State of California
The Resources Agency
DEPARTMENT OF FISH AND GAME

# BIOMASS ESTIMATES OF PACIFIC HERRING, *CLUPEA PALLASI*, IN CALIFORNIA FROM THE 1989-90 SPAWNING-GROUND SURVEYS

by

Jerome D. Spratt

MARINE RESOURCES DIVISION

Administrative Report No. 90-13

JULY 1990

# BIOMASS ESTIMATES OF PACIFIC HERRING, *CLUPEA PALLASI*, IN CALIFORNIA FROM THE 1989-90 SPAWNING-GROUND SURVEYS[1]/

by

Jerome D. Spratt[2]/

## ABSTRACT

The 1989-90 spawning biomass estimate of Pacific herring, *Clupea pallasi*, from spawning-ground surveys in San Francisco Bay was 71,000 tons, a 5,000 ton increase over the 1988-89 biomass estimate of 66,000 tons. The San Francisco Bay herring biomass has been on an upward cycle since 1984, and results from spawning-ground surveys indicated that the population was at its highest level in eight years.

In Tomales Bay the 1989-90 herring spawning biomass estimate was 345 tons. This was the third consecutive poor season. Herring have nearly abandoned Tomales Bay, and reduced freshwater in flows due to the current drought condition in California were the probable cause for the change in spawning behavior.

An additional 445 tons were found in Bodega Bay by hydroacoustic surveys. The total herring biomass estimate for Tomales-Bodega area was 790 tons.

January was the month of peak spawning activity in San Francisco Bay, with 30,000 tons of herring spawning during the month. In Tomales there was only one spawning run; it occurred on January 31, 1990.

In San Francisco Bay, 67% of all spawning occurred along the San Francisco waterfront, and only 6% of all spawning activity was in the northern part of the bay. No spawning was found near Tiburon, Belvedere, Richmond, Berkeley, Candlestick Point, Sierra Point, Oyster Point, or Coyote Point.

A total of 3.5 million $m^2$ of eelgrass, *Zoster marina*, was measured in Tomales Bay this season, a decline of about 10% over the past two seasons.

Eelgrass density $kg/m^2$ did not change significantly this season.

---

1/Marine Resources Administrative Report No. 90-13.

2/Marine Resources Division, 2201 Garden Road, Monterey, California 93940.

ACKNOWLEDGEMENTS

I wish to thank Deborah Epperson, Karen Haberman, Kim Raum, and Robert Suryan for collecting samples of spawn deposition in San Francisco Bay and Tomales Bays and for their diligence in processing said samples.

Tom Moore, Northern Ocean Management Biologist at Bodega Bay, assisted with spawning-ground surveys in Tomales Bay. Subtidal vegetation samples in San Francisco Bay were collected by Department divers Jack Ames and Fred Wendell.

## INTRODUCTION

The California Department of Fish and Game has estimated the annual spawning biomass of Pacific herring, Clupea pallasi, in Tomales and San Francisco Bays since 1973. Biomass was derived from estimates of herring eggs deposited during the spawning season (Spratt 1981). Both bays are relatively small and well suited for intensive spawning-ground surveys.

This report includes spawning biomass estimates for Tomales Bay and San Francisco Bay during the 1989-90 season, and continues the series of annual herring spawning biomass estimates from 1973-74. These data provide the basis for managing the herring roe fishery.

## 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 more than 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 present distribution of eelgrass (Figure 1), which is unchanged from the previous season. There are other species of marine flora in Tomales Bay, but eelgrass is the primary one used as a herring spawning substrate.

### San Francisco Bay

The portion of San Francisco Bay where regular daily (Mon.-Fri.) surveys were attempted 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 vegetation beds such as Zostera marina, 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 are not utilized by herring as spawning areas.

## METHODS

### Tomales Bay Sampling Techniques

Spawning-ground surveys were conducted from December 2, 1989 to March 9, 1990. Every eelgrass bed (Figure 1) was sampled daily (Mon.-Fri.), as weather permitted, from the project's 4.6 m (15 ft) boat. Spawn deposition and area ($m^2$) were determined by dragging a vegetation sampler (rake) through the eelgrass beds at random locations and along the perimeter of each spawn. Processing of 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, 1989b). 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

In December 1989, eelgrass blade length and width measurements were taken from eelgrass samples collected from the project's boat with a vegetation sampler. Between 6 and 10 sets of eelgrass blade lengths and widths were collected from each bed in Tomales Bay. The 1989-90 eelgrass density values were computed by substituting these eelgrass data in the regression formula.

The area ($m^2$) of most eelgrass beds was re measured. The perimeter of smaller eelgrass beds was determined with a recording fathometer, then marked with anchored floats. Measuring lines were stretched across the beds to determine bed length and width, which were used to calculate area. Larger beds were measured by triangulating 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, 1989 to March 10,1990. The techniques used to sample both subtidal and intertidal spawns in San Francisco Bay have been unchanged since the 1983-84 season (Spratt 1984). A two-stage random sampling plan was used to select sample sites for intertidal shoreline spawns. Spawnings on pier pilings were not sampled randomly but were sampled at regular intervals 274 to 457 m (300 to 500 yards) apart throughout the entire linear length of a spawn. For intertidal spawnings, three 100 $cm^2$ samples of eggs were removed at each sampling site and counted to estimated density (eggs/$m^2$).

In the case of subtidal spawning, samples were collected randomly throughout the spawn by towing weighted rake. These samples provided the ratio of eggs-per-kg of vegetation. To quantify the number of eggs, vegetation density (kg/$m^2$) must be obtained by SCUBA.

Subtidal vegetation densities were determined prior to the spawning season by collecting samples from 1/4 $m^2$ quadrats with SCUBA from permanent stations at Belvedere Cove, Kiel Cove, Angel Island, and Brooks Island (Figures 3 and 4). Richardson Bay stations have been eliminated because Richardson Bay was no longer a primary spawning area.

## 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 (Wendell and Oda 1990).

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 1989-90 biomass estimates.

## RESULTS

### Tomales Bay

There were 36 eelgrass beds in Tomales Bay. Spawning has also been found in two Gracilaria sp. beds, numbers 28B and 29 (Figure 1). Most of the eelgrass beds were remeasured this season, and the resulting area estimates (Table 1) were used in biomass calculations.

The total eelgrass area consistently ranged between 3.8 and 4.0 million $m^2$ annually until 1989. However, in the 1989-90 season, the eelgrass area totaled only 3.5 million $m^2$, about

10% below average. This may have been a gradual decline in area because all eelgrass beds are not measured each season.

Eelgrass Density Estimates From Regression

Beginning with the 1987-88 season, eelgrass density was estimated from regression using eelgrass 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 1989-90 season, eelgrass density was estimated from eelgrass blade length and width measurements collected in December 1989, 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 the average of 6 to 10 individual estimates.

No trend was apparent when eelgrass density was compared with density estimates from the previous two seasons; about half of the beds increased in density and half decreased.

Spawning Biomass

The only spawning run found occurred on January 31, at vegetation beds 28, 28A and 28B (Figure 1). The resulting spawning escapement estimate for Tomales Bay was 345 tons (Table 3). Tomales Bay was closed to fishing for the 1989-90 season, thus spawning escapement equaled spawning biomass (Table 4).

An additional 350 tons of herring were found by hydroacoustic survey in the northern part of Bodega Bay on February 22, 1990 (Wendell and Oda, 1990). There were also 95 tons of herring caught in Bodega Bay. The total biomass of herring found in

the Bodega Bay area this season was 445 tons (Table 5). Spawning biomass for the 1989-90 season in the Tomales-Bodega area totaled 790 tons (Table 5).

