Humboldt Bay (Figure 3).

METHODS

Tomales Bay Sampling Techniques

Spawning-ground surveys were conducted from November 26, 1991 to March 31, 1992. The frequency of surveys was changed from daily to a minimum of 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 (kg/m^2) of eelgrass for beds with 100% bottom cover was estimated using a multiple linear regression between density and eelgrass blade measurements (Spratt, 1989). Estimated eelgrass densities had to be adjusted downward if bottom coverage was less than 100%. The multiple regression model is represented by the following equation:

$$Y = a_1(\text{length}) + a_w(\text{width}) + B$$

where:

Y = kg eelgrass per m^2

a_1 = slope of regression for length variable

a_w = slope of regression for width variable

B = Y intercept

During December, January, and February eelgrass blade length and width measurements were taken from eelgrass samples collected from the project's boat with a vegetation sampler. Between 6 and 48 sets of eelgrass blade lengths and widths were collected from 30 of the 37 eelgrass beds in the bay. The 1991-92 eelgrass density values were computed by substituting these eelgrass data in the regression formula.

The area (m^2) of 15 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

Spawning-ground surveys were conducted in San Francisco Bay from November 15, 1991 to March 6, 1992. The project was fully staffed this season and regular daily surveys (Mon.-Fri.) were re-instituted. 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 prespawning SCUBA surveys were used. Vegetation densities were determined by collecting samples with SCUBA from 1/4 m^2 quadrats from permanent stations at Kiel Cove, Angel Island, Oakland, and Alameda (Figure 4 and 5). Belvedere Cove and Brooks Island stations were eliminated this season due to lack of spawning activity in those areas.

In areas of hard bottom or shell beds, the rake was effective in picking up pieces of shell or clusters of eggs. In these cases, the layers of eggs deposited were recorded (1 layer of eggs = 750,000 $eggs/m^2$).

Humboldt Bay Sampling Techniques

The techniques used to sample herring spawns in Humboldt Bay eelgrass beds were similar to those used in Tomales Bay. Densities for eelgrass beds 1 through 7 in north Humboldt Bay (Figure 3) were determined on November 4, 1991, by measuring eelgrass blade lengths and widths and substituting them in the regression equation developed for Tomales Bay eelgrass. However, most of the eelgrass beds in north Humboldt Bay were sparse and density estimates from regression were reduced by the percent bottom coverage of eelgrass in each bed.

Weather permitting, weekly spawning-ground surveys were conducted. The project also had available the voluntary assistance of Ken Bates, a local herring fisherman, who notified us of the time and place of spawning activity that he noted. He made daily trips across the Bay to hydroacoustically assess herring school movement. When Mr. Bates reported a suspected herring spawn, or project personnel found evidence of spawning, a spawn survey was conducted. 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 (K. Oda, pers. comm). 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 1991-92 biomass estimates.

In Tomales Bay and Humboldt Bay when sex ratio data was not available 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 estimates for a given spawning event, the estimates were averaged. If one method encountered a survey problem (weather, equipment failure, or unable to sample adequately etc.), estimates from the other method was used. Because both surveys have strengths and weaknesses, a merged biomass estimate emphasizes the strengths of both methods. This procedure reduces a conservative bias and probably more accurately reflects the actual spawning biomass.

RESULTS

Tomales Bay

There were 37 eelgrass beds in Tomales Bay (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. About 40% of the eelgrass beds were remeasured this season (Table 1). Most of those eelgrass beds decreased in area (Table 2). Eelgrass beds that were not remeasured appeared to cover about the same area 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).

We estimated eelgrass density for the 1991-92 season using eelgrass data that were collected between December and February and substituted in the regression formula:

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

Estimated eelgrass density estimates in Tomales Bay are generally not adjusted for percent bottom coverage, because most beds have 100 % bottom coverage. The computed eelgrass density for each bed (Table 3) was compared with density estimates from the previous season. The vegetation density declined in most beds, and the majority of herring spawning occurred in eelgrass beds that decreased in density. In addition no Gracilaria sp. was found in beds 28B or 29 (Figure 1).

Spawning Biomass

There were six distinct periods of spawning activity this season, the most in four years. Spawning also began earlier than usual, with a small spawn occurring about November 22, 1991 in vegetation bed 1A (Figure 1 and Table 4). The first significant spawning occurred December 19, 1991 at bed 28 and 28A.

The largest spawn this season on January 16-18, 1992 covered several vegetation beds (28, 28A, 1, 1A, 1B, 1C, and 2), and included an intertidal spawn near Marconi Cove (Figure 1 and Table 4). Another large spawn also occurred on February 6, 1992 at bed 1A.

On February 14, a series of light spawns began that covered 12 vegetation beds. Spawning began in bed 28A and progressed toward the mouth of the bay ending at bed 11 on February 17, 1992. The season's last spawn occurred on March 15, 1992 at bed 3.

This season's spawning escapement estimate for Tomales Bay was 1,214 tons (Table 4). Tomales Bay has been closed to fishing for the past two seasons, therefore spawning escapement equals spawning biomass (Table 5).

No hydroacoustic surveys were attempted in Bodega Bay this season. When weather permitted, hydroacoustic monitoring in outer Bodega Bay indicated the presence of large schools of fish.

However, samples of the herring catch from this area contained a significant bycatch of white croaker, Genyonemus lineatus, and Pacific tomcod, Microgadus proximus. Without midwater trawl sampling, it was not possible to distinguish herring from the other two species, and hydroacoustic estimates could not be made. Consequently, only the 24 tons of herring caught from Bodega Bay were included in the 1991-92 herring biomass estimate for the Tomales/Bodega area.

Herring spawning biomass has increased in Tomales Bay for the third consecutive season, and the 1991-92 season's spawning biomass estimate for the Tomales/Bodega Bay area was 1,238 tons of herring (Table 6).

San Francisco Bay

Vegetation Density Estimates

Quantitative samples of subtidal vegetation were collected by Department divers on November 7, 1991. Subtidal vegetation increased 57% at Kiel Cove, but decreased 30% at Angel Island (Figure 4), when compared to 1990 densities (Spratt 1991). Vegetation densities at stations in south San Fran-cisco Bay also varied. Densities increased over 200% near Ballena Bay and 300% near Bay Farm Island, but decreased 24% at the north end of Bay Farm Island (Figure 5). Even with these increases, vegetation densities in San Francisco Bay are low compared to Humboldt and Tomales Bays.

Spawning Biomass

There were at least nine spawning runs this season. This is the second consecutive season that spawning was reported to have occurred in San Pablo Bay, which is outside our regular survey area.

The first spawn of the season (3 tons) occurred on November 13, 1991 at Belvedere Cove (Table 7, Figure 6). On January 2-5, 1992, an estimated 6,280 tons of herring spawned along the Sausalito shoreline. This was the largest herring spawn in this area since the 1981-82 season.

The largest spawn of the season, over 16,000 tons, occurred in the Oakland-Alameda area. For the first time, this area accounted for about 50% of a season's spawning escapement (Table 7, Figure 7a and 7b). The San Francisco Bay waterfront, which has been the Bay's major spawning area for the past nine seasons, accounted for only 30% of this season's spawn escapement.

Subtidal spawning was found in Belvedere Cove on Ulva sp. and in Richardson Bay on Gracilaria sp. and eelgrass (Table 7 and Figure 6). Subtidal herring eggs were also found on January 20, 1992 by dragging our vegetation sampler in about 12m (40 ft) of water off San Francisco's Pier 50, in an area where herring gillnetters had been fishing. Eggs were deposited on tube worm cases (polycheat hydroids). No quantitative samples could be collected.

The 1991-92 season spawn escapement estimate was 33,603 tons of herring (Table 7). Including the catch of 7,417 tons of prespawning herring from the roe fishery, the spawning biomass estimate for the 1991-92 season was 41,020 tons (Table 8).

