Use of the San Francisco Bay Estuary for Spawning by Pacific Herring, *Clupea pallasi*: 1973 to Present.

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Introduction

San Francisco Bay provides spawning and rearing habitat for California's largest and near southern most reproductive population of Pacific herring, *Clupea pallasi*. As a species herring are important ecologically and economically to the bay. Embryos, larvae, juveniles and adults are food sources for a variety of birds, mammals, fishes and invertebrates. San Francisco Bay's population also supports a valuable fishery for herring roe, or *kazunoko*, a traditional Japanese delicacy (Fig. 1). Since the inception of the roe fishery in 1973, the California Department of Fish and Game has conducted annual surveys of spawning in San Francisco Bay as part of their ongoing monitoring of this population and management of the fishery. Throughout spawning season, the Department documents the occurrence and location of spawns, area, substrates used, and the biomass of adult spawners

Traditional Herring Fishing Boat

From November through March, schools of adult Pacific herring enter San Francisco Bay to spawn. Upon entering, they typically hold in deeper portions of the Bay for up to three weeks to ripen and prepare for spawning. Spawning takes place along the shoreline in intertidal and shallow subtidal areas of the Bay, primarily between the Richmond-San Rafael bridge in the north to Candlestick Point in the south. Females extrude adhesive eggs on a variety of silt-free substrates, including: subtidal vegetation such as *Gracilaria spp.* and eelgrass, rocks, shell fragments, and man-made structures such as pier pilings, rip rap, and boat hulls. Herring young-of-the-year remain in the Bay into September before entering the ocean.

Here we present a summary and analysis of the areas of the Bay utilized by Pacific herring for spawning.

Methods

Spawn Escapement Biomass Estimates. Spawn escapement biomass refers to the amount of adult herring (expressed in short tons) that spawn, and are not caught by the fishery. From 1973 through 1978, only intertidal spawns were sampled; therefore, these surveys likely underestimated spawn escapement biomass. Since 1979, subtidal spawns have been included in the surveys. Searches for herring spawn activity are conducted by Department of Fish and Game (DFG) biologists from November through March each year, approximately four days per week, during low tide. The primary search area for spawning activity lies between the Richmond-San Rafael Bridge in the north to Candlestick Point to the south. Locations outside of this primary search area are checked when reports of spawning activity are received by the DFG biologists from fishermen or the interested public. Because this entire area cannot be covered in a single low tide, portions are searched on a rotating basis.

Spawns are located and sampled by finding embryos on various substrates exposed at low tide or on subtidal vegetation, which is often preceded by the sight of milt in the water, bird and mammal feeding activity, and/or fishing in the area. Spawns are sampled and their areas determined based on the methods of Spratt (1981) with slight modifications described by Watters and Oda (1997). Samples are used to calculate the number of embryos per square meter, which is expanded to an estimate of total embryos spawned, taking into consideration the substrate spawned upon. This estimate is then used to back-calculate the tons of adult spawners using the formula:

$$\frac{1}{F \times (f/P) \times (g/lb) \times (lbs/short\ ton)}$$

where:

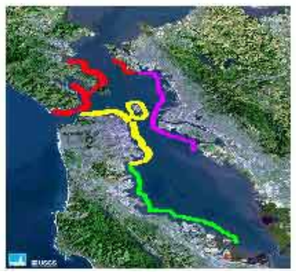
F = **fecundity (113 eggs/g body wt., males and females combined)**

f = percent females in a given spawning run

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

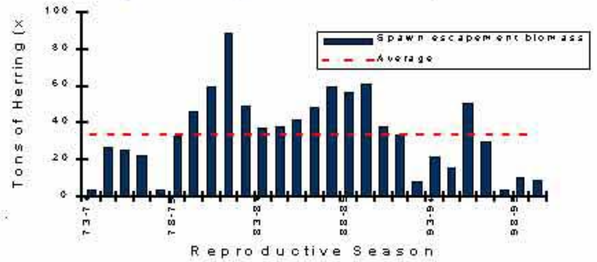
Spawning Regions in San Francisco Bay

To analyze the use of San Francisco Bay by Pacific herring for spawning, we sorted spawn data into four regions: (1) Northern Central Bay is the area between Point Bonita outside the Golden Gate and the Richmond-San Rafael bridge and includes Angel Island and Richmond; (2) San Francisco extends from the south side of the Golden Gate to Candlestick Point and includes Treasure Island and Yerba Buena Island; (3) East Bay includes Eastern Central Bay from the Berkeley flats to Bay Farm Island; and (4) South Bay includes the western shoreline of the Bay south of Candlestick Point. Since 1973, Pacific herring spawns have been recorded by DFG from as far north as Point San Pablo and as far south as Redwood City. For each reproductive season, percentages per area were calculated based on total spawn escapement estimate for that season.