## San Francisco Bay

### Vegetation Density Estimates

Quantitative samples of subtidal vegetation were collected by Department divers on October 31, 1989. Subtidal vegetation densities increased over 1988-89 estimates (Spratt 1989a) at all permanent stations (Figure 3 and 4), except Brooks Island. However, vegetation densities remain depressed compared to historic levels, and no spawning occurred in known vegetation beds.

### Spawning Biomass

There were nine periods of spawning activity during the 1989-90 season. The first spawn was found November 28, 1989 near San Francisco (Table 6, Figure 5a and 5b). The largest spawn occurred from January 2, 1990 to January 6, 1990, when almost 23,000 tons of herring spawned in the vicinity of San Francisco, Oakland, Alameda, and Treasure Island (Figure 5b, and 6).

The San Francisco waterfront was the major spawning area during the season, accounting for about 67% of the spawning escapement (Table 6, Figure 5a and 5b). There were no spawns at Belvedere, Tiburon, Angel Island, Richmond, or Berkeley. Only 6% of the spawning activity occurred in the northern part of the bay (Table 6 and Figure 6).

Only two subtidal spawnings were found, both were near Alameda (Table 6 and Figure 7 ). In this area the bay is

shallow, less than 1.5 m (5 ft.) deep. The bottom is composed of hard sand and oyster shells with little vegetation. Predation on spawn by diving birds has been a recurring problem in this area and has made it difficult to estimate the size of spawns. The spawn of February 18, 1990 was a major subtidal spawn. This spawn was not found until four days after it happened and by that time most of the herring eggs had been removed by predators. Consequently, it was necessary to use the herring project's alternative hydroacoustical estimate of 7,400 tons for this spawn (Wendell and Oda, 1990).

Another herring school of approximately 400 tons was found by hydroacoustic survey in March (Wendell and Oda, 1990), after spawn deposition surveys ended. This school was also included in the 1989-90 biomass estimate (Table 6).

This is the first season in which hydroacoustic biomass estimates were needed to estimate the size of a spawning run because of inadequate spawn-ground surveys.

The 1989-90 season spawning escapement was estimated at 61,950 tons of herring (Table 6). Including the catch of pre-spawning herring from the roe fishery, the spawning biomass for the 1989-90 season was 70,912 tons (Table 7). The San Francisco Bay population estimate from spawning-ground surveys increased about 7% this season to the highest level since 1982.

## Confidence Limits

Confidence limits of herring spawning escapement estimates in Tomales Bay were calculated from variation in the density of egg deposits. Each run 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 calculated for each spawn site individually. The 95% confidence intervals for 1989-90 season were broad (Table 8) due to the very light and patchy distribution of spawn. Biomass estimate precision was relatively unimportant compared to the decline in herring spawning biomass in Tomales Bay.

Confidence limits of San Francisco Bay spawn estimates were calculated for each spawn site individually from variation in the density of egg deposits. A spawning run may be spread out over several spawning sites. Nine of this season's spawning sites (68% of total escapement) had 95% confidence intervals ranging between 11% and 40% of the estimate (Table 9).

There were two minor ($\leq$ 110 tons) spawning runs with 95% confidence limits that were more than 70% of the estimate. On December 13, 1989 herring spawned at Treasure Island and on January 2, 1990 herring spawned near Alameda. Both spawns were difficult to sample because of patchy distribution of egg deposits.

## DISCUSSION

### Tomales Bay

Spawning escapement increased in Tomales Bay (Table 4) but remained only 6% of the long-term average. It is felt that herring have nearly abandoned Tomales Bay in favor of other spawning areas. Decreased spawning activity began in the 1983-84 season, coinciding with El Nino. After five seasons of erratic spawning activity, which saw unusual fluctuations in spawning biomass, escapement decreased to extremely low levels in the 1988-89 and 1989-90 seasons (Table 4). During these seven years

the age composition of the gill net catch remained stable, suggesting the population had not declined due to recruitment failures (Spratt 1990). The drought in California since 1984 was an important environmental factor, resulting in less freshwater run off into Tomales Bay. These two factors suggest a change in spawning behavior of Tomales Bay herring and a probable cause.

Humboldt Bay and Crescent City Harbor herring fisheries have not declined during this period, and results from spawning-ground surveys suggest the San Francisco population is at its highest level in eight years. Herring that normally spawn in Tomales Bay may have moved to San Francisco Bay. In the 1977-78 season, spawning escapement in Tomales Bay more than doubled previous season totals (Spratt 1981). This record year was undoubtedly due to movement of herring from the San Francisco Bay area. When the drought ends, herring probably will return to Tomales Bay. Average spawning escapement levels could be reached in one season by a movement of only 5 - 10% of the San Francisco Bay population, such as occurred in the 1977-78 season.

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. No surveys were conducted in 1978-79, and in the 1985-86 season biomass was estimated by cohort analysis.

The distribution of herring spawn within Tomales Bay has gradually changed since the 1982-83 season. The larger eelgrass beds near Walker Creek (Figure 1) no longer account for the majority of spawning activity in the bay. Eelgrass beds 10

through 20, nearer the mouth of the bay, have steadily declined in use by herring (Table 10). Eelgrass beds in the inner part of the bay (1A, 27, 28, 28A, 28B and 29) have increased in use by herring and have accounted for nearly 50% of spawning escapement since the 1987-88 season (Table 10). The change in the spawning distribution of herring still utilizing Tomales Bay could also be related to the drought.

San Francisco Bay

Population estimates derived from spawning-ground surveys in San Francisco Bay, although relatively stable since 1987-88, attained the highest level since 1982 during the 1989-90 season (Table 7). This biomass estimate was 13,000 tons higher than results obtained by the Department's independent hydroacoustic survey. The hydroacoustic population estimate was 58,100 tons, a decrease in biomass of about 8,000 tons over last season (Wendell and Oda 1990). These differences are not significant; the 95% confidence interval of estimates from spawning-ground surveys generally range between 20 and 50% of the estimate.

The 1989-90 San Francisco Bay herring population estimate from spawning-ground surveys included hydroacoustic estimates for two spawning runs. This reflects the Department's intent to generate one biomass estimate for San Francisco Bay, by combining results from the two techniques. The two surveys will remain independent during the season, but results will be combined at the end of the season to obtain the biomass estimate that will be used as a basis for setting herring catch quotas. The combined estimate more accurately reflects population size

because estimates of individual spawning runs may be better suited to one technique over the other. If both techniques yielded acceptable results for a given spawning run, then both estimates would be averaged to generate the biomass estimate for that particular run. This change in methodology should provide for better management of the fishery.

Spawning Escapement by Area 1973 to 1990

Spawning-ground surveys have been conducted in San Francisco Bay for 17 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 11). This trend was more distinct this season when nearly 70% of all spawning was in the San Francisco area.

## CONCLUSION

Because of the low spawning escapement estimates since the 1987-88 season, the Tomales Bay herring fishery was closed in 1989-90 and the future of the fishery remains uncertain. Tomales Bay should remain closed to herring fishing until a significant increase in spawning activity has been verified by spawning-ground surveys or hydroacoustical estimates.

The San Francisco Bay herring population did not change significantly in 1989-90, and based on results from spawning-ground surveys, the population achieved a post El Nino high.

## REFERENCES


Hardwick, J.E. 1973. Biomass estimates of spawning herring, Clupea harengas pallasi, herring eggs, and associated vegetation in Tomales Bay, Calif. Fish and Game 59(1):36-61.