The San Francisco Bay population estimate from spawning-ground surveys peaked in 1989-90 at 71,000 tons (Spratt 1990), but has declined the past two seasons to the lowest point in nine years.

Combined Acoustical and Spawn Survey Biomass Estimate

Both hydroacoustic surveys (prespawning) and spawning-ground surveys (post spawning) failed to adequately assess biomass at times during the season. A major herring school of over 6,000 tons, which spawned at Sausalito in early January, was not detected acoustically. Another herring school found by acoustical surveys in mid February is believed to have spawned undetected in San Pablo Bay. In both of these cases, one survey method compensated for a weakness in the other.

For the first time, both survey methods failed at the same time. A deepwater spawning off Pier 50 in San Francisco on January 12, 1992 could not be quantified by spawning-ground survey methods. The catch of 3,100 tons of herring from this school was 73% of the 4,250 ton hydroacoustical estimate; implying that 73% of the herring were caught. This is an unlikely scenario, it is probable that additional herring entered the bay and joined this school just prior to spawning, as commonly occurs; and, that the amount of herring that actually spawned during January 12-14 was more than 4,250 tons. This estimate was adjusted based on the catch to spawning biomass ratios for all prior spawns in the 5,000 to 10,000 ton range in which both roundhaul and gillnet boats were active. The highest catch to spawn ratio was 38%. Therefore, the 3,100 tons catch from the

January 12-14 spawn was expanded by a factor of 2.63 (100/38) to 8,000 tons. Although the 8,000 ton estimate cannot be verified, we consider this estimate better than the results of either survey method.

The limitations of both survey methods were evident this season; but, the compensatory nature of both surveys was also evident, which provides strong support for continuing both spawning-ground and hydroacoustic surveys.

Merging both survey estimates for the season produced a combined 1991-92 season biomass estimate of 46,600 tons, a 9% decline from the 1990-91 combined estimate of 51,000 tons. The 1992-93 San Francisco Bay herring quotas will be based on a biomass estimate of 46,600 tons.

Humboldt Bay

Vegetation Density Estimates

Eelgrass density was estimated for bed numbers 1 through 7 (Figure 3), where herring were expected to spawn. The multiple regression formula developed to estimate eelgrass density in Tomales Bay (Spratt 1989) was also used to estimate eelgrass density in Humboldt Bay. However, the Tomales Bay regression formula assumes 100 % bottom coverage in eelgrass beds. In Humboldt Bay eelgrass density estimates from regression were reduced by the percent bottom coverage in each bed. Densities ranged from 0.75 kg/m^2 at bed number 4 to 1.4 kg/m^2 at bed number 2.

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, the highest densities were found in the southern part of Humboldt Bay.

Spawning Biomass

A large school of herring entered Humboldt Bay about January 1, 1992 and spawning had not occurred through January 22, 1992. Field surveys conducted on January 24, 1992 found spawn at eelgrass bed number 1 (Figure 3). The estimated spawning escapement was 77 tons (Table 9).

Another spawn took place on January 28 and 29, 1992, but adverse weather conditions necessitated postponing the survey until February 7, 1992. Spawn was found on eelgrass beds no. 1, 3, 4, 5, and 7 (Figure 3). However, many of the eggs had hatched by the time the survey was completed, and the biomass estimate of 85 tons (Table 9) should be considered a minimum estimate. The 1991-92 spawning biomass including the catch of 62 tons was 225 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). Some spawning sites were stratified into areas of similar egg density, because of a wide range in egg density within the spawning site. The confidence intervals were calculated for each spawn site or strata individually. The 95% confidence intervals for 1991-92 season (Table 10) were broad for most sites due to the very light and patchy distribution of spawn.

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. Six of this season's spawning sites (92% of biomass) had 95% confidence intervals ranging between 13% and 37% of the estimate (Table 11).

Confidence limits for the season's smaller spawns were generally broad due to difficulty in obtaining samples. In addition spawn deposition ranged from very light to heavy, resulting in high between-sample variance.

Humboldt Bay

Confidence limits of herring spawn estimates for Humboldt Bay were calculated for each spawn site from variation in egg density. Confidence limits were broad due to the wide range of spawn density which increased between-sample variance (Table 12). Increased sampling levels will improve confidence limits.

DISCUSSION

Tomales Bay and Bodega Bay

Spawning escapement estimates in Tomales Bay have increased each of the past three seasons (Table 5). The bay has been closed to herring fishing during this time, and the increase in biomass estimates could be linked to reduced fishing pressure.

The recovery of the Tomales Bay herring spawning stock will be dependent either on rebuilding the remaining population or on environmental conditions which favor attracting herring to Tomales Bay. We assumed that the reduced spawning biomass in Tomales Bay was attributed to drought related reduced freshwater inflow. Although the California drought has not officially ended, this winter's rainfall was near normal.

The timing of spawning events in Tomales Bay this season was related to rainfall and reduced salinity. About 74% of this season's spawning activity occurred in January when rainfall lowered the salinity to <25 ppt in the central and upper bay. In addition, February spawning took place in areas influenced by run-off from Walker Creek (Figure 1); these areas have not been used by herring since the 1985-86 season. However, the bulk of the season's rainfall was in February and March, without any significant spawning.

Herring biomass estimates in Bodega Bay have been difficult to obtain due to open ocean conditions which have limited our ability to conduct acoustical and spawn escapement surveys. Conducting acoustical surveys from small vessels when weather conditions permit has proven to be difficult. The high incidence of bycatch in the Bodega Bay herring catch points to the need for coincident midwater trawling to determine species composition of schools detected acoustically. It is doubtful that acoustical surveys will be effective in Bodega Bay, except on rare occasions when good weather and pure concentrations of herring coincide. Intermittent surveys will not be adequate to estimate total biomass or manage the herring fishery.

The age composition of the Bodega Bay fishery indicates a stable healthy stock (Spratt and Moore 1992). However, the relatively small Bodega Bay herring quota of 200 tons has not been taken during the past three seasons, suggesting that the biomass is either relatively small or of limited availability. Weather was a key factor this past season, and sea conditions were unsafe for fishing during a large part of the season.

The relationship between herring caught in Bodega Bay and herring that spawn in Tomales Bay remains unknown. The probability remains that herring caught in Bodega Bay may be bound for the spawning grounds in Tomales Bay.

Spawning by Area 1973 to 1992

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 four years. Most spawning now occurs in the upper part of the bay (Table 13 and 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.

This season some minor spawning occurred in eelgrass beds closer to the mouth of the bay, in an area influenced by runoff from Walker Creek (Table 13 and Figure 1).

San Francisco Bay

The San Francisco Bay herring population biomass estimate has declined significantly over the past three years (Table 8). This decline is attributed to unfavorable oceanic conditions during 1990 and very poor recruitment of the 1990 year class into the 1991-92 spawning population.

Environmental conditions during 1992 were again unfavorable with above normal ocean temperatures and below normal upwelling of nutrient rich sea water. If the 1992 oceanographic conditions remain unfavorable for herring, the San Francisco population may decline further by the 1992-93 season.

Spawning Escapement by Area 1973 to 1992

Spawning-ground surveys have been conducted in San Francisco Bay for 19 seasons. During this time, the distribution of herring spawning in the bay has changed from Richardson Bay, Sausalito, and Richmond to the San Francisco Bay waterfront and the Oakland-Alameda area (Table 14). During the past three seasons spawning has increased in the vicinity of Oakland-Alameda, and for the first time it was the major spawning area.

Humboldt Bay

In the 1990-91 season, herring spawning biomass in Humboldt Bay was estimated to be 400 tons; this was the first herring population estimate for Humboldt Bay in 15 years. The 1991-92 season herring biomass estimate was 225 tons or about half the 1990-91 estimate. However, we suspect that more spawning occurred than our surveys detected in both seasons, and due to broad confidence limits of the biomass estimates these data should be used cautiously.

