STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF FISH AND GAME
FISH BULLETIN 171
Status of The Pacific Herring, Clupea Harengus Pallasii, Resource In California 1972 to 1980

by
Jerome D. Spratt
1981

ABSTRACT

The California Department of Fish and Game has conducted periodic studies on Pacific herring since 1953. This report concentrates on the period from 1972 through 1980 during which the herring fishery underwent a dramatic resurgence due to the opening of a lucrative market for herring roe in Japan.

The spawning biomass of Pacific herring was estimated by determining numbers of eggs spawned and using previously derived estimates of eggs per gram of fish to convert this figure to short tons of herring. Spawning biomass estimates for Tomales Bay ranged from 4,728 tons in the 1974–75 season to 22,163 tons in the 1977–78 season. Estimates for San Francisco Bay ranged from 6,179 tons in 1973–74 season to 52,869 tons in the 1979–80 season.

Sampling the roe fishery catch in Tomales and San Francisco Bays revealed that age 2 and 3 herring dominated the round haul fishery, and ages 5 and 6 dominated the gill net fishery. Gill nets consistently caught larger herring and a higher percentage of females than round haul nets.

Comparison of length at age of herring from Tomales and San Francisco Bays revealed a statistical difference in growth rates between populations of the two bays. Tomales Bay herring are larger at a given age than San Francisco Bay herring.

Spawning time was related to the tidal cycle in San Francisco Bay. From 1973 through 1976, 88% of all spawnings occurred when the daily high tide was at night.

The resurgence of the fishery and evolution of current management strategies of quotas, seasons, and resource monitoring are discussed.

TABLE OF CONTENTS

ACKNOWLEDGMENTS

This project would not have been possible without the dedicated people who, at times, literally risked life and limb collecting samples of herring eggs during severe weather conditions. I express my undying gratitude and respect to the following: Douglas Chessmore, James Coleman, Howard Cunningham, William Fairgrieve, Robert Fountain, Berry Gammell, Brenton Garmire, A. Rucker Hartmann, Francis Henry, Theodore Holmbeck, Robert King, John Kriegsman, Terry Libby, John Moss, Larry Schramm, Randall Smith, Tom Studley, Kenneth Taniguchi, and Marcia Valladares. Sampling the fishery would not have been possible without the cooperation of several wholesale fish buyers including Ken Sato and Warren Nobusada of Sea Products and W. F. "Zeke" Grader of Ocean Traders.

Norman J. Abramson, Director of the National Marine Fisheries Service Laboratory at Tiburon, kindly provided laboratory space for our work and freely gave use of equipment when needed. John J. Geibel, Nancy C. H. Lo, and Phillip Law of the Department provided statistical analysis of data, and Gene Witeck helped devise sampling plans.

Many people reviewed various phases of this report, but Herbert W. Frey and John L. Baxter were the principal reviewers of early drafts. The manuscript was typed by Nancy C. Durell.

INTRODUCTION

The Pacific herring, Clupea harengus pallasii, is a member of the herring family, Cluperdae, which also includes the Pacific sardine, Sardinops sagax caeruleus, and American shad, Alosa sapidissima. It ranges from Baja California to Alaska and across the north Pacific to Japan. Within this range abundance generally increases with latitude and the largest populations are centered off Canada and Alaska. Spawning begins during November in California an ends during June in Alaska, becoming progressively later from south to north. During the spawning season herring congregate in dense schools and migrate inshore where they deposit their eggs on vegetation found in intertidal and shallow subtidal areas of bays and estuaries. A homing instinct has been demonstrated in Canada (Tester 1937) and it is likely that each spawning ground supports a stock that is distinct to some degree from adjacent stocks. California's major spawning areas are Tomales and San Francisco Bays. Herring that spawn in these areas from December through March have become the target of an intensive roe fishery which started in 1973 when Japan began importing herring roe. Immediately after spawning, herring return to the open ocean where their movements are largely unknown. Commercial quantities are found in Monterey Bay during the summer where a small bait and animal food fishery exists.

When the roe fishery began in 1973, it became apparent that an insufficient data base existed for herring in California.

Life history data presented in this report are the result of field work conducted during the 1972–73 through 1979–80 herring spawning seasons in Tomales and San Francisco Bays, and were collected in direct response to the need for biological and statistical data with which to manage the current herring fishery. Spawning biomass estimates for Tomales and San Francisco Bays, and biological data are presented.

These data form the basis for a management plan for the Pacific herring resource in California. Because quotas for the fishery are established in short tons, all biomass estimates given are in short tons with metric equivalents.

1. THE FISHERY

1.1. Historical Fisheries

Herring fishing in California dates from at least the mid 1800's. Catch records are not well documented prior to 1916, but annual catches were low with most of the fish sold fresh. Small amounts also were salted or pickled for human consumption. Harvesting occurred near the populated areas of Humboldt Bay, Bodega Bay, Tomales Bay, San Francisco Bay, Monterey Bay, and San Diego Bay.

From 1916–1919 herring were canned or reduced into oil and meal (Scofield 1918). In 1918 the catch reached 8,000,000 lb (3,629 mt), mostly from Tomales Bay (Table 1). The Reduction Act of 1919 prohibited the reduction of whole herring into fish meal. This action ended the largest component of the fishery, although a small fishery for human consumption continued.

Annual landings remained low until the late 1940's when processors began to can herring as a replacement for sardines because that fishery was declining (Scofield 1952). This product was not well accepted by the public and by 1954 landings dropped to less than 1 million lb (454 mt) (Table 1).

The fishery for human consumption (fresh and pickled herring) and bait has continued and today composes a minor part of the catch.

1.2. Herring Eggs on Seaweed Fishery

In 1965 a new use for California herring products developed when Japan began importing herring roe on seaweed, "Kazunoko Kombu", which is considered a delicacy. The Fish and Game Commission accepted separate sealed bids for the right to harvest herring eggs on seaweed in Tomales and San Francisco Bays. The highest bidder for each bay was awarded the opportunity to take 5 tons (4.5 mt) of eggs on seaweed. The amount of the bid was a royalty per ton paid to the Department after harvesting took place. The quota included the total weight of the seaweed with eggs attached. Herring eggs on Gracilaria spp. and Laminaria sp. are preferred and harvesting was done by divers. This fishery expanded to San Francisco Bay in 1966. The 5-ton quota has never been reached in either bay, but this continues to be a viable fishery with harvests every year since 1965 (Table 2).

TABLE 1. California Pacific Herring Catch in Pounds, 1916–1980.

Year	Crescent City	Eureka	Tomales Bay	Bodega Bay	San Francisco Bay	Monterey	Morro Bay	Santa Barbara	Los Angeles	San Diego	Total
1916	-	-	1,494,773	-	806,419	-	-	-	-	-	2,909,391*
1917	-	-	4,318,582	-	3,059,758	-	-	-	-	-	7,425,307*
1918	-	7,211	3,190,886	-	4,734,383	5,800	-	-	-	-	7,938,280
1919	-	7,146	3,740,515	-	541,385	750	-	-	-	100	4,289,896
1920	-	7,275	83,519	-	183,270	-	-	-	-	-	274,364
1921	-	7,186	12,780	-	520,370	1,300	-	279	-	-	540,194
1922	-	8,222	12,850	-	321,232	1,800	-	517	-	-	343,821
1923	-	3,340	28,005	-	335,872	198	-	-	-	16,516	383,930
1924	-	3,260	5,973	-	414,283	1,450	-	202	-	11,189	435,620
1925	-	3,222	3,876	-	843,193	2,136	-	1,480	-	9,065	862,974
1926	-	8,801	10,078	-	422,739	-	-	290	-	13,699	453,607
1927	-	50,294	252,800	-	845,700	2,980	-	542	-	15,945	1,168,321
1928	-	42,442	441,471	-	611,108	505	-	570	-	22,327	1,118,682
1929	-	31,374	374,172	-	546,829	375	-	325	-	4,488	957,563
1930	-	71,869	308,900	-	358,937	-	-	229	-	42,279	717,624
1931	-	17,819	270,710	-	383,308	16,236	-	79	20	17,393	685,759
1932	-	8,609	313,880	-	413,008	18,136	-	130	-	11,861	765,724
1933	-	-	242,100	-	302,802	51,595	-	182	-	4,885	601,440
1934	-	3,300	405,739	-	349,975	11,200	-	390	-	30,797	801,601
1935	-	12,040	451,395	-	340,105	47,280	-	427	-	51,448	903,285
1936	-	1,849	382,845	-	449,760	1,315	-	225	-	1,333	840,330
1937	-	6,495	298,453	-	314,928	4,335	-	30	-	7,119	631,330
1938	-	5,125	340,115	-	153,506	707	-	42	-	3,329	508,094
1939	-	14,475	76,825	-	201,774	1,175	-	1,456	-	6,737	302,242
1940	-	34,003	356,400	-	57,898	3,595	-	200	-	1,009	453,193
1941	-	1,292	205,175	-	481,843	102,582	-	39	-	40	790,753
1942	-	22,042	65,400	-	43,022	59,730	-	21	-	-	190,815
1943	-	125,564	91,892	-	402,449	9,150	-	452	-	-	630,358
1944	-	101,394	6,901	-	263,623	50,337	-	-	-	-	422,255
1945	-	56,505	6,015	-	303,290	88,280	-	-	-	3,965	460,455
1946	-	17,470	148,930	-	309,327	5,099	-	-	-	770	481,776
1947	-	69,309	128,800	-	535,457	923,224	-	-	-	-	1,656,850
1948	-	120,502	1,435,894	-	6,005,890	438,621	-	115	2,200	70	8,002,692
1949	-	2,700	53,230	-	221,324	100,131	-	-	-	1,921	379,311
1950	-	20,488	620,014	-	586,187	206,115	-	962	-	3,554	1,435,351

TABLE 1. California Pacific Herring Catch in Pounds, 1916–1980

1951	-	58,900	3,468,933	-	182,450	1,193,270	-	12	-	-	4,923,655
1952	-	60,541	2,788,606	-	501,278	5,901,212	-	15,555	266,000	3,764	9,495,366
1953	-	-	2,361,900	-	2,450,158	2,567,105	-	342,825	-	237	7,801,908
1954	-	5,288	125,630	-	349,331	429,901	-	1,556	-	-	911,906
1955	-	79,227	744,520	-	402,047	719,727	-	-	-	-	1,946,521
1956	-	68,658	617,300	-	307,261	736,466	-	4,634	686	-	1,735,776
1957	-	42,270	358,000	-	189,726	597,792	-	210	-	-	1,188,090
1958	-	44,277	1,249,987	-	373,394	733,592	-	300	-	-	2,398,730
1959	-	7,262	1,330,005	-	49,149	340,100	-	130	-	-	1,726,966
1960	-	6,730	1,154,500	-	200,197	439,245	-	-	-	-	1,800,672
1961	-	70	976,510	-	82,094	352,784	-	-	8,500	-	1,401,248
1962	-	85	794,969	-	27,193	492,825	-	521	94	-	1,305,589
1963	-	4,425	332,204	-	44,816	246,572	70	-	-	-	630,097
1964	-	320	3,148	-	27,532	315,273	-	-	-	-	349,270
1965	-	-	11,475	-	21,648	483,046	150	-	-	-	516,319
1966	-	-	7,750	-	22,271	211,952	-	-	-	-	241,973
1967	-	-	2,262	-	19,675	250,935	-	-	-	-	272,902
1968	-	-	3,980	-	49,255	304,634	-	-	-	-	357,869
1969	-	-	15,220	95	12,112	143,105	-	-	-	-	170,532
1970	-	-	5,308	-	24,032	286,618	-	-	-	10	315,968
1971	-	-	11,748	-	6,890	222,300	-	-	-	-	240,938
1972	-	-	13,000	-	108	103,640	-	-	-	-	116,748
1973	24,155	-	1,209,912	-	963,538	684,882	-	-	-	-	2,813,287
1974	119,043	4,478	1,042,717	-	3,877,093	209,901	-	-	-	-	5,252,254
1975	26,052	60	1,033,962	-	1,099,924	332,468	220	-	-	-	2,423,676
**1976	2,100	23,134	288,000	955,000	3,478,203	111,661	-	15	-	-	4,858,113
**1977	-	42,000	588,000	524,000	8,402,000	148,000	-	-	-	-	9,804,000
**1978	26,000	24,000	1,292,000	140,000	9,974,000	96,000	-	-	-	-	11,552,000
**1979	24,000	98,000	680,000	216,000	8,242,000	80,000	-	-	-	-	9,340,000
**1980	52,000	99,000	98,000	1,108,000	12,860,000	-	-	-	-	-	14,217,000

* Includes statewide catch of unknown origin.
** Approximate catch. These are preliminary figures; final annual catch data has not been published by the Department at this time and may differ from preliminary figures.

TABLE 1—Cont'd.

TABLE 2. California Pacific Herring Egg on Seaweed Harvest in Pounds, 1965–1980.

Season (Dec–Mar)	Tomales Bay	San Francisco Bay
1965–66	150	–
1966–67	3,000	4,000
1967–68	9,600	3,720
1968–69	6,600	960
1969–70	–	4,600
1970–71	–	6,087
1971–72	–	9,700
1972–73	1,850	4,350
1973–74	450	7,600
1974–75	2,200	7,800
1975–76	–	7,500
1976–77	–	4,800
1977–78	closed	7,875
1978–79	closed	5,495
1979–80	closed	3,007

TABLE 2. California Pacific Herring Egg on Seaweed Harvest in Pounds, 1965–1980

1.3. Herring Roe Fishery

1.3.1. Events Leading to Roe Fishery

In contrast to the herring egg on seaweed fishery which occurs after the eggs are spawned, the roe fishery takes place just prior to spawning. The herring egg skein (Figure 1) is salted and sold as "Kazunoko", also a delicacy in Japan.

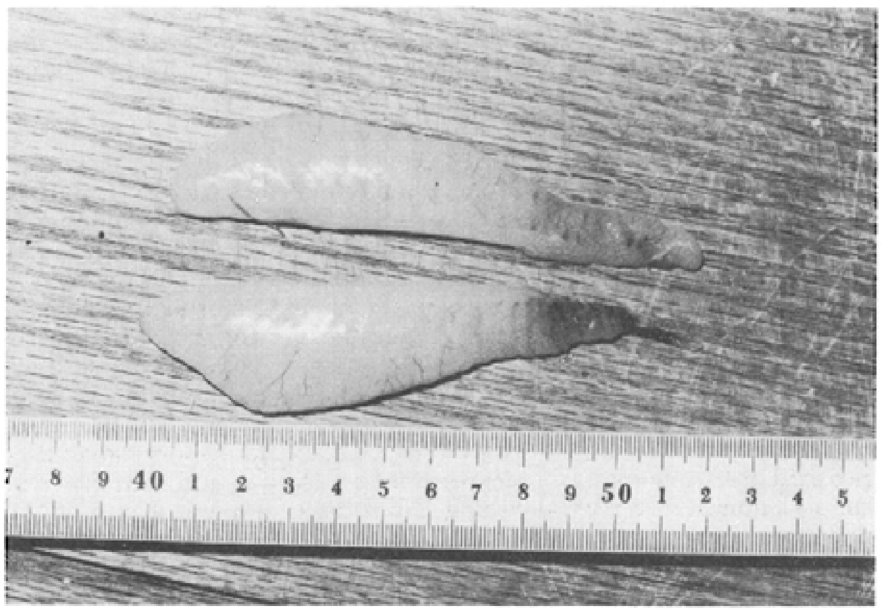

FIGURE 1. Herring roe.

FIGURE 1. Herring roe

In 1971 a series of events began that were to culminate in the establishment of our present herring roe fishery. In the spring of that year the U.S.S.R. banned Japanese herring fishermen from the Sea of Okhotsk. This action reduced Japan's catch of roe-bearing herring by 3,000 mt. The following winter the Japanese herring fleet experienced poor fishing in the Bering Sea. In May 1972 Japan imported 4,000 tons (3,629 mt) of frozen herring from Canada; previously all herring imports had been from the U.S.S.R. and the People's Republic of China. In 1972 Japan's import quota on herring was increased from 2,000 to 10,000 mt.

The demand for herring roe continued and the failure of the 1972 Japanese winter herring fishery in the Bering Sea set the stage for expansion to California. Wholesale prices for roe reached $3.00 per pound in Japan and threatened the industry. It was feared that the consumers would not pay the high price.

Canadian and Alaskan herring suppliers were aware of Japan's demand for herring roe and offered to accept bids from Japanese buyers for catches during the 1973 fishery. A bidding war ensured between Japanese buyers and prices climbed to $3.00 per pound for roe in Canada, equal to the previous wholesale price in Japan.

A wholesale firm, Sea Products Company of Moss Landing, California, spurred by the demand for herring roe in Japan, attempted to start a fishery in San Francisco Bay in 1972, but had little success generating interest. As the winter of 1972–73 approached, Japan's demand for herring roe finally generated sufficient interest among California's wholesale fish dealers that a roe fishery was initiated in January 1973. During 1973 Japan imported 8,000 mt of herring roe from Pacific coast fisheries.

1.3.2. Fishing Season and Areas

Herring attain their highest value when the developing ova of females reach maturity. The roe content, or percentage body weight of female sex products, is highest just prior to spawning and this is when fishing must occur to yield the highest quality herring roe. This limits the roe fishery to the months of peak spawning activity, which, in California, are December through March. Known spawning areas for herring in California are: San Diego Bay, San Luis River, Morro Bay, Elkhorn Slough, Tomales Bay, Bodega Bay, Russian River, Noyo River, Shelter Cove, Humboldt Bay, and Crescent City Harbor (Figure 2). Only Tomales Bay and San Francisco Bay have populations large enough to support a major fishery. Small fisheries exist at Humboldt Bay and Crescent City Harbor, and with Fish and Game Commission approval fishing could be attempted at any of the known spawning areas.

The herring dead bait and animal food fishery occurs during the summer months with catches from Monterey Bay. Live bait may be taken at any time in San Francisco Bay.

There is also a sportfishery for herring in San Francisco Bay and the Noyo River. Fish are caught with hook and line and hoop nets. Herring are generally taken by sportsmen of Asian ancestry for their roe content and by others for pickling. The sportfishery occurs as the herring move into shallow areas to spawn and fishing occurs at a furious pace while the herring are spawning, then ends abruptly when spawning is over. Also there is a sportfishery for herring eggs on algae. Herring eggs may be collected by diving or at low tide when egg deposits are exposed. This sportfishery is very popular in San Francisco Bay.

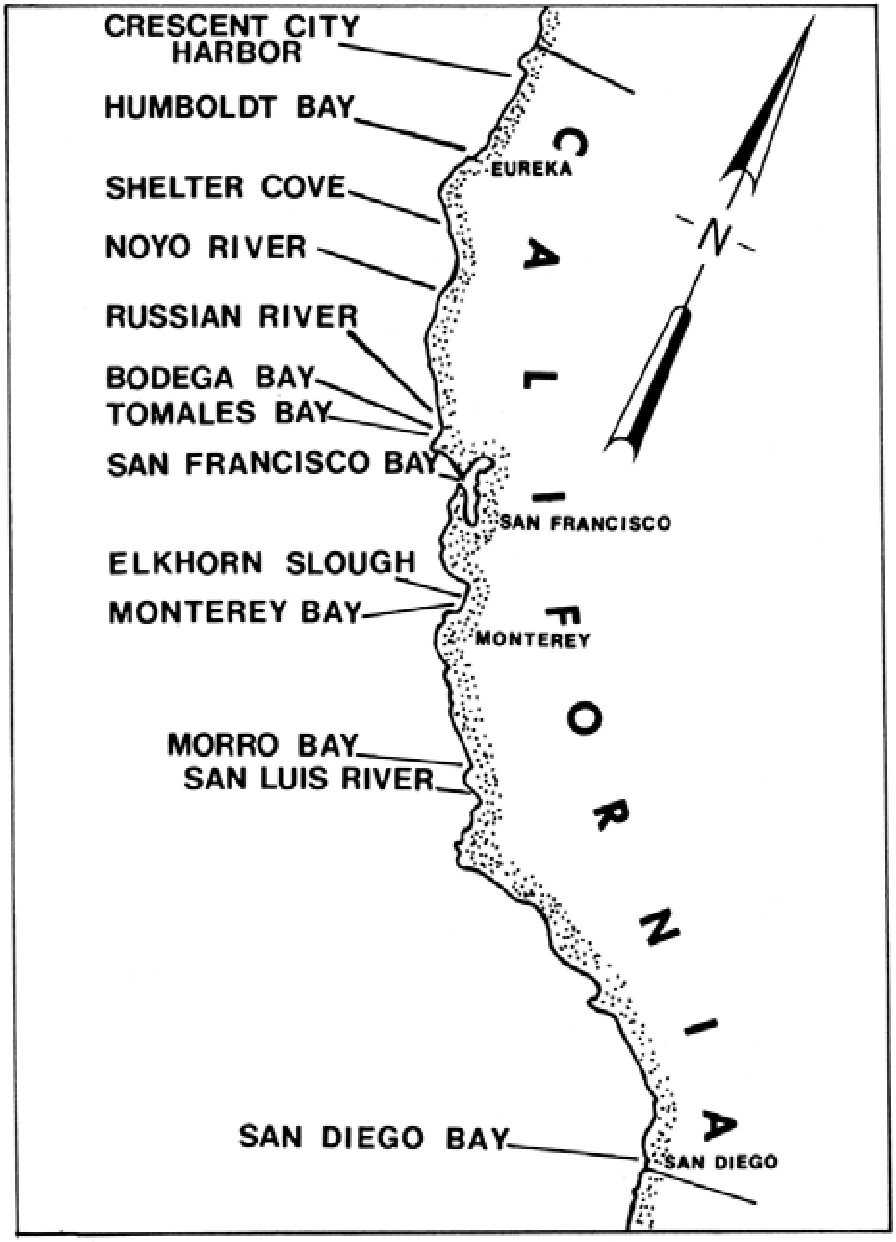

FIGURE 2. Known herring spawning areas.

FIGURE 2. Known herring spawning areas

1.3.3. *Annual Landings*

California Department of Fish and Game began tabulating annual landings in 1916. Annual landings are given by area as the historical data allow (Table 1). The 1979–80 roe fishery quota of 7,320 tons (6,639 mt) exceeded the previous high annual catch of about 5,600 tons (5,080 mt) in 1978. Over the years Tomales Bay and San Francisco Bay have provided the bulk of the catch, but Monterey Bay has provided good catches in some years. Other areas, such as San Diego Bay, Noyo River, Humboldt Bay, and Crescent City Harbor, have contributed minor amounts to the catch.

The herring roe fishery occurs at year's end and landings overlap two calendar years. This results in two totals for herring landings, the annual herring landings published by the Department (Table 1) and the seasonal landings from the roe fishery that is regulated by a quota system (Table 3). Seasonal landings are recorded separately, but are only important with regard to seasonal quotas set to regulate the roe fishery.

TABLE 3. California Pacific Herring Roe Fishery Data by Season.

Season	*Permits*	*Quotas * (tons)*	*Catch (tons)*	*Price range ($/Ton)*
1972–73 **				
Tomales Bay	5	750	598	50–100
San Francisco Bay	12	1,500	436	50–100
Crescent City Harbor	Open	No Limit	12	50–100
1973–74				
Tomales Bay	5	450	521	120–180
San Francisco Bay	12	500	1,938	120–180
Humboldt Bay		20	2	200
Crescent City Harbor		No Limit	59	200
1974–75				
Tomales Bay	10	500	518	160
San Francisco Bay	22	600	514	125–160
Humboldt Bay	Open	20	–	–
Crescent City Harbor	Open	No Limit	13	100–180
1975–76 †				
Tomales Bay	14	625	144	200–300
Bodega Bay	Open	No Limit	477	200–300
San Francisco Bay	58	3,050	1,719	200–300
Humboldt Bay	Open	20	11	200–300
Crescent City Harbor	Open	0	0	
1976–77				
Monterey Bay	Open	No Limit	74	160
Tomales Bay	17	825	344	240–400
Bodega Bay	24	350	262	240–400
San Francisco Bay	231	4,015	4,201	40–360
Humboldt Bay	6	50	21	
Crescent City Harbor	–	0	0	
1977–78				
Monterey Bay	Open	No Limit	48	200
Tomales Bay	38	600	646	600–1,200
Bodega Bay	30	575	70	600–1,200
San Francisco Bay	285	5,025	4,987	600–1,200
Humboldt Bay	4	50	12	600–1,200
Crescent City Harbor	1	30	13	600–1,200
1978–79				
Monterey Bay	Open	No Limit	40	200–300
Tomales and Bodega Bays	69	1,210	448	1,000–2,300
San Francisco Bay	278	5,020	4,121	1,000–2,300
Humboldt Bay	4	50	49	1,000–2,300
Crescent City Harbor	3	30	12	1,000–2,000
1979–80				
Monterey Bay	Open	No Limit	25	400–500
Tomales and Bodega Bays	69	1,210	603	1,000–3,000
San Francisco Bay	272	6,020	6,430	1,000–3,000
Humboldt Bay	4	50	49	1,000–3,000
Crescent City Harbor	3	30	26	1,000–3,000

* To convert short tons to metric tons, multiply by 0.907.
** Quotas were set by State Legislature in 1972–73 through 1974–75 seasons.
† Quotas have been set by Fish and Game Commission since the 1975–76 season.

TABLE 3. California Pacific Herring Roe Fishery Data by Season

1.3.4. *Vessels and Gear*

Historically, beach seines and gill nets were used to take herring in Tomales and San Francisco Bays. In 1952 lamparas were introduced in Tomales Bay and were very effective (Scofield 1952). The lampara is a round haul net that is set in a circle around a school of fish. It has no purse rings, and fish are forced into a bag by retrieving both ends of the net simultaneously. Lamparas are most effective in shallow water when the lead line rests on the bottom. Lampara boats are small, between 33 and 51 ft. The smaller boats use lighters (storage barges) with a capacity of 20–30 tons (18–27 mt) of fish.

In 1973, lamparas returned to Tomales and San Francisco Bays for the roe fishery. Purse seines were introduced in 1974. Gill nets and beach seines were used continually through the years, but gill nets did not become a major gear type again until 1975–76 season.

Today there are three major gear types in the fishery: gill nets, purse seines, and lamparas. Beach seines continue to be used in Tomales Bay by local fishermen, but they only supply a minor part of the catch.

Gill nets became more competitive when "set" or anchored nets were permitted in the 1976–77 season. The roe fishery shifted then from a round haul dominated fishery to a gill net dominated fishery. In the 1977–78 season round haul nets were prohibited in all areas except San Francisco Bay. This shift is continuing because buyers prefer the larger fish and higher percentage of females taken by gill nets.

During the 1979–80 season 363 vessels participated in the roe fishery, more than any other California commercial fishery except hook and line fisheries, and 306 of these vessels were gillnetters.

1.3.5. *Description of Roe Fishery By Season*

1972–73 Season. As the 1972–73 season approached, the Department took a "wait and see" attitude. It soon became apparent that an almost unlimited number of fishing boats might descend on our relatively small stocks of herring, which we felt could easily be overfished. In addition, there was considerable public opposition to the herring fishery. Emergency legislation was passed to temporarily control the fishery. The act imposed limits of 750 tons (680 mt) for Tomales Bay and 1,500 tons (1,363 mt) for San Francisco Bay (Table 3) and expired after 61 days.

Fishing began in Tomales Bay on January 6, 1973, and by January 25th a total of 598 tons (542 mt) were taken (Table 3). Fishing then centered on San Francisco Bay and from January 29th to March 3rd 436 tons (395 mt) were taken (Table 3). The quota was not reached in San Francisco Bay because fishing did not start until the season's spawning was nearly half over.