Reilly, P.N. and T.O. Moore 1986. Pacific herring, Clupea harengus pallasi, studies in San Francisco Bay, in central and northern California and Washington, March 1985 to May 1986. Calif. Dept. Fish and Game, Mar. Res. Admin. Rept. 86-6:1-88.

Spratt, J.D. 1981. Status of the Pacific herring Clupea harengus pallasi, in California to 1980. Calif. Fish and Game, Fish Bull. 171:1-104.

_____. 1984. Biomass estimates of Pacific herring, Clupea harengus pallasi, in California from the 1983-84 spawning-ground surveys. Calif. Dept. Fish and Game, Mar. Resources Admin. Rept. 84-2:1-29.

_____. 1989a. Biomass estimates of Pacific herring, Clupea harengus pallasi, in California from the 1988-89 spawning-ground surveys. Calif. Dept. Fish and Game, Mar. Resources Admin. Rept. 89-6:1-32.

_____. 1989b. The distribution and density of eelgrass, Zostera marina, in Tomales Bay, California. Calif. Fish and Game, 75(4):204-212.

_____. 1990. Biological characteristics of the gill net catch from the 1989-90 Pacific herring, Clupea pallasi, roe fishery in California. Calif. Dept. Fish and Game, Mar. Res. Admin. Rept. 89-5:1-15.

Wendell, F. and K. Oda 1990. Pacific herring, Clupea pallasi, Studies in San Francisco and Bodega Bays, April 1989 to March 1990. Calif. Dept. Fish and Game, Mar. Res. Admin. Rept. 90-?

TABLE 1. Tomales Bay Eelgrass Bed Measurements, 1989-90 Season.

| Bed number | Area 2 m | Season last surveyed | Bed number | Area 2 m | Season last surveyed |
|---|---|---|---|---|---|
| 1 | 6,200 | | 12 | 1,700 | |
| 1A | 19,300 | | 13 | 0 | |
| 1B | 15,000 | 1988-89 | 14 | 700 | |
| 1C | 1,100 | 1988-89 | 15 | 0 | |
| 2 | 6,600 | | 16 | 8,800 | |
| 2A | 330 | | 16A | 7,800 | |
| 3 | 4,500 | | 17 | 2,000 | |
| 3A | 0 | | 18 | 0 | |
| 4 | 330 | | 19 | 38,000 | |
| 5 | 6,500 | | 20 | 135,500 | |
| 6 | 8,300 | | 20A | 33,400 | |
| 7 | 9,500 | | 21 | 1,488,000 | |
| 8 | 4,000 | | 22 | 140,000 | |
| 9 North | 14,400 | 1988-89 | 23 | 1,209,000 | |
| 9 South | 17,900 | 1988-89 | 24 | 45,500 | |
| 10 | 2,600 | | 25 | 102,000 | |
| 11 North | 21,700 | 1988-89 | 26 | 120,000 | |
| 11 Middle | 11,000 | 1988-89 | 27 | 6,200 | |
| 11 South | 1,600 | 1988-89 | 28 | 18,300 | |
| | | | 28A | 7,300 | |

Total area = 3,515,060 $m^2$

TABLE 2. December 1989 Eelgrass Density Estimates ($kg/m^2$) for Most Tomales Bay Eelgrass Beds, Calculated from Multiple Regression.

| Bed no. | Density $kg/m^2$ | Standard error | Percent of 1988 density |
|---|---|---|---|
| 1 | 1.67 | .23 | - 21 |
| 1A | 1.44 | .09 | + 232 |
| 1B | 2.03 | .27 | + 40 |
| 1C | 1.41 | .18 | + 25 |
| 2 | 1.61 | .12 | + 30 |
| 3 | 1.23 | .23 | + 23 |
| 3A | 0 | | No data |
| 4 | 0.93 | .21 | - 33 * |
| 5 | 1.24 | .12 | - 18 |
| 6 | 1.04 | .14 | - 3 |
| 7 | 1.24 | .39 | - 3 |
| 8 | 1.33 | .26 | - 15 |
| 9S | 1.46 | .16 | + 14 |
| 9N | 1.18 | .26 | - 26 |
| 10 | 2.06 | .15 | + 1 |
| 11 | 1.19 | .21 | - 10 |
| 12 | 1.16 | .12 | - 11 |
| 13 | 0 | | 0 |
| 14 | 0.68 | .11 | - 60 |
| 15 | 0 | | 0 |
| 16 | 1.76 | .18 | + 2 * |
| 16A | 2.03 | .34 | + 29 |
| 17 | 1.59 | .22 | No data |
| 18 | 0 | | 0 |
| 19 | 1.79 | .17 | No data |
| 20 | 1.14 | .13 | No data |
| 20A | 0.86 | .10 | No data |
| 21 | 2.78 | .14 | + 39 |
| 22 | 1.98 | .23 | - 26 |
| 23 | 1.75 | .18 | - 16 |
| 24 | 1.28 | .21 | - 39 |
| 25 | 1.55 | .31 | + 41 |
| 26 | 1.47 | .08 | + 38 |
| 27 | 1.11 | .12 | - 24 |
| 28 | 1.35 | .18 | No data |
| 28A | 1.83 | .18 | + 305 * |

* Percent 1986 density, most recent data.

Table 3. Tomales Bay Herring Spawn Data, 1989-90 Season.

| Date | Location* | Area $m^2$ | Eggs per kg. | Kg. veg. per $m^2$ | Eggs per $m^2$ | Millions of eggs | Conversion Factor $X\ 10^6$ | Tons |
|---|---|---|---|---|---|---|---|---|
| 31 Jan 90 | 28 | 18,300 | 161,000 | 1.3 | 209,000 | 3,824 | .0097 | 40 |
| 31 Jan 90 | 28A | 7,400 | 1,292,000 | 1.8 | 2,326,000 | 17,212 | .0097 | 170 |
| 31 Jan 90 | 28B | 14,000 | | | 1,004,000 | 14,000 | .0097 | 135 |
| Total | | 39,700 | | | | 35,036 | | 345 |

* See Figure 1.

TABLE 4. Tomales Bay Pacific Herring Biomass Estimates 1973-74 Through 1989-90 seasons.

| Season | Spawn estimate (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 |

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

TABLE 5. Tomales and Bodega Bay Herring Biomass Estimates for the 1988-89 and 1989-90 Seasons.

| Season | Area | Biomass estimate * | Catch | Total tons |
|---|---|---|---|---|
| 1988-89 | | | | |
| | Tomales Bay | 167 | 0 | 167 |
| | Bodega Bay | NO SURVEY | 213 | 213 |
| | Total | 167 | 213 | 380 |
| 1989-90 | | | | |
| | Tomales Bay | 345 | 0 | 345 |
| | Bodega Bay | 350 | 95 | 445 |
| | Total | 695 | 95 | 790 |

* Estimates are from spawning-ground surveys in Tomales Bay and hydroacoustic surveys in Bodega Bay.