CONCLUSION

Tomales Bay

The Tomales Bay herring fishery has been closed since 1989-90 because of low spawning escapement. However, while the Tomales Bay closure was in effect a 200 ton herring quota was allowed in Bodega Bay. During the three-year closure, spawning escapement in Tomales Bay increased to over 1,200 tons. However, the biomass is still well below the long-term mean of 5,000 to 6,000 tons present prior to the depressed state.

The Department has proposed a herring quota reduction for the Tomales/Bodega Bay herring fishery from 200 tons to 120 tons for the 1992-93 season. The quota was set at 10% of estimated spawn escapement in Tomales Bay. The low harvest level (10%) was selected for two reasons. First, the Tomales Bay stock is still depressed, although some recovery has been documented. Second, the ultimate effect of the 1992 El Nino on herring is unknown, but, some detrimental effects are expected.

The Tomales/Bodega Bay herring quota should be set no higher than 10% of the previous season's biomass until the population recovers to at least 2,000 tons.

San Francisco Bay

The San Francisco Bay herring population has declined over the past two years. This season's combined spawn escapement and hydroacoustic biomass estimate of 46,600 tons is below the 10 year population mean of 60,000 tons. Consequently, the herring quotas will be further reduced next season. The prospects of another El Nino coupled with a weak 1990 year class occurring when the population is already depressed are not encouraging.

Humboldt Bay

Over the past two seasons, 1990-91 and 1991-92, the Humboldt Bay herring spawning biomass has averaged over 300 tons, and appears large enough to support the existing small fishery.

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TABLE 1. Tomales Bay Eelgrass Bed Measurements, 1991-92 Season.

Bed number	Area m^2	Season last surveyed	Bed number	Area m^2	Season last surveyed
1	6,100		12	1,700	1989-90
1A	31,000		13	0	
1B	14,000		14	700	1989-90
1C	1,100		15	0	1989-90
2	8,700		16	4,500	1990-91
2A	0		16A	7,800	1989-90
3	3,100		17	2,000	1989-90
3A	0		18	0	1989-90
4	0		19	38,000	1989-90
5	4,200		20	135,500	1989-90
6	4,400		20A	33,400	1989-90
7	6,200		21	1,488,000	1990-91
8	4,700		22	140,000	1990-91
9 North	9,750		23	1,209,000	1990-91
9 South	17,900	1988-89	24	45,500	1989-90
10	1,500	1990-91	25	102,000	1989-90
10A	330		26	120,000	1989-90
11 North	10,500	1990-91	27	27,800	1990-91
11 Middle	3,800	1990-91	28	42,000	
11 South	1,300		28A	13,000	

Total area = 3,539,480 m^2

TABLE 2. Comparison of Tomales Bay Eelgrass Bed Measurements.

Eelgrass bed no.	Area m^2 1990-1991	Area m^2 1991-1992	Percent Change
1	5,000	6,100	+ 22
1A	43,400	31,000	- 29
1B	5,400	14,000	+ 159
1C	2,700	1,100	- 59
2	9,500	8,700	- 8
2A	0	--	--
3	4,300	3,100	- 28
3A	0	0	0
4	2,500	0	- 100
5	6,500	4,200	- 35
6	8,300	4,400	- 47
7	9,500	6,200	- 35
8	4,000	4,700	+ 18
9 North	14,400	9,750	- 32
9 South	17,900	--	--
10	1,500	--	--
10A	3,000	330	- 89
11 North	10,500	--	--
11 Middle	3,800	--	--
11 South	1,750	1,300	- 26
12	1,700	--	--
13	0	0	0
14	700	--	--
15	0	--	--
16	4,500	--	--
16A	7,800	--	--
17	2,000	--	--
18	0	0	0
19	38,000	--	--
20	135,000	--	--
20A	33,000	--	--
21	1,488,000	--	--
22	140,000	--	--
23	1,209,000	--	--
24	45,500	--	--
25	102,000	--	--
26	120,000	--	--
27	27,800	--	--
28	65,000	42,000	- 35
28A	5,900	13,000	+ 120

TABLE 3. Eelgrass Density Estimates (kg/m^2) for Most Tomales Bay Eelgrass Beds, Calculated from Multiple Regression.

Bed no.	89-90 Density	90-91 Density	91-92 Density	Percent Change 90-91 vs. 91-92
1	1.67	.88	1.39	+ 58
1A	1.44	1.99	1.85	- 7
1B	2.03	2.10	1.94	- 8
1C	1.41	1.61	1.24	- 23
2	1.61	1.46	1.63	+ 12
3	1.23	1.11	0.93	- 16
3A	no data	0.77	no data	--
4	0.93	1.22	no data	--
5	1.24	0.69	0.34	- 51
6	1.04	1.08	0.60	- 44
7	1.24	1.13	1.17	+ 4
8	1.33	no data	0.48	--
9S	1.46	0.83	0.72	- 13
9N	1.18	0.83	0.92	+ 11
10	2.06	1.45	1.09	- 25
10A	no data	0.94	1.19	+ 27
11	1.19	1.07	0.95	- 11
12	1.16	no data	1.03	--
13	no data	"	no data	--
14	0.68	"	0.47	--
15	no data	"	0.44	--
16	1.76	1.09	no data	--
16A	2.03	no data	0.83	--
17	1.59	1.17	2.16	+ 85
18	0	no data	no data	--
19	1.79	"	"	--
20	1.14	0.42	"	--
20A	0.86	0.43	"	--
21	2.78	0.96	1.18	+ 23
22	1.98	1.99	2.08	+ 5
23	1.75	0.98	1.35	+ 38
24	1.28	1.83	1.86	+ 2
25	1.55	no data	0.14	--
26	1.47	0.63	0.30	- 52
27	1.11	2.07	0.72	- 65
28	1.35	1.91	1.09	- 43
28A	1.83	2.08	1.17	- 44

TABLE 4. Tomales Bay Herring Spawn Data, 1991-92 season.

Date	Location*	Area m^2	Eggs per m^2	Millions of eggs	Conversion factor X 10^{-8}	Tons
22 Nov 91	1A	4,000	6,800	27	1.20	T
19 Dec 91	28	41,800	260,500	10,900	1.07	120
19 Dec 91	28A	12,900	198,000	2,640	1.07	30
16 Jan 92	28	41,800	940,000	39,300	.97	380
16 Jan 92	28A	11,700	356,300	4,160	.97	40
18 Jan 92	**	16,900	900,000	15,200	.97	150
18 Jan 92	1A	30,800	656,400	20,220	.97	200
18 Jan 92	1B	3,000	330,300	990	.97	10
18 Jan 92	1	6,100	1,124,500	6,860	.97	70
18 Jan 92	1C	1,100	1,297,500	1,430	.97	15
18 Jan 92	2	8,700	286,900	2,500	.97	25
6 Feb 92	1A	30,800	522,500	16,090	.97	160
14 Feb 92	28A	7,000	27,000	189	.97	2
15 Feb 92	1B	1,700	70,100	119	.97	1
16 Feb 92	1C	1,100	3,000	3	.97	T
16 Feb 92	2	4,000	206,200	825	.97	8
16 Feb 92	25					T
17 Feb 92	5	4,200	6,000	25	.97	T
17 Feb 92	6	4,400	11,600	51	.97	T
17 Feb 92	7	6,200	19,000	117	.97	1
17 Feb 92	8	4,700	800	3	.97	T
17 Feb 92	9	17,900	1,200	22	.97	T
17 Feb 92	10A	330	5,800	2	.97	T
17 Feb 92	11	1,500	3,300	5	.97	T
15 Mar 92	3	3,000	59,400	180	.88	2
Total		265,630		121,858		1,214

* See Figure 1.