1973–74 Season. When the emergency legislation expired March 4, 1973, the herring fishery was again open to unlimited fishing. Some confusion existed as to what should be done regarding the upcoming season. The Department felt that a limited fishery should be allowed although there was considerable public opinion against any fishing; the fishing industry wanted few restrictions on the fishery. The controversy resulted in new legislation that imposed limits, except for bait, of 450 tons (408 mt) in Tomales Bay and 500 tons (454 mt) in San Francisco Bay (Table 3), and directed that the catch limits remain in effect for 2 years (1974 and 1975) during which time the Department would estimate the spawning biomass of herring in both bays. At the end of the 2-year study, regulatory authority over the fishery would revert to the California Fish and Game Commission. New catch limits would be based on the results of the field studies.

The fishery was limited to five boats in Tomales Bay and 12 boats in San Francisco Bay to be decided by lottery. An applicant drawn for one bay was not eligible for the other. No permittee was allowed to take more than 150 tons (136 mt).

Fishing began on January 4th in Tomales Bay and January 14th in San Francisco Bay. The quota in both bays was exceeded due to 12 vessels that caught herring for bait purposes. Herring for bait was not included in the catch limits because of an apparently very limited market. The fishery principally had been for herring roe, intended for human consumption. Bait fishing in Tomales Bay was stopped voluntarily by the fishermen when the intent of the regulations was explained.

It became apparent that bait herring landings in San Francisco Bay would be excessive and emergency legislation was introduced to include bait herring under the quota. By the time this legislation became law on February 14, 1974, over 1,400 tons (1,270 mt) of "bait" herring had been landed. How this "bait" herring was processed is questionable. Once herring is shipped out of State, the Department loses jurisdiction. The emergency act also raised the quota for the 1974–75 season to 500 tons (454 mt) in Tomales Bay and 600 tons (544 mt) in San Francisco Bay (Table 3). These quotas included both roe and bait herring.

Additional legislation established a 20 ton (18 mt) quota for Humboldt Bay (Table 3) and directed a 2-year study be done to estimate the resource size.

1974–75 Season. The California Fish and Game Commission set the opening of the 1974–75 herring fishing seasons for January 5, 1975, in Tomales Bay and January 20th in San Francisco Bay. Three lampara boats, one purse seiner, and one gill netter were drawn by lottery for the Tomales Bay roe fishery and five special bait permits were issued (Table 3). A large spawning run appeared in Tomales Bay during the 2nd week of the season and the quota of 450 tons (409 mt) for human consumption was exceeded in only 2.5 days. By the time fishing was stopped, 518 tons (470 mt) had been taken (Table 3).

Twelve boats were drawn by lottery for the San Francisco Bay herring roe fishery. Only 10 boats landed herring: five purse seiners and five lampara boats. of the 10 bait permitees, only five landed herring, two gill netters and three lampara boats.

Fishing began on January 20, 1975, and excellent catches were made. Fishing was stopped on January 22nd for a tonnage count and resumed on January 26th, but the herring schools which were being fished had spawned and left the bay. A new spawning run appeared on February 2nd and the quota of 500 tons (454 mt) was then reached (Table 3).

1975–76 Season. Legislative control expired after the 1974–75 season and regulatory authority over the fishery in Tomales and San Francisco Bays reverted to the Fish and Game Commission.

New regulations adopted by the Fish and Game Commission continued the lottery and increased catch quotas (Table 3). Round haul boats were limited to 100 tons (91 mt) each and gill net boats 25 tons (23 mt). In addition, 10 bait (dead) permits of 5 tons (4 mt) each were made available on a first-come, first-serve basis. Five round haul boats and four gill net boats were drawn for Tomales Bay. Round haul quotas were 100 tons (91 mt) per boat and gill-net quotas were 25 tons (22 mt) per boat. There were also five bait permits issued at 5 tons (4 mt) each for a total quota of 625 tons (567 mt) (Table 3).

The season opened January 5, 1976, in Tomales Bay but fishing did not begin until January 13th because of a brief price dispute. The quota was not reached because over 60% of the season's herring spawning had been completed before fishing began. In addition, 477 tons (433 mt) of herring were taken from Bodega Bay (Table 3), and a separate quota had to be established for Bodega Bay during the 1976–77 season.

In San Francisco Bay the season opened January 19, 1976, after 70% of the season's herring spawning had been completed. Landings totaled only 1,719 tons (1,559 mt) (Table 3) because the fleet fished only one goodsized run.

1976–77 Season. The Fish and Game Commission retained control of the fishery in all ocean waters, including Humboldt Bay, after legislative control expired following the 1975–76 season.

The lottery was discontinued in San Francisco Bay and permits were issued to all qualified applicants applying before October 15, 1976. Permits were issued to 165 gill netters, 39 purse seiners and 27 lampara boats. Separate quotas were established: 1,000 tons (907 mt) for gill net and 1,500 tons (1,361 mt) each for purse seine and lampara. A 15-ton (14-mt) fresh fish market quota also was established making the season quota in San Francisco Bay 4,015 tons (3,642 mt) (Table 3). The season opened January 3, 1977, and the gill net and purse seine quotas were filled by January 24th. Total catch for the season was 4,201 tons (3,811 mt) (Table 3). Set gill nets were legalized this season and resulted in much better gill net catches. The price for gill net caught fish averaged about $280 compared with $200 for round haul caught fish. Gill netters consistently caught larger herring with a higher roe content. Price was determined by percentage roe content and ranged from $40 per ton for spawned out herring to $360 per ton for a few selected catches.

In Tomales Bay the lottery was retained and five lampara and seven gill net permits were issued. Five special gear permits were also available on a first-come, first-serve basis. The seasonal quota was 825 tons (748 mt) (Table 3), and was divided as follows: round haul, 550 tons (499 mt); gill net, 250 tons (227 mt); and special gear, 25 tons (23 mt). The season opened January 3, 1977. About 80% of the spawning activity had already taken place and the fleet had difficulty catching herring throughout the season. By season's end, March 31st, the catch totaled approximately 344 tons (312 mt) (Table 3).

In Bodega Bay a quota of 350 tons (318 mt) was established for gill nets only and 24 permits were issued. Landings totaled 262 tons (238 mt). In Humboldt Bay a quota of 50 tons (45 mt) had been established for gill nets only, and 21 tons (19 mt) were landed. No quota was established for the Crescent City area. However, spawn surveys were initiated and data gathered were to be used to set quotas for the 1977–78 season.

1977–78 Season. New quotas (Table 3) and regulations were adopted by the Fish and Game Commission. Permits were issued to permittees from the previous season who re-applied. An additional 164 permits were issued based on qualifying points earned over the past 10 years; one point earned for every year that the applicant participated in the herring fishery, and 1 point for each year the applicant had a California commercial fishing license; the maximum number of points possible was 20. All applicants with 20 points were issued permits. Applicants with lower point totals were issued permits until 155 gill net, 5 round haul, and 4 beach seine permits were issued. The Fish and Game Commission also prohibited round haul nets in Tomales and Bodega Bays.

The roe fishery quota in San Francisco Bay was allocated as follows: gill net, 2,000 tons (1,814 mt); purse seine and lampara, 1,500 tons (1,361 mt) each. The gill net season opened December 15, 1977, in Tomales Bay, Bodega Bay and San Francisco Bay. The remaining fisheries opened January 2, 1978.

Quotas were reached in each area except Bodega Bay (Table 3) where gill net boats had difficulty catching herring throughout the season.

1978–79 Season. No new permits were issued for the 1978–79 season. Everyone who fished in the 1977–78 season and applied this season was issued a permit. A total of 354 permits was issued, 294 of these were gill net permits. New regulations required that gill nets be anchored by 16-kg (35-lb) weights and lighted at each end; a limit of 130 fathoms per vessel on gill nets was imposed in San Francisco Bay and 195 fathoms in Tomales Bay.

A new quota system was instituted for San Francisco Bay in the 1978–79 season because of poor spawning escapement in the 1977–78 season. The initial quota was set at 1,020 tons (925 mt), 1,000 tons (907 mt) for the roe fishery and 20 tons (18 mt) for fresh fish markets. The quota was increased by 1,000 ton (907 mt) intervals, up to a maximum of 5,020 tons (4,553 mt) (Table 3), as spawning escapement occurred. Gear quotas were retained with gill net vessels alloted 40%, purse seiners 30% and lampara 30% of the total quota. Due to congestion on the fishing grounds, gill net permittees in San Francisco Bay were divided into two platoons, fishing alternate weeks. To ease problems in monitoring landings and enforcing quotas, no permittee was allowed to take or possess more than 40 tons in one load.

The Tomales and Bodega Bay quotas were combined (Table 3) and the permittees split into two platoons that fished alternate weeks.

The quota in San Francisco Bay was not reached because lamparas were not able to fill their individual gear quota. In Tomales and Bodega Bays fishing was slow throughout the season. The combined Tomales and Bodega Bay quotas have not been taken since round haul boats were prohibited in the 1977–78 season.

1979–80 Season. No new permits were issued. All fishermen that fished in the 1978–79 season and applied were issued permits. The Fish and Game Commission established guidelines for allowing new permittees in the fishery, but limited new permits to gill nets and made no provisions for additional purse seine or lampara permits. New gill net permits would not be issued for San Francisco Bay until 1980–81 season and no new gill net permits will be issued for Tomales and Bodega Bays until the number of permittees drops below 69, the current number.

When new permits become available they will be issued to applicants based on qualifying points under the following rules:

1. One point for each year the applicant has held a valid California commercial fishing license.
2. A total of 10 points for those applicants who participated in the California herring fishery in each of the past 3 years.
3. Seven points for participation in two of the past three herring fisheries.
4. Five points for participation in one of the past three herring fisheries.
5. A drawing will be held if more applicants are in the same point category than there are permits available.

Gear quotas remained in effect in San Francisco Bay and in addition to the 40 ton (36 mt) load limit, a season limit of 100 tons (907 mt) was imposed on all permittees.

The San Francisco Bay quota was exceeded slightly (Table 3), but Tomales and Bodega Bay permittees generally had poor success. Spawn surveys in Tomales Bay indicated adequate spawning escapement but the fish were apparently not available to the fleet.

1.3.6. Bait and Animal Food Fishery

This fishery is almost entirely at Monterey and occurs during the summer months. The Fish and Game Commission established an April 1st to September 30th season in 1976. In 1979 the season was extended to December 1st. Since 1970 landings have averaged 102 tons (92 mt) and the peak year was 1973 when 342 tons (310 mt) were taken. This fishery supplies markets for animal food at zoos. There is a large bait market for herring and the fishery cannot satisfy the demand. Bait herring must be about 150 mm (6 inches) TL and most herring in Monterey Bay during the summer are too large.

1.4. Discussion

The present herring roe fishery is totally dependent on the Japanese market. The price for herring increased dramatically in 1978 and 1979 to a peak of about $4,000 per ton, then dropped to $1,000 per ton in 1980. Competing Japanese companies drove the wholesale price of herring roe to $27/lb and Japanese consumers balked at the high prices, causing the market to collapse. Washington State herring prices in 1980 stabilized at $600/ton (Trumble, pers. commun.). Future prices in California probably will be well below the peak reached in 1979 and, although Japan is still importing herring roe, the fishery may never be as lucrative as it once was.

2. BIOLOGICAL CHARACTERISTICS OF CATCHES

The herring fishery in California was insignificant from 1955 to 1972 and during this time landings were not sampled. The Department initiated a seasonal program to evaluate the herring resource in 1973 when the roe fishery began. This program included sampling the landings for age, size, sex, and maturity.

2.1. METHODS

2.1.1. Catch Sampling

The San Francisco Bay and Tomales Bay fisheries have been sampled annually since 1973. Sampling of herring landings at Humboldt Bay and Crescent City has been irregular and those data are not included in this report.

Gill nets, purse seines, and lamparas are the major types of fishing gear utilized in the fishery. Because of the selectivity of each gear type, I attempted to sample each separately. At least one sample was taken per day for each gear and the same boat was not sampled on successive days, unless it was the only successful boat. A sample consisted of a scoop of herring totaling about 2.3 kg (5 lb) taken while the boat was unloading.

Samples were processed by placing every other fish on a scale until a sub-sample weighing 1 kg (2.2 lb) was reached. Then the other fish selected were weighed. If the weights of the two sub-samples differed by more than 0.1 kg (0.2 lb), all fish were mixed thoroughly and the process repeated until two sub-samples of approximately equal weight were obtained. Every fish in the first 1-kg sub-sample was weighed to the nearest 0.1 g, measured in millimeters body length (BL), and its sex and stage of maturity determined. Maturity was recorded as spent or mature. Body length was used as the unit of measurement because the fleshy caudal peduncle of herring makes the hypural plate difficult to locate. Body length was measured from the tip of the snout to the end of the silvery part of the body. Otoliths were removed for age determination. The remaining 1-kg sample was discarded. Catch sampling techniques remained unchanged from 1973 to 1980. The number of samples collected during a season is proportional to the amount of herring caught and the length of the fishing season.

2.1.2. Age Determination

Historically, Pacific herring have been aged using scales (Rounsefell 1930); although more recently, otoliths have proven reliable indicators of age in many species of marine fishes. I used herring otoliths for age determinations because I had experience in reading northern anchovy (Engraulis mordax) otoliths (Spratt 1975) and because of the similarity between the two.

The herring spawning season in California is relatively short. Although spawning occurs November through April, most activity takes place December through March and peaks in January–February. There is a winter anchovy fishery in Monterey Bay (Figure 3) where herring are commonly

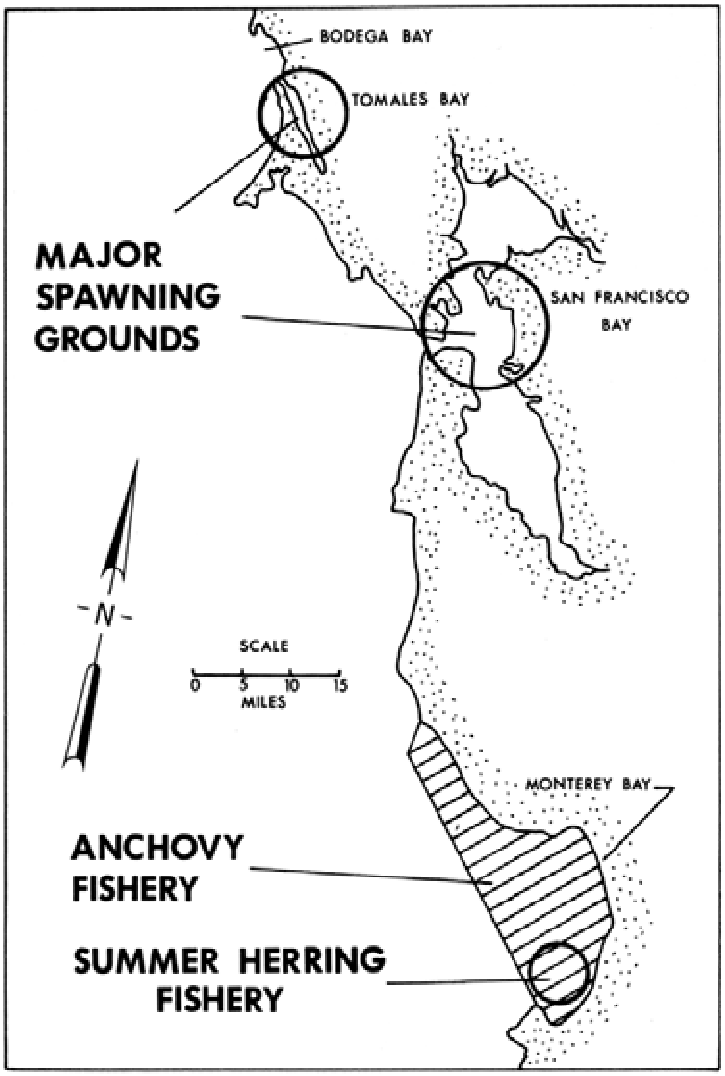

FIGURE 3. Monterey Bay anchovy and herring fishing areas and relationship to major herring spawning grounds.

FIGURE 3. Monterey Bay anchovy and herring fishing areas and relationship to major herring spawning grounds

caught with anchovy, and a summer bait fishery for herring in Monterey Bay. Therefore, I was able to follow herring throughout an entire year by sampling both the seasonal herring and anchovy fisheries. Because the herring spawning season is short, it was relatively easy to follow modal sizes of young-of-the-year herring through time by sampling the catch. I had little doubt as to the age of the young fish.

During January and February 2-year-old herring in the spawning runs average 162 mm (6.4 inches) BL. During the same period immature (1-year-old) herring in Monterey Bay average 113 mm (4.4 inches) BL. These young-of-the-year herring first appear mixed with anchovy catches from the previous August and September when they are about 90 mm (3.5 inches) BL. Growth is very rapid during summer but slows during winter, and herring reach 113 mm BL by the time they are 1-year-old. None of these young-of-the-year herring form a visible opaque ring on the otolith during their first year (Figure 4a). If they do form an opaque ring in their first spring following hatching, it is not evident because it becomes part of the nucleus. The first true opaque annual ring (Figure 4b) is formed in spring when herring are about 14- to 15-months-old and about 125 mm (4.9 inches) BL. Because age is defined as the number of complete growing seasons, winter herring complete one more growing season than the number of annual rings on the otolith would indicate. In the summer herring fishery a fish with two opaque rings would be 2+ years old, or partly through its third growing season. Because the winter herring roe fishery takes place just before ring formation, all fish taken in the roe fishery have just completed a growing season, and age in years is assigned as one more than the number of annual (opaque) rings.

2.2. RESULTS

2.2.1. Age Composition

2.2.1.1. *Tomales Bay*

Recruitment into the round haul fishery begins at age 2 and is complete by age 3. Two- and 3-year-old herring have dominated the round haul catch consistently, averaging 57% by number and 43% by weight of the catch for the 1972–73 through 1976–77 seasons (Table 4).

The Tomales Bay fishery was restricted to gill nets only in 1978. Recruitment into the gill net fishery begins at age 4 and is complete at age 5 or 6. Five through 7-year-old herring dominate the catch consistently (Table 4). The change in age composition after the 1976–77 season is indicative that the gill net fishery is size selective and not representative of the population age structure.

There were no samples taken during the 1978–79 season because of sporadic fishing that made it impossible to anticipate when landings might occur.

In the 1979–80 season landings were again very sporadic and very few samples were taken.

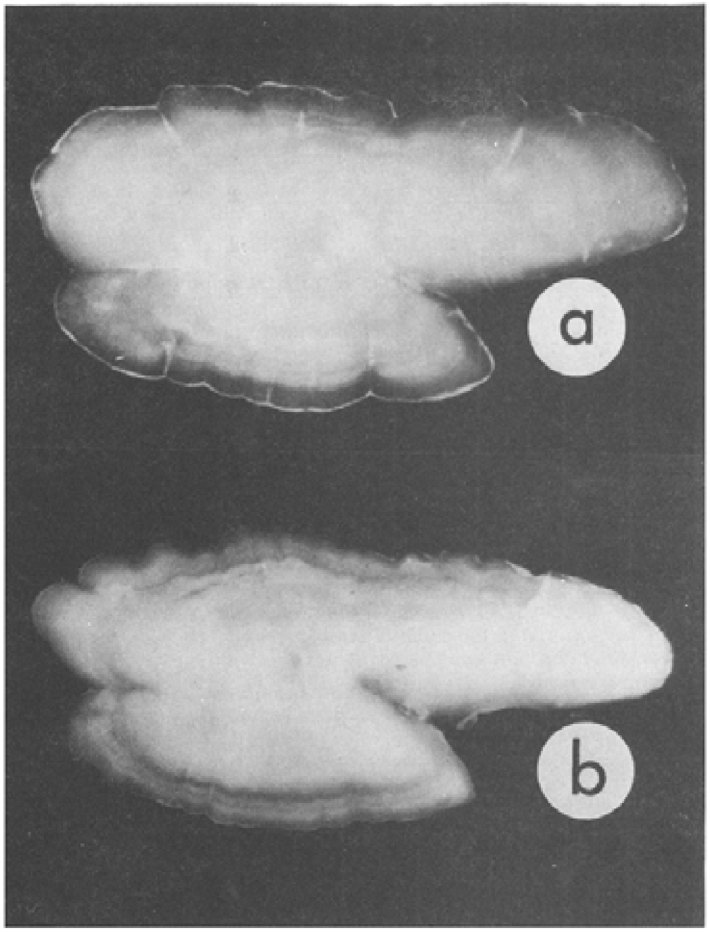

FIGURE 4. a) Otolith from 1-year-old herring. b) Otolith from 2-year-old herring.

FIGURE 4. a) Otolith from 1-year-old herring. b) Otolith from 2-year-old herring

TABLE 4. Age and Weight Composition of the Tomales Bay Catch, 1972–73 through 1979–80 Seasons.

	Age (years)									
	0	1	2	3	4	5	6	7	8	9
1972–73 season										
Percent by number	–	–	34	19	15	12	12	7	1	–
Percent by weight	–	–	21	16	16	16	19	11	1	–
1973–74 season										
Percent by number	–	–	34	22	11	10	12	7	3	1
Percent by weight	–	–	21	18	11	13	18	12	6	1
1974–75 season										
Percent by number	–	–	19	29	23	14	7	7	1	–
Percent by weight	–	–	9	28	24	15	12	10	2	–
1975–76 season										
Percent by number	–	–	29	28	19	16	5	3	–	–
Percent by weight	–	–	19	25	23	20	8	5	–	–
1976–77 season										
Percent by number	–	–	49	21	15	9	3	2	–	–
Percent by weight	–	–	36	22	20	13	5	4	–	–
1977–78 season *										
Percent by number	–	–	–	–	1	11	41	29	17	1
Percent by weight	–	–	–	–	1	11	40	29	18	1
1978–79 season										
Percent by number					No samples taken					
Percent by weight										
1979–80 season										
Percent by number	–	–	–	–	14	41	27	4	14	–
Percent by weight	–	–	–	–	12	39	26	5	18	–

* The fishery was restricted to gill nets only in the 1977–78 season.

TABLE 4. Age and Weight Composition of the Tomales Bay Catch, 1972–73 through 1979–80 Seasons

2.2.1.2. San Francisco Bay

The age composition of the round haul catch was estimated by number and weight (Table 5). During the three seasons, 1973–74 through 1975–76, 2-year-olds dominated the catch. Recruitment of 2-year-olds into the fishery remained constant and the percentage of herring over 5 years old in the catch increased.

TABLE 5. Age and Weight Composition of the San Francisco Bay Round Haul Catch, 1973–74 through 1979–80 Seasons.

	Age (years)									
	0	1	2	3	4	5	6	7	8	9
1973–74 season										
Percent by number	–	–	41	22	17	13	5	1	1	–
Percent by weight	–	–	30	21	21	19	7	1	1	–
1974–75 season										
Percent by number	–	–	41	19	13	10	9	6	2	–
Percent by weight	–	–	31	23	14	11	10	8	3	–
1975–76 season										
Percent by number	–	–	40	27	8	9	9	6	1	–
Percent by weight	–	–	26	24	9	13	14	12	2	–
1976–77 season										
Percent by number	–	–	24	34	20	9	5	4	3	1
Percent by weight	–	–	15	30	22	12	8	7	5	1
1977–78 season										
Percent by number	–	–	29	26	28	9	2	1	3	2
Percent by weight	–	–	22	24	31	12	2	1	6	3
1978–79 season										
Percent by number	–	–	20	29	20	21	8	1	–	1
Percent by weight	–	–	15	25	21	25	11	2	–	1
1979–80 season										
Percent by number	–	–	39	13	19	15	8	4	1	1
Percent by weight	–	–	28	11	21	19	11	6	2	2

TABLE 5. Age and Weight Composition of the San Francisco Bay Round Haul Catch, 1973–74 through 1979–80 Seasons

In the 1976–77 season the catch quotas in San Francisco Bay were increased and the fishery extended over most of the spawning season. This is the only season in which samples were collected throughout the season, and the resulting age composition is the best estimate of the entire spawning population we have been able to obtain. Although 2-year-old herring were strongly represented (24% by number, 15% by weight), it is apparent that herring are not fully recruited to the fishery at age 2. Three-year-old herring dominated the 1976–77 catch accounting for 34% by number and 30% by weight of the catch (Table 5).

In the 1978–79 season the round haul fishery was late in the spawning season. This resulted in fewer old herring in the catch and also suggested that the incoming 1977 year class (2-year-olds) was weak.

In the 1979–80 season the 1977 year class (3-years-olds) was weak but recruitment from 1978 year class (2-year-olds) was up. Therefore, the 1977 year class was the only one to show poor recruitment since 1973.

Herring caught in the gill net fishery in San Francisco Bay are not representative of the population. Gill nets select for age 5 through 7. These three age groups comprised an average of 76% of the catch by number from 1977 to 1980 (Table 6).

TABLE 6. Age and Weight Composition of the San Francisco Bay Gill Net Catch, 1973–74 and 1976–77 through 1979–80 Seasons.

	Age (years)									
	0	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1973–74 season										
Percent by number	–	–	29	21	19	19	8	4	–	–
Percent by weight	–	–	19	18	20	25	12	6	–	–
1976–77 season										
Percent by number	–	–	–	1	6	21	26	26	13	7
Percent by weight	–	–	–	1	5	19	25	28	14	8
1977–78 season										
Percent by number	–	–	–	–	2	7	35	34	19	3
Percent by weight	–	–	–	–	2	6	34	35	20	3
1978–79 season										
Percent by number	–	–	–	3	12	38	28	10	5	4
Percent by weight	–	–	–	2	11	36	29	11	6	5
1979–80 season										
Percent by number	–	–	–	0.5	13	36	32	13	5	0.5
Percent by weight	–	–	–	0.4	12	34	33	15	5	0.6

TABLE 6. Age and Weight Composition of the San Francisco Bay Gill Net Catch, 1973–74 and 1976–77 through 1979–80 Seasons

2.2.2. Size composition

2.2.2.1. Tomales Bay

Sampling of the Tomales Bay round haul catch indicates spawning herring range from 140 to 248 mm (5.6 to 9.8 inches) BL (Appendix I).

The average length of herring taken by gear types has fluctuated from season to season but generally Tomales Bay herring are larger than San Francisco Bay herring (Table 7).

The gill net catch increased in the 1976–77 season, and data collected from the gill net fishery during the 1976–77 to 1979–80 seasons indicate herring ranged in size from 180 to 248 mm (7.0 to 9.8 inches) BL (Table 7) (Appendix I). The gill net fishery took place simultaneously with the lampara fishery yet the length compositions were very different. It is clear that gill nets were selective toward large herring.

TABLE 7. Mean Length of Pacific Herring from the Tomales and San Francisco Bay Roe Fisheries, 1973–74 through 1979–80 Seasons.

	Tomales Bay		San Francisco Bay			
	Round Haul		Gill Net		Round Haul	
Season	Mean length (mmBL)	Size range (mmBL)	Mean length (mmBL)	Size range (mmBL)	Mean length (mmBL)	Size range (mmBL)
1972–73	186	150–234	–	–	–	–
1973–74	190	146–248	–	–	177	134–222
1974–75	189	142–236	–	–	178	132–226
1975–76	184	150–230	–	–	178	128–230
1976–77	169	140–216	212	192–236	181	142–228
1977–78 *	217	194–248	211	178–236	178	144–232
1978–79	No samples		203	164–234	183	146–222
1979–80	214	196–236	206	184–230	180	148–220

* Tomales Bay was restricted to gill nets only in 1977.

TABLE 7. Mean Length of Pacific Herring from the Tomales and San Francisco Bay Roe Fisheries, 1973–74 through 1979–80 Seasons

2.2.2.2. San Francisco Bay

Sampling the round haul catch from 1973–74 to 1979–80 indicated spawning herring ranged in size from 128 to 232 mm (5.0 to 9.1 inches) BL (Table 7) (Appendix II). The average size of herring taken each season showed normal variation and reflected the time the fishery took place in relation to spawning activity. The larger herring spawned early in the season.