Table 6. San Francisco Bay Herring Spawn Data, 1989-90 Season.

| Date | Location | Area $m^2$ | No. eggs per kg. veg | Kg. veg. $m^2$ per m | Eggs $m^2$ per m | Millions of eggs | Conversion factor $-6$ X 10 | Tons |
|---|---|---|---|---|---|---|---|---|
| 28-29 Nov 89 | San Francisco | 8,800 | " | | 1,220,000 | 10,700 | .0097 | 100 |
| 30 Nov-1 Dec 89 | Sausalito | 54,000 | " | | 1,200,000 | 64,800 | .0097 | 630 |
| 5-8 Dec 89 | San Francisco | 135,000 | " | | 2,670,000 | 360,000 | .0097 | 3,500 |
| 13-15 Dec 89 | Treasure Island | 8,400 | " | | 1,340,000 | 11,260 | .0102 | 110 |
| 14-18 Dec 89 | San Francisco | 400,000 | " | | 2,450,000 | 980,000 | .0102 | 10,000 |
| 2-3 Jan 90 | Alameda | 200,000 | 2,750,000 | .024 | 6,600 | 1,320 | .0092 | 10 |
| 2-3 Jan 90 | Oakland-Alameda | 105,000 | " | | 4,700,000 | 493,500 | .0092 | 4,500 |
| 3-4 Jan 90 | Treasure Island | 74,000 | " | | 6,550,000 | 484,700 | .0092 | 4,500 |
| 3-4 Jan 90 | San Francisco | 250,000 | " | | 2,370,000 | 592,500 | .0092 | 5,500 |
| 3-6 Jan 90 | San Francisco | 530,000 | | | 1,730,000 | 916,900 | .0092 | 8,400 |
| 17 Jan 90 | Angel Island | 17,000 | " | | 1,830,000 | 31,110 | .0092 | 300 |
| 17-18 Jan 90 | Sausalito | 87,000 | " | | 3,300,000 | 287,100 | .0092 | 2,600 |
| 18 Jan 90 | Sausalito | 10,000 | " | | 915,000 | 9,150 | .0092 | 100 |
| 17-19 Jan 90 | San Francisco | 230,000 | " | | 1,910,000 | 439,300 | .0092 | 4,000 |
| 5-6 Feb 90 | San Francisco | 185,000 | " | " | 1,776,000 | 328,560 | .0084 | 2,800 |
| 18 Feb 90 | Alameda | | | | | | | 7,400 + |
| 28 Feb-Mar 2 | San Francisco | 325,000 | " | " | 2,510,000 | 815,750 | .0087 | 7,100 |
| March | | | | | | | | 400 + |
| | Total | 2,619,200 | | | | 5,826,650 | | 61,950 |

* Vegetation parameters are only used to estimate subtidal spawn density. They are not required for intertidal spawn estimates.

+ Hydroacoustic estimate.

TABLE 7. San Francisco Bay Pacific Herring Biomass Estimates from Spawning-Ground Surveys 1973-74 Through 1989-90 Seasons.

| Season | Spawn estimate (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 |

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

**Includes hydroacoustical estimates totaling 7,800 tons from Table 6.

TABLE 8. Confidence Limits of the Tomales Bay Herring Spawn Estimates During the 1989-90 Season.

| Spawn date | Location | Standard error eggs per m | D. F. N-1 | Estimated tons | 95% Conf.int. |
|---|---|---|---|---|---|
| 1/31 | 28 | 106,000 | 4 | 40 | ±52 |
| 1/31 | 28A | 580,000 | 4 | 170 | ±114 |
| 1/31 | 28B | -- | | 135 | -- |
| | Total | | | 345 | |

TABLE 9. Confidence Limits of the San Francisco Bay Herring Spawn Estimates During the 1989-90 Season.

| Spawn starting date | Location | Standard error eggs per m | D. F. N-1 | Estimated tons | 95% Conf. int. |
|---|---|---|---|---|---|
| 11/28 | San Francisco | 180,000 | 3 | 100 | ±40 |
| 11/30 | Sausalito | 178,000 | 7 | 630 | ±220 |
| 12/5 | San Francisco | 430,000 | 5 | 3,500 | ±1,500 |
| 12/13 | Treasure Island | 310,000 | 3 | 110 | ±80 |
| 12/14 | San Francisco | 250,000 | 17 | 10,000 | ±2,100 |
| 1/2 | Alameda | 3,700 | 4 | 10 | ±20 |
| 1/2 | Oalkand-Alameda | 612,000 | 10 | 4,500 | ±1,300 |
| 1/3 | Treasure Island | 1,327,000 | 6 | 4,500 | ±2,200 |
| 1/3 | San Francisco | 85,000 | 3 | 5,500 | ±600 |
| 1/3 | San Francisco | 277,000 | 13 | 8,400 | ±2,900 |
| 1/17 | Angel Island | -- | 1 | 300 | -- |
| 1/17 | Sausalito | 190,000 | 2 | 2,700 | ±650 |
| 1/17 | San Francisco | 464,000 | 16 | 4,000 | ±2,100 |
| 2/5 | San Francisco | 249,000 | 10 | 2,800 | ±1,000 |
| 2/18 | Alameda | -- | -- | 7,400 | * |
| 2/28 | San Francisco | 242,000 | 15 | 7,100 | ±1,500 |
| 3/? | Acoustical estimate | | | 400 | * |
| | Total | | | 61,950 | |

* Acoustical estimates were used for these spawning runs and confidence limits could not be calculated.

TABLE 10. Average Herring Spawning Escapement by Area for Tomales Bay, Expressed as % of Season Total.

| Vegetation bed no. | Season: 1973-74 to 1982-83 | Season: 1983-84 to 1989-90 | Season: 1987-88 to 1989-90 |
|---|---|---|---|
| 1 | 0.84 | 1.02 | 2.81 |
| 1A | 1.93 | 7.72 | 11.22 |
| 1B | -- | 0.51 | 0.16 |
| 1C | -- | -- | -- |
| 2 | 3.97 | 3.92 | 0.16 |
| 2A | -- | 0.30 | -- |
| 3 | 1.14 | 0.60 | -- |
| 3A | -- | 0.13 | -- |
| 4 | 0.04 | -- | -- |
| 5 | 0.32 | 1.58 | -- |
| 6 | 0.54 | 2.86 | 0.16 |
| 7 | 1.06 | 1.88 | 1.32 |
| 8 | 0.53 | 3.50 | -- |
| 9 | 11.00 | 4.35 | 2.64 |
| 10 | 0.81 | -- | -- |
| 11 | 3.41 | 2.86 | 0.16 |
| 12 | 0.10 | 0.09 | -- |
| 13 | -- | -- | -- |
| 14 | 0.01 | 0.09 | -- |
| 15 | -- | -- | -- |
| 16 | 2.83 | 0.21 | -- |
| 16A | 0.30 | 1.19 | -- |
| 17 | -- | -- | -- |
| 18 | -- | -- | -- |
| 19 | 1.17 | -- | -- |
| 20 | 2.42 | 1.83 | -- |
| 20A | 0.50 | -- | -- |
| 21 | 23.22 | 15.36 | 40.10 |
| 22 | 19.24 | 23.17 | -- |
| 23 | 16.16 | 3.71 | -- |
| 24 | 0.81 | -- | -- |
| 25 | 3.36 | 6.61 | 4.95 |
| 26 | 3.68 | 4.99 | -- |
| 27 | 0.13 | 2.86 | 7.92 |
| 28 | 0.32 | 0.30 | 2.15 |
| 28A | 0.05 | 3.24 | 9.25 |
| 28B | -- | 1.71 | 13.20 |
| 29 | -- | 0.55 | 3.80 |
| Intertidal | -- | 2.86 | -- |
| Total | 100.00 | 100.00 | 100.00 |
| Tons average escapement * | 7,926 | 2,344 | 606 |

* No spawn surveys were conducted in 1978-79 or 85-86.