** Intertidal spawn from Reynolds to past Marconi Cove.

TABLE 5. Tomales Bay Herring Biomass Estimates 1973-74 Through 1991-92 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
1991-92	1,214	--	1,214

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

TABLE 6. Tomales/Bodega Bay Area Herring Biomass Estimates. 1/

Season	Tomales Bay	Bodega Bay	2/ Catch in tons	Total tons
1988-89	167	NO SURVEY	213	380
1989-90	345	350	95	790
1990-91	779	NO SURVEY	95	874
1991-92	1,214	NO SURVEY	24	1,238

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 7. San Francisco Bay Herring Spawn Data, 1991-92 season.

Date	Location	Area m^2	Eggs per m^2	Millions of eggs	Conversion factor X 10^{-8}	Tons
11/13/91	Belvedere Cove	6,300	28,000	176	1.5	3
12/1-4/91	San Francisco	115,000	1,560,000	179,400	1.2	2,200
12/12-14/91	San Francisco	210,000	1,600,000	336,000	1.07	3,600
12/27-30/91	Oakland-Alameda	350,000	4,615,000	1,615,250	1.02	16,500
1/2-4/92	San Francisco	35,000	2,220,000	77,700	"	800
1/2-5/92	Sausalito	165,000	3,700,000	610,500	"	6,200
1/2-5/92	Sausalito	7,000	1,100,000	7,700	"	80
1/4-5/92	Richardson Bay	320,000	150,000	48,000	"	500
1/12-14/92	San Francisco	50,000	1,300,000	65,000	1.03	700
2/2-4/92	Oakland	10,000	2,150,000	21,500	"	220
2/4-5/92	San Francisco	63,000	2,000,000	126,000	"	1,300
2/23-25/92	San Francisco	71,000	1,800,000	127,800	1.21	1,500
Total		1,402,300		3,215,026		33,603

TABLE 8. San Francisco Bay Herring Biomass Estimates from Spawning-Ground Surveys, 1973-74 Through 1991-92 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
1991-92	33,603	7,417	41,020

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

**Includes hydroacoustical estimates totaling 7,800 tons.

TABLE 9. 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
22-23 Jan 92	1a	100,000	1,600	160	.97	2
22-23 Jan 92	1b	451,000	17,000	7,600	"	75
28-29 Jan 92	1a	268,000	2,600	700	"	7
28-29 Jan 92	1b	669,000	2,800	1,900	"	19
28-29 Jan 92	3	125,000	2,400	300	"	3
28-29 Jan 92	4	151,000	7,500	1,100	"	10
28-29 Jan 92	5	920,000	4,900	4,500	"	45
28-29 Jan 92	7	67,000	2,600	170	"	2
Total		2,751,000		16,430		163

* See Figure 3.

TABLE 10. Confidence Limits of the Tomales Bay Herring Spawn Estimates During the 1991-92 Season.

Spawn date	Location	S. E. eggs per m	D. F. N-1	Estimated tons	95% Conf.int.
11/22	1A	--	0	T	--
12/19	28	117,231	6	120	±480
12/19	28A*	102,087	2	26	±3
	28A	423,424	1	4	±6
1/16	28*	262,292	2	22	±45
	28	1,353,006	3	347	±540
	28	37,475	1	11	±30
1/16	28A	237,618	2	40	±70
1/18	**	97,949	3	150	±25
1/18	1	418,782	3	70	±40
1/18	1A	781,498	4	200	±300
1/18	1B	222,896	1	10	±60
1/18	1C	533,763	2	15	±14
1/18	2	234,046	5	25	±20
2/6	1A	299,550	11	160	±60
2/14	28A	36,174	2	2	±6
2/14	1B	134,074	2	1	±2
2/16	1C	--	0	T	--
2/16	2	239,663	5	8	±10
2/16	25	--	0	T	--
2/17	5	--	0	T	--
2/17	6	--	0	T	--
2/17	7	--	0	1	--
2/17	8	--	0	T	--
2/17	9	--	0	T	--
2/17	10A	--	0	T	--
2/17	11	--	0	T	--
3/15	3	67,818	3	2	±2
	Total			1,214	

* Partitioned into sub-areas of similar egg density.
** Intertidal spawn near Marconi Cove, not on eelgrass.

TABLE 11. Confidence Limits of the San Francisco Bay Herring Spawn Estimates During the 1991-92 Season.

Spawn starting date	Location	S. E. eggs per m	D. F. N-1	Estimated tons	95% Conf. int.
11/13	Belvedere Cove	16,300	2	3	±6
12/1	San Francisco	248,000	10	2,200	±750
12/12	San Francisco	220,000	11	3,600	±1,100
12/27	Oakland-Alameda	293,000	15	16,500	±2,200
1/2	San Francisco	160,000	3	800	±200
1/2	Sausalito	180,000	3	6,200	±1,000
1/2	Sausalito	433,000	1	80	±400
1/4	Richardson Bay	72,000	2	500	±1,000
1/12	San Francisco	383,000	4	700	±550
2/2	Oakland	686,000	4	220	±200
2/4	San Francisco	428,000	7	1,300	±650
2/23	San Francisco	166,000	8	1,500	±300
	Total			33,603	

TABLE 12. Confidence Limits of the Humboldt Bay Herring Spawn Estimates During the 1991-92 Season.

Spawn date	Location *	S. E. eggs per m	D. F. N-1	Estimated tons	95% Conf.int.
1/22	1a	204	2	2	±1.5
1/22	1b	5,245	2	75	±100
1/22	1a	320	3	7	±2
1/22	1b	600	4	20	±11
1/28	3	400	2	3	±2
1/28	4	--	0	11	--
1/28	5	850	3	43	±24
1/28	7	--	0	3	--
	Total			163	

* See Figure 3.

TABLE 13. Average Herring Spawning Escapement by Area for Tomales Bay, Expressed as % of Season Total.

Vegetation bed no.	Season 1983-84 to 1987-88	1988-89 to 1990-91	1991-92
1	0.98	1.17	5.5
1A	7.69	8.20	29.2
1B	0.50	0.47	0.9
1C	--	--	1.3
2	4.05	--	2.8
2A	0.29	--	--
3	0.62	--	0.2
3A	0.15	--	--
4	--	--	--
5	1.63	--	0.02
6	2.96	--	0.04
7	1.95	--	0.1
8	3.54	--	--
9	4.49	--	0.02
10	--	--	--
10A	--	--	--
11	2.96	--	--
12	0.06	--	--
13	--	--	--
14	0.06	--	--
15	--	--	--
16	0.20	--	--
16A	1.24	--	--
17	--	--	--
18	--	--	--
19	--	--	--
20	1.92	--	--
20A	--	--	--
21	15.97	--	--
22	24.10	--	--
23	3.84	--	--
24	--	--	--
25	6.86	--	--
26	5.17	--	--
27	2.99	--	--
28	--	47.54	41.5
28A	2.13	21.08	6.0
28B	--	20.14	--
29	0.59	--	--
Intertidal	2.96	1.40	12.5-
Total	100.00	100.00	100.00
Tons average escapement *	3,382	427	1,214

* No spawn surveys were conducted in 1978-79 or 1985-86.