The gill net fishery was clearly selective toward larger herring. The mean length of the gill net catch was consistently larger than the round haul catch (Table 7).

2.2.3. Growth Rate

The growth rate of Pacific Herring in California waters has not been well documented. Miller and Schmidtke (1956) stated that California herring are smaller than Alaska herring but they did not present length at age data or growth rates. Samples from 1972–73 to 1974–75 seasonal landings provided data to compute herring growth rates in Tomales and San Francisco Bays. Three years' sampling data were combined to give length frequency by age class for Tomales Bay (Table 8), and 2 years of sampling data were combined for San Francisco Bay (Table 9). Because 1-year-old herring do not spawn, the length frequencies for both bays include 1-year-old herring which were sampled during the winter at Monterey.

The von Bertalanffy growth equation poorly estimated length for older year classes in both Tomales and San Francisco Bay.

A better fit was obtained with the least squares regression: $y = A + B (\ln X)$ Where: y = length in mmBL A = X intercept B = slope (rate of growth) $\ln X$ = log of age in months

With fitted constants (Table 10) the least squares regression yields lengths at age that fit the data very well (Table 11). The least squares growth curves calculated for both bays (Figure 5) indicate that Tomales Bay herring are from 1 to 10 mm (0.04 to 0.4 inches) larger at each age than San Francisco Bay herring. The estimated lengths at age from the least squares regression also show that the growth rates of fish from the two bays diverge, reaching a difference of 10 mm (0.4 inches) at age 8.

TABLE 8. Length Frequency of the Tomales Bay Catch for the 1972–73 through 1974–75 Seasons Combined.

Length (mmBL)	*Age (years)*								
	*1**	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
250								1	
248									
246									
244									
242									
240									1
238									
236							1	1	
234							3		
232						1	3	1	
230						2	1		
228						1	3	2	
226						5	5		
224					1	5	2	2	
222					1	2	4		
220					2	4	2		
218					3	3			
216				1	2	4	3		
214					3	3			
212					3	3	1		
210					7	2	1		
208				1	4	2			
206					3				
204				2	3	3			
202				3	7	4			
200			1	8	4	3			
198				7	4				
196			1	10	2				
194			1	5	2				
192			3	9	1				
190			5	6					
188			1	5					
186		1	8	4					
184		1	13	3					
182		1	14	1					
180			12	2					
178		1	9						
176			6	1					
174		7	8						
172		13	4						
170		8	1						
168		15	4						
166		9	2						
164		22	1						
162		12	1						
160		15	1						
158		6							
156		1	1						
154		10							
152		5							
150		4							
148		1							
146		2							
144									
142		1							
140									
138									
136	1								
134	1								
132									
130	1								
128	2								
126	1								
124	2								

TABLE 8. Length Frequency of the Tomales Bay Catch for the 1972–73 through 1974–75 Seasons Combined

TABLE 8.–Continued

Length (mmBL)	Age (years) 1*	2	3	4	5	6	7	8	9
122	2								
120	2								
118	5								
116	10								
114	9								
112	7								
110	7								
108	10								
106	5								
104	4								
102	3								
100	3								
98	1								
96									
94	1								
92									
90									
N	77	135	97	68	52	47	29	7	1
Mean	113	164	180	193	207	216	224	231	240

* Age 1 herring are from Monterey Bay, and were taken during the winter.

TABLE 8—Cont'd.

TABLE 9. Length Frequency of San Francisco Bay Catch for the 1973–74 and 1974–75 Seasons Combined.

Length (mmBL)	Age (years) 1*	2	3	4	5	6	7	8
250								
248								
246								
244								
242								
240								
238								
236								
234								
232								
230								
228								
226							1	
224					1		1	1
222						1	1	1
220					1	4	4	
218					2			
216						5	2	
214					1	3	3	
212				1	1	2	1	
210					5	4		1
208					4	4		
206				1	6	4	1	
204				1	13	6		
202				2	11	1		
200			1	3	12	3		
198				6	12	2	1	
196				10	10	3		
194			2	9	6	1		
192				8	3			
190			2	15	3	3		
188			3	13	1			
186		2	5	10	2			
184			15	12	2			
182		2	8	9	2			
180		1	11	4				
178		2	10	1	1			
176		4	12	1	1			
174		7	15	2				
172		11	18					
170		15	13	1				
168		21	5	2				
166		26	4	2				
164		21	3					
162		22	3					
160		21	3					

TABLE 9. Length Frequency of San Francisco Bay Catch for the 1973–74 and 1974–75 Seasons Combined

TABLE 9.—Continued

Length (mmBL)	Age (years) 1*	2	3	4	5	6	7	8
158		16	1	1				
156		17						
154		12	3					
152		17	1					
150		9	1					
148		4						
146		7						
144		6						
142								
140		3						
138								
136	1							
134	1	1						
132		2						
130	1							
128	2							
126	1							
124	2							
122	2							
120	2							
118	5							
116	10							
114	9							
112	7							
110	7							
108	10							
106	5							
104	4							
102	3							
100	3							
98	1							
96								
94	1							
92								
90								
N	77	249	139	114	100	46	15	3
Mean	113	161	175	188	200	207	216	219

* Age 1 herring are from Monterey Bay and were taken during the winter.

TABLE 9—Cont'd.

TABLE 10. Constants for Least Squares Regression Formulas for Tomales and San Francisco Bay Herring

Constants	Tomales	San Francisco Bay
A	−17.866	−0.792
B	55.09	49.30

TABLE 10. Constants for Least Squares Regression Formulas for Tomales and San Francisco Bay Herring

TABLE 11. Estimated Length at Age for Tomales and San Francisco Bay Herring

Age (years)	Tomales Bay: Length from regression	Tomales Bay: Observed length	San Francisco Bay: Length from regression	San Francisco Bay: Observed length
1	119	113	122	113
2	157	164	156	161
3	180	180	176	175
4	195	193	190	188
5	208	207	201	200
6	218	216	210	207
7	226	224	218	216
8	234	231	224	219
9	240	240	–	–

TABLE 11. Estimated Length at Age for Tomales and San Francisco Bay Herring

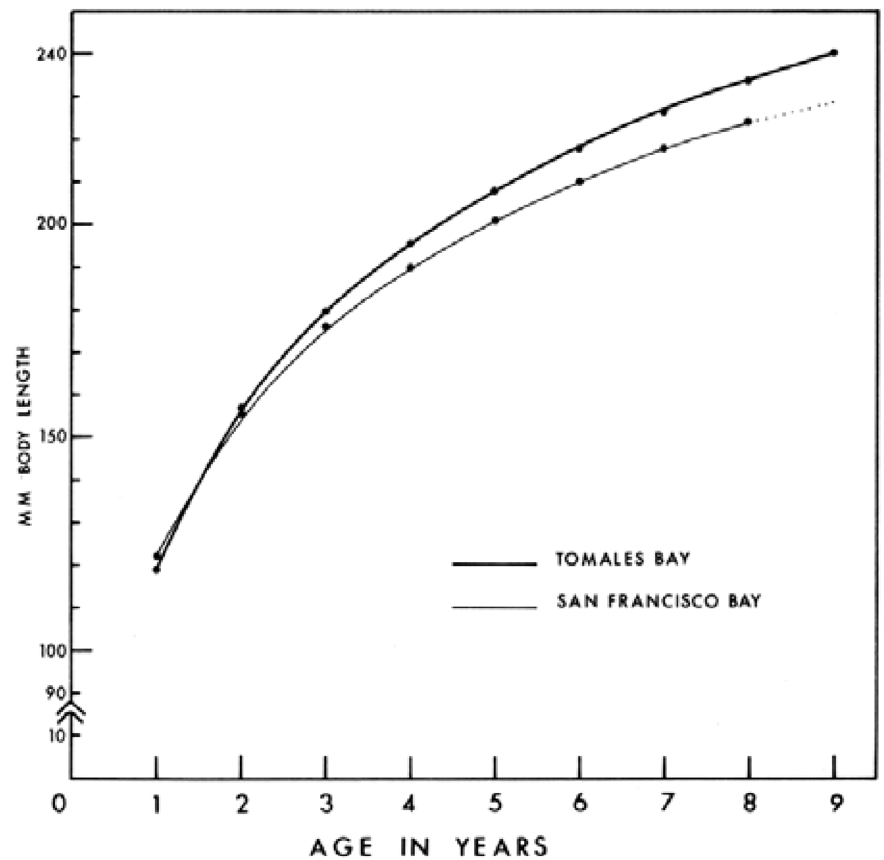

FIGURE 5. Herring growth curves for Tomales and San Francisco Bays calculated by least squares method.

FIGURE 5. Herring growth curves for Tomales and San Francisco Bays calculated by least squares method

An analysis of covariance indicates that the rate of growth of Tomales and San Francisco Bay herring is significantly different at the 99.5% level (F = 29.34). This difference may be evidence that the herring populations in Tomales Bay and San Francisco Bay are distinct. The faster growth of Tomales Bay herring is probably genetic in origin. Some mixing likely takes place between stocks from the two bays while in the ocean, but is not sufficient to mask the divergent growth rates.

2.2.4. Length-weight Relationship

Length-weight data on 1,070 herring from San Francisco Bay and 634 herring from Tomales Bay were collected from 1973 through 1977. The length-weight relationship was determined by using the following formula: $W = AL B$ where: W = fish weight L = fish length A = y intercept B = slope

The relationship was determined for each year in both bays and an F test applied to determine annual variation within bays by testing the equality between slopes. For San Francisco Bay the relationship in 1977 was significantly different from 1974 and 1976. And in Tomales Bay the relationship of 1975 and 1976 to 1973, 1974, and 1977 was significantly different.

When all length-weight data within each bay were combined, the relationships generated for each bay were averages reflecting variation in the year classes as they entered the spawning population. The constants and F values for Tomales Bay and San Francisco Bay (Table 12) indicate males and females do not have significantly different length-weight relationships in either bay. A comparison of the length-weight relationship between San Francisco Bay and Tomales Bay populations reveals a difference (Table 12). However, a plot of the data shows that two curves cross at 215 mm (8.5 inches) BL (Figure 6). Most of the variation between the two curves comes from the extremes and for all practical purposes the length-weight relationship of herring in the size range of 160–220 mm (6.3–8.7 inches) BL does not differ between San Francisco and Tomales Bays.

TABLE 12. Length-Weight Formula Constants and F Test Results

	Within Tomales Bay		*Within San Francisco Bay*		*Between*	
	Males	*Females*	*Males*	*Females*	*Tomales Bay*	*San Francisco Bay*
B	2.8694	2.9635	3.1673	3.2438	2.9316	3.2317
A	0.2848E-4	0.1855E-4	0.5815E-5	0.4118E-5	0.2125E-4	0.4278E-5
Correlation coefficient	0.9303	0.9047	0.9440	0.9571	0.9303	0.9495
Number	332	302	529	541	634	1070
* F		1.09		1.42		30.59

* $F_{.99}$ (1,) = 6.63, $F_{.95}$ (1,) = 3.84

TABLE 12. Length-Weight Formula Constants and F Test Results

2.2.5. Age at Maturity

In California herring enter the spawning population at 2 years of age and by age 3 all herring are mature. One-year-old herring have not been taken during routine sampling of the roe fishery, but it is possible that some 1-year-old herring may spawn unobserved near the end of the season. There is a gradual shift in the age and size structure of spawning runs as the season progresses. Early runs are composed of a low percentage of 2- and 3-year-old herring. These younger herring mature later in the season and compose a high percentage of late season spawning runs.

Age at first maturity occurs later in more northern herring stocks. In British Columbia, herring mature at age 3 and all are mature by age 4 (Outram and Humphreys 1974).

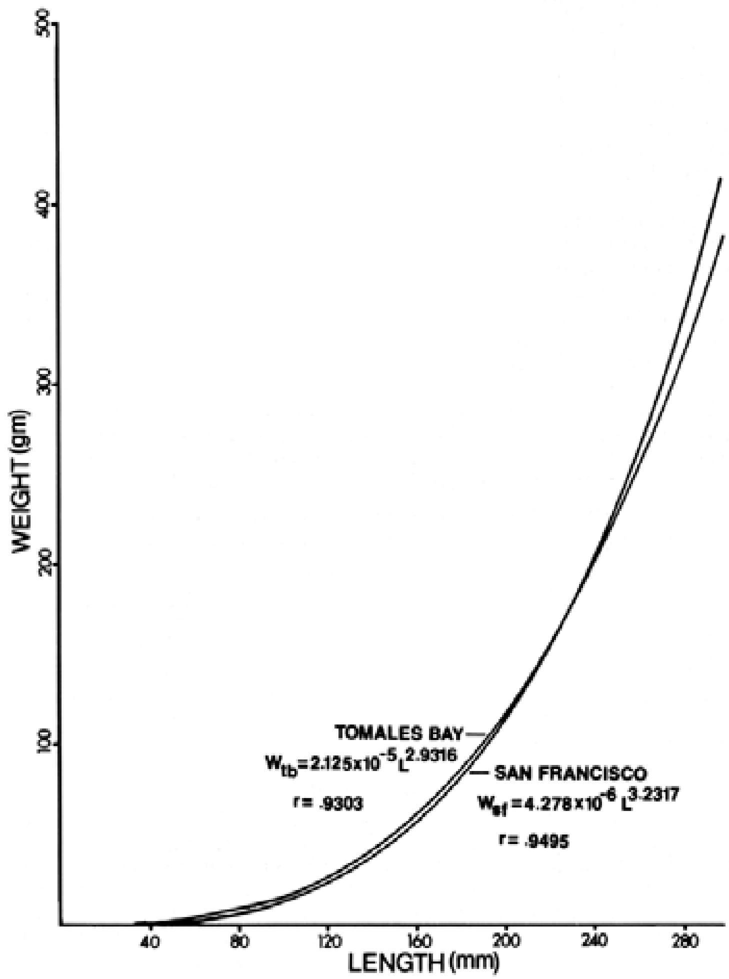

FIGURE 6. Length-weight relationship for Tomales and San Francisco Bay herring.

FIGURE 6. Length-weight relationship for Tomales and San Francisco Bay herring

2.2.6. Sex Ratio

Sex and biomass (weight) ratios have been determined for each season by gear type for San Francisco and Tomales Bay fisheries.

The female to male numerical ratio of the Tomales Bay round haul catch ranged between 1:1 and 1:1.3 from 1973 to 1977 (Table 13). Males held a consistent edge in numbers, but weight ratios indicated the biomass of females and males were nearly equal. For an as yet undetermined reason, females weighed more than males. Hardwick (1973) found a female to male biomass ratio of 1:1. In the 1977–78 season the fishery was restricted to gill nets and the sex ratios changed dramatically. The gill net female to male numerical ratio ranged between 1:0.5 and 1:0.7 from 1978 to 1980. Gill nets were not only size selective, but they also selected for female herring.

TABLE 13. Sex and Biomass (Weight) Ratios of the Tomales Bay Herring Roe Fishery, 1972–73 through 1979–80 Seasons.

Season	*Sex ratio Female:Male*	*Biomass ratio Female:Male*
1972–73	1:1.1	1:1.0
1973–74	1:1.3	1:1.2
1974–75	1:1.0	1:0.9
1975–76	1:1.2	1:0.9
1976–77	1:1.0	1:0.9
1977–78*	1:0.5	1:0.5
1978–79	No samples	
1979–80	1:0.7	1:0.5

* The fishery was restricted to gill net only in 1977.

TABLE 13. Sex and Biomass (Weight) Ratios of the Tomales Bay Herring Roe Fishery, 1972–73 through 1979–80 Seasons

In San Francisco Bay the female to male numerical ratio of the round haul catch (Table 14) ranged between 1:1.3 and 1:0.7 between 1973 and 1980. The gill net landings which began in 1977 have been nearly two-thirds females, substantiating the selectivity of gill nets for female herring.

TABLE 14. Sex and Biomass (Weight) Ratios of the San Francisco Bay Herring Roe Fishery, 1973–74 through 1979–80 Season.

	Round haul		*Gill net*	
Season	*Sex ratio (female:male)*	*Biomass ratio (female:male)*	*Sex ratio (female:male)*	*Biomass ratio (female:male)*
1973–74	1:1.3	1:1.2		
1974–75	1:1.2	1:1.2		
1975–76	1:0.8	1:0.7		
1976–77	1:0.9	1:0.8	1:0.5	1:0.5
1977–78	1:1.0	1:0.9	1:0.7	1:0.6
1978–79	1:0.7	1:0.5	1:0.7	1:0.6
1979–80	1:0.8	1:0.7	1:0.7	1:0.5

TABLE 14. Sex and Biomass (Weight) Ratios of the San Francisco Bay Herring Roe Fishery, 1973–74 through 1979–80 Season

2.3. DISCUSSION

Analysis of the catch is difficult for many reasons. The opening date of the fishery is set prior to the spawning season. The spawning pattern of herring has varied from season to season and this directly bears on results obtained from sampling the fishery. When the fishery opens before a significant amount of spawning is completed a higher percentage of older herring is caught. Conversely, a higher percentage of younger herring is caught when the fishery opens after a majority of spawning is completed. Seasonal catch quotas are small in relation to the fishing capacity of the fleet and quotas can be filled in a week or less. Therefore, it has not been possible to sample an entire season's spawning run and samples become biased toward a single run or toward either old or young herring. Effects of the fishery on the population are difficult to detect; however, large scale changes in relative year class strengths should be detectable.

The average size of herring in the Tomales Bay catch decreased (Table 7) from 1973 to 1976 and showed an expected amount of variation. Since 1977 the average size has increased due to the gill net fishery.

The age composition of the Tomales Bay catch (Figure 7) also reflects the late season fishery in 1976–77. There were very few fish over 5 years old taken in the round haul fishery and an unusually high percentage of 2-year-olds. The gill net fishery in the 1977–78 season was dominated by 6-, 7-, and 8-year-old herring indicating that these older fish were present in the population during the 1976–77 season. No samples were taken in the 1978–79 season and very few samples in the 1979–80 season.

No trends are apparent from examining mean length (Table 7) or percent age composition (Figure 8) of the San Francisco Bay catch. The mean length and age composition of the catch are dependent on the length or timing of the fishing season and changes may not be related to fishing pressure. However, no large scale changes have occurred since the fishery began. Recruitment into the San Francisco Bay round haul fishery begins at age 2 and is complete at age 3. The older age classes (6 through 9) remain well represented after 7 years of fishing.

The gill net fishery since the 1976–77 season documented the selectivity of gill nets with about 1% of the gill net catch being 3-year-olds. Gill nets catch larger herring than round haul nets, and also land a much higher percentage of females.

The female to male ratio does not appear dependent on the time or length of the fishery with near equal numbers of both sexes present from season to season. However, gill nets are selective toward females. The fishery is a roe fishery and the percentage of roe-bearing females in the catch has a direct effect on price paid to fishermen. A gill net fishery yields a higher economic return per unit of catch than a similar round haul fishery.

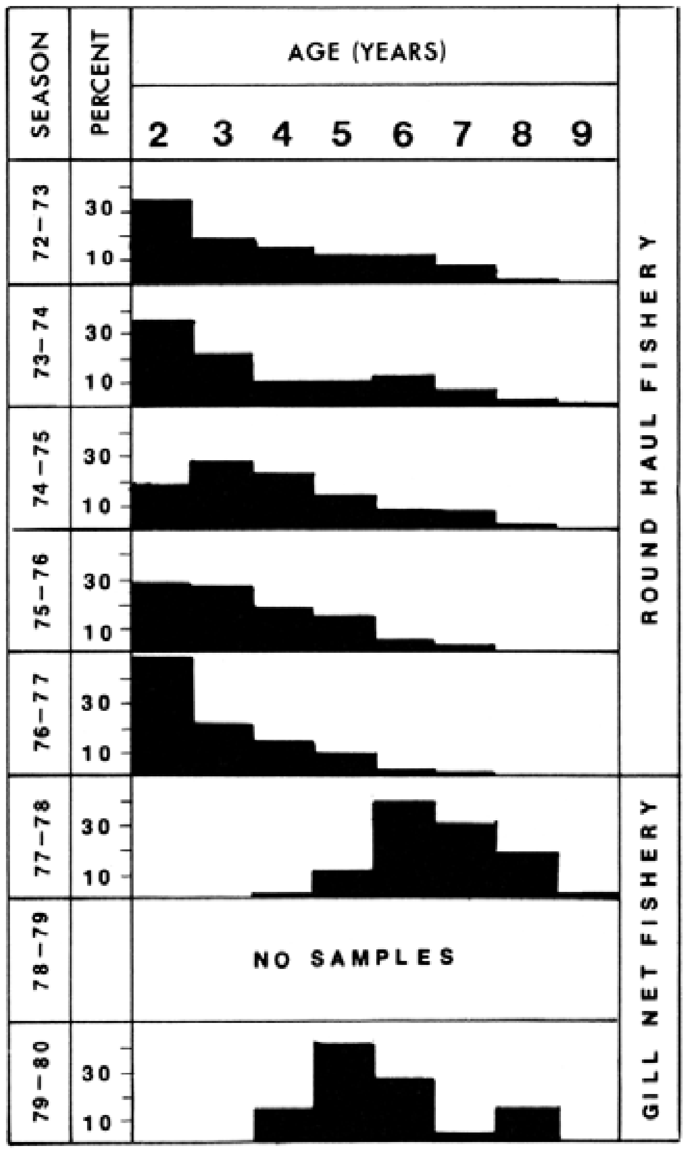

FIGURE 7. Age composition of the Tomales Bay herring roe fishery, 1972–73 through 1979–80 seasons.

FIGURE 7. Age composition of the Tomales Bay herring roe fishery, 1972–73 through 1979–80 seasons

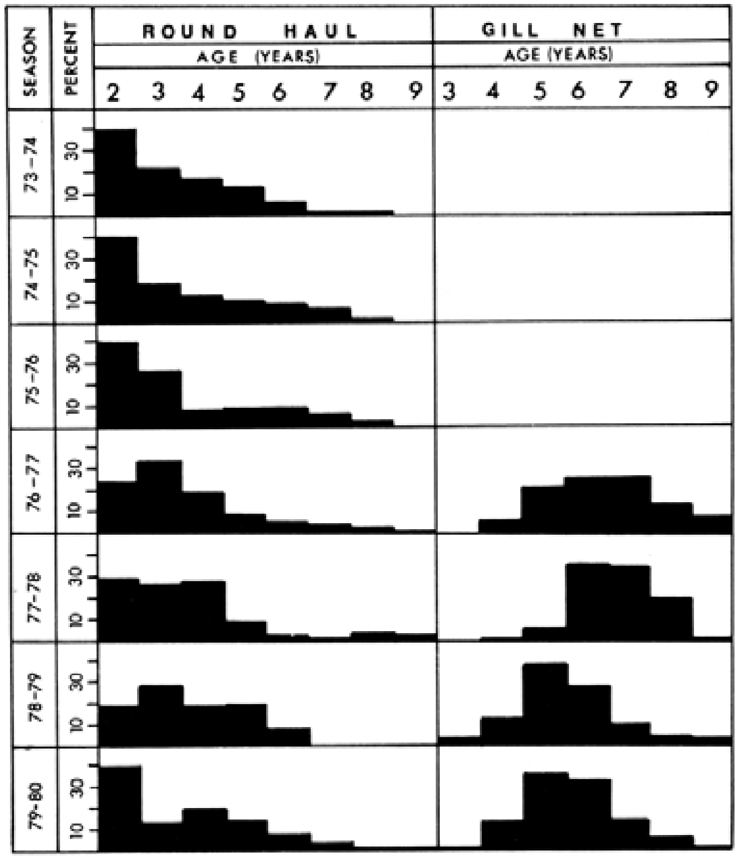

FIGURE 8. Age composition of the San Francisco Bay herring roe fishery, 1973–74 through 1979–80 seasons.

FIGURE 8. Age composition of the San Francisco Bay herring roe fishery, 1973–74 through 1979–80 seasons

3. SPAWNING BIOMASS ESTIMATES

3.1. INTRODUCTION

Herring are known to spawn at many locations along California's coast. Spawning areas south of San Francisco Bay are minor and spawning probably does not occur at each area every year. Spawning areas from San Francisco Bay north to Crescent City (Figure 2) (except for the Russian River and Shelter Cove area) have established sport or commercial fisheries and can be considered as regular spawning areas. This report includes spawning biomass estimates for Tomales and San Francisco Bays only.

3.1.1. Description of Spawning Areas

Tomales Bay and San Francisco Bay are the primary spawning areas in California and are described in detail. A brief description of other spawning areas and available knowledge of associated spawning populations is given for comparison only.

3.1.1.1. *San Francisco Bay*

San Francisco Bay is sheltered from the ocean and influenced by freshwater. Spawning areas are primarily the intertidal zone and immediately adjacent subtidal areas to a depth of 4.5 m (15 ft). Herring literally cover the rocky and sandy shoreline and its associated vegetation with spawn. The only areas not utilized are mud flats with no vegetation. The shoreline areas most often utilized by herring are just inside the Golden Gate Bridge along the Marin Peninsula, the Tiburon Peninsula, Angel Island, and across the bay between Richmond and Oakland (Figure 9). This constitutes over 30 miles of shoreline and is our survey area for intertidal spawns. Miller and Schmidtke (1956) also found herring spawning primarily within this area. Herring have been known to spawn at the northern terminus of San Pablo Bay (Croker 1930) and limited spawning has been observed in south San Francisco Bay.

The major subtidal spawning areas are Richardson Bay and the large shallow area between Richmond and Oakland (Figure 9). The vegetation in both of these areas is predominantly Gracilaria spp. with small patches of Zostera marina found in localized areas. The subtidal spawning areas were discovered in 1978 and have proven to be the major spawning areas for herring in the bay.

3.1.1.2. *Tomales Bay*

Tomales Bay lies in Marin County, a short distance north of San Francisco (Figure 3). It is 20.1 km (12.5 miles) long and averages nearly 1.6 km (1 mile) wide. The bay is completely sheltered from oceanic wave action, and considerable freshwater runoff enters the bay.

Hardwick (1973) documented the species composition and biomass of the marine flora in Tomales Bay and found that eel grass, Zostera marina, comprised 75% by weight of all vegetation in the bay. Although herring spawn on Fucus spp., Ulva spp., Macrocystis sp., Gracilaria spp., Philospadix sp., Gigartina spp., and other algae, eel grass is the primary spawning substrate (Figure 10).

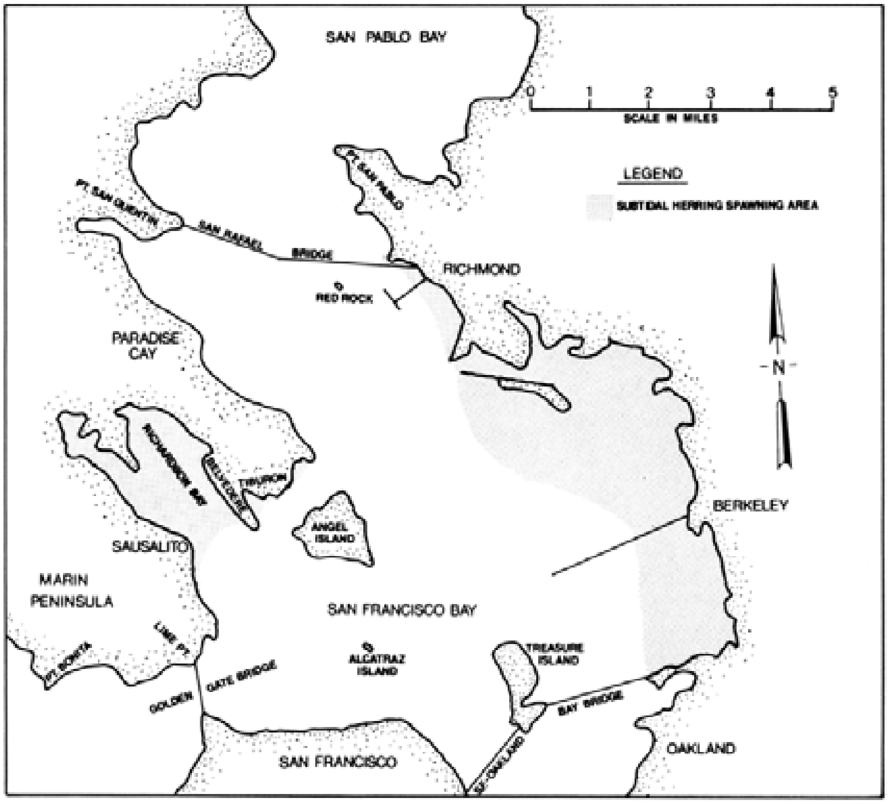

FIGURE 9. San Francisco Bay shoreline and subtidal areas utilized as herring spawning grounds.