TABLE 11. 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 1989-90

| Spawning area | Average % of seasonal biomass | Average escapement (tons) |
|---|---|---|
| San Francisco | 61.5 | 30,396 |
| Oakland-Alameda | 9.6 | 4,727 |
| Sausalito | 9.4 | 4.658 |
| Belvedere-Tiburon | 5.8 | 2,845 |
| Angel Island | 4.0 | 1.971 |
| Treasure Island | 2.9 | 1.432 |
| South Bay | 2.9 | 1,418 |
| Belvedere Cove | 1.0 | 479 |
| Tiburon | 0.9 | 464 |
| Kiel Cove | 0.9 | 430 |
| Richardson Bay | 0.5 | 227 |
| Richmond | 0.4 | 207 |
| Belvedere | 0.2 | 114 |
| Coyote Point | <0.1 | 24 |
| Berkeley | 0.0 | - - |
| Total | 100.0 | 49,392 |

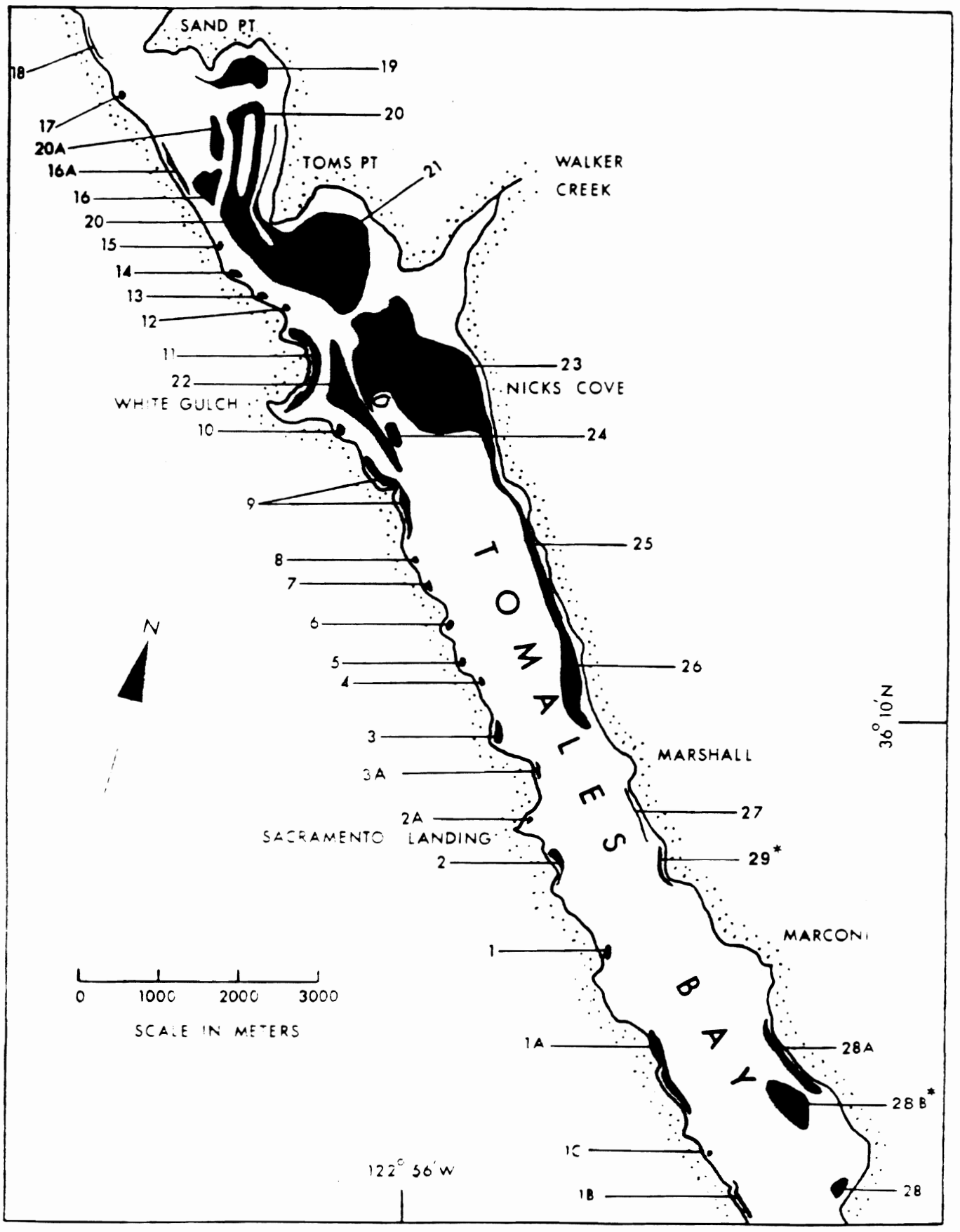


FIGURE 1. Tomales Bay with numbered vegetation beds. All beds are eelgrass except where (*) indicates Gracilaria sp.