Results

Spawn Escapement Biomass by Season

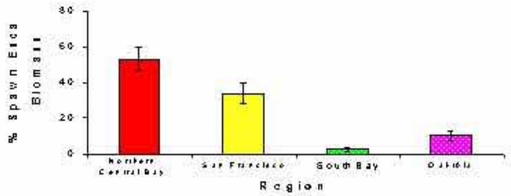


Spawn escapement biomass estimates have ranged from a high of 89,080 tons in 1981-82 to a low of 3,526 tons in 1997-98. Lows often coincided with warm-water or El Nino events

Percent Spawn Activity by Month

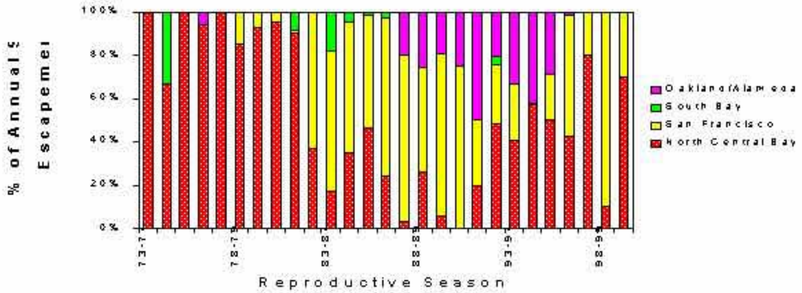
For the entire study period, peak spawning occurs during January, followed by December and February. Bars are the weighted average of percentage spawn by month for each year of the surveys. Error bars = std error.

Average Regional Spawning in San Francisco Bay



On an average percent basis, the majority of spawning activity has taken place in the Northern Central Bay and San Francisco, with 53% of spawn escapement biomass recorded in the Northern Central Bay, and 34% recorded in the San Francisco waterfront

Spawn Escapement Biomass by region for each year the study



North Central Bay Throughout the study period, the Northern Central Bay has been the most consistently used by Pacific herring for spawning, with spawns recorded there every season of the study. The majority of spawning activity in the Bay has been recorded in this region for 15 of the 27 seasons of the study; in particular the period from 1973 through 1982. In recent seasons, the majority of spawning has occurred in this area during the 1997-98 and 1999-00 seasons.

San Francisco The San Francisco waterfront has also been consistently used by herring; spawning has been recorded in this region for 21 of the 27 seasons of the study. From 1982 through 1991, San Francisco was the predominant spawning region for herring in the Bay, exceeding 50% of the total spawn escapement biomass recorded for each season during that period. More recently, the majority of herring spawning activity has occurred in San Francisco during the 1996-97 and 1998-99 seasons.

Oakland/Alameda Spawning activity increased in the Oakland/Alameda region from 1987 through 1996 and this was the predominant region used in the 1991-92 season. However, little or no spawning has been recorded in the Oakland/Alameda region since 1996.

South Bay Pacific herring spawning has been recorded in the South Bay for 9 of the 27 seasons of the study. Spawns in the South Bay have been recorded at Oyster Point, Sierra Point, Coyote Point, and at Redwood City.

Discussion

Although the majority of documented Pacific herring spawns are located between Point San Pablo and Redwood City, over the years DFG receives anecdotal reports of spawning beyond this range; such reports for the most part have been unconfirmed. While the majority of spawning in San Francisco Bay has been documented in the North Central Bay and San Francisco regions, the importance of all regions where spawning occurs to the subsequent survival of herring embryos and larvae is not well-understood. Mortality at the embryonic and larval stages can be high (Hardwick 1973), and survival is affected by a variety of factors, including salinity and temperature, density of spawn, turbidity, desiccation, predation, circulation patterns, and anthropomorphic factors such as creosote (Vines, et al. 2000). San Francisco Bay is near the southern end of the range for Pacific herring and conditions for survival here are more variable and extreme than in more northerly latitudes. This may explain why San Francisco Bay herring spawn over a protracted period of time compared to their northern counterparts, as a means of increasing the chance of spawn success. For the same reason, it is also possible that less-frequently used spawning regions of the Bay may be equally important to Pacific herring reproduction as those most frequently used.

Literature Cited

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