FIGURE 9. San Francisco Bay shoreline and subtidal areas utilized as herring spawning grounds

3.1.1.3. *Bodega Bay*

Herring spawnings have been reported in Bodega Bay (Figure 3) by Miller and Schmidtke (1955) and Hardwick (1973). Although there are known spawning areas in the bay, no surveys have been conducted.

3.1.1.4. *Russian River*

Spawnings have been reported in this area but their location and magnitude are unknown.

3.1.1.5. *Fort Bragg*

The Noyo River estuary at Fort Bragg has limited eel grass beds which herring utilize. A small sportfishery provides herring for private use.

3.1.1.6. *Shelter Cove*

Miller and Schmidtke (1956) reported herring spawning in this area but the location and magnitude of spawns have not been determined.

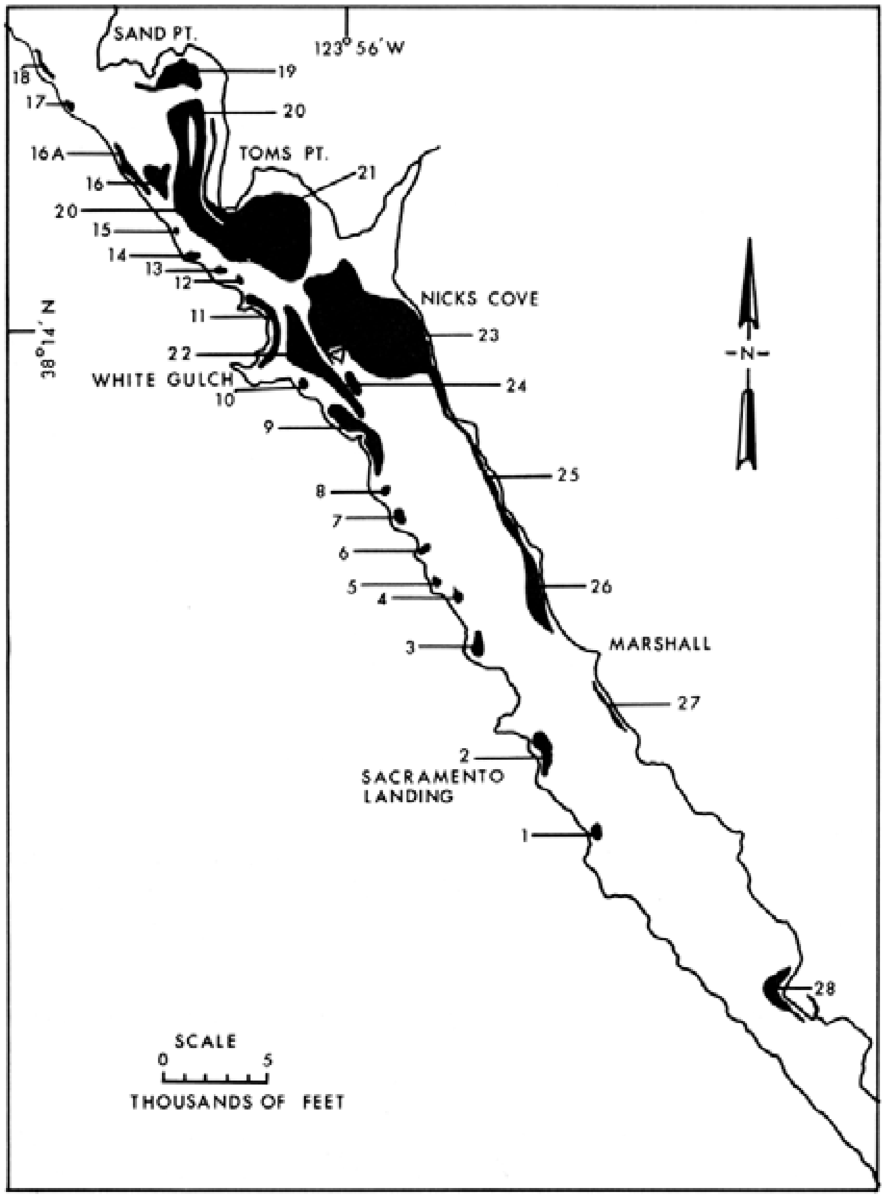

FIGURE 10. Tomales Bay with numbered eel grass beds.

FIGURE 10. Tomales Bay with numbered eel grass beds

3.1.1.7. *Humboldt Bay*

Herring spawning biomass was estimated to be 372 tons (388 mt) in 1975 and 241 tons (219 mt) in 1976 by Rabin and Barnhart (1976). They found that herring spawn primarily on eel grass beds in the northern part of the bay. There are also extensive eel grass beds in the south part of Humboldt Bay that were not utilized by herring.

3.1.1.8. *Crescent City Harbor*

The harbor breakwater and all rocky areas and kelp beds near the harbor provide spawning habitat. Spawns sampled in 1976 indicate moderately heavy spawnings occur over limited areas inside Crescent City Harbor.

3.1.2. Fecundity

Hardwick (1973) estimated herring fecundity at 114 eggs/g of fish, both sexes combined. Kaill (unpublished manuscript) estimated 108 eggs/g of herring. Both estimates were arrived at independently for Pacific herring in Tomales Bay. Rabin and Barnhart (1977) estimated fecundity at 110 eggs/g of herring. I have used Hardwick's fecundity estimate in calculating spawning biomass estimates for Tomales and San Francisco Bays.

3.2. METHODS

3.2.1. Tomales Bay

The method used to estimate spawning biomass in Tomales Bay involves estimating the total number of eggs spawned during a season and using fecundity to convert number of eggs to biomass of adult spawners.

3.2.1.1. *Sampling Techniques*

The principal spawning substrate in Tomales Bay is eel grass. Every eel grass bed in the Bay (Figure 10) was sampled daily, weather permitting, from early December through mid-March. Spawn samples were collected by towing a rake through the eel grass beds. The rake also was used to determine both the perimeter of spawnings and the perimeter of the eel grass beds. The eel grass beds were reached with a 4.5-m (15-ft) outboard motorboat. A survey of the entire bay took approximately 4 hr if no spawnings were found.

Before spawning began in the 1973–74 season, the eel grass beds were measured and the area recorded. These measurements were revised seasonally. Most of the beds with an area of less than 10,000 m^2 (12,000 $yards^2$) were measured directly in the field. The larger beds between White Gulch and Toms Point (Figure 10) were plotted on Coast and Geodetic Survey Chart 5603 by triangulation with landmarks and their area determined. The area of beds changed annually but in March 1980 all beds combined totaled 3.9 million m^2 (Table 15).

TABLE 15. Tomales Bay Eel Grass Beds as Measured in March 1980.

Bed number	Area (m^2)	Bed number	Area (m^2)
1	5,900	16	37,200
2	9,300	16A	11,400
3	12,500	17	2,200
4	100	18	0
5	6,150	19	116,600
6	10,000	20	235,500
7	19,400	21	1,488,000
8	2,700	22	140,000
9	30,500	23	1,209,000
10	3,700	24	20,900
11	27,800	25	207,000
12	2,400	26	270,000
13	100	27	12,400
14	1,800	28	24,000
15	100		
		TOTAL AREA	3,906,650

TABLE 15. Tomales Bay Eel Grass Beds as Measured in March 1980

Spawnings on small eel grass beds generally covered the entire bed. This simplified our surveys because the beds were already measured. Spawnings on larger eel grass beds quite often covered only a portion of the bed. When this happened, the spawning area was plotted and estimated.

Spawning runs seldom were restricted to a single eel grass bed, but often covered several beds in one night or in a series of nights. Each bed was sampled as a separate spawning, and the totals were summed. Sampling rates were determined by area of each spawning site. Generally, we took no less than three samples from small spawning sites and no more than 10 samples from extensive spawning sites. A sample consisted of a single tow with the rake through the eel grass. In dense beds we would collect 1 kg (2.2 lb) or more of eel grass, while in sparse beds it might be less than 100 g (0.2 lb). The location for starting each tow was not predetermined but tows were scattered throughout each bed. The entire sample of eel grass collected by the rake was placed in a plastic bag, labeled with sample number, day, and location from which the sample was taken. Samples were refrigerated if they could not be worked up within a few hours.

Eel grass samples were processed by removing a representative subsample of 1 to 10 g (0.002 to 0.02 lb) from the bag and weighing it. The denser the egg deposits, the smaller the subsample because of the large numbers of eggs that had to be counted. The eggs were counted while they adhered to the eel grass. If several layers of eggs were on the eel grass, many eggs were removed and large clusters broken into small ones then counted. The total number of eggs was recorded, then all remaining eggs were stripped from the eel grass and the clean eel grass weighed. We then had the total number of eggs spawned per unit weight of eel grass.

3.2.1.2. *Eel Grass Densities*

The density of eel grass (kg/m^2) was an integral part of our population estimates, but varied widely from bed to bed as well as within individual beds. It was one of the major sources of error in our estimates.

Department divers determined densities of the eel grass beds in April, after the 1976 spawning season. Due to poor weather conditions and prior commitments by the divers, only a minimal survey was completed. Three areas were surveyed: Bed 9, a very dense bed; Bed 22, of medium density;

and Bed 23, with low density (Figure 10). Thirty-meter (100-ft) transects were laid out randomly within each bed. The divers swam along the transects and determined the percentage of the bed that was actually eel grass. Most beds have a patchy distribution of eel grass. Three transects were made in Bed 9 and two transects each in Beds 22 and 23. Three 0.25 m^2 samples of eel grass were taken from Bed 9 and two each from Beds 22 and 23. The samples were taken from areas of 100% eel grass. The 0.25 m^2 samples of eel grass were weighed and a subsample taken and stripped of excess water. The eel grass was weighed to determine the percentage weight change due to moisture loss. In this manner the weight of eel grass was determined in the same manner as the spawn density (eggs per unit weight of eel grass). Eel grass densities (Table 16) were applied to similar areas throughout the bay. Even though eel grass density samples were taken from beds that had not been decimated by birds, the eel grass density figures are considered conservative due to cropping by birds during the season before densities were determined.

TABLE 16. Densities of Selected Tomales Bay Eel Grass Beds.

	Bed 9			*Bed 22*		*Bed 23*	
	Transect 1	*Transect 2*	*Transect 3*	*Transect 1*	*Transect 2*	*Transect 1*	*Transect 2*
% bottom cover	0.93	0.92	0.74	0.96	0.82	0.58	0.54
Kg eel grass per m^2	2.015	2.076	2.450	0.976	1.520	1.108	0.816
Bed density (kg/m^2)	1.873	1.909	1.813	0.934	1.246	0.643	0.441
Mean bed density (kg/m^2)		1.865		1.090		0.542	

TABLE 16. Densities of Selected Tomales Bay Eel Grass Beds

3.2.1.3. *Effect of Predation*

The total predation on herring spawn deposits by gulls, diving birds, and fish can be extensive. In Canada, Outram (1958) estimated total predation at 56% to 99% and found 66% of predation occurred within 3 days of spawning. Cleaver and Franett (1946) estimated 66% predation after 4 days. Hardwick (1973) implies predation could reach 90% a week after spawning occurs in Tomales Bay. These are maximum rates, predation is actually quite variable and no general rate can be applied to spawnings that occur.

Predation in Tomales Bay was not considered a factor in estimating biomass. Most of the spawnings were sampled less than 1 day after they occurred. In many cases no predation was observed because we found the spawnings before birds gathered in the area. Nevertheless, the density (kg/m^2) of eel grass is greatly reduced by diving birds. The leaves are torn off and often whole plants are pulled out of the substrate. By the end of the spawning season many lush beds of eel grass have been cropped by diving birds to within a few inches of the substrate.

3.2.1.4. *Biomass Computation*

Four separate estimates are needed to compute spawning biomass: (i) number of eggs/kg eel grass; (ii) kg eel grass/m^2; (iii) m^2 of spawn; and (iv) fecundity. Each of these estimates contributes to the variance of the biomass estimates and makes it extremely difficult to determine confidence limits. The total number of eggs spawned at a given time is represented as:

$$\frac{\text{no. of eggs}}{\text{kg eel grass}} \times \frac{\text{kg eel grass}}{\text{m}^2} \times \text{m}^2 \text{ spawn area} = \text{total eggs}$$

EQUATION

The total number of eggs is converted to short tons of herring by multiplying by 0.966 X 10^{-8}, which is:

$$\frac{1}{\text{fecundity} \times \frac{\text{grams}}{\text{pound}} \times \frac{\text{pounds}}{\text{short ton}}} = 0.966 \times 10^{-8}$$

EQUATION

3.2.2. San Francisco Bay

3.2.2.1. *Sampling Techniques for Intertidal Spawns*

Herring will spawn on all types of substrate (except mud) in intertidal and shallow subtidal areas. Therefore, sampling techniques dfferent than those used in Tomales Bay were necessary. A daily search of the intertidal area (Figure 9) was conducted at or near low tide. The intertial area was observed from a boat cruising parallel to the shoreline. We made occasional stops for close-up inspection of the area, but spawnings were usually unmistakable due to the presence of gulls in the area (Figure 11).

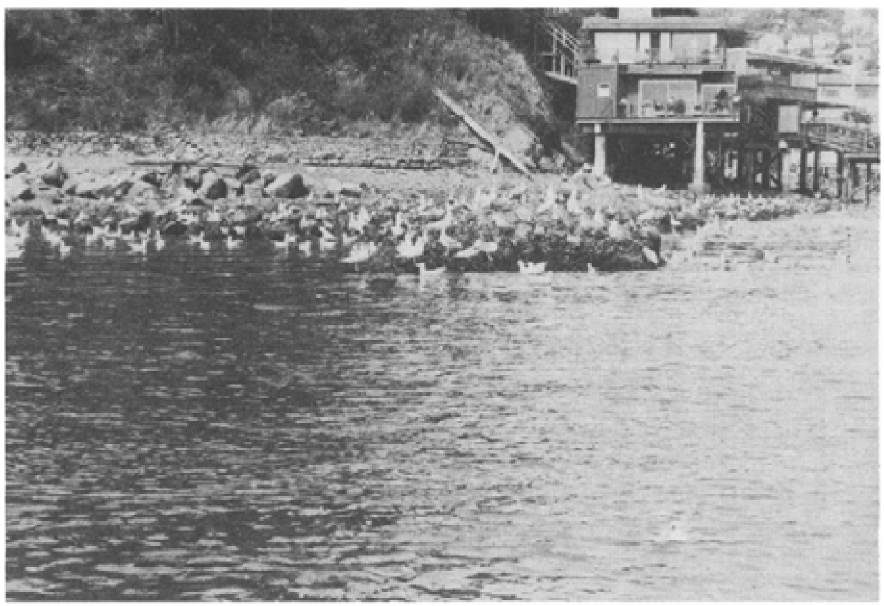

FIGURE 11. Predation by gulls on herring spawn in San Francisco Bay.

FIGURE 11. Predation by gulls on herring spawn in San Francisco Bay

When an intertidal spawn occurred, the perimeters were determined and marked on Coast and Geodetic Chart 5532 and the length of shoreline was measured from the chart. The width of the spawning area was measured at three to five sites and the results averaged. Measurements were made from the high tide mark to the outer limit of egg deposits, which is subtidal and could not be determined readily from the surface. We found that in rocky areas a 2.4-m (8-ft) length of pipe threaded at one end, if probed along the bottom, would pick up herring eggs in the threads. In soft bottom areas the rake was used to determine the outer edge of spawn deposits. At low tide the spawn rarely extended to a depth greater than 4.5 m (15 ft) and these proved simple, fast instruments of measuring spawn widths. The spawning area was computed from the linear shoreline length and average width measurements. I found that widths in light to moderate spawning generally were 11 to 18 m (12 to 20 yd), and 18 to 27 m (20 to 30 yd) in heavy spawnings.

I used a two-stage, random sampling plan to collect egg samples in San Francisco Bay. Each sample consisted of three subsamples. The shoreline at each spawning site was divided into equal sections of approximately 930 m^2 (10,000 ft^2). Between 3 and 10 of the 930 m^2 (10,000 ft^2) sections were randomly selected. From each selected section, I took three, 100 cm^2 (15.5 $inch^2$) random subsamples. The calculated density of egg deposits for each section was the mean value from the three subsamples. The 100 cm^2 (15.5 $inch^2$) subsample areas were selected near the water line and all eggs and algae were removed from the area. When algae was not present, eggs were scraped off rocks or the rock was removed and saved if practical. Occasionally, when densities were very light, it was possible to count the eggs in the field. Otherwise, the egg and alga samples were placed in plastic bags, labeled with sample number, date, and location, and refrigerated until they could be processed.

Beginning in the 1974–75 season we placed 152-mm (6-inch) diameter cement disks throughout the spawn area after we finished sampling to determine if additional spawning occurred. When additional spawnings occurred, the average number of eggs on the disks was determined and extrapolated over the spawn area. The additional spawning biomass was added to that determined from the regular samples. The disks had not been used during the 1973–74 season; however, we did examine spawns periodically for newly deposited eggs.

Eggs and algae in the 100 cm^2 subsample were weighed. The number of eggs was estimated by weighing an aliquot of the subsample, counting the eggs in that portion, and calculating the number of eggs in the subsample.

Spawning area is measured in the field as a flat surface. Actually this is not the case; there is considerably more surface available in rocky or irregular substrates. To compensate for this irregular substrate, area expansion factors were determined during the 1976–77 season and are included in the estimates. The shoreline of the Bay was mapped according to rock diameter (Figure 12) and divided into four size categories: (i) sand or cobble under 152 mm (6 inches); (ii) rocks 152 to 305 mm (1 ft); (iii) rocks 305 to 914 mm (3 ft); (iv) breakwater rocks over 914 mm. Three horizontal, 8.5-m (10-yard) transects were measured in each size category area. Then the same transects were measured following the contour of the rocks. Expansion factors for each size category were determined by averaging the length of the three contour transects and dividing by 8.5 m (10 yards). Expansion factors of 1.13, 1.22, or 2.10 were applied to each individual sample of eggs according to substrate size (categories 2, 3, or 4, respectively) at the sample site, and egg densities were increased accordingly. Spawnings on sand or cobble substrate were not expanded.

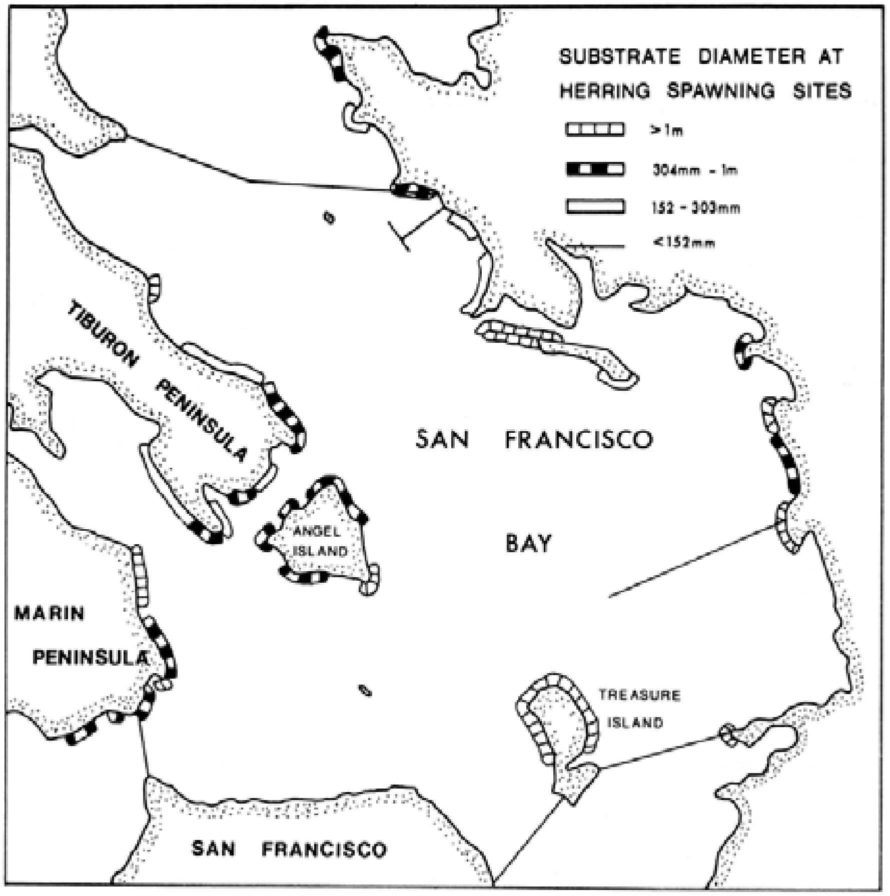

FIGURE 12. **Diameter of rocky intertidal spawning substrate utilized by herring in San Francisco Bay.**

FIGURE 12. Diameter of rocky intertidal spawning substrate utilized by herring in San Francisco Bay

3.2.2.2. Sampling Techniques for Subtidal Spawns

Vegetation Survey. It was necessary to estimate the density (kg/m^2) of subtidal vegetation in order to calculate spawning biomass. Divers collected samples of subtidal vegetation in Richardson Bay during November 1979. I mapped the vegetation in Richardson Bay by collecting qualitative samples with a rake. The area was divided into sections of light, medium, and heavy densities. Five random stations were selected from each section by placing a grid over the area to be sampled, numbering the points where grid lines intersected, and drawing random numbers to determine station points (Figure 13). Divers collected from 10, 0.25 m^2 quadrats at each station. Samples of vegetation were sorted by species and weighed. Gracilaria sp. and Zostera marina were the only species of vegetation collected in Richardson Bay. The combined density (kg/m^2) of Gracilaria sp. and Zostera marina ranged between 0.003 and 0.164 kg/m^2 (Figure 13).

FIGURE 13. Vegetation density (kg/m^2) at randomly selected stations in Richardson Bay.

FIGURE 13. Vegetation density (kg/m^2) at randomly selected stations in Richardson Bay

Divers also surveyed the east side of San Francisco Bay between Richmond and Oakland in January 1980 (Figure 14). This survey was inconclusive because vegetation densities had been drastically reduced by predation on previous spawns or by tidal action which is strong enough to pull spawn laiden Gracilaria from the soft mud bottom. Only one small area of extremely dense (1.5 kg/m^2) Gracilaria sp. in Richmond inner harbor remained undisturbed. Gracilaria sp. densities in all other areas of the east bay were determined subjectively by assigning vegetation densities from Richardson Bay to areas of similar density in the east bay. Three broad categories, 0.01 kg/m^2, 0.1 kg/m^2, and 0.2 kg/m^2 were used (Figure

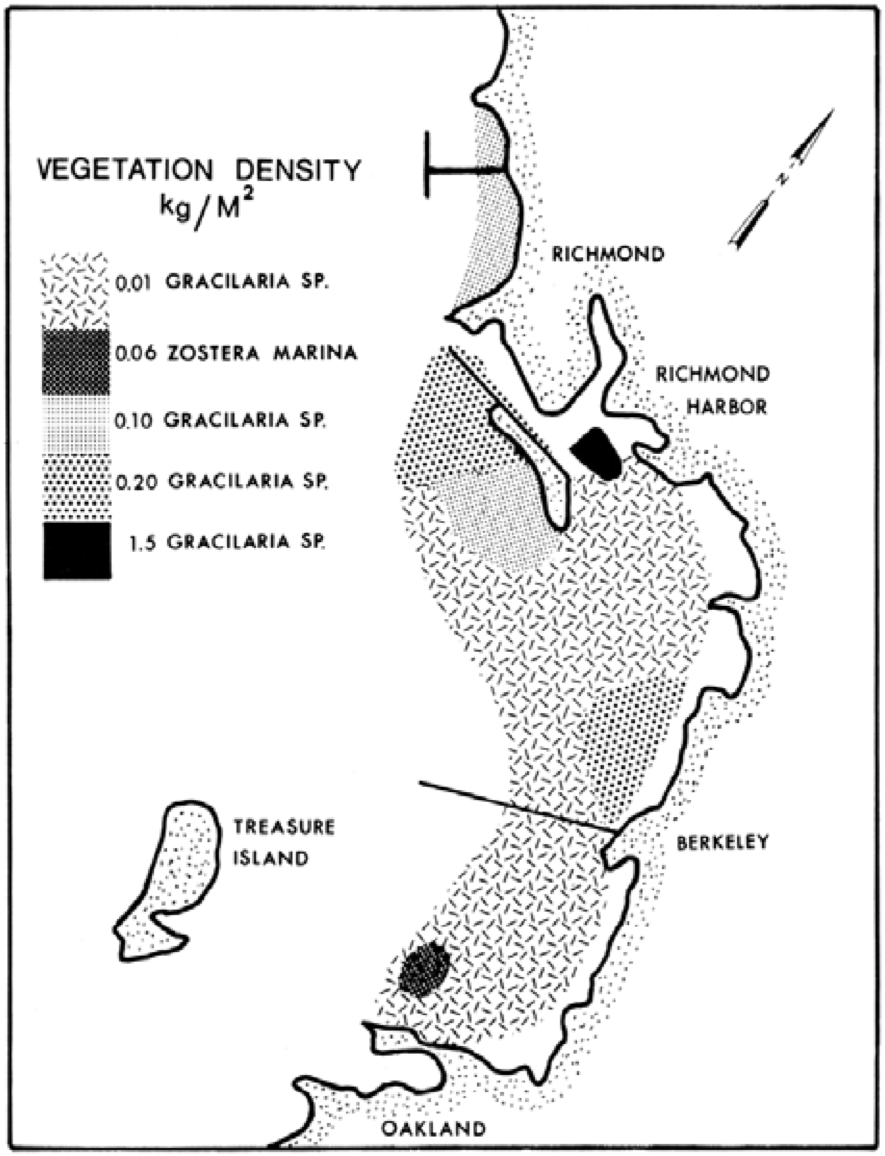

FIGURE 14. Distribution and density of vegetation used to estimate biomass of subtidal herring spawn in San Francisco Bay on December 13–15, 1979.

FIGURE 14. Distribution and density of vegetation used to estimate biomass of subtidal herring spawn in San Francisco Bay on December 13–15, 1979

14). These densities are my best estimate of the vegetation present before the 1979–80 spawning season began.

3.2.2.3. Spawn Sampling

Samples were collected from a small boat by towing a rake through vegetation. A random sampling plan was not utilized but samples were collected throughout each spawn area, then placed in a labeled plastic bag. The sample was processed by first washing vegetation and attached eggs then damp drying and weighing. The eggs were counted on the vegetation, or removed and estimated when large numbers of eggs were present by determining the number of eggs per gram and multiplying by total grams of eggs. While eggs were being removed the clean vegetation was placed in water to prevent drying and when all eggs were removed the clean vegetation was damp dried and reweighed. This process yields the number of eggs per unit weight of vegetation.

3.2.2.4. Biomass Computation

The average number of eggs per square meter was calculated, and total number of eggs determined and converted to short tons of herring.