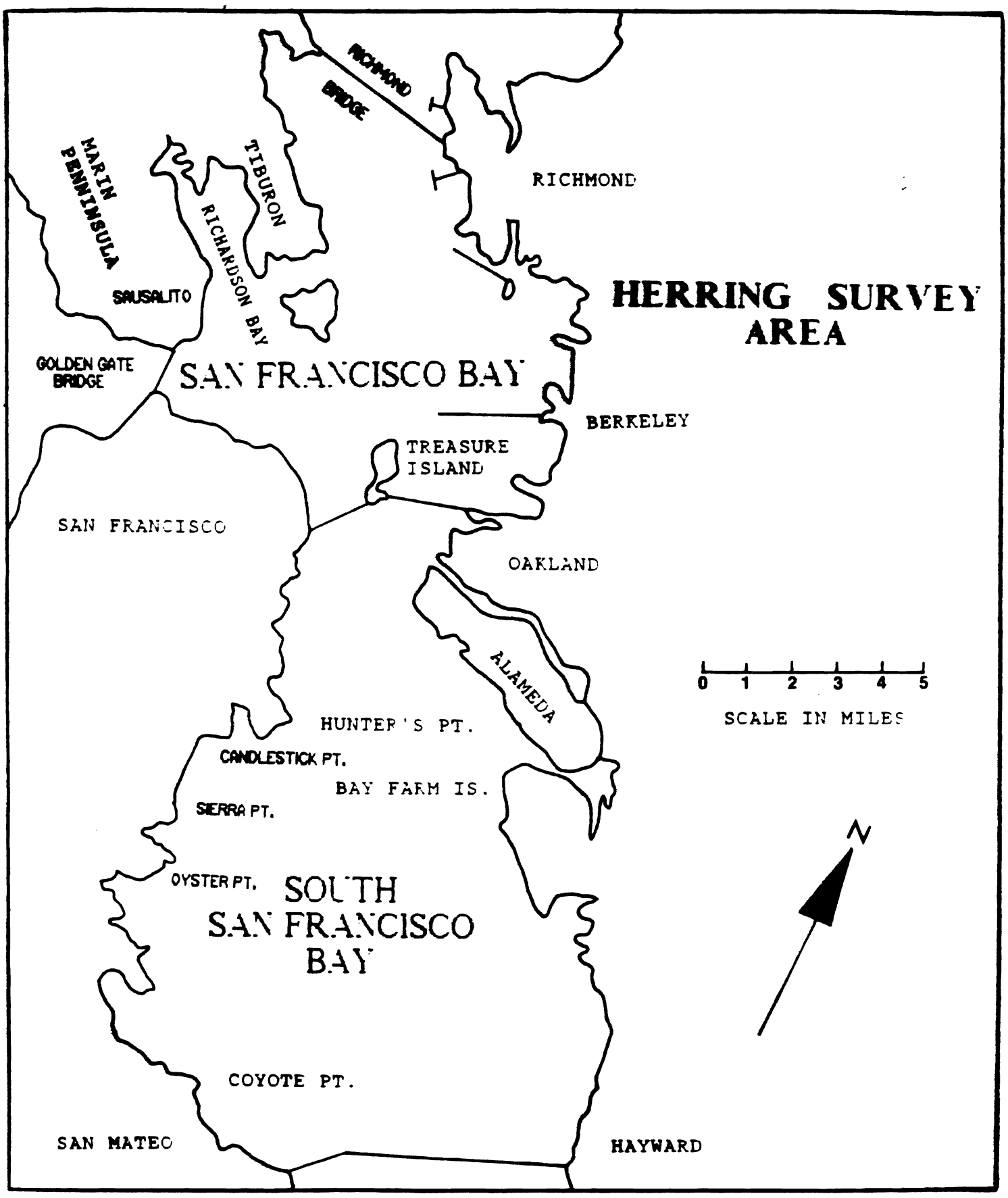


**FIGURE 2. San Francisco Bay herring survey area.**

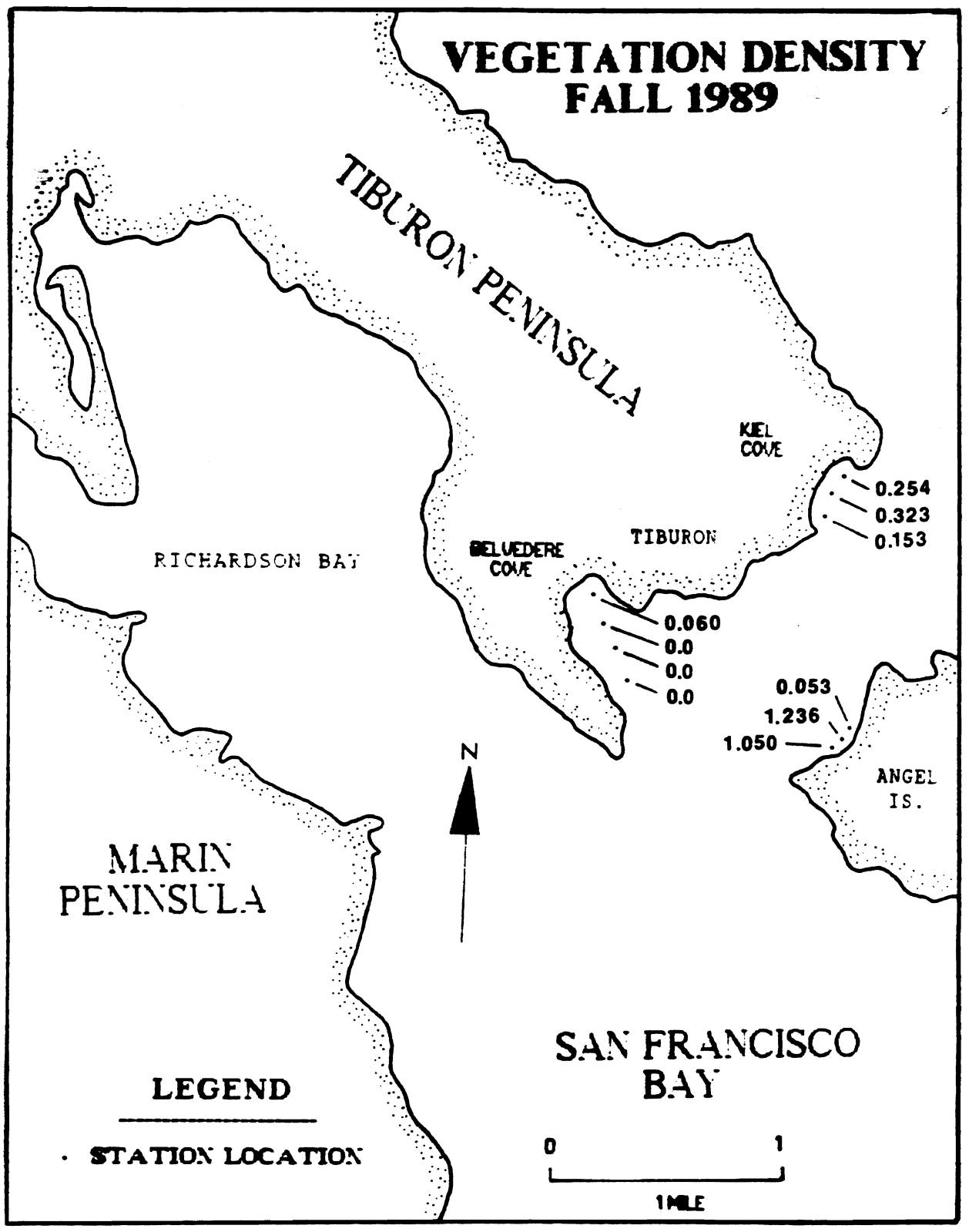


FIGURE 3. Vegetation densities kg/m$^2$ in San Francisco Bay in the fall of 1989.