TABLE 14. 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	- -
Alcatraz	0.0	- -
Total	100.0	34,536

1982-83 to 1991-92		
Spawning area	Average % of seasonal biomass	Average escapement (tons)
San Francisco	59.2	27,629
Oakland-Alameda	13.8	6,434
Sausalito	9.3	4,359
Belvedere-Tiburon	3.5	1,650
Angel Island	3.4	1,575
Treasure Island	3.4	1,575
South Bay	2.4	1,132
Tiburon	2.2	1,003
Belvedere Cove	0.8	389
Kiel Cove	0.7	343
Richardson Bay	0.5	232
Richmond	0.4	167
Belvedere	0.2	92
Alcatraz	0.1	62
Coyote Point	<0.1	19
Berkeley	0.0	- -
Total	100.0	46,660

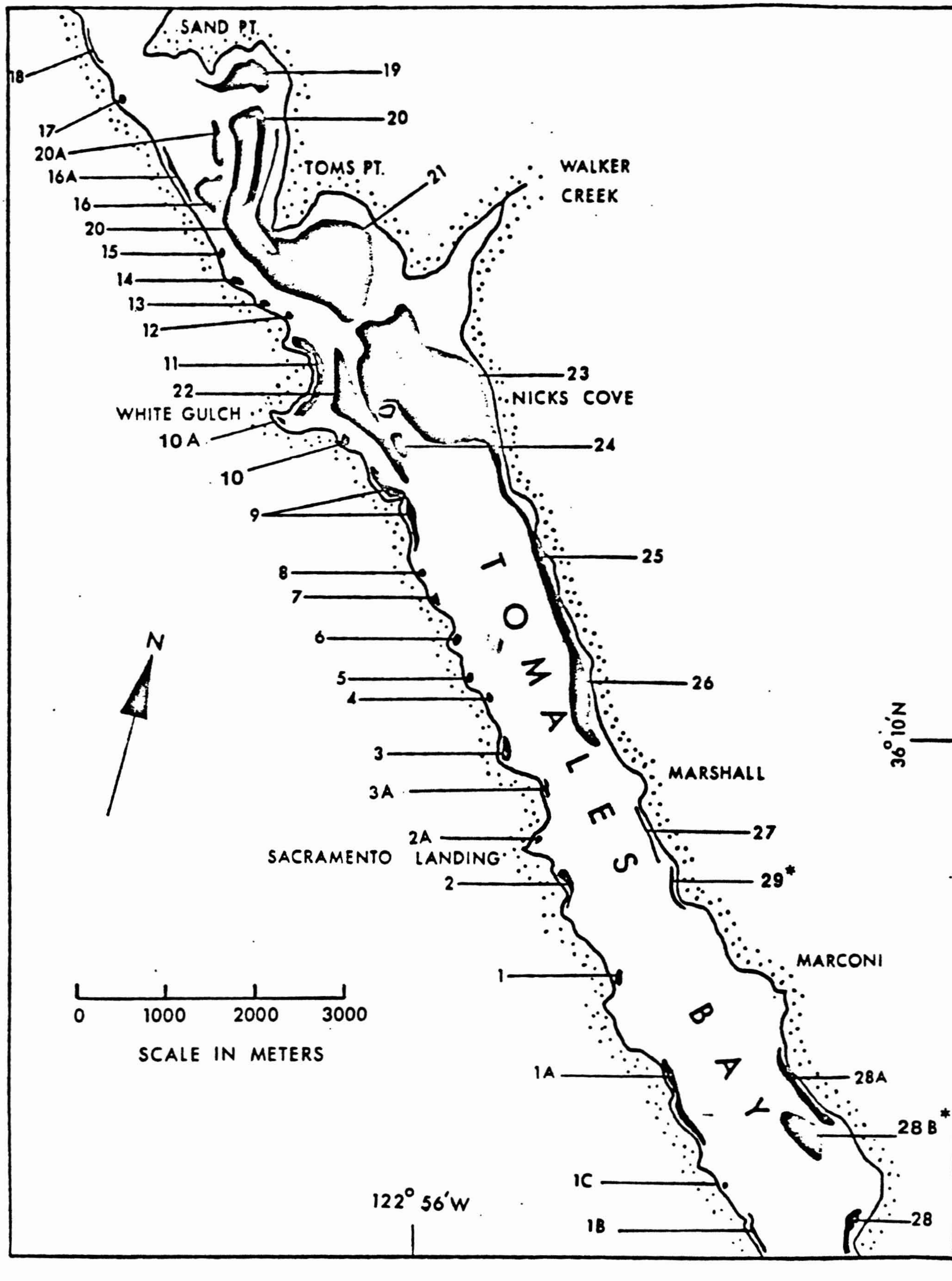

FIGURE 1. Tomales Bay with numbered vegetation beds. All beds are eelgrass except where (*) indicates _Gracilaria_ sp.

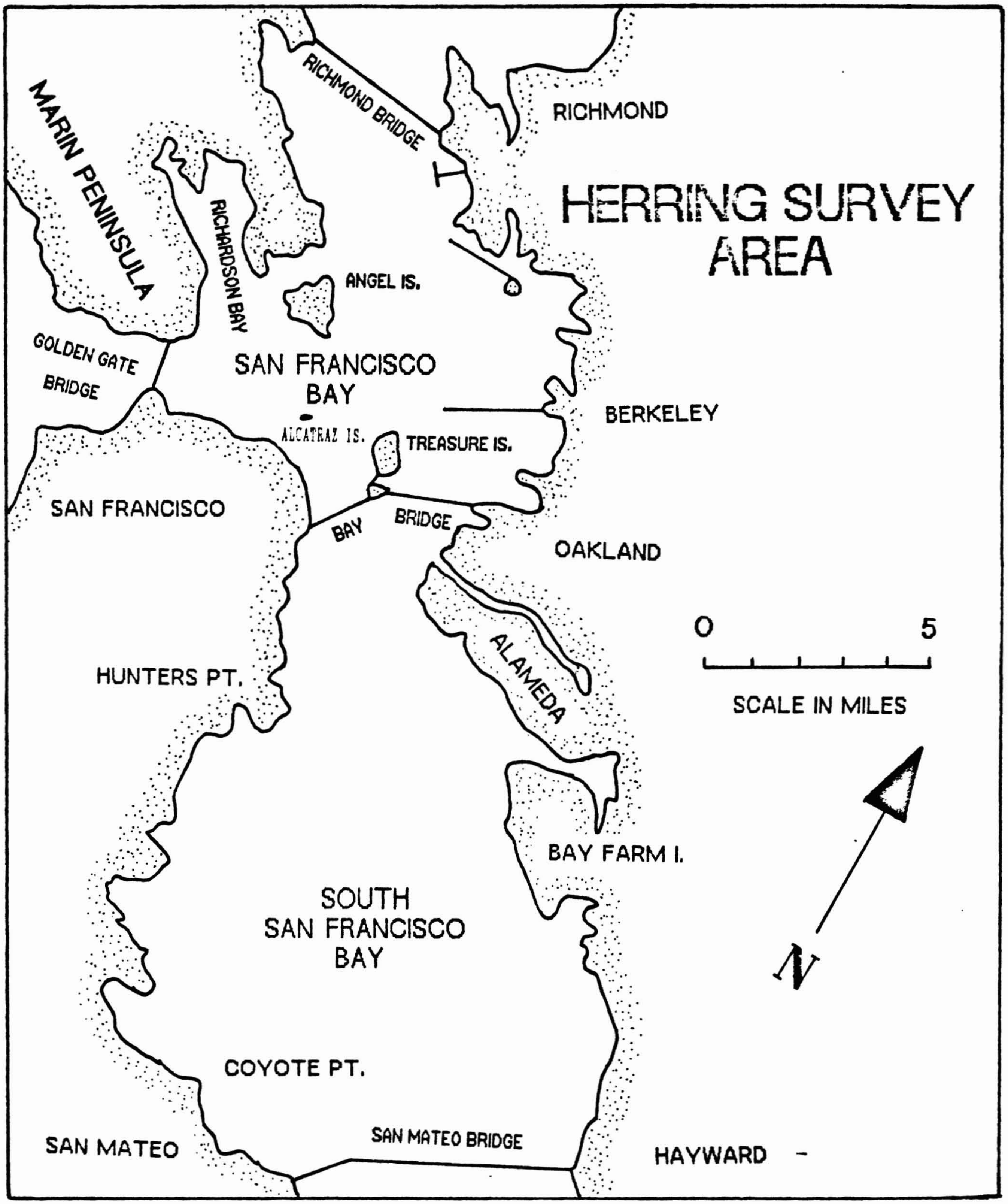

FIGURE 2. San Francisco Bay survey area.