During low tide as much as 50% of a spawn may be exposed and subjected to severe predation by gulls. Although predation occurs on every spawn it is probably not a critical factor in determining year class strengths. However, in order to estimate the number of eggs spawned, it must be taken into consideration. We conducted replicate sampling on two occasions during the 1973–74 season. A second series of samples was collected from the same sample locations 1 day later and indicated a predation rate of 82%. During the 1974–75 season replicate samples were collected 1 week after a spawn occurred and yielded predation rates of 87% (Table 17) indicating that most predation occurs the first few days after a spawn.

TABLE 17. Estimate of Predation on Intertidal Herring Spawn in San Francisco Bay.

Spawn date	Millions of eggs spawned	Millions of eggs remaining		Predation rate	95% confidence interval
		1 day later	1 week later		
19 December 73	26,301	4,208	–	83%	± 19%
5 February 74	4,300	798	–	82%	± 11%
26 February 75	511,920	–	66,240	87%	± 4%

TABLE 17. Estimate of Predation on Intertidal Herring Spawn in San Francisco Bay

These predation rates were applied to portions of certain spawns in 1973–74 because we could not sample the day after spawning occurred. All spawns in 1974–75 were sampled soon after they occurred and no corrections for predation were applied, even though gulls were feeding in the area before our samples were taken. It was difficult to estimate the effect of a few hours of predation. From 1975–76 through 1979–80 corrections for predation were applied cautiously, and only used on intertidal spawns when egg loss was severe.

3.3. RESULTS

3.3.1. Tomales Bay Spawning Biomass Estimates

Eel grass is the principal substrate used for spawning in Tomales Bay. The biomass of herring that spawned on substrate other than eel grass was undetermined and estimates of spawning biomass arrived at from surveying only eel grass beds are conservative.

3.3.1.1. 1973–74 Season

There were 33 separate spawning sites and there could have been as many as eight spawning runs. Nevertheless, there were only four major spawnings which accounted for 93% of the herring spawning biomass estimate.

It is not necessary to describe each spawning individually because they were all similar, generally differing only in size of spawning area. Date, location, area, density, and biomass estimates were recorded for each of the 33 spawn sites (Appendix III).

The larger beds near White Gulch and Toms Point accounted for most of the biomass estimate, but spawns were no more frequent there than on the smaller beds along the south shoreline (Figure 11).

My estimates indicate a minimum of 626 billion eggs were spawned, equivalent to 6,041 tons (5,480 mt) of herring. The season's catch was 521 tons (472 mt) of prespawners. Adding this catch to our estimate, the spawning biomass becomes 6,562 tons (5,953 mt) (Table 18).

TABLE 18. Tomales Bay Pacific Herring Spawning Biomass Estimates, 1973–74 through 1979–80 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	21,517	646	22,163
1978–79	–	448	–
1979–80	5,420	603	6,023

TABLE 18. Tomales Bay Pacific Herring Spawning Biomass Estimates, 1973–74 through 1979–80 Seasons

3.3.1.2. 1974–75 Season

There were 23 separate spawning sites. Intervals between spawns indicate 8 to 11 runs occurred during the season. As in the 1973–74 season, four major spawns accounted for 92% of all spawning activity.

Date, location, and estimated biomass were recorded for each of the 23 spawn sites (Appendix III). The larger eel grass beds near White Gulch and Toms Point accounted for most of the estimate (Figure 11), but spawning occurred on these beds no more frequently than on the smaller beds along the north and south shore (Figure 11).

My estimates indicate a minimum of 436 billion eggs spawned by 4,210 tons (3,819 mt) of herring. The season's catch was 518 tons (470 mt). Adding the catch to the estimate, the spawning biomass becomes 4,728 tons (4,289 mt) of herring (Table 18).

3.3.1.3. 1975–76 Season

There were 47 separate spawning sites during the season. This represents a 42% increase over the 1973–74 season and 104% increase over the 1974–75 season. There were at least 10 spawnings during the season, but the four largest spawnings accounted for 91% of the season's spawning activity. Date, location, and estimated biomass were recorded for each of the 47 spawning sites (Appendix III).

The 1975–76 season estimate was second only to the 1977–78 season for herring in Tomales Bay. Including the catch of 144 tons, the spawning biomass for the season was 7,913 tons (7,178 mt) (Table 18).

3.3.1.4. 1976–77 Season

Eight runs took place during the season. The first spawn occurred December 1, 1976, and by January 6, 1977, about 85% of the season's spawning activity was completed. As in previous years four major spawns accounted for 90% of the spawning biomass. Biomass estimates were computed for each of the 65 individual spawn sites (Appendix III). More spawn sites were found this year but spawn densities were generally lower and areas smaller than previous years.

I estimated 490.6 billion eggs were spawned by 4,739 tons (4,299 mt) of herring. By including the catch of 344 tons (312 mt) the season's spawning biomass is increased to 5,083 tons (4,610 mt) (Table 18).

3.3.1.5. 1977–78 Season

Herring spawned at 49 locations in Tomales Bay. At least 12 spawning runs took place. Two major spawns from January 10 to 25 totaled 88% of the season's estimate. The total spawning area utilized and density of egg deposits (Appendix III) were the highest recorded during the 7 years of the survey.

I estimated 2,227 billion eggs spawned by 21,517 tons (19,519 mt) of herring. Including the catch of 646 tons (586 mt) the season's spawning biomass becomes 22,163 tons (20,105 mt) (Table 18). The increase this season in Tomales Bay of approximately 15,000 tons (13,608 mt) corresponds with a decrease of about 19,000 (17,236 mt) tons in San Francisco Bay estimates. The cause(s) of these changes in abundance are not well understood, but the herring obviously altered their normal spawning pattern this season and it is possible that San Francisco Bay herring spawned in Tomales Bay.

3.3.1.6. 1978–79 Season

Tomales Bay was not surveyed during the 1978–79 season and no estimates of spawning biomass were determined.

3.3.1.7. 1979–80 Season

There were 24 separate spawning sites during the season. Only seven spawning runs took place and the two largest spawns totaled 86% of the season's estimate (Appendix III). Eel grass beds near Hog Island (Figure

11) accounted for over 66% of the spawning activity during the season. No spawns were found in Tomales Bay during March, but a small spawn was reported just outside Tomales Bay at Tomales Point.

An estimated 561 billion eggs were spawned by 5,420 tons (4,916 mt) of herring. By including the catch of 603 tons (547 mt) the season's spawning biomass estimate is increased to 6,023 tons (5,463 mt) (Table 18).

3.3.2. San Francisco Bay Spawning Biomass Estimates

Only intertidal or shoreline spawns were surveyed in San Francisco Bay until the 1978–79 season, when subtidal spawns were first included.

3.3.2.1. *1973–74 Season*

Four spawnings occurred during the 1973–74 spawning season (Appendix IV). The first, December 16–19, 1973, occurred along the Tiburon Peninsula (Figure 15) and the spawn estimate was 333 tons (302 mt) of herring. Because of darkness, sampling was not completed until the following day. Thus a predation rate of 82% was applied to that area not sampled the first day, and this increased the spawn estimate to 351 tons (318 mt) of herring.

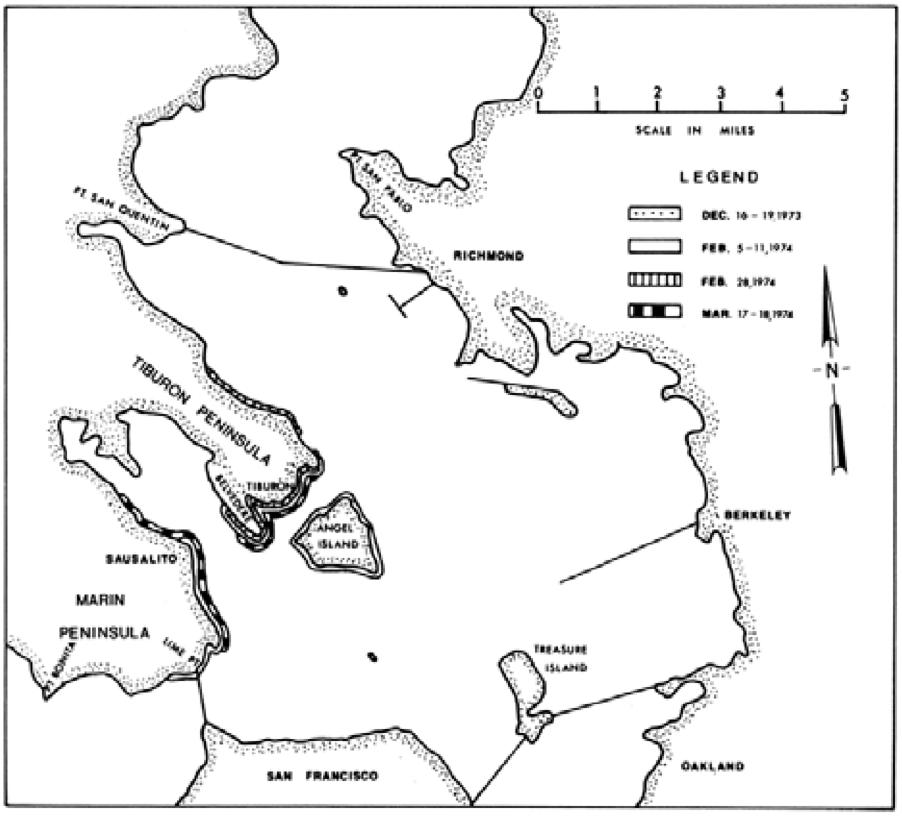

FIGURE 15. San Francisco Bay herring spawn locations during the 1973–74 season.

FIGURE 15. San Francisco Bay herring spawn locations during the 1973–74 season

The next spawning began on February 5, 1974, and lasted 7 days. This was the most extensive spawning of the season (Figure 15). The spawn was estimated at 1,102 tons (1,000 mt) of herring.

Predation was again a factor. Part of this spawning took place over a weekend and was not sampled until the following Monday. Gulls were common throughout the area, and a predation rate of 82% increased the original estimate to 1,777 tons (1,612 mt) of herring.

The third spawning on February 28th extended along the north side of the Tiburon Peninsula (Figure 15). Unfortunately, this spawning occurred during severe weather conditions and was not located until nearly 1 week after it occurred. Predation was evident and assumed to be 95%. As a result the estimate was increased to 140 tons (127 mt) of herring.

The fourth spawning (Figure 15) on March 17, 1974, was not sampled until Monday, March 18th. The 82% predation factor was applied and increased the estimate to 1,973 tons (1,790 mt) of herring.

All four spawnings with corrections for predation totaled 4,241 tons (3,847 mt) of herring which spawned 439 billion eggs. The catch of 1,938 tons (1,758 mt) placed the estimated spawning population for the 1973–74 season at 6,179 tons (5,605 mt) (Table 19).

TABLE 19. San Francisco Bay Pacific Herring Spawning Biomass Estimates, 1973–74 through 1979–80 Seasons.

Season	*Spawn estimate (tons)*	*Catch (tons)*	*Spawning biomass (tons)*
1973–74	4,241	1,938	6,179
1974–75	26,820	514	27,334
1975–76	25,318	1,719	27,037
1976–77	22,375	4,201	26,576
1977–78	3,682	4,987	8,669
1978–79	32,580	4,121	36,701
1979–80	46,439	6,430	52,869

TABLE 19. San Francisco Bay Pacific Herring Spawning Biomass Estimates, 1973–74 through 1979–80 Seasons

Spawning biomass estimates for the 1973–74 season were much lower than estimates obtained in following seasons. This season should be considered a trial season in which methods evolved and personnel became familiar with techniques used in the field. We did not have a good method for detecting repeat spawnings in areas before the initial spawn deposits hatched and repeat spawnings are very common. Also weather conditions were severe and hampered our field work on many occasions.

3.3.2.2. *1974–75 Season*

Five spawnings occurred during the 1974–75 season (Appendix IV). Spawnings that could not be sampled until 1 to 3 days after they occurred exhibited either no predation or egg deposits were so heavy that predation by gulls had little impact and our 82% predation rate for moderate spawnings seemed inappropriate. No correction for predation was applied to any of the spawnings during the 1974–75 season.

The first spawning occurred on December 8, 1974, along the west side of the Tiburon Peninsula (Figure 16). The second spawning of the season occurred on January 3–4, along the Tiburon Peninsula and Sausalito (Figure 16).

One of the more extensive spawnings ever recorded in the Bay occurred January 20–25, 1975. Over 37 km (23 miles) of shoreline were covered over the 6-day period. This series of spawnings covered nearly the entire survey area (Figure 16).

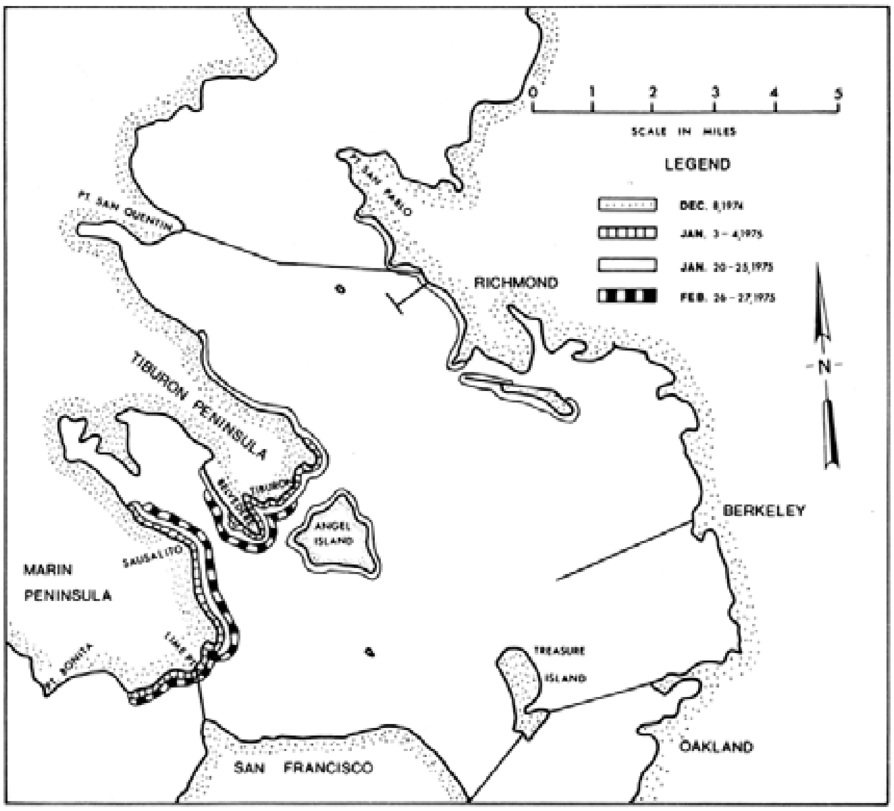

FIGURE 16. San Francisco Bay herring spawn locations during the 1974–75 season.

FIGURE 16. San Francisco Bay herring spawn locations during the 1974–75 season

The fourth spawning of the season occurred about February 15, 1975, outside of our survey area at Coyote Pt. in the southern part of San Francisco Bay (Figure 17). I believe this was the only spawning in south Bay that year. A ranger at Coyote Pt. Park reported herring have spawned at their marina in past years. Miller and Schmidtke (1956) also reported that spawning had taken place near this area. This spawning was not sampled because most of it was subtidal. The spawning area was measured and totaled only 8,300m^2 (9,900 yds^2).

I estimated a total of 2,776 billion eggs deposited during the season by 26,820 tons (24,330 mt) of herring (Table 19). This season's catch was not included in biomass estimates because an undetermined amount of spent herring were caught.

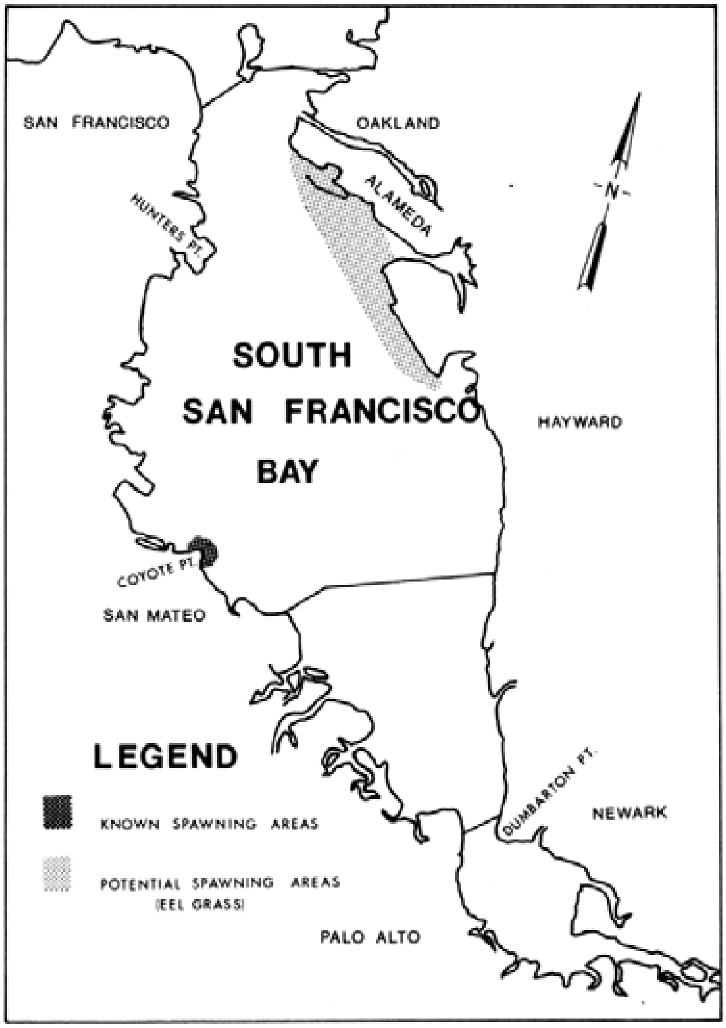

FIGURE 17. Known and potential spawning areas in south San Francisco Bay.

FIGURE 17. Known and potential spawning areas in south San Francisco Bay

3.3.2.3. *1975–76 Season*

Five spawnings occurred within the survey area this season (Appendix IV). Two minor spawnings at Coyote Point in south San Francisco Bay were not included.

The first recorded spawning of the season occurred on December 17, 1975, along the Tiburon Peninsula (Figure 18).

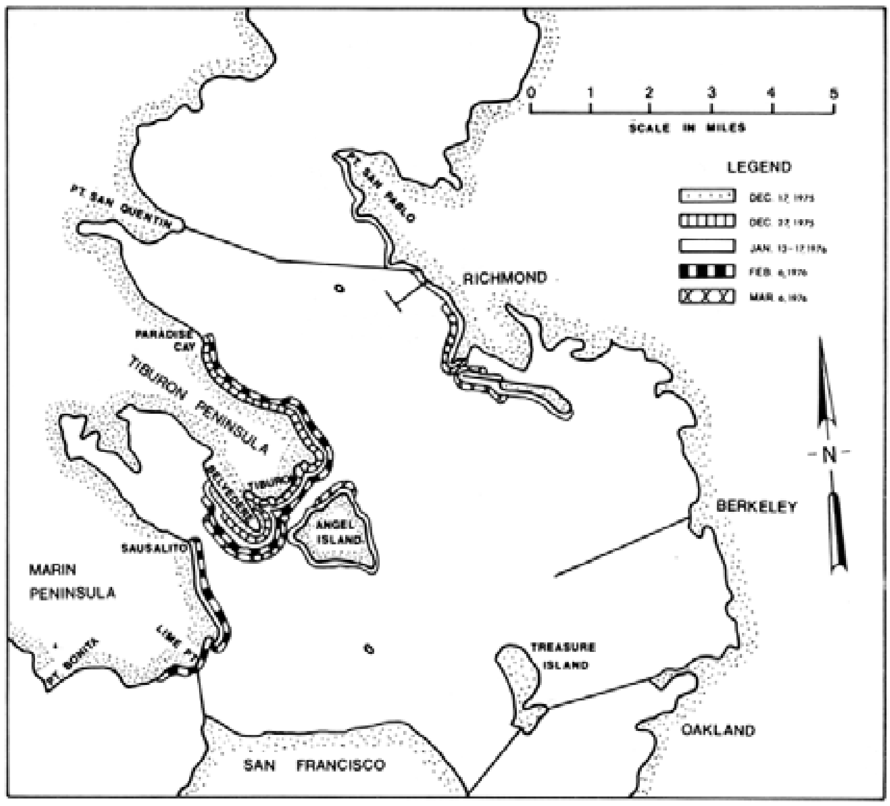

FIGURE 18. San Francisco Bay herring spawn locations during the 1975–76 season.

FIGURE 18. San Francisco Bay herring spawn locations during the 1975–76 season

The third spawning was the second largest spawning ever recorded in the Bay. The pattern of one massive spawning per year was repeated this season. From January 13 through 17, 1976, herring spawned on over 32 km (20 miles) of shoreline, covering nearly the entire survey area (Figure 18). The total area covered by this spawning did not equal the third spawning of 1974–75, but the egg deposits were among the heaviest ever recorded. A total of 1,543 billion eggs was deposited by 14,902 tons (13,519 mt) of herring.

The fourth spawning occurred on February 6, 1976, along Sausalito and the Tiburon Peninsula (Figure 18). Predation by gulls was noticeable but not extremely heavy, and an arbitrary predation rate of 50% was applied to the Sausalito portion of spawning and raised the estimate to 6,246 tons (5,666 mt) of herring.

An estimated 2,621 billion eggs were deposited during the season by 25,318 tons (22,968 mt) of herring. Including the catch of 1,719 tons (1,559 mt), the spawning biomass estimate for the season was 27,037 tons (24,527 mt) (Table 19).

3.3.2.4. *1976–77 Season*

Eight spawnings were surveyed during the 1976–77 season (Appendix IV). An arbitrary predation rate of 50% was applied to the spawning of December 17, 1976, because predation was evident but not severe. All other spawnings were sampled the day after they occurred or exhibited very little predation by gulls.

The first spawning of the season occurred December 2, 1976, near Belvedere (Figure 19) and was estimated at 72 tons (65 mt) of herring.

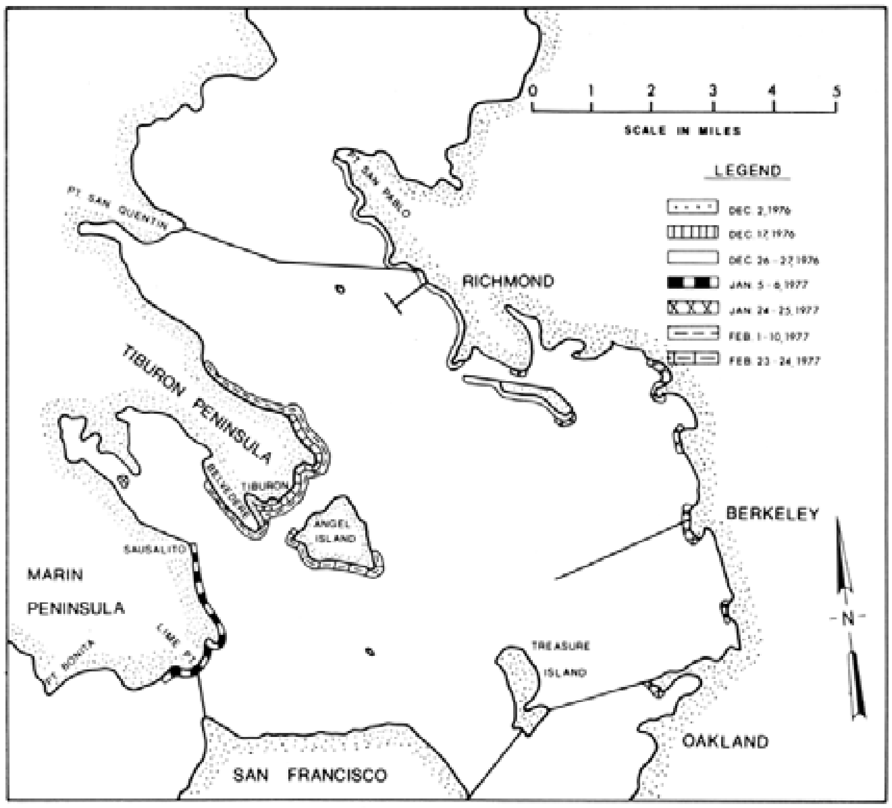

FIGURE 19. San Francisco Bay herring spawn locations during the 1976–77 season.

FIGURE 19. San Francisco Bay herring spawn locations during the 1976–77 season

The largest spawning of the season occurred from February 1 to 10, 1977. This pattern of one spawning much larger than any of the others was evident during the 1974–75, 1975–76, and 1976–77 seasons. The area of this spawning, 239,400 m^2 (286,000 yds^2), was not extensive but the spawn densities were the heaviest ever recorded at 4,214,900 eggs/m^2 compared to the next heaviest 2,777,000 eggs/m^2 in January 1976. The spawning covered most of the Tiburon Peninsula shoreline (Figure 19). A total of 1,007 billion eggs were spawned by 9,371 tons (8,829 mt) of herring.

There were two subtidal spawnings during the season that could not be measured quantitatively; although I sampled the area involved and found heavy egg deposits. I felt these spawnings should be included in our estimates and used conservative spawn density figures to estimate spawning biomass in both cases.

The first subtidal spawning occurred on January 25, 1977, in Richardson Bay (Figure 19). Eggs were deposited on Gracilaria sp. and appeared to be very heavy. Spawnings of similar density on eel grass in Tomales Bay have had as high as 13 million eggs/m^2 and 5 to 7 million eggs/m^2 were common. I used a conservative estimate of 1 million eggs/m^2 for the Richardson Bay spawning, and estimated that 104 billion eggs were spawned by 1,005 tons (913 mt) of herring.

The other subtidal spawning occurred February 23–24, 1977, near Angel Island (Figure 19). A quantitative sample could not be taken but a 13-mm (0.5-inch) layer of eggs was grappled from the bottom in several places. This egg density approaches the density of the February 1–10 spawning or about 4.2 million eggs/m^2. To be conservative, I used an egg density figure of 2.1 million eggs/m^2, or about one-half that of the February 1st spawning, and estimated 140 billion eggs were spawned by 1,359 tons (1,233 mt) of herring.

For the entire 1976–77 season I estimated 2,316 billion eggs were spawned by 22,375 tons (20,298 mt) of herring. The catch of approximately 4,201 tons (3,811 mt) brings the season spawning biomass to 26,576 tons (24,109 mt) (Table 19).

Four additional spawnings were found during the season, but no biomass estimates were made because they were either too difficult to sample or were outside our survey area. Two were at Coyote Point in south San Francisco Bay and two were in Sausalito where wharves and yacht harbors made sampling difficult. Therefore, spawning population estimates are conservative but still compare favorably with previous seasons.

3.3.2.5. *1977–78 Season*

Eight spawns were surveyed during the 1977–78 season (Appendix IV). A predation rate of 50% was applied to part of the spawn on December 19, 1977, because it was not sampled immediately after the spawn occurred; predation was evident but not severe. The spawn on January 9, 1978, was not sampled until the eggs were about to hatch and a predation rate of 95% was applied.

The first spawn began December 16, 1977, on the Tiburon Peninsula and near Richmond (Figure 20). On December 20, 1977, the spawning activity spread to include Angel Island. This was the largest spawn found that season and totaled 1,878 tons (1,703 mt) of herring.