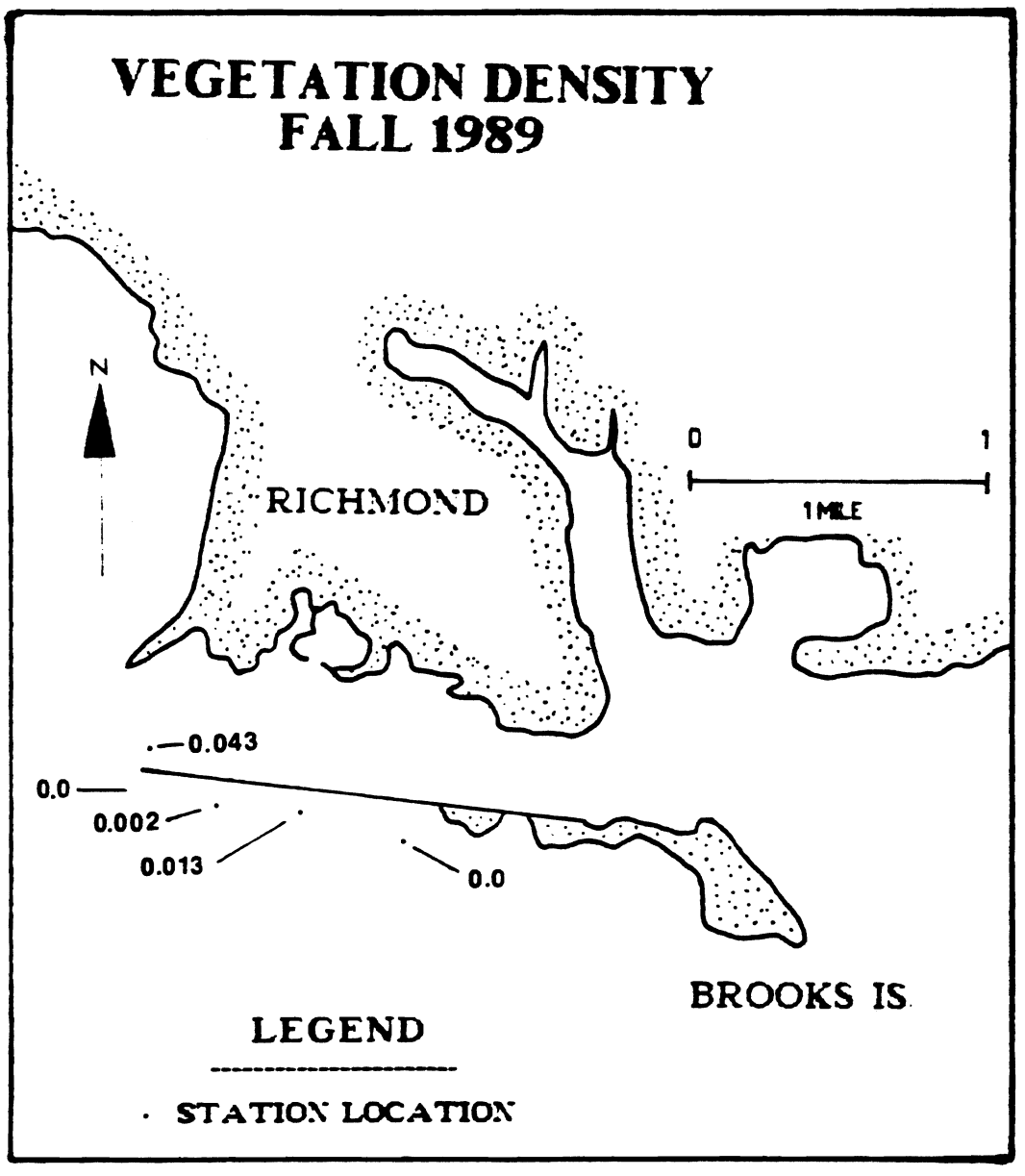


FIGURE 4. Vegetation densities kg/m$^2$ near Brooks Island San Francisco Bay in the fall of 1989.

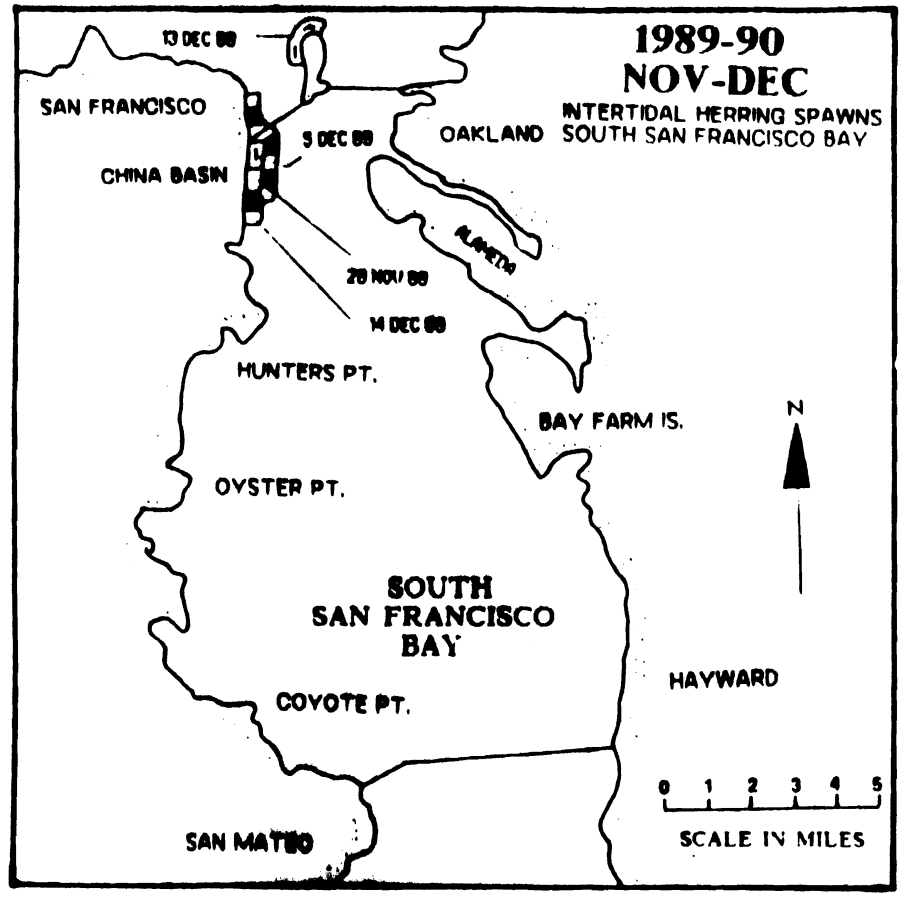


FIGURE 5a. South San Francisco Bay intertidal herring spawns and spawn starting dates during November and December 1989.

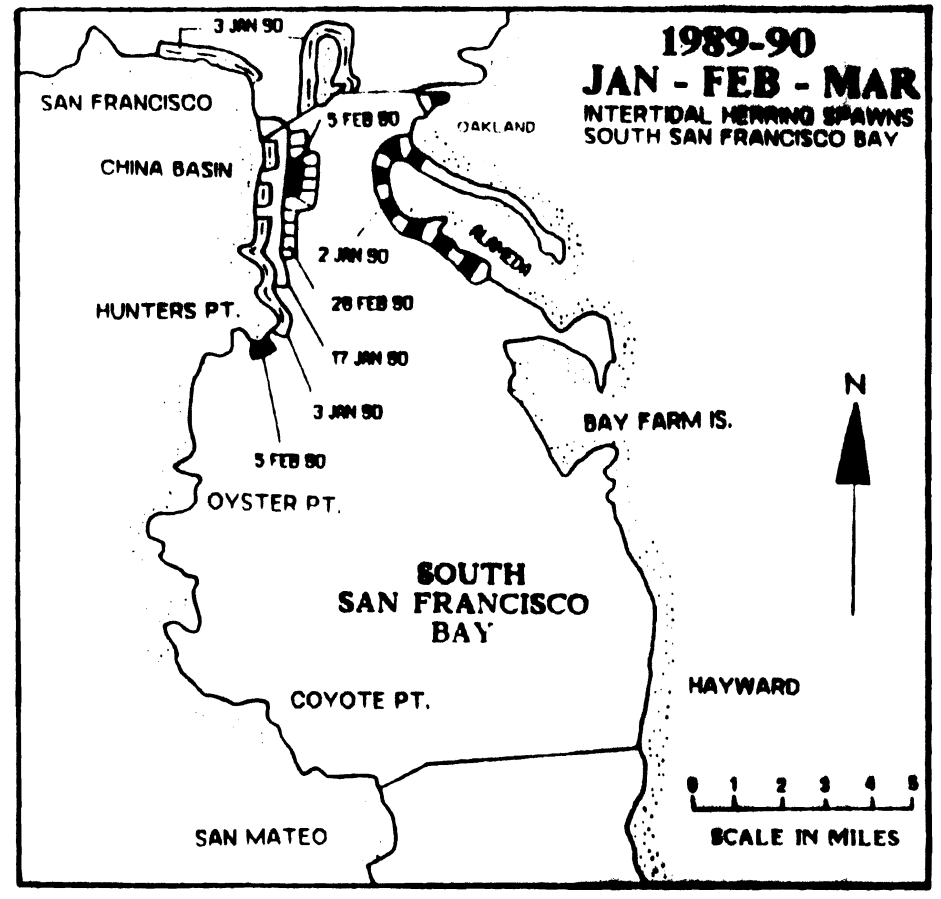


FIGURE 5b. South San Francisco Bay intertidal herring spawns and spawn starting dates during January, February, and March 1990.