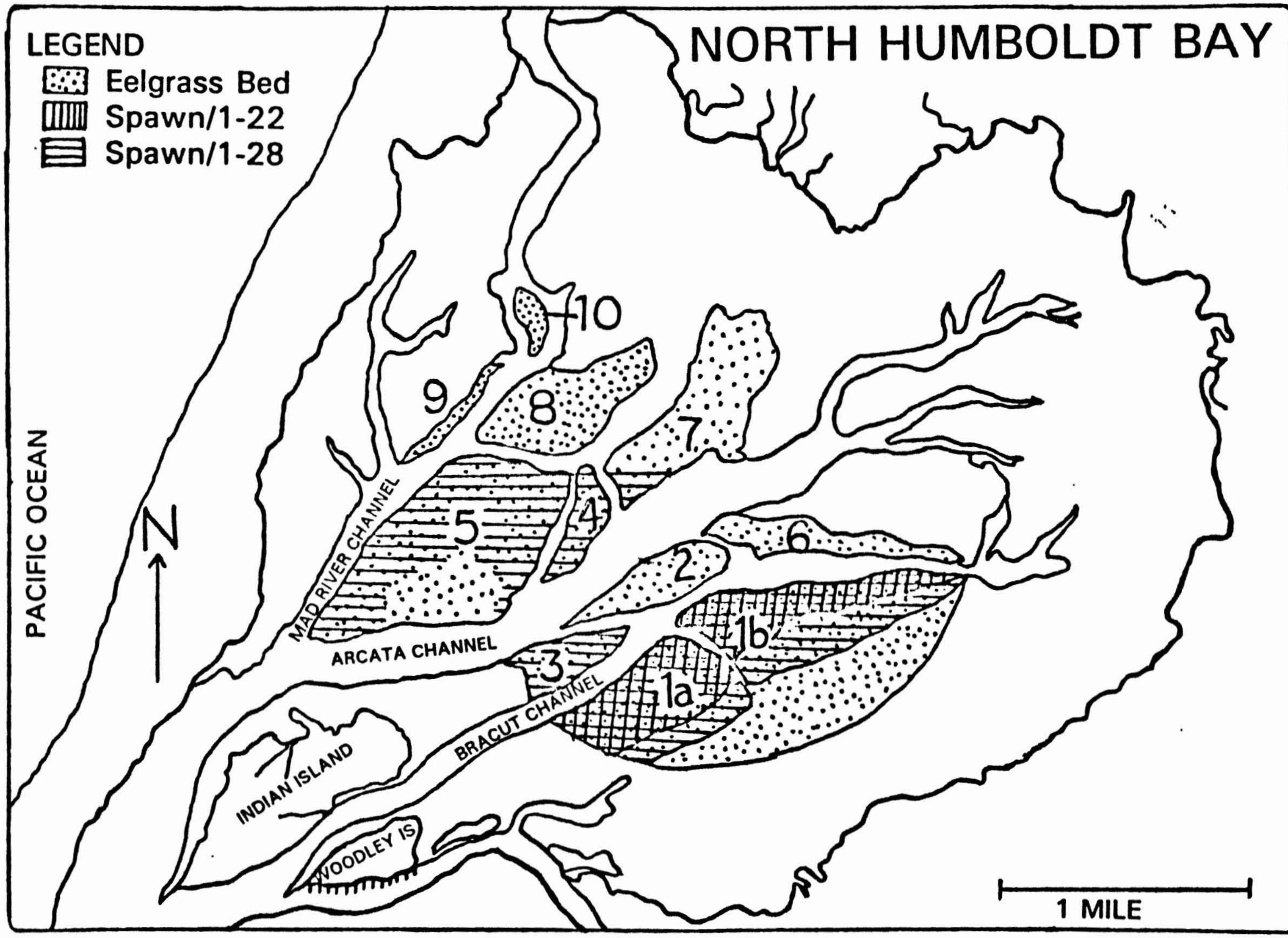

FIGURE 3. North Humboldt Bay with herring spawn locations and general location of eelgrass beds.

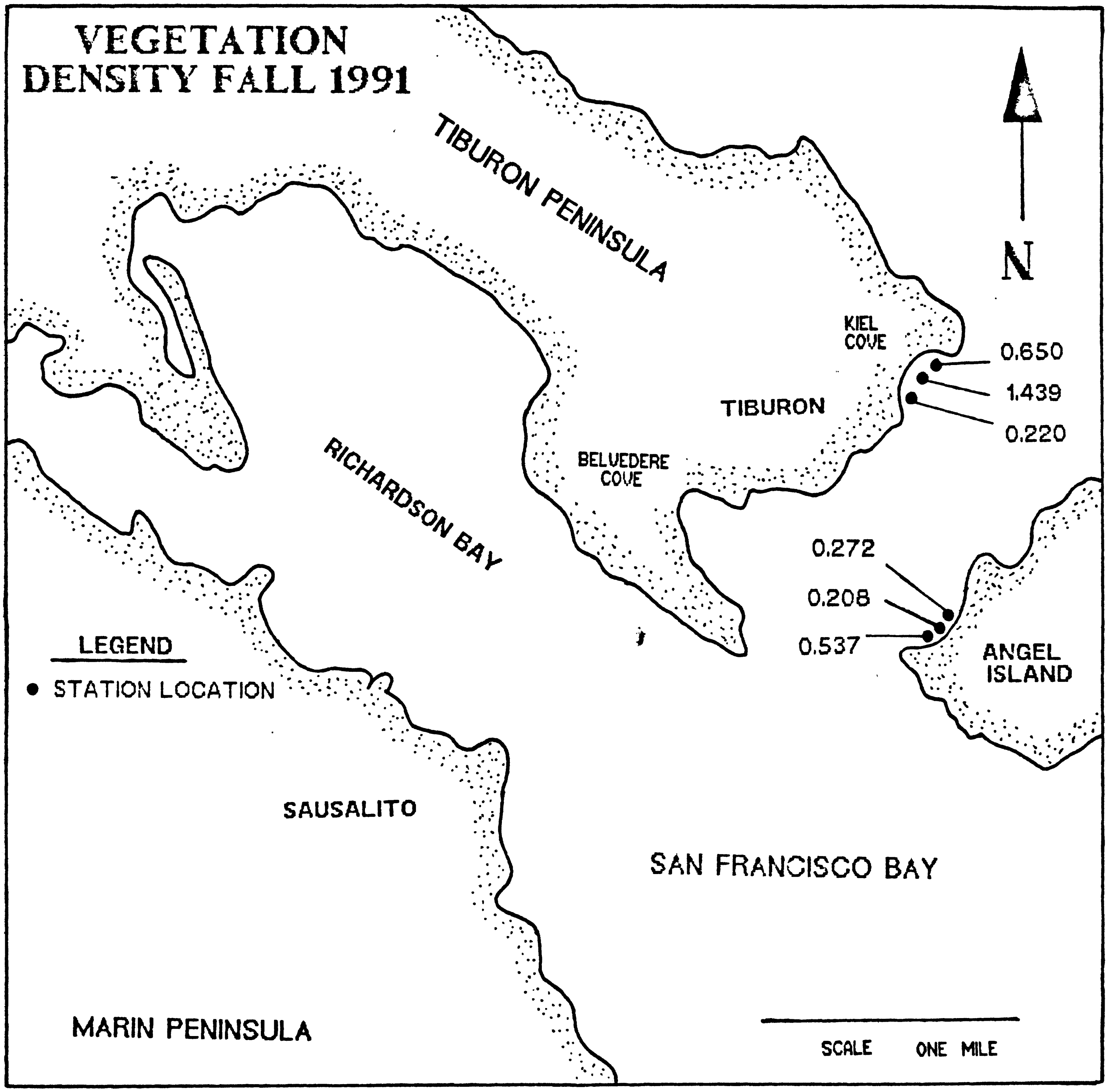

FIGURE 4. Vegetation densities kg/m^2 in San Francisco Bay during the fall of 1991.