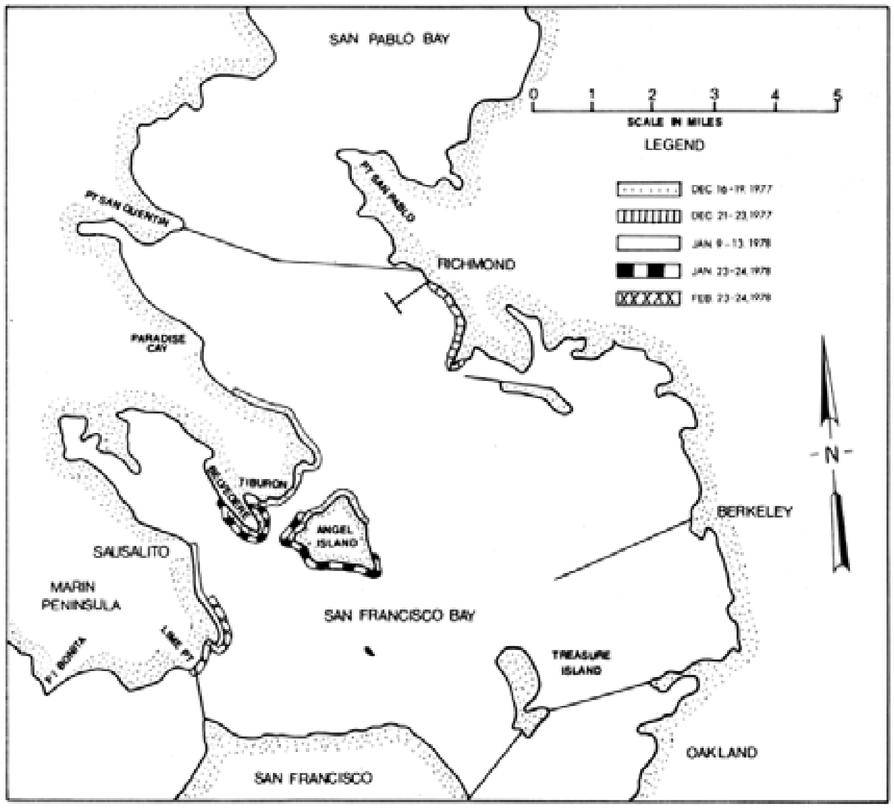

FIGURE 20. San Francisco Bay herring spawn locations during the 1977–78 season.

FIGURE 20. San Francisco Bay herring spawn locations during the 1977–78 season

Only one other large spawn was found that season. On January 23–24, 1978, a total of 1,217 tons (1,104 mt) of herring spawned along the Marin Peninsula and Angel Island.

For the season I estimated that 381 billion eggs were spawned by 3,682 tons (3,340 mt) of herring. The catch during the roe fishery was 4,987 tons (4,524 mt) and raised the spawning biomass estimate to 8,669 tons (7,864 mt) (Table 19). This is the lowest estimate since the 1973–74 season and coincides with an unusually high estimate for Tomales Bay. It is possible that a significant portion of San Francisco Bay herring altered their normal spawning pattern and spawned in Tomales Bay during the 1977–78 season.

3.3.2.6. *1978–79 Season*

We found nine spawns during the 1978–79 season (Appendix IV). On January 20, 1979, a major subtidal spawn was located in Richardson Bay (Figure 21). This is the first significant subtidal spawn to be included in the estimates, and it is likely that other large subtidal spawns went undetected in previous seasons when our surveys concentrated on the intertidal areas of the Bay. The total area of the Richardson Bay spawn, nearly 5 million m^2 (5.9 million yds^2), was many times the total spawning area in any previous season. We were not prepared to sample subtidal spawns, but arrived at an estimate by qualitatively dividing the area into heavy and light egg deposits and using spawn density figures of 500,000 and 100,000 per m^2. Most of the spawn area had heavy egg deposits and the average egg density was calculated to be 339,000 eggs/m^2. This estimate is conservative and equal to a relatively light spawn in eel grass. I estimated 1,676 billion eggs were spawned by 16,200 tons (14,696 mt) of herring. I now believe that areas with subtidal vegetation in San Francisco Bay are of equal or greater importance than intertidal areas.

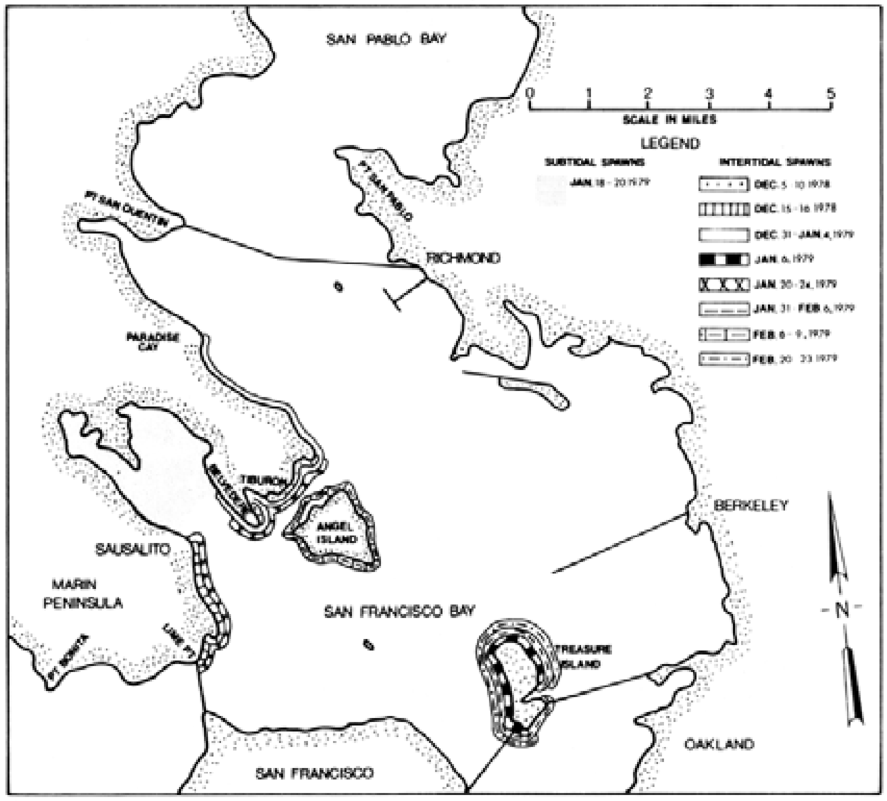

FIGURE 21. San Francisco Bay herring spawn locations during the 1978–79 season.

FIGURE 21. San Francisco Bay herring spawn locations during the 1978–79 season

The other eight spawns found during the season were intertidal and no predation rates were applied to any of these spawns. For all nine spawns I estimated that 3,372 billion eggs were spawned by 32,580 tons (29,556 mt) of herring. The catch of 4,121 tons (3,738 mt) during the season increased the spawning biomass to 36,701 tons (33,294 mt) (Table 19).

3.3.2.7. 1979–80 Season

The 1979–80 season is the first season in which a concerted effort was made to estimate the magnitude of subtidal spawning in San Francisco Bay. Ten spawns were found during the season (Appendix V). The total spawning area utilized was over 31 million m^2. Only 3% of this area was intertidal, but the intertidal egg densities were higher than subtidal egg densities and intertidal spawning accounted for 21% of the estimated spawning biomass for the season. The intertidal areas of the Bay remain important spawning areas but it is evident that the primary spawning grounds of San Francisco Bay are those shallow subtidal areas with dense vegetation.

The largest spawn of the season occurred December 13, 1979, in the shallow part of the east Bay between Richmond and Oakland (Figure 22).

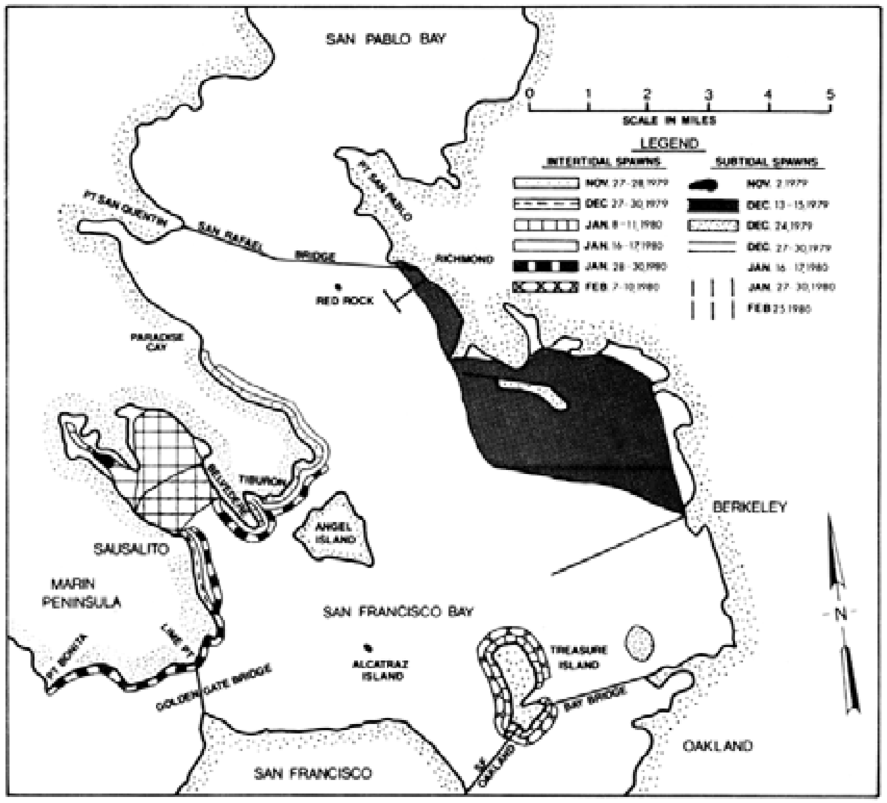

FIGURE 22. San Francisco Bay herring spawn locations during the 1979–80 season.

FIGURE 22. San Francisco Bay herring spawn locations during the 1979–80 season

The 1979–80 season's spawning estimate is the largest to date. I estimated 4.8 billion eggs were deposited by 46,439 tons (42,129 mt) of herring. Including the catch of 6,430 tons (5,833 mt), the spawning biomass estimate for the season is 52,869 tons (47,962 mt) (Table 19).

3.3.3. Biomass Estimates Humboldt Bay

The herring spawning stock size was estimated for Humboldt Bay during the 1974–75 and 1975–76 spawning seasons (Rabin and Barnhart, unpublished manuscript). A summary of their results is included here to give a complete picture of what is known about herring stock sizes in California. Rabin and Barnhart estimated that 372 tons (337 mt) and 241 tons (218 mt) spawned in 1975 and 1976, respectively. While eel grass is found throughout Humboldt Bay, about 99% of the spawning activity was in the northern half of Humboldt Bay.

3.3.4. Tidal Relationship

The tides are known to control the spawning of California grunion, Leuresthes tenuis (Walker 1952). Herring spawnings are quite often intertidal and the possibility of a tidal relationship exists.

The days that herring spawned from 1974 to 1976 were plotted on a December to March time scale. No relationship was evident when compared with daily high tides in Tomales Bay and spawnings did not relate to new or full moon. However, San Francisco Bay herring did show a relationship with the tides, but in an unexpected manner.

Along the Pacific coast, there are two high tides daily. If the highest daily tide is plotted as occurring during daylight or darkness and compared with days when spawning took place (Figure 23), a relationship is apparent. From 1973 to 1976, 16 intertidal spawnings occurred and 14 of these at least partially took place on days when the highest daily tide was during darkness. During the 1973–74 and 1974–75 seasons, at least part of every spawning occurred when the highest daily tide was at night, but in the 1975–76 season two spawnings did not follow this pattern.

Over the years, 53% of the highest daily tides were at night and, if spawning was random, about one-half of the spawnings should have occurred on these nights. Our surveys found that 88% of all spawnings occurred on these nights. This difference is significant at the 99% level ($X^2 = 16.21$ with 2 D.F.). This pattern continued during the 1977 season when 40% of the highest daily tides were at night and 57% of the spawnings occurred on these nights.

Using this relationship of herring spawnings with the tidal cycle in San Francisco Bay, it appears possible to predict the time when runs are most likely to occur.

3.4. DISCUSSION

3.4.1. Tomales Bay

Estimates of Pacific herring spawning biomass for Tomales Bay from 1973 through 1980 were higher than any previously recorded. For all practical purposes, the resource was not fished commercially from 1963 to 1973, and fishing was light for the 10-year period prior to that (Table 1). An increase in the herring population size could have occurred during this 20-year period.

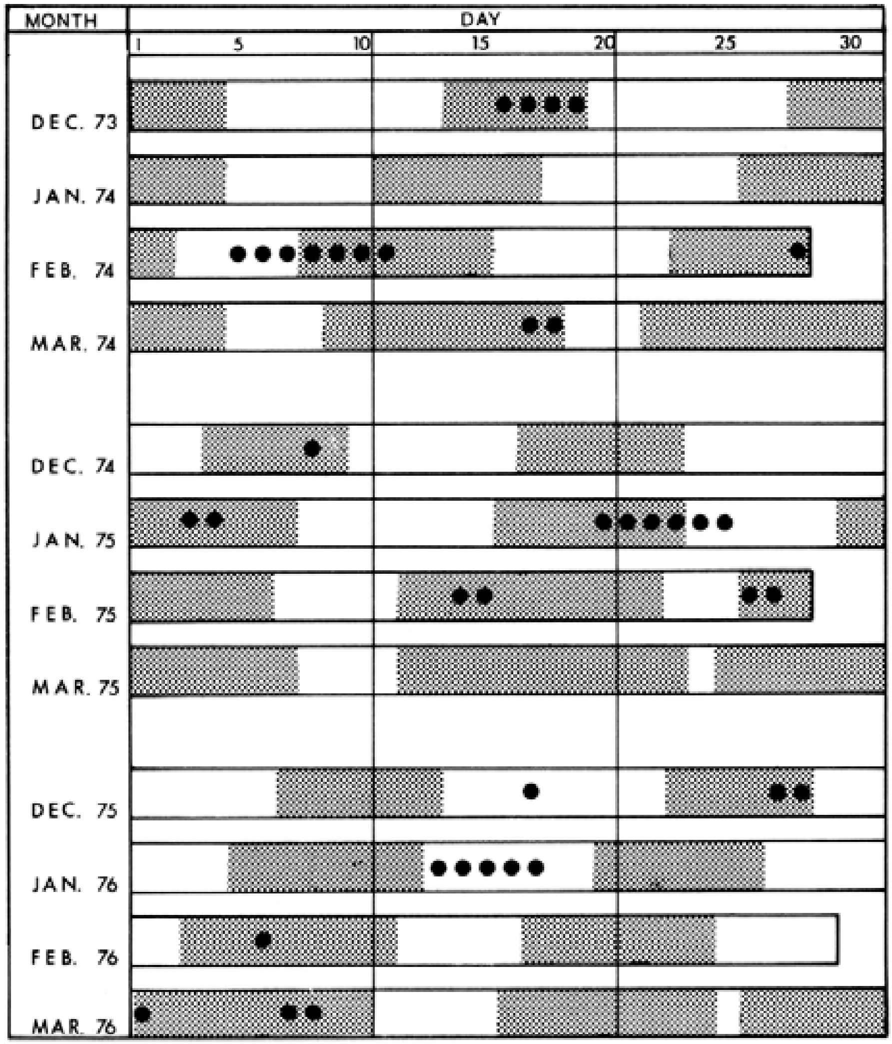

FIGURE 23. **Herring spawn relative to tidal state, 1973–74 through 1975–76 seasons. Shaded areas are days when the highest daily high tide occurred during darkness; dots represent days that herring spawned each month.**

FIGURE 23. Herring spawn relative to tidal state, 1973–74 through 1975–76 seasons. Shaded areas are days when the highest daily high tide occurred during darkness; dots represent days that herring spawned each month

Hardwick (1973) found that methods used by Miller and Schmidtke (1956) in Tomales Bay were in need of revision; fecundity estimates particularly were necessary because data were not available for herring in California. Miller and Schmidtke used fecundity data for Canadian herring (Hourston 1953). Hardwick estimated that 1 short ton of herring would spawn 103 million eggs, whereas Miller and Schmidtke used a fecundity of 59 million eggs per short ton of herring.

Hardwick (1973) estimated 2,500 tons (2,268 mt) of spawning biomass in 1971 and 1,600 tons (1,451 mt) in 1972. Hardwick's improved fecundity data when applied to 1955 results lowered Miller and Schmidtke's (1956) estimate from 4,000 tons (3,629 mt) to 2,200 tons (1,996 mt).

Past data were quite comparable then, with estimates ranging from 1,600 to 2,500 tons (1,451 mt to 2,268 mt). However, neither Miller and Schmidtke (1956) nor Hardwick (1973) made allowance for predation on spawn deposits before they were sampled. Miller and Schmidtke sampled once or twice per week at the most, while Hardwick states that most of the spawns he found were 5 to 6 days old. I have shown that predation can be severe in San Francisco and that spawn on eel grass in Tomales Bay is also subject to heavy predation. Hardwick did not estimate predation rates but implied predation was severe by the time he sampled spawns. Outram (1958) and Cleaver and Franett (1946) indicated that predation could be as high as 66%, 3 to 4 days after a spawn and might reach 99% before the eggs hatch.

Failure to take predation into account undoubtedly was a major cause for Miller and Schmidtke's and Hardwick's lower estimates. In fact, it is conceivable that some spawns were completely missed by these researchers because of predation.

It became quite clear that predation must be accounted for, and I chose to make an intensive daily search for spawn sites. In some cases, samplers found herring while they were spawning, and in nearly all cases, spawns were located the morning after they occurred. The predation factor was not eliminated entirely, but was kept to a minimum.

Estimates of spawning biomass, ranging between 4,728 tons (4,289 mt) in 1974–75 and 22,163 tons (20,106 mt) in 1977–78 (Table 18), still must be considered conservative for the following reasons: (i) only spawnings on eel grass were included; (ii) some spawning probably occurred before surveys were initiated in December and after surveys were terminated in March; and (iii) predation, although kept to a minimum, continued to occur.

3.4.2. San Francisco Bay

Results over the 7 years of this study differed considerably from year to year. Sampling methods were improved in 1975 and again in 1979 and have resulted in increasingly higher estimates. I now believe that the actual spawning biomass in 1974 was much larger than the estimate of 6,179 tons (5,605 mt) (Table 19). Weather conditions in 1974 differed markedly from succeeding years. Rainfall reached near record amounts during the winter of 1973–74, while December and January were relatively dry in 1974–75, 1975–76, and 1976–77. Increased run-off from the nearly continuous rain during 1973–74 could have affected herring spawning habits that year. The same number of major spawnings was found each year, but subtidal spawnings could have been more extensive in 1973–74. In the 1979–80 season spawn estimates increased to 52,869 tons (47,962 mt) (Table 19) due to the inclusion of subtidal spawns in our surveys.

Published estimates indicate the spawning population in San Francisco Bay was on the order of 12,000 tons (10,886 mt) in 1955 (Miller and Schmidtke 1956). However, the methods used to calculate population size were not comparable with mine; the principal differences were in fecundity estimates, predation rates on egg deposits, and surveys of intertidal spawns only. Applying Hardwick's (1973) improved fecundity figure to data from Miller and Schmidtke (1955) produced a spawning biomass estimate of 6,800 tons (6,169 mt), or about one-half the original estimate. Miller and Schmidtke made no allowance for effects of predation, thus their estimate was low by an undetermined amount. Miller (California Dept. Fish and Game, pers. commun.) places little confidence in the accuracy of his estimates from spawning surveys because most of the effort in 1955 was spent on acoustic survey techniques, which met with difficulties and poor results.

My estimate of nearly 27,000 tons (24,494 mt) spawning biomass for San Francisco Bay from 1974–75 to 1976–77 is conservative and as such should be considered a minimum figure for the following reasons: (i) subtidal spawnings were undetected; and (ii) a predation rate was applied to spawnings only when predation was severe, although some predation occurred on all spawnings before they were sampled.

The 1979–80 season estimate of 52,869 tons (47,962 mt) (Table 19) is the most accurate estimate of the herring spawning biomass in San Francisco Bay obtained during the study because more sampling effort was spent to detect subtidal spawning. The importance of subtidal spawning is apparent and future surveys will concentrate on detecting subtidal spawns. The relatively large subtidal areas in relation to intertidal areas of the Bay suggest that future stock estimates for San Francisco Bay may continue to increase.

4. STATUS OF RESOURCE

There is no proof that separate populations exist in California. However, each spawning area is treated as if it contains a separate population.

4.1. Tomales Bay Population

Data in this report indicate that current spawning populations of Pacific herring in Tomales Bay are larger than prior estimates indicated. Spawning population estimates have ranged from 4,728 tons (4,289 mt) in 1975 to 23,163 tons (20,106 mt) in 1978 and estimates have averaged about 6,000 tons per year except for 1977–78 when estimates were unusually high. Although biomass estimates are higher than previously recorded, they should be considered conservative.

In the 1975–76 season, 70% of the spawning took place before fishing began. With a fixed season and small catch quotas, it is difficult to obtain a representative sample of the entire spawning population. The data on relative year class strength in this report may not be representative of the spawning population of herring in Tomales Bay and should be used cautiously. Nevertheless, samples from each year's catch indicate that recruitment has remained good with age groups 2 and 3 consistently dominating the round haul fishery and age group 5 and 6 dominating the gill net fishery since the 1977–78 season. Catch quotas have never exceeded 16% of the estimated spawning biomass in any one season, and it is difficult to evaluate the effect of quotas because they are rarely taken. The population appears stable, and fishing at present levels has had no noticeable effect on the resource.

4.2. San Francisco Bay Population

The 1979–80 season's spawning biomass estimates for San Francisco Bay indicate a population of 52,869 tons (47,962 mt). The figure is more than quadruple the 12,000 tons (10.886 mt) spawning biomass estimated by Miller and Schmidtke (1956) from surveys in 1955. Although the population could have increased in the past 20 years because of the lack of a substantial fishery, it is more reasonable to believe that the higher estimates obtained by this study reflect the intensive survey and improved techniques that were utilized.

An analysis of the age composition of each season's catch is difficult for the same reasons as discussed for Tomales Bay. However, recruitment has remained good with age groups 2 and 3 consistently dominating the catch. The 1976–77 fishery lasted for nearly the entire spawning season and I obtained the best measure of age composition for any season. Ages 6 through 9 continued to be well represented after four fishing seasons. Catch quotas have been increased gradually since 1975 without any noticeable effect on the resource. Fishing at current levels should be sustainable, assuming recruitment is successful each year. As more accurate biomass estimates become available, I believe the San Francisco Bay population will prove to be even larger than the best estimate to date of 52,869 tons (47,962 mt).

4.3. Bodega Bay Population

Spawning has been observed near the entrance to Tomales Bay and in Bodega Harbor. The magnitude of these spawns has never been determined. The Bodega Bay fishery is very likely conducted mainly on herring about to enter Tomales Bay to spawn, as well as some herring that will spawn in Bodega Bay itself. If these stocks are separate, a large fishery in Bodega Bay may cause overfishing of the limited Bodega Bay population.

4.4. Humboldt Bay Population

This is a very small population in relation to the spawning area available. The estimate of 372 tons (337 mt) in 1975 and 241 tons (218 mt) in 1976 are only large enough to support a minor fishery.

4.5. Crescent City Harbor Population

There is limited spawning area in and around the harbor, although heavy intertidal egg deposits have been observed by the local harbormaster. Sixty tons (54 mt) were taken in 1974 and it appears that Crescent City Harbor supports a population large enough for a small fishery.

The fishery may be expanded after the population size is determined.

4.6. Other Populations

Known spawning areas south of San Francisco Bay such as Elkhorn Slough, Morro Bay, San Luis River, and San Diego Bay, are believed to have populations too small to support a commercial fishery.

Little is known about Shelter Cove, Noyo River, or Russian River populations and no commercial fishing should be allowed in these areas until each spawning population's size has been determined.

5. MANAGEMENT RECOMMENDATIONS

5.1. Quotas

Until maximum sustained yield has been determined, quotas should be set no higher than 20% of the previous season's spawning biomass in each area. The annual mortality rate of herring has not been calculated due to the inability to obtain an unbiased sample of the age composition. However, the best data available suggest that the annual mortality rate will range from .4 to .5 and maximum quotas are set at one-half of the lowest mortality rate expected. In practice, quotas have been increased cautiously. Quotas for the 1980–81 season were recommended to be 20% and 14% of the previous season's spawning biomass in Tomales and San Francisco Bays, respectively. In-season adjustments to quotas may be made if spawning escapement is different than expected.

5.2. Seasons

The herring fishery is a roe fishery and herring must be taken just before spawning occurs. The time of peak spawning is variable from year to year and a fixed season is undesirable because peak spawning may be missed in a given year. I suggest a flexible opening date each year based on results of acoustic surveys to determine when herring arrive in the bays.

5.3. Resource Monitoring

As the fishery continues, monitoring the fishery and spawning activity will become increasingly important. Annual estimates of recruitment into the spawning population and spawning surveys must continue in order to detect spawning failures and poor recruitment.

6. REFERENCES

Cleaver, Fred C., and D.M. Franett. 1946. The predation by sea birds upon the eggs of Pacific herring, Clupea pallasii, at Holms Harbor during 1945. Wash. Dept. Fish, Div. of Sci. Res., Biol. Rep., (46B):1–17.

Croker, Richard S. 1930. Herring in Carquinez Straits. *In* N.B. Scofield (ed.), Commercial Fishery Notes. Calif. Fish Game, 16(2):188.

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

Hourston, A.S. 1953. Estimation of herring population size by means of echosounder tracings and its application to herring research. Can., Fish. Res. Bd., Circ., (26):1–18.

Miller, Daniel J., and John Schmidtke. 1956. Report on the distribution and abundance of Pacific herring (Clupea pallasii) along the coast of central and southern California. Calif. Fish Game, 42(3):163–187.

Outram, D.N. 1958. Seagulls biggest killers of herring spawn. Western Fish., 57(1):38–41.

Outram, D.N., and R.D. Humphreys. 1974. The Pacific herring in British Columbia waters. Can., Fish. Res. Bd., Pac. Biol. Station, Circ., 100:1–26.

Rabin, D.J., and R.A. Barnhart. 1977. Fecundity of Pacific Herring, Clupea harengus pallasii. Calif. Fish Game, 63(3):193–196.

Rabin, D.J., and R.A. Barnhart. 1976. Unpublished. Population characteristics of Pacific Herring, Clupea harengus pallasii, in Humboldt Bay, California. A report to the California Department of Fish and Game. 3 p.

Rounsefell, G.A. 1930. Contribution to the biology of the Pacific herring, Clupea pallasii, and the condition of the fishery in Alaska. U.S. Bur. Fish., Bull., (45):227–320.

Scofield, N.B. 1918. The herring and the development of the herring industry in California. Calif. Fish Game, 4(2):65–70.

Scofield, W.L. 1952. The Tomales Bay Herring Fishery. Calif. Fish Game, 38(4):499–504.

Spratt, J.D. 1975. Growth rate of the northern anchovy, Engraulis mordax, in southern California waters, calculated from otoliths. Calif. Fish Game, 61(3):116–126.

Tester, A.L. 1937. Populations of Herring (Clupea pallasii) in the Coastal Waters of B.C. J. Biol. Board Can., 3(2):108–144.

Walker, Boyd W. 1952. A Guide to the Grunion. Calif. Fish Game, 38(3):409–420.