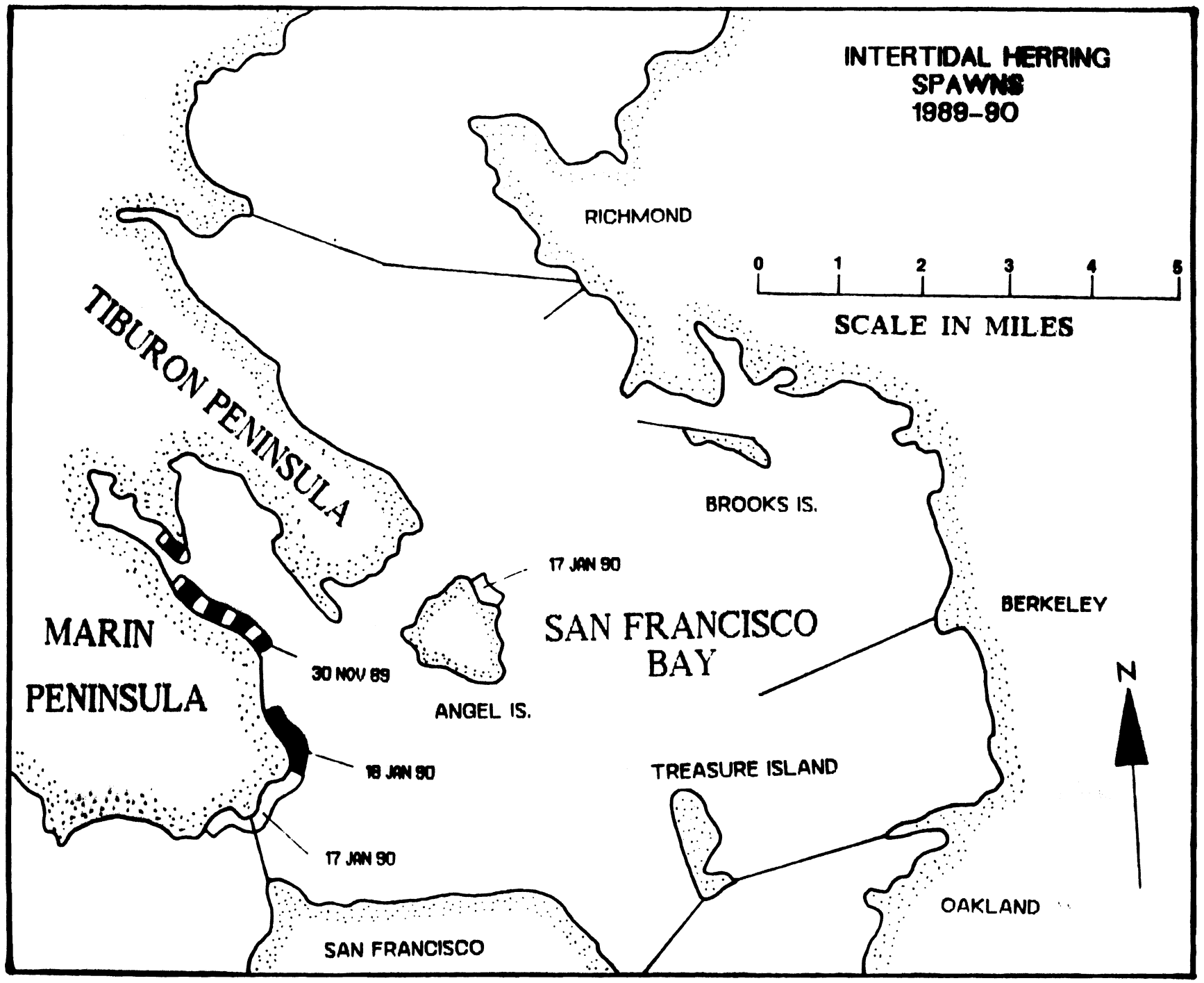


FIGURE 6. Intertidal herring spawns and starting dates in San Francisco Bay during the 1989-90 season.

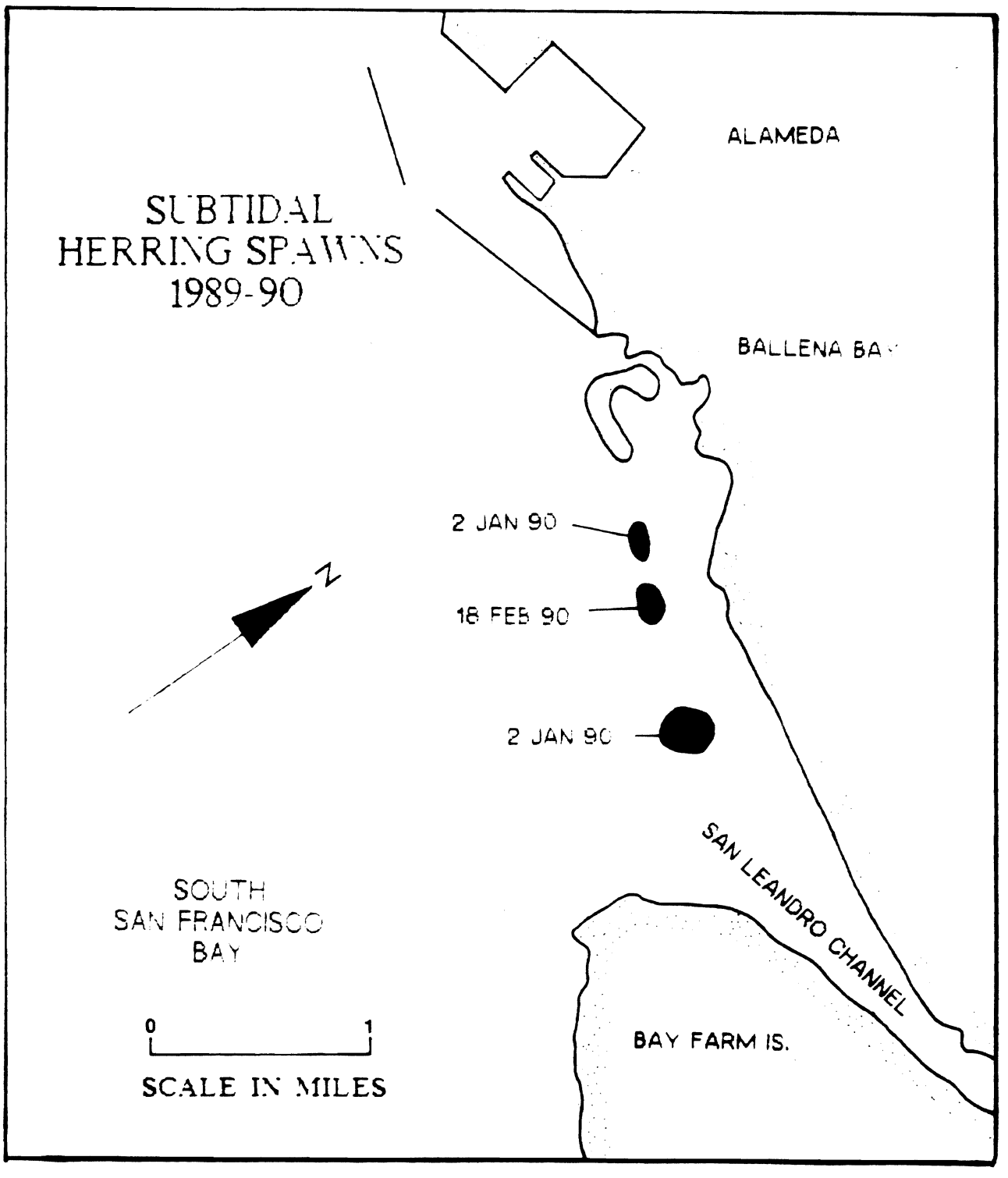


FIGURE 7. Subtidal herring spawns and spawn starting dates in South San Francisco Bay during the 1989-90 season.