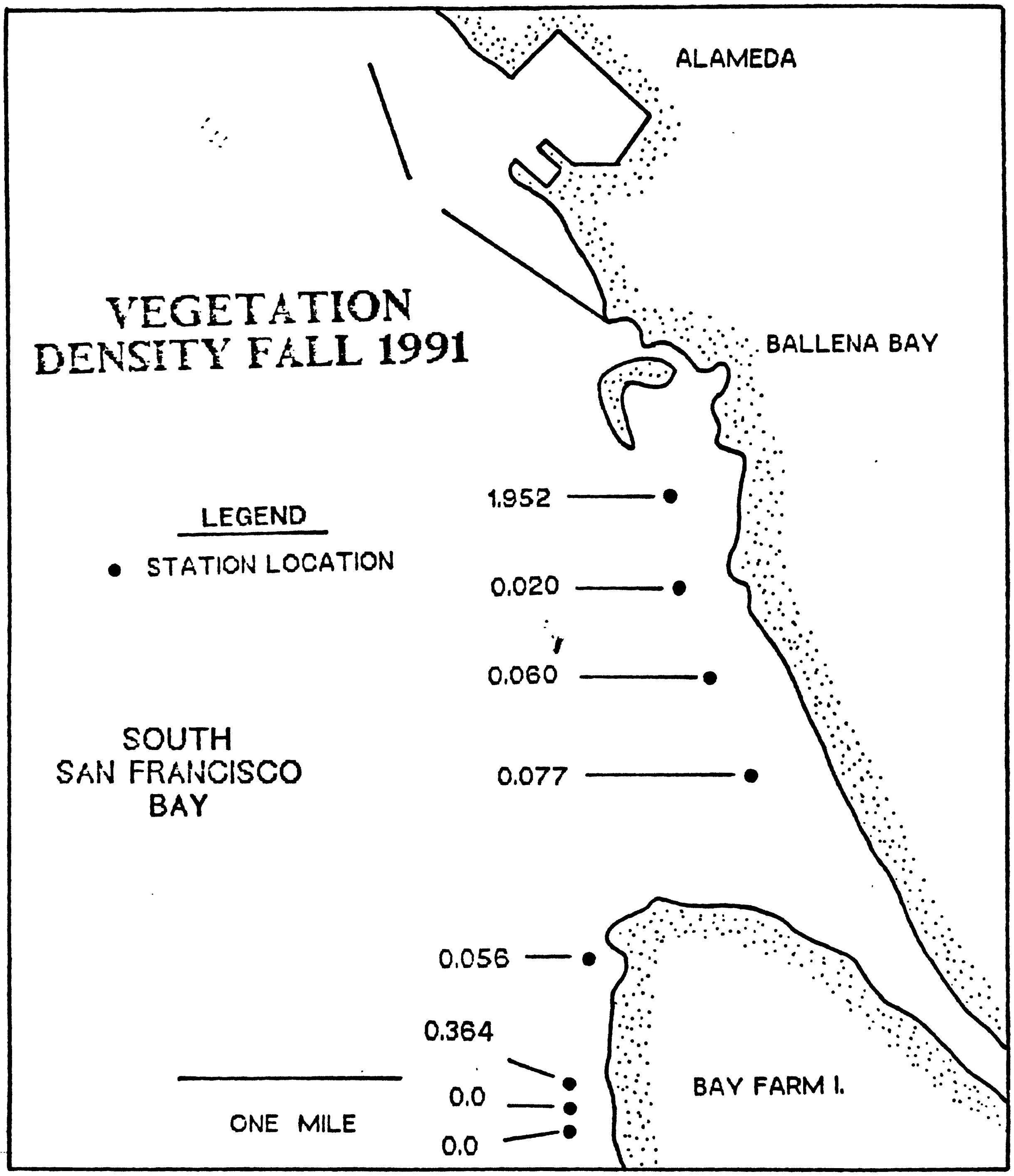

FIGURE 5. Vegetation densities kg/m^2 in south San Francico Bay in the fall of 1991.

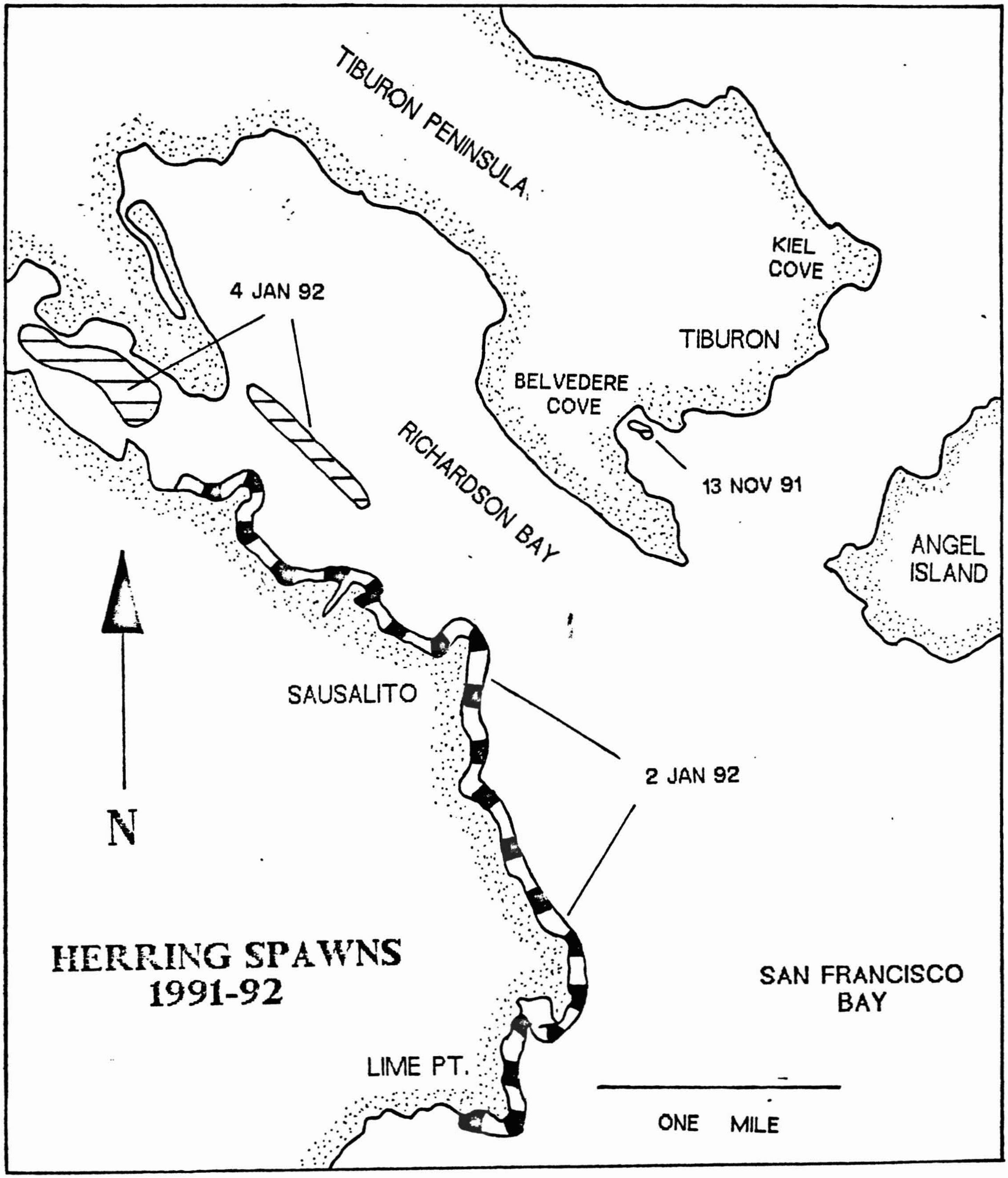

FIGURE 6. Herring spawns and starting dates in the north part of San Francisco Bay during the 1991-92 season.