APPENDICES

APPENDIX I

Length Frequency of Tomales Bay Herring
Round Haul Catch, 1972–73

Length (mmBL)	*Age (years)*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
234							1	
232							1	
230								
228							1	
226						1	1	
224						4	1	
222							2	1
220						4	2	
218						2		
216					1	2	1	
214								
212					1	2	1	
210					5	1		
208					1	2		
206					2			
204				2	1	2		
202				1	5	2		
200				2	3			
198				3	1			
196				5	2			
194			1					
192				4				
190				2				
188			1	3				
186			2	1				
184			5	3				
182			4					
180			8	1				
178		1	1					
176			2					
174		3	4					
172		5	1					
170		2	1					
168		3	1					
166		6	2					
164		13						
162		5						
160		11						
158		3						
156		1						
154		5						
152		2						
150		2						
N	–	62	33	27	22	22	11	1
Mean	–	163	179	193	205	215	223	222
Standard deviation	–	6	6	6	6	8	6	–

APPENDIX I
Length Frequency of Tomales Bay Herring

APPENDIX I (cont'd)

Round Haul Catch, 1973–74

Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8	9
248								1	
246									
244									
242									
240									1
238									
236								1	
234							2		
232							2	1	
230						2			
228						1	2	2	
226						4	3		
224					1	1			
222					1	2	1		
220					1				
218					2	1			
216					1	1	1		
214					3	2			
212					1	1			
210					1	1			
208				1	1				
206									
204									
202				1	1	2			
200				3					
198				2	1				
196				1					
194				2					
192			1	2	1				
190			3	2					
188				1					
186		1	5						
184		1	4						
182		1	3	1					
180			3	1					
178			3						
176			3						
174		4	2						
172		7	1						
170		5							
168		11	2						
166		1							
164		5	1						
162		5	1						
160		3	1						
158		3							
156			1						
154		2							
152		2							
150		1							
148									
146		1							
N	–	53	34	17	15	18	11	5	1
Mean	–	166	179	194	212	220	228	234	240
Standard deviation	–	8	9	7	9	8	5	8	–

APPENDIX 1—Cont'd.

APPENDIX I (cont'd)

Round Haul Catch, 1974–75

Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8
236							1	
234								
232						1		
230							1	
228								
226							1	
224							1	1
222							1	
220					1			
218					1			
216				1		1	1	
214						1		
212					1			
210					1		1	
208					2			
206					1			
204					2	1		
202				1	1			
200			1	3	1	3		
198				2	2			
196			1	4				
194				3	2			
192			2	3				
190			2	2				
188				1				
186			1	3				
184			4					
182			7					
180			1					
178			5					
176			1	1				
174			2					
172		1	2					
170		1						
168		1	1					
166		2						
164		4						
162		2						
160		1						
158								
156								
154		3						
152		1						
150		1						
148		1						
146		1						
144								
142		1						
N	–	20	30	24	15	7	7	1
Mean	–	159	182	194	205	209	223	224
Standard deviation	–	9	7	8	8	12	9	–

APPENDIX 1—Cont'd.

APPENDIX I (cont'd)

Round Haul Catch, 1975–76

Length (mmBL)	Age (years) 1	2	3	4	5	6	7
232							
230						1	
228							1
226					1	1	
224							
222							
220							1
218							
216							
214					1		
212						1	
210							
208							
206					2	1	
204				1	2		
202					1		
200			1	1			
198				2	1		
196				3	1		
194				1			
192			1	3	3		
190				1			
188			2				
186			2	2			
184			1				
182			3				
180			1				
178			2				
176			3	1			
174		1	2				
172			1				
170		1					
168			2				
166		6	1				
164		3					
162		6					
160		2					
158		2					
156							
154							
152		1					
150		1					
N	–	23	22	15	12	4	2
Mean	–	163	180	192	203	218	224
Standard deviation	–	5	8	7	10	11	6

APPENDIX I—Cont'd.

APPENDIX I (cont'd)

Round Haul Catch, 1976–77

Length (mmBL)	Age (years) 1	2	3	4	5	6	7
220							
218							
216							1
214							
212							1
210							
208							
206							
204							
202							
200						1	
198					2	2	
196							
194							
192					1		
190				1	1		
188			1	2	1		
186				2	2		
184			1	3			
182			2	2	2		
180			1	2			
178			1	1			
176		1	1	2			
174			2				
172		1	3				
170		2	1				
168		2	2				
166							
164		2	3				
162		3	3				
160		4					
158		3					
156		6					
154		4					
152		5					
150		4					
148		2					
146		3					
144		5					
142							
140		1					
N	–	48	21	15	9	3	2
Mean	–	155	172	183	189	199	214
Standard deviation	–	8	8	4	6	1	3

APPENDIX I—Cont'd.

APPENDIX I (cont'd)

Gill Net Catch, 1976–77

Length (mmBL)	*Age (years)*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
240								
238								
236						1		
234								
232								
230								
228						1		
226								
224								1
222						1		
220							2	1
218					1	1	3	1
216					1	2		
214				1			3	
212					1	2		
210					1	6	1	1
208						7	1	
206					4	5		
204				2	2	6	1	
202					4	5		
200				3	2	1		
198				2	9	2	2	
196				4	6	6	1	
194				4	2			
192					3			
190				5	1	1		
188				2				
186								
184				1				
182			1	1				
180				2				
Total	–	–	1	27	37	47	14	4
Mean	–	–	182	194	200	206	211	218
Standard deviation	–	–	–	8	7	8	9	6

APPENDIX I—Cont'd.

APPENDIX I (cont'd)

Gill Net Catch, 1977–78

(years) Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8	9
248									1
246									
244									
242						1			
240								1	
238									
236							1		
234						1			
232							1		
230								3	
228						1			
226							1	1	
224					1	2	2	1	
222					1	5		2	
220						3	3	1	
218					1	4	2	1	
216						2	2	2	
214					2	3	4		
212					1	5	2		
210				1		1			
208							4		
206						1			
204						1	2	1	
202									
200					1			1	
198					2				
196						2			
194						1			
192									
N	–	–	–	1	9	33	24	14	1
Mean	–	–	–	210	211	216	216	221	248
Standard deviations	–	–	–	–	10	10	8	10	

APPENDIX I—Cont'd.

APPENDIX I (cont'd)

Gill Net Catch, 1979–80

Length (mmBL)	*Age (years)* 1	2	3	4	5	6	7	8
236								1
234								
232								
230								
228								1
226								1
224								
222						1		
220								
218							1	
216					2	2		
214					1	2		
212					3			
210								
208				1	2			
206				2				
204								
202						1		
200								
198								
196					1			
194								
N	–	–	–	3	9	6	1	3
Mean	–	–	–	207	210	214	218	230
Standard deviation	–	–	–	1	6	7	–	5

APPENDIX I—Cont'd.

APPENDIX II

Length Frequency of San Francisco Bay Herring Round Haul Catch, 1973–74 Season

Length (mmBL)	*Age (years)*							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
222								1
220						1	1	
218					1			
216						3		
214						1		
212				1		1	1	
210					2	1		
208					2	2		
206				1	5	3		
204					8	3		
202				1	5			
200			1	1	5			
198				4	5	1		
196				5	8	1		
194				5	3			
192				7	2			
190			1	8	8	3		
188			1	7	1			
186			3	9				
184			5	6	3			
182		2	5	2				
180		1	7					
178		1	4	2				
176		1	3	2	1			
174		6	14					
172		8	11	2				
170		11	10					
168		12	4	1				
166		18	4					
164		21	2					
162		14	1					
160		14	2					
158		7	1					
156		8						
154		6	2					
152		12						
150		3						
148		1						
146		1						
144		2						
142								
140		2						
138								
136								
134		1						
N	–	152	81	64	59	20	2	1
Mean	–	162	174	189	198	206	216	222
Standard deviation	–	8	8	8	8	9	6	–

APPENDIX II
Length Frequency of San Francisco Bay Herring

APPENDIX II (cont'd)

Round Haul Catch, 1974–75 Season

Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8
226								
224								
222								
220						1	2	
218					1			
216							1	
214						1	2	
212								
210						1		1
208						2		
206					1	1	1	
204						1		
202					1	1		
200						1		
198					2	2	1	
196					2	1		
194			1	3	2			
192					1			
190				1	1			
188			2	4	1			
186								
184			4	2				
182			2	3				
180			3	1	1			
178		1	1					
176		1	6	1				
174		1		1				
172		1	3					
170		2	1					
168		3						
166		4						
164		2						
162								
160		4	1					
158		6						
156		7						
154		1						
152		1						
150		4						
148		2						
146		5						
144		5						
142								
140		1						
138								
136								
134								
132		1						
N	–	52	24	16	13	12	7	2
Mean	–	157	179	186	196	205	213	218
Standard deviation	–	10	7	6	9	7	8	11

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Round Haul Catch, 1975–76 Season

Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8
230							1	
228								
226						1		1
224					1			
222							2	
220					1	3	2	
218						1		
216						2	2	
214						1		1
212					1			
210					3	2	1	
208					2	1		
206						1	1	
204					1		1	
202				2	1			
200					4	1	2	
198						2		
196				1		1		
194								
192			1	2	1	1		
190			2	1				
188			1	3				
186			2	4	2			
184			2					
182			1	2				
180			7					
178			5					
176			1					
174			8					
172		2	4					
170		4	2					
168		7	4					
166		6	1					
164		11	4					
162		4	2					
160		3	1					
158		7	2					
156		9						
154		4	1					
152		1						
150		7						
148		1						
146		4						
144		2						
142		2						
140								
138								
136								
134								
132								
130								
128		1						
N	–	75	51	15	17	17	12	2
Mean	–	158	174	190	204	210	214	220
Standard deviation	–	9	9	6	10	10	10	8

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Round Haul Catch, 1976–77 Season

Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8	9
230									
228								2	
226							1		
224						1	1		1
222						1	3		1
220								1	
218					1		3	1	
216									1
214							2	1	
212					1	1		1	
210					1	2		2	
208					1	4		2	
206					2				
204					4	2	2	1	
202			1		2		1		
200				1	3	3	1		
198			1	4	3	2			
196				4	3	2	1		
194			1	9	4	1	1		
192				7	4				
190			4	14	5	2			
188			8	8	1				
186		2	8	7					
184		1	12	4	1				
182			11	8					
180			14	4	1				
178		2	13	1					
176		1	9	7					
174			11	2					
172		3	13	2					
170		6	5						
168		10	5	1					
166		3	7						
164		19	2						
162		11	5						
160		4	3						
158		9	5						
156		4							
154		7							
152		4							
150									
148		5							
146		2							
144		2							
142		1							
140									
N	–	96	138	83	37	21	16	11	3
Mean	–	162	177	187	198	204	212	215	221
Standard deviation	–	9	9	7	8	9	11	8	4

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Gill Net Catch, 1976–77 Season

Length (mmBL)	*Age (years)* 1	2	3	4	5	6	7	8	9
236									1
234							1		1
232									
230							1		1
228							1	1	
226								1	
224							2	1	
222						1		2	1
220						1	2	2	
218						1	2		2
216				1	3	1	1	1	
214					1	5	2	2	
212					5		3	1	
210					1	4	1		1
208					1	5	5	1	
206					1	1	2	1	
204					1	5			
202				1	4		1		
200				2	1	1			
198			1		1				
196					1				
194				1	1				
192				1					
190									
N	–	–	1	6	21	25	24	13	7
Mean	–	–	198	201	207	210	215	218	224
Standard deviation	–	–	–	8	7	5	8	7	10

4—80024

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Round Haul Catch, 1977–78 Season

Length (mmBL)	Age (years)								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
232									1
230									
228									
226									
224									
222									
220									
218								2	
216									
214									
212									1
210							1	1	
208					1				
206					1				
204				1				1	
202						1			
200									
198				2					
196				2		1			
194				1	2				
192				2	1				
190				3	2				
188			1	1					
186			1	4	1				
184			2	3	1				
182		1	1	1					
180			3	2					
178		1	3	3	1				
176		1	1	4					
174		2	4	1					
172		2	1	1					
170		3	4		1				
168		3	6	1					
166		2	1						
164		2							
162		1							
160		2	2						
158		3							
156		1							
154		1							
152		1							
150		3							
148									
146		3							
144		2							
142									
N	–	34	30	32	11	2	1	4	2
Mean	–	162	174	185	190	199	210	212	222
Standard deviation	–	11	7	9	11	4	–	6	14

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Gill Net Catch, 1977–78 Season

Length (mmBL)	Age (years) 1	2	3	4	5	6	7	8	9
236							1		
234									1
232							1	1	
230							2	1	
228							1	1	
226							3	1	
224						1	1	1	
222						1	2	1	
220						1	1		1
218						3	2		
216						2	2		
214						3	1	2	
212						2	4	3	
210						2	2	2	
208						2			
206						4	2	1	
204						2			
202						1	3		
200					2	2			
198						2			
196						3	1	2	
194					1				
192					1	1			
190					1				
188				1	1				
186									
184									
182									
180									
178				1					
176									
174									
172									
170									
168									
166									
164									
162									
160									
N	–	–	–	2	6	32	29	16	2
Mean	–	–	–	183	195	208	217	215	227
Standard deviation	–	–	–	7	5	9	10	11	10

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Round Haul Catch, 1978–79 Season

Length (mmBL)	*Age (years)*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
222									1
220									
218									
216									
214							1		
212									
210				1		4			
208					1				
206					1				
204					3				
202						1			
200					4	2	1		
198				2	4	4			
196				1	5	3			
194			2		4				
192				6	2				
190			1	2	6				
188			3	4					
186			4	3	1				
184			3	3	2				
182			5	6					
180			2	2	2				
178			5						
176		1	7						
174		2	4	1					
172		3	2						
170		5	4	3	1				
168		4	6						
166		5							
164		2	1						
162		1		1					
160		4	1						
158		4							
156									
154									
152		1							
150		1							
148									
146		1							
144									
N	–	34	50	35	36	14	2	–	1
Mean	–	165	178	186	194	202	207	–	222
Standard deviation	–	7	8	9	8	6	10		–

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Gill Net Catch, 1978–79 Season

Length (mmBL)	Age (years)								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
234									1
232									1
230							1		1
228							1		
226									1
224								1	
222						1		1	
220						1		2	
218									1
216						3	1		
214					1	2	1	1	1
212						2	1		
210					3	4	2	1	
208				2	2	2		1	
206					2	6	3		
204					10	5	3		
202				2	4	2			
200				1	6	5	2		
198					14	4			
196				2	7	4			
194			1	3	4			1	
192			1	4	2	1			
190				2	1	1			
188				1	1				
186				1					
184			1		1				
182				1					
180									
178									
176									
174									
172			1						
170									
168									
166									
164		1							
N	–	1	4	19	58	43	15	8	6
Mean	–	164	186	195	200	205	210	214	226
Standard deviation	–	–	10	7	6	7	9	10	8

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Gill Net Catch, 1979–80 Season

Length (mmBL)	*Age (years)*								
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
230						1		2	1
228							3		
226						1		1	
224						2			
222					1	3			
220						1	6		
218				1	1	3	2		
216					3	3		1	
214				1	4	4	2	3	
212					7	6	4		
210				2	8	10	3	1	
208				1	6	5	2		
206				5	10	10	4		
204				3	8	3			
202				3	3	4		1	
200			1	2	7	5	1		
198				1	5	1			
196				3	4	1			
194				2	2				
192									
190				2	1	1			
188				1					
186					1				
184					1				
N	–	–	1	27	72	64	27	9	1
Mean	–	–	200	202	205	210	214	217	230
Standard deviation	–	–	–	7	7	8	7	9	–

APPENDIX II—Cont'd.

APPENDIX II (cont'd)

Round Haul Catch, 1979–80 Season

Length (mmB.)	Age (years) 1	2	3	4	5	6	7	8	9
220									1
218					1	1	2		
216							1	1	
214						1	1		
212					1	3	1		1
210				1					
208						2			
206						2	1		
204				1		1			
202				1	3	2			
200				2	3	1	1		
198				2	4				
196			1	1	3	1			
194			1	2	5	2			
192				2	1	1			
190			1	4	1	1			
188				4	2				
186				10					
184			1	2	1				
182				1	1				
180		1	2		1				
178			4						
176		2	5	1					
174		3	2					1	
172		4							
170		3	3						
168		4	2						
166		7	1						
164		5							
162		12							
160		8							
158		6							
156		7							
154		4							
152		3							
150		3							
148		1							
146									
N	–	73	23	34	27	18	7	2	2
Mean	–	160	177	191	196	204	212	195	216
Standard deviation	–	19	8	7	8	8	7	30	6

APPENDIX II—Cont'd.

APPENDIX III

Herring Spawning Data for Tomales Bay,
1973–74 Season

Date	*Location* *	*Area m* *	*No. eggs/ kg eel grass*	*Kg eel grass/ m* *	*No. eggs/ m* *	*Millions eggs*	*Spawn Estimate (Tons)*
25 Dec 73	1	3,348	138,500	1.9	263,100	887	8
25 Dec 73	2	5,022	1,621,000	1.9	3,080,000	15,400	149
25 Dec 73	3	236	42,000	1.9	80,000	21	0.2
25 Dec 73	4	45	26,200	1.9	49,800	3	–
25 Dec 73	5	5,200	19,800	1.9	37,600	195	2
26 Dec 73	7	5,750	11,100	1.9	21,000	120	1
27 Dec 73	22 & 24	162,100	227,100	1.1	250,000	40,500	391
19 Jan 74	9	16,700	479,600	1.9	911,200	15,214	147
19 Jan 74	9	20,000	1,123,000	1.9	2,134,800	44,825	433
19 Jan 74	23	441,000	129,400	0.6	77,600	34,222	331
19 Jan 74	9	9,100	527,000	1.9	1,020,000	9,282	90
20 Jan 74	10	3,700	776,400	1.9	1,475,300	5,475	53
20 Jan 74	11	2,700	25,595	1.9	48,600	131	1
20 Jan 74	11	5,000	337,100	1.9	640,500	3,200	31
20 Jan 74	11	19,300	249,300	1.9	473,700	9,142	88
20 Jan 74	22	141,146	600,600	1.1	661,000	93,301	900
20 Jan 74	24	20,900	226,200	1.1	249,000	5,209	51
20 Jan 74	10	7,900	Intertidal Spawn		224,200	1,772	17
28 Jan 74	2	11,160	217,250	1.9	412,300	4,604	44
8 Feb 74	2	11,160	73,000	1.9	139,040	1,554	15
8 Feb 74	26	71,200	34,800	1.0	34,800	2,508	27
11 Feb 74	21 & 23	273,400	291,800	0.6	175,000	47,775	462
11 Feb 74	26	102,100	99,800	1.0	99,800	10,159	98
15 Feb 74	19 & 20	365,000	629,000	1.1	692,000	252,580	2,440
25 Feb 74	1	2,800	573	1.9	1,100	3	–
25 Feb 74	2	11,160	267,800	1.9	508,800	5,649	54
25 Feb 74	3	4,200	789,500	1.9	1,500,000	6,300	61
25 Feb 74	5	5,200	207,160	1.9	393,600	2,043	20
25 Feb 74	6	5,750	9,421	1.9	17,900	103	1
26 Feb 74	7	5,750	773,400	1.9	1,469,500	8,446	81
26 Feb 74	8	2,800	176,375	1.9	335,100	938	9
26 Feb 74	9	16,700	79,241	1.9	150,600	2,505	24
11 Mar 74	3	770	127,700	1.9	242,600	186	2
TOTAL		1,759,365				625,807	6,041.2

* See Figure 11.

APPENDIX III
Herring Spawning Data for Tomales Bay,

APPENDIX III (cont'd)

1974–75 Season

Date	Location *	Area m²	No. eggs/ kg eel grass	Kg eel grass/ m²	No. eggs/ m²	Millions eggs	Spawn Estimate (Tons)
27 Dec 74	2	11,100	1,148,000	1.9	2,182,000	24,221	234
27 Dec 74	25	133,800	12,800	0.5	6,300	842	8
27 Dec 74	5	5,560	71,500	1.9	135,900	756	7
27 Dec 74	3 & 4	349	1,221,000	1.9	2,320,000	809	8
31 Dec 74	9	46,700	158,800	1.9	301,700	14,089	136
31 Dec 74	10	3,700	269,500	1.9	512,300	1,898	18
31 Dec 74	8	2,800	11,500	1.9	21,800	61	0.6
31 Dec 74	23	100,000	23,400	0.4	9,360	936	9
9 Jan 75	23	348,700	182,400	0.6	109,400	38,054	357
19 Jan 75	23	418,500	229,500	0.6	137,800	57,684	557
19 Jan 75	21	697,300	294,800	0.6	176,900	123,369	1,192
29 Jan 75	23	550,560	140,100	0.5	70,100	38,555	372
29 Jan 75	11	35,400	359,700	1.9	683,400	24,075	240
6 Feb 75	25	10,400	56,500	0.5	28,250	945	9
10 Feb 75	9	16,700	866,000	1.9	1,645,000	27,471	265
10 Feb 75	22	140,000	333,000	1.1	366,300	51,240	495
16 Feb 75	9	21,000	25,800	1.9	49,000	1,029	10
18 Feb 75	11	19,200	151,700	1.9	288,200	5,472	53
23 Feb 75	16	37,200	55,850	4.0	223,400	8,310	80
24 Feb 75	25	50,200	54,500	0.5	27,300	1,370	13
27 Feb 75	9	13,000	50,200	1.9	95,400	1,240	12
1 Mar 75	26	170,000	79,700	1.0	79,700	13,500	131
5 Mar 75	9	29,900	4,800	1.9	9,100	272	3
TOTAL		2,886,329				436,038	4,210.6

* See Figure 11.

APPENDIX III—Cont'd.

APPENDIX III (Cont'd)

1975–76 Season

Date	Location*	Area m^2	No. eggs/ kg eel grass	Kg eel grass/ m^2	No. eggs/ m^2	Millions eggs	Spawn Estimate (Tons)
17 Dec 75	3	5,000	186,900	1.9	355,100	1,775	17
17 Dec 75	4	93	804,800	1.9	1,529,100	142	1
17 Dec 75	5	5,200	196,500	1.0	196,500	1,021	10
17 Dec 75	23	535,000	53,500	1.1	58,850	31,484	304
17 Dec 75	25	50,600	82,800	0.5	41,400	2,097	20
22 Dec 75	25 & 26	172,500	85,900	0.7	60,130	10,372	100
1 Jan 76	3	5,000	958,000	1.9	1,820,200	9,101	88
1 Jan 76	4	93	1,832,500	1.9	3,481,700	323	3
1 Jan 76	5	1,400	209,000	1.0	209,000	290	3
1 Jan 76	6	1,350	111,500	1.0	111,500	150	1
1 Jan 76	7	7,500	89,400	1.0	89,400	670	6
1 Jan 76	8	2,800	262,200	1.9	498,200	1,394	13
1 Jan 76	9	40,400	1,030,200	1.9	1,957,400	79,079	764
1 Jan 76	10	3,700	3,265,600	1.9	6,812,000	25,204	243
1 Jan 76	11	21,900	503,500	1.9	956,650	20,953	201
1 Jan 76	12	140	316,700	1.9	601,730	84	1
1 Jan 76	21	83,700	69,500	1.5	104,250	8,725	84
1 Jan 76	22	139,500	505,700	1.1	556,300	77,604	750
1 Jan 76	23	123,200	133,700	1.5	200,500	24,701	239
1 Jan 76	24	20,900	178,600	1.1	196,500	4,106	40
1 Jan 76	16A	11,400	270,300	1.9	513,600	5,855	56
8 Jan 76	3	5,000	93,900	1.9	178,400	892	9
8 Jan 76	4	93	33,800	1.9	64,300	5	–
8 Jan 76	8	93	3,900	1.9	7,400	0.6	–
8 Jan 76	9	40,400	1,650	1.9	3,100	125	1
8 Jan 76	11	21,800	727,500	1.9	1,382,300	30,131	291
8 Jan 76	12	140	2,600	1.9	4,900	0.6	–
8 Jan 76	21	14,100	18,200	1.5	27,300	4	–
8 Jan 76	22	140,000	133,100	1.1	146,400	20,496	198
8 Jan 76	23	10,700	127,600	1.5	191,400	2,048	20
8–14 Jan 76	1	3,800	3,736,400	1.9	7,099,200	26,976	261
8–14 Jan 76	2	7,800	7,183,300	1.9	13,648,300	103,727	1,002
8–14 Jan 76	23	161,000	118,500	1.5	177,800	28,561	280
17 Jan 76	16	37,200	154,000	4.0	616,000	22,915	221

APPENDIX III—Cont'd.

17 Jan 76	21	75,200	455,500	1.5	683,200	51,376	456
6 Feb 76	11	21,200	481,300	1.9	914,500	19,938	193
6 Feb 76	12	140	965,100	1.9	1,833,700	258	2
6 Feb 76	14	93	301,900	1.9	572,600	0.3	-
6 Feb 76	22	162,500	907,400	1.1	998,100	162,191	1,567
6 Feb 76	15A	2,000	204,200	1.9	388,000	776	7
10–14 Feb 76	25	50,800	80,750	.5	40,400	2,052	20
10–14 Feb 76	26	95,000	152,100	1.0	152,100	14,449	140
23 Feb 76	9	2,700	6,000	1.9	11,400	30	-
1 Mar 76	1	5,000	323,200	1.9	614,080	3,070	30
9 Mar 76	1	2,000	211,600	1.9	402,040	1,507	15
13 Mar 76	16	37,200	50,000	6.0	300,000	7,440	72
TOTAL		3,131,435					7,769

* See Figure 11.

APPENDIX III—Cont'd.

APPENDIX III (cont'd)

1976–77 Season

Date	Location*	Area m^2	No. eggs/ kg eel grass	Kg eel grass/ m^2	No. eggs/ m^2	Millions eggs	Spawn Estimate (Tons)
1 Dec 76	25	250	189,000	1.0	189,000	47	0.4
2 Dec 76	26	100	28,000	1.0	28,000	3	-
21 Dec 76	5	2,000	280,500	1.9	533,000	1,064	10
21 Dec 76	6	5,200	66,000	1.9	125,500	662	6
21 Dec 76	7	7,500	143,000	1.9	272,000	2,040	20
21 Dec 76	8	2,800	543,000	1.9	1,032,000	2,890	28
21 Dec 76	9	33,400	2,080,000	1.9	3,952,000	131,997	1,275
21 Dec 76	9	16,000	1,596,000	1.9	3,032,000	48,512	469
21 Dec 76	10	3,700	148,000	1.9	281,000	1,039	10
21 Dec 76	11	18,000	415,000	1.9	789,000	14,184	137
26 Dec 76	25	16,300	256,000	1.0	256,000	4,173	40
26 Dec 76	27	750	84,000	1.0	84,000	63	0.6
27 Dec 76	25	6,500	115,000	1.0	115,000	750	6
3 Jan 77	23	188,100	300,000	1.1	330,000	62,040	599
3 Jan 77	17	2,200	168,000	1.9	315,000	699	7
3 Jan 77	15A	11,400	737,000	1.9	1,400,000	15,960	154
3 Jan 77	15	93	1,198,000	1.9	2,276,000	212	2
3 Jan 77	14	150	2,571,000	1.9	4,885,000	732	7
3 Jan 77	13	93	403,000	1.9	766,000	71	0.7
3 Jan 77	12	1,500	2,685,000	1.9	5,102,000	7,653	74
3 Jan 77	11	36,400	617,000	1.9	1,172,000	42,661	412
3 Jan 77	10	3,700	746,000	1.9	1,417,000	5,243	51
3 Jan 77	9	16,000	233,000	1.9	443,000	7,088	68
5 Jan 77	25	13,800	206,000	1.0	206,000	2,843	28
5 Jan 77	21	368,000	108,000	1.5	162,000	59,616	576
5 Jan 77	16	100	10,600	4.0	42,000	4	-
6 Jan 77	2	9,700	291,000	1.9	553,000	5,364	52
10 Jan 77	2	4,900	50,500	1.9	96,000	470	4
26 Jan 77	1	3,800	44,400	1.9	84,000	319	3
26 Jan 77	2	2,500	50,000	1.9	94,000	235	2
26 Jan 77	3	2,200	80,000	1.9	151,000	332	3
26 Jan 77	4	100	17,000	1.9	13,000	1	-
26 Jan 77	5	2,000	155,000	1.9	291,000	582	6
26 Jan 77	6	3,000	131,000	1.9	250,000	750	7
26 Jan 77	7	7,200	107,000	1.9	204,000	1,330	15
26 Jan 77	8	2,800	182,000	1.9	348,000	974	9

APPENDIX III—Cont'd.