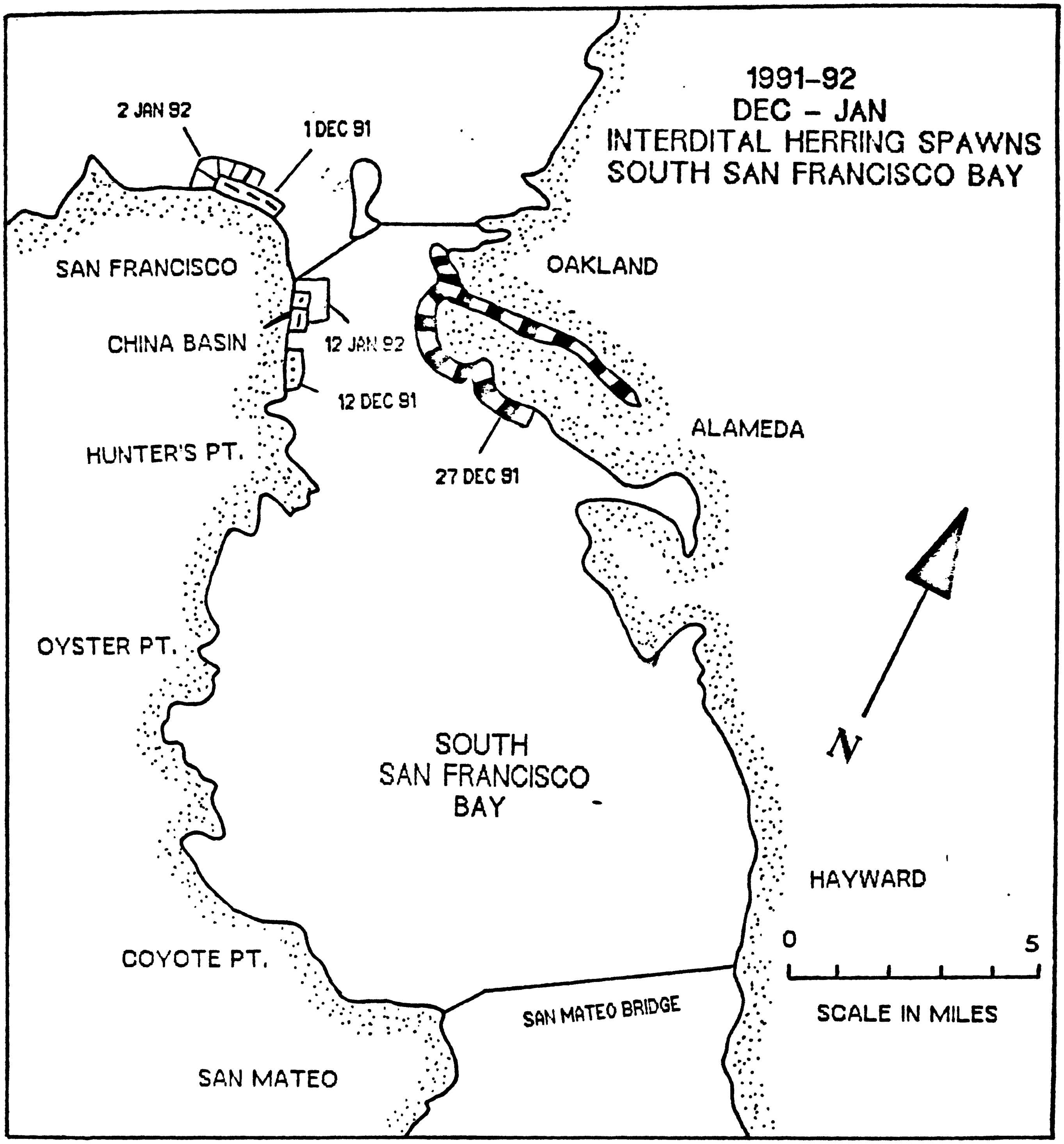

FIGURE 7a. South San Francisco Bay intertidal herring spawns and spawn starting dates during December 1991 and January 1992.

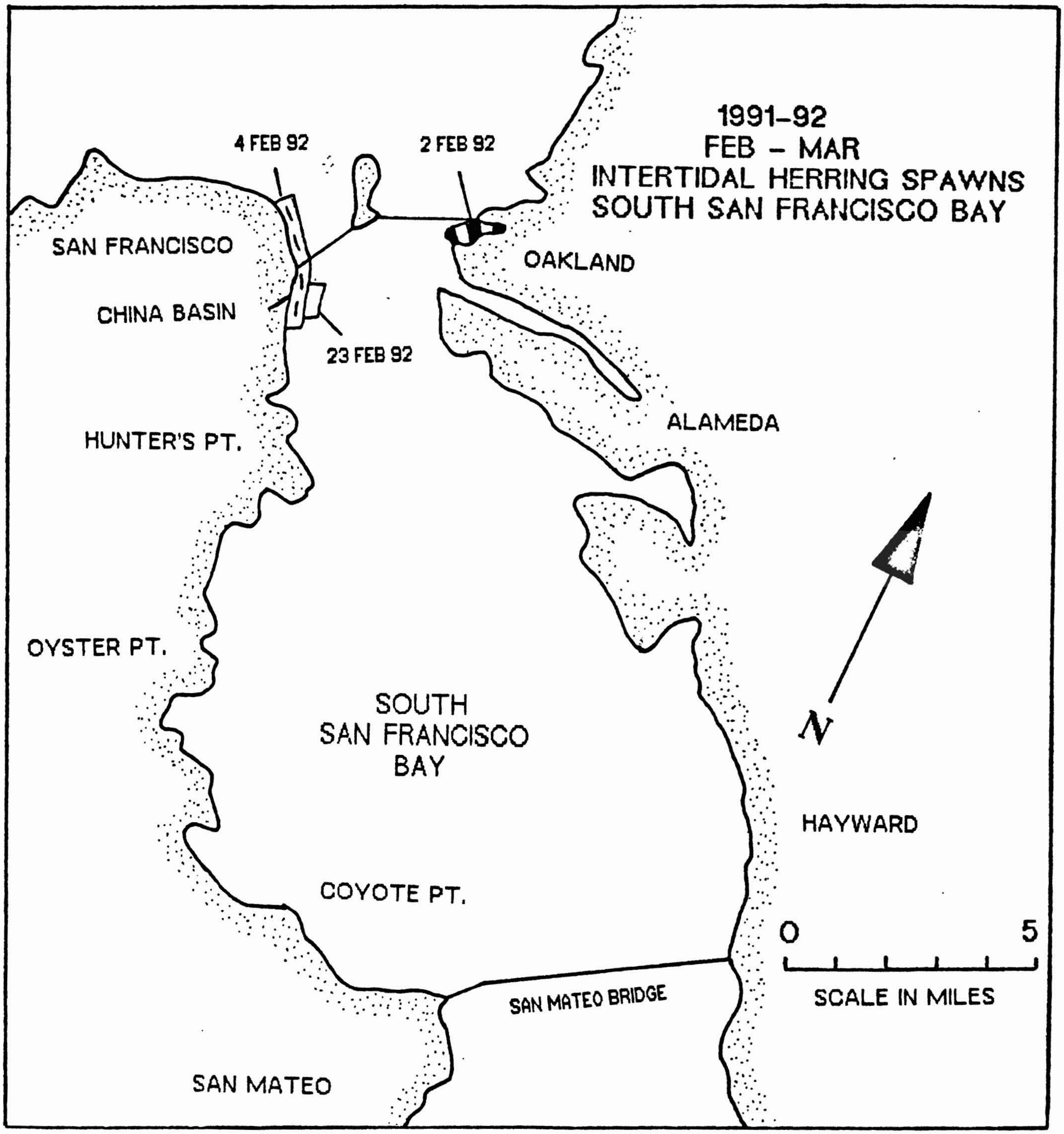

FIGURE 7b. South San Francisco Bay intertidal herring spawns and spawn starting dates during February and March 1992.