26 Jan 77	9	49,400	136,000	1.9	258,000	12,743	123
26 Jan 77	10	3,700	250,000	1.9	474,000	1,753	17
26 Jan 77	25	16,700	142,000	1.0	142,000	2,371	23
26 Jan 77	27	10,300	226,000	1.0	226,000	2,305	22
27 Jan 77	23	16,700	63,400	1.1	70,000	1,169	11
3 Feb 77	28	17,000	42,400	1.9	81,000	1,377	13
16 Feb 77	28	30,000	362,000	1.9	688,000	20,640	198
21 Feb 77	2	2,500	310,000	1.9	590,000	1,475	14
21 Feb 77	1	3,900	98,000	1.9	186,000	726	7
21 Feb 77	3	2,200	68,000	1.9	129,000	283	3
24 Feb 77	25	8,000	224,000	1.0	224,000	1,792	17
4 Mar 77	3	2,200	2,200	1.9	4,200	9	–
4 Mar 77	4	100	15,400	1.9	29,000	3	–
4 Mar 77	5	2,000	2,700	1.9	5,200	10	0.1
4 Mar 77	6	1,800	11,200	1.9	21,000	37	0.4
4 Mar 77	7	1,000	9,400	1.9	18,000	18	0.2
4 Mar 77	27	500	38,000	1.0	38,000	19	0.2
5 Mar 77	10	3,700	11,900	1.9	22,000	81	0.8
5 Mar 77	11	26,400	24,200	1.9	46,000	1,074	16
5 Mar 77	22	140,000	10,700	1.1	12,000	1,680	16
5 Mar 77	23	200	21,300	1.1	23,400	4	–
5 Mar 77	24	21,000	7,300	1.1	8,000	168	2
6 Mar 77	2	9,700	145,000	1.9	276,000	2,677	26
6 Mar 77	25	25,100	325,000	1.0	325,000	8,225	79
7 Mar 77	1	3,800	63,000	1.9	120,000	456	4
7 Mar 77	25	17,000	175,000	1.1	192,000	3,264	32
7 Mar 77	23 & 25	16,000	21,500	1.1	24,000	384	4
7 Mar 77	9	25,000	50,000	1.9	95,000	2,375	23
7 Mar 77	8	2,800	3,600	1.9	6,900	19	0.2
TOTAL		1,217,446				486,615	4,739

* See Figure 11.

APPENDIX III—Cont'd.

APPENDIX III (cont'd)

1977–78 Season

Date	Location *	Area m²	No. eggs/ kg eel grass	Kg eel grass/ m²	No. eggs/ m²	Millions eggs	Spawn Estimate (Tons)
13 Dec 77	25	146,300	135,700	1.0	135,700	19,856	192
13 Dec 77	26	183,800	76,400	1.0	76,400	14,042	136
13 Dec 77	27	12,400	260,000	1.0	260,000	3,224	31
16 Dec 77	8	2,800	11,600	1.9	22,040	62	0.6
19 Dec 77	2	9,700	752,300	1.9	1,430,000	14,065	136
19 Dec 77	5	2,000	224,700	1.9	426,900	854	8
19 Dec 77	6	5,300	175,300	1.9	333,100	1,758	17
19 Dec 77	7	7,500	24,200	1.9	45,900	344	3
19 Dec 77	11	22,000	481,000	1.9	913,900	20,750	208
23 Dec 77	25	91,900	346,100	1.0	346,100	32,860	321
23 Dec 77	9	23,400	61,000	1.9	116,000	2,674	27
6 Jan 78	3	2,800	660,000	1.9	1,260,000	3,542	37
6 Jan 78	4	100	1,420,000	1.9	2,698,000	269	2.6
6 Jan 78	5	2,000	584,000	1.9	1,107,000	2,214	21
6 Jan 78	6	5,000	730,000	1.9	1,387,000	6,935	67
6 Jan 78	24	20,900	325,000	1.1	357,500	7,471	72
10 Jan 78	7	7,300	346,000	1.9	657,400	4,827	48
10 Jan 78	8	2,800	519,000	1.9	986,100	2,758	27
10 Jan 78	9	49,400	2,369,000	1.9	4,501,800	245,630	2,353
10 Jan 78	10	3,700	1,020,000	1.9	1,938,000	7,170	69
10 Jan 78	11	8,100	160,000	1.9	304,000	2,462	24
20 Jan 78	1	3,800	1,190,000	1.9	2,266,000	8,614	83
20 Jan 78	2	9,700	1,114,000	1.9	2,116,000	20,709	200
24 Jan 78	25	120,600	880,000	1.0	880,000	106,272	1,027
24 Jan 78	26	130,000	1,310,000	1.0	1,310,000	170,555	1,643
25 Jan 78	16	37,200	656,500	4.0	2,626,000	97,687	944
25 Jan 78	20	10,000	821,200	1.5	1,232,000	13,488	130
25 Jan 78	21	476,500	1,770,000	1.0	1,770,000	843,405	8,147
25 Jan 78	23	1,100,000	372,000	1.1	409,200	450,120	4,348
26 Jan 78	24	20,500	960,000	1.1	1,056,000	21,648	212
27 Jan 78	22	80,800	522,000	1.1	574,200	46,395	449
27 Jan 78	11	13,700	221,000	1.9	419,900	5,740	55
27 Jan 78	12	1,500	186,000	1.9	353,000	530	5
27 Jan 78	16A	3,800	13,900	1.9	26,410	100	1
13 Feb 78	25	1,400	526,000	1.0	526,000	736	7
13 Feb 78	26	14,400	220,000	1.0	220,000	3,168	31
13 Feb 78	27	5,100	7,500	1.0	7,500	38	0.4

APPENDIX III—Cont'd.

15 Feb 78	7	7,500	34,700	1.9	65,900	494	5
15 Feb 78	8	5,800	30,000	1.9	57,000	160	1.5
15 Feb 78	9	7,300	80,900	1.9	39,700	290	3
15 Feb 78	10	3,700	675,000	1.9	902,500	3,339	32
15 Feb 78	21	28,800	14,500	1.0	14,500	629	4
15 Feb 78	22	324,500	78,300	1.1	86,000	28,724	277
15 Feb 78	26	81,200	54,800	1.0	54,800	4,433	43
15 Feb 78	26	6,200	21,800	1.0	21,800	135	1.3
16 Feb 78	11	3,800	100,700	1.9	191,300	689	[illegible]
16 Feb 78	22	3,300	13,500	1.1	14,800	48	0.5
20 Feb 78	8	4,900	850,000	1.9	1,615,000	7,913	76
20 Feb 78	3	3,200	112,000	1.9	212,800	405	4
TOTAL		3,154,300				2,257,463	21,517

* See Figure 11.

APPENDIX III—Cont'd.

APPENDIX III (cont'd)

1979–80 Season

Date	Location *	Area m^2	No. eggs/ kg eel grass	Kg eel grass/ m^2	No. eggs/ m^2	Millions eggs	Spawn Estimate (Tons)
27–28 Nov 79	25	50,000	13,290	1.0	13,290	664	6
7 Dec 79	3	12,480	2,370	1.9	4,500	60	0.6
7 Dec 79	26	24,000	36,280	1.9	68,900	1,655	16
23–24 Dec 79	9	15,750	185,800	1.9	353,000	5,540	53
24 Dec 79	23	459,000	93,800	1.0	93,800	42,960	415
26 Dec 79	23	155,700	97,100	1.1	106,800	16,630	161
29 Dec 79	7	19,400	18,750	1.9	35,650	690	7
7 Jan 80	3	9,280	268,800	1.9	510,800	4,730	46
7 Jan 80	4	93	198,900	1.9	377,900	35	0.3
7 Jan 80	5	6,150	271,400	1.9	515,600	3,170	31
7 Jan 80	6	10,000	410,200	1.9	779,350	7,790	75
7 Jan 80	7	19,400	401,400	1.9	762,700	14,800	143
7 Jan 80	8	2,700	421,000	1.9	799,900	2,160	21
7 Jan 80	9	40,420	594,700	1.9	1,130,000	45,650	441
7 Jan 80	10	3,700	641,800	1.9	1,219,500	4,510	43
7 Jan 80	11	5,000	453,700	1.9	862,100	4,310	42
7 Jan 80	23	440,000	62,300	1.1	68,500	30,480	294
7 Jan 80	27	12,400	231,100	1.0	231,100	2,865	28
20 Jan 80	21	224,700	135,100	1.5	202,700	45,550	440
20 Jan 80	22	217,000	612,800	1.9	1,164,300	252,590	2,440
20 Jan 80	23	882,000	56,600	1.1	62,300	54,950	531
20 Jan 80	24	20,900	81,400	1.9	154,600	3,230	31
20 Jan 80	25	40,000	143,400	1.0	143,400	5,736	55
24 Feb 80	3	12,480	436,500	1.9	829,400	10,350	100
TOTAL		1,687,563				561,100	5,420

* See Figure 11.

APPENDIX III—Cont'd.

APPENDIX IV

Herring Spawning Data for San Francisco Bay,
1973–74 through 1978–79 Season

Spawning date	Location	Area (m^2)	Eggs/m^2	Millions of eggs	Tons	Biomass with predation correction
1973–74						
16-19 Dec 73	Fig. 15	69,900	494,000	34,506	333	331
5-11 Feb 74	Fig. 15	249,000	460,000	114,590	1,102	1,777
28 Feb 74	Fig. 15	23,400	30,000	720	7	140
17-18 Mar 74	Fig. 15	132,000	1,125,000	149,625	1,445	1,973
TOTAL		474,300		298,931	2,887	4,241
1974–75						
8 Dec 74	Fig. 16	6,000	533,000	3,198	31	-
3-4 Jan 75	Fig. 16	209,500	942,000	196,875	1,902	-
20-25 Jan 75	Fig. 16	815,400	2,017,000	1,649,808	15,938	-
14-16 Feb 75	Fig. 16	8,260	NOT SAMPLED			
26-27 Feb 75	Fig. 16	442,000	2,096,000	926,400	8,940	-
TOTAL		1,484,860		2,776,282	26,820	-
1975–76						
17 Dec 75	Fig. 18	2,600	730,100	18,918	183	-
27 Dec 75	Fig. 18	255,800	1,158,000	267,300	2,579	-
13-17 Jan 76	Fig. 18	555,500	2,777,000	1,542,623	14,902	-
6 Feb 76	Fig. 18	440,200	1,469,000	646,654	6,246	-
6-10 Mar 76	Fig. 18	115,200	1,265,000	145,733	1,406	-
TOTAL		1,368,100		2,620,932	25,316	
1976–77						
2 Dec 76	Fig. 19	45,200	166,400	7,503	72	-
17 Dec 76	Fig. 19	69,900	1,333,000	92,046	889	-
26-27 Dec 76	Fig. 19	209,900	1,494,500	309,221	2,987	-
5-6 Jan 77	Fig. 19	141,000	3,658,700	515,919	4,984	-
24 Jan 77	Fig. 19	57,300	2,436,300	139,582	1,348	-
1-10 Feb 77	Fig. 19	229,400	4,214,000	1,007,365	9,731	-
Subtotal		748,700		2,071,636	20,011	

APPENDIX IV
Herring Spawning Data for San Francisco Bay,

APPENDIX IV (cont'd)

Spawning date	*Location*	*Area (m²)*	*Eggs/m²*	*Millions of eggs*	*Tons*	*Biomass with predation correction*
25 Jan 77	Fig. 19	104,500	1,000,000	104,500	1,035	–
23–24 Feb 77	Fig. 19	66,900	2,100,000	140,000	1,359	–
TOTAL		930,100		2,316,356	22,375	
1977–78						
16–23 Dec 77	Fig. 20	292,000	666,000	194,486	1,878	–
9 Jan 78	Fig. 20	42,200	587,750	24,800	240	–
13 Jan 78	Fig. 20	5,200	2,180,000	11,336	110	–
22–24 Jan 78	Fig. 20	29,100	843,400	24,543	227	–
23–24 Jan 78	Fig. 20	68,800	1,604,100	109,400	1,057	–
23–24 Feb 78	Fig. 20	33,900	480,000	16,800	160	–
TOTAL		470,600		381,165	3,692	
1978–79						
5–10 Dec 78	Fig. 21	50,000	640,000	32,000	310	–
15–16 Dec 78	Fig. 21	96,000	1,177,000	113,000	1,090	–
31 Dec 78	Fig. 21	208,000	1,315,000	396,000	3,840	–
4 Jan 79	Fig. 21	6,900	637,000	4,400	40	–
6 Jan 79	Fig. 21	36,000	687,000	24,700	240	–
18–20 Jan 79	Fig. 21	4,944,000	339,000	1,676,000	16,200	–
20–21 Jan 79	Fig. 21	100,000	445,000	44,500	430	–
20–24 Jan 79	Fig. 21	162,000	3,368,000	546,000	5,300	–
31 Jan–6 Feb 79	Fig. 21	130,000	1,157,000	161,000	1,550	–
6–8 Feb 79	Fig. 21	84,000	753,000	63,000	610	–
20–23 Feb 79	Fig. 21	73,250	4,080,000	307,000	2,970	–
TOTAL		5,908,150		3,372,600	32,580	

APPENDIX IV—Cont'd.

APPENDIX V

Herring Spawning Data for San Francisco Bay, 1979–80 Season

Spawning date	*Location*	*Area (m²)*	*No. eggs/ kg vegetation*	*kg vegetation/ m²*	*No. eggs/ m²*	*Millions of eggs*	*Spawning estimate (Tons)*
2 Nov 79	Fig. 22	301,000	210,000	.060	12,600	3,800	37
27–28 Nov 79	Fig. 22	66,800	1,388,000	.600	833,000	55,700	538
27–28 Nov 79	Fig. 22	117,000	*	*	1,236,000	144,600	1,397
13–15 Dec 79	Fig. 22	14,300,000	1,506,000	.114	171,700	2,458,000	23,552
24 Dec 79	Fig. 22	616,700	1,656,000	.064	106,000	65,600	633
27–30 Dec 79	Fig. 22	3,180,000	2,729,000	.038	103,700	328,000	3,167
27–30 Dec 79	Fig. 22	66,800	868,000	.600	417,000	27,500	270
27–30 Dec 79	Fig. 22	88,800	4,250,000	.600	2,550,000	224,400	2,167
27–30 Dec 79	Fig. 22	192,000	*	*	1,000,000	192,000	1,855
9–11 Jan 80	Fig. 22	150,000	*	*	1,000,000	150,000	1,367
16–17 Jan 80	Fig. 22	18,700	*	*	500,000	9,340	90
16–17 Jan 80	Fig. 22	2,019,000	183,500	.085	15,600	31,500	304
28–30 Jan 80	Fig. 22	104,500	*	*	979,000	102,300	987
27–30 Jan 80	Fig. 22	4,456,000	1,269,300	.026	33,000	147,200	1,422
30 Jan 80	Fig. 22	200,000	*	*	1,127,000	226,000	2,184
7–10 Feb 80	Fig. 22	125,000	*	*	1,400,000	175,400	1,694
26 Feb 80	Fig. 22	3,656,000	1,467,000	.049	71,900	263,000	2,540
TOTAL		31,379,200				4,807,270	46,439

* These were intertidal spawns and vegetation parameters are not used to calculate estimates.

APPENDIX V
Herring Spawning Data for San-Francisco Bay,

CALIFORNIA DEPARTMENT OF FISH AND GAME FISH BULLETINS

* No. 1. Report on Fish Conditions, 1913; 48 p., figs.

* No. 2. The Scientific Investigation of Marine Fisheries, as Related to the Work of the Fish and Game Commission in Southern California. By Will F. Thompson. 1919; 27 p., 4 figs.

* No. 3. The Spawning of the Grunion (Lauresthes tenuis) . By Will F. Thompson, assisted by Julia Bell Thompson. 1919; 29 p., 9 figs.

* No. 4. The Edible Clams, Mussels, and Scallops of California. By Frank W. Weymouth. 1920; 72 p., 19 pls. 26 figs.

* No. 5. A Key to the Families of Marine Fishes of the West Coast. By Edwin C. Starks. 1921; 16 p., 4 figs.

* No. 6. A History of California Shore Whaling. By Edwin C. Starks. 1923; 38 p., 22 figs.

* No. 7. The Life-History and Growth of the Pismo Clam. By Frank W. Weymouth. 1923; 120 p., 15 figs., 18 graphs.

* No. 8. Racial and Seasonal Variation in the Pacific Herring, California Sardine and California Anchovy. By Carl L. Hubbs, 1925; 23 p., 4 pls.

* No. 9. Preliminary Investigation of the Purse Seine Industry of Southern California. By Tage Skogsberg. 1925; 95 p., 23 figs.

* No. 10. The Life History of Leuresthes tenuis, an Atherine Fish with Tide Controlled Spawning Habits. By Frances N. Clark. 1925; 51 p., 6 graphs, 7 pls.

* No. 11. The California Sardine. By the Staff of the California State Fisheries Laboratory. 1926; 221 p., 74 figs.

* No. 12. The Weight-Length Relationship of the California Sardine (Sardina caerulea) at San Pedro. By Frances N. Clark. 1928; 58 p., 11 figs.

* No. 13. The Seasonal Average Length Trends at Monterey of the California Sardine (Sardina caerulea) . By Carroll B. Andrews. 1928; 12 p., 6 figs.

* No. 14. Report on the Seals and Sea Lions of California. By Paul Bonnot. 1928; 61 p., 38 figs.

* No. 15. The Commercial Fish Catch of California for the Years 1926 and 1927. By the Bureau of Commercial Fisheries. 1929; 93 p., 52 figs.

* No. 16. The Life History of the California Jack Smelt (Atherinopsis californiensis) . By Frances N. Clark. 1929; 22 p., 12 figs.

* No. 17. Sacramento-San Joaquin Salmon (Oncorhynchus tschawytscha) Fishery of California. By G. H. Clark. 1929; 73 p., 32 figs.

* No. 18. The Pismo Clam: Further Studies of Its Life History and Depletion. By William C. Herrington. 1930; 67 p., 16 figs.

* No. 19. Sardine Fishing Methods at Monterey, California. By W. L. Scofield. 1929; 61 p., 27 figs.

* No. 20. The Commercial Fish Catch of California for the Year 1928. By the Staff of the Bureau of Commercial Fisheries. 1930; 109 p., 62 figs.

* No. 21. Analysis of Boat Catches of White Sea Bass (Cynoscion nobilis) at San Pedro, California. By S. S. Whitehead, 1930; 26 p., 20 figs.

* No. 22. A Bibliography of the Tunas. By Genevieve Corwin. 1930; 103 p.

* No. 23. Success of the Purse Seine Boat in the Sardine Fishery at Monterey, California (1929–1930 Fishing Season). By J. B. Phillips. 1930; 28 p., 19 figs.

* Out of print.

* No. 24. An Analysis of the Catch Statistics of the Striped Bass (Roccus lineatus) Fishery of California. By J. A. Craig. 1930; 41 p., 22 figs.

* No. 25. Fishing Areas Along the California Coast for the Sardine (Sardina caerulea) . By the California State Fisheries Laboratory. 1930; 44 p., 25 figs.

* No. 26. Seasonal Changes in the Daily Average Length of the California Sardine (Sardina caerulea) . By Frances N. Clark. 1930; 20 p., 11 figs.

* No. 27. The Ring Net, Half Ring Net, or Purse Lampara in the Fisheries of California. By Donald H. Fry, Jr. 1931; 65 p., 28 figs.

* No. 28. Handbook of Common Commercial and Game Fishes of California. By Lionel A. Walford. 1931; 181 p., 137 figs.

* No. 29. The Striped Bass of California (Roccus lineatus) . By Eugene C. Scofield. 1931; 82 p., 47 figs.

* No. 30. The Commercial Fish Catch of California for the Year 1929. By the Staff of the Bureau of Commercial Fisheries. 1931; 133 p., 75 figs.

* No. 31. Studies of the Length Frequencies of the California Sardine (Sardina caerulea) . By the California State Fisheries Laboratory. 1931; 53 p., 24 figs.

* No. 32. The California Halibut (Paralichthys californicus) and an Analysis of the Boat Catches. By G. H. Clark. 1931; 52 p., 25 figs.

* No. 33. Fishing Methods for the Bluefin Tuna (Thunnus thynnus) and an Analysis of the Catches. By S. S. Whitehead. 1931; 32 p., 22 figs.

* No. 34. Salmon of the Klamath River, California. By John O. Snyder. 1931; 130 p., 44 figs.

* No. 35. A Distributional List of the Species of Freshwater Fishes Known to Occur in California. By Barton W. Evermann and Howard Walton Clark. 1931; 67 p.

* No. 36. A Bibliography of the Sardines. By Genevieve C. Wheeler. 1931; 133 p.

No. 37. The California Barracuda (Sphyraena argentea) . By Lionel A. Walford. 1932; 120 p., 32 figs., 6 pls.

* No. 38. The California Shrimp Industry. By Paul Bonnot. 1932; 20 p., 11 figs.

* No. 39. Fluctuations in the Abundance of Striped Bass (Roccus lineatus) in California. By G. H. Clark. 1933; 18 p., 7 figs.

* No. 40. The California Mackerel Fishery. By Richard S. Croker. 1933; 149 p., 73 figs.

* No. 41. Early Life History of the California Sardine (Sardina caerulea) , with Special Reference to Distribution of Eggs and Larvae. By Eugene C. Scofield. 1934; 48 p., 24 figs.

* No. 42. Maturity of the California Sardine (Sardina caerulea) . Determined by Ova Diameter Measurements. By Frances N. Clark. 1934; 49 p., 19 figs.

* No. 43. The Sizes of California Sardines Caught by the Different Fishing Gear and in the Different Localities of the Monterey and San Pedro Regions. By the California State Fisheries Laboratory. 1935; 59 p., 27 figs.

* No. 44. The Commercial Fish Catch of California for the Years 1930–1934, inclusive. By the Staff of the Bureau of Commercial Fisheries. 1935; 124 p., 19 figs.

* No. 45. The Sharks and Rays of California. By Lionel A. Walford. 1935; 66 p., 58 figs.

* No. 46. A Contribution Toward the Life Histories of Two California Shrimps, Crago franciscorum (Stimpson) and Crago nigricauda (Stimpson). By Hugh R. Israel. 1936; 28 p., 9 figs.

* No. 47. Interseasonal and Intraseasonal Changes in Size of the California Sardine (Sardinops caerulea) . By Frances N. Clark. 1936; 28 p., 11 figs.

* No. 48. Fishing Localities for the California Sardine, Sardinops caerulea, 1928–1936. By Frances N. Clark. 1937; 11 p., 5 figs.
* No. 49. The Commercial Fish Catch of California for the Year 1935. By the Bureau of Commercial Fisheries. 1937; 170 p., 114 figs.

No. 50. Sizes of California Sardines Caught in the Different Areas of the Monterey and San Pedro Regions. By J. B. Phillips. 1937; 31 p., 12 figs.

No. 51. The High Seas Tuna Fishery of California. By H. C. Godsil. 1938; 41 p., 20 figs.

* No. 52. Historical Account of the Los Angeles Mackerel Fishery. By Richard S. Croker. 1938; 62 p., 37 figs.
* No. 53. Measures of Abundance of the Sardine, Sardina caerulea, in California Waters. By Frances N. Clark. 1939; 45 p., 19 figs.
* No. 54. The Fishes of the Family Sciaenidae (Croakers) of California. By Tage Skogsberg. 1939; 62 p., 16 figs.
* No. 55. Report on Returns of Drift Bottles Released off Southern California, 1937. By Richard B. Tibby. 1939; 36 p., 22 figs.
* No. 56. Development of the Eggs and Early Larvae of Six California Fishes. By Paul L. Budd. 1940; 50 p., 13 pls.
* No. 57. The Commercial Fish Catch of California for the Years 1936–1939, Inclusive. By the Staff of the Bureau of Marine Fisheries. 1940; 100 p., 9 figs.
* No. 58. The Commercial Fish Catch of California for the Year 1940. By the Staff of the Bureau of Marine Fisheries. 1942; 47 p., 7 figs.
* No. 59. The Commercial Fish Catch of California for the Years 1941 and 1942. By the Staff of the Bureau of Marine Fisheries. 1944; 68 p., 8 figs.
* No. 60. A Systematic Study of the Pacific Tunas. By H. C. Godsil and Robert D. Byers. 1944; 131 p., 76 figs.
* No. 61. Results of Tagging Experiments in California Waters on the Sardine (Sardinops caerulea) . 1945; 90 p., 15 figs.
* No. 62. Catch per-Unit-of-Effort in California Waters of the Sardine (Sardinops caerulea) . 1932–42. By Ralph P. Silliman and Frances N. Clark. 1945; 76 p., 22 figs.
* No. 63. The Commercial Fish Catch of California for the Years 1943 and 1944. By the Staff of the Bureau of Marine Fisheries. 1946, 81 p., 6 figs.
* No. 64. The Biology of the Soupfin, Galeorhinus zyopterus, and Biochemical Studies of the Liver. 1946; 93 p., 41 figs.

No. 65. Analysis of Populations of the Pacific Sardine on the Basis of Vertebral Counts. By Frances N. Clark. 1947; 26 p., 3 figs.

No. 66. Drift and Set Line Fishing Gear in California. By W. L. Scofield. 1947; 38 p., 16 figs.

* No. 67. The Commercial Fish Catch of California for the Years 1945 and 1946. By the Staff of the Bureau of Marine Fisheries. 1947; 80 p., 7 figs.
* No. 68. Common Marine Fishes of California. By Phil M. Roedel. 1948; 150 p., 111 figs.
* No. 69. Age and Length Composition of the Sardine Catch off the Pacific Coast of the United States and Canada, 1941–42 through 1946–47. By Frances E. Felin and Julius B. Phillips. 1948; 122 p.
* No. 70. A Preliminary Population Study of the Yellowfin Tuna and the Albacore. By H. C. Godsil, 1948; 90 p., 22 figs.

No. 71. Growth of the Sardine, Sardinops caerulea, 1941–42 through 1946–47. Julius B. Phillips. 1948; 33 p., 12 figs.

No. 72. Trawling Gear in California. By W. L. Scofield. 1948; 60 p., 24 figs.

No. 73. Tagging Experiments on the Pacific Mackerel (Pneumatophorus diego) . By Donald H. Fry, Jr., and Phil M. Roedel. 1949; 64 p., 15 figs.

No. 74. The Commercial Fish Catch of California for the Year 1947 With an Historical Review, 1916–1947. By the Staff of the Bureau of Marine Fisheries. 1949; 267 p., 99 figs.

* No. 75. California Sharks and Rays. By Phil M. Reodel and Wm. Ellis Ripley. 1950; 88 p., 65 figs.

No. 76. Average Lunar Month Catch by California Sardine Fishermen, 1932–33 through 1948–49. By Frances N. Clark and Anita E. Daugherty. 1950; 28 p., 6 figs.

* No. 77. A Comparison of the Bluefin Tunas, Genus Thunnus, from New England, Australia and California. By H. C. Godsil and Edwin K. Holmberg. 1950; 55 p., 15 figs.

* No. 78. The Life History of the Starry Flounder, Platichthys stellatus (Pallas). By Harold George Orcutt. 1950; 64 p., 52 figs.

* No. 79. A Key to Some Southern California Fishes Based on Vertebral Characters. By Charles R. Clothier. 1950; 82 p., 22 figs., 23 pls.

No. 80. The Commercial Fish Catch of California for the Years 1948–1949 with Yield per Area of the California Sardine Fishing Grounds 1937–1949. By the Staff of the Bureau of Marine Fisheries. 1951; 87 p., 9 figs.

No. 81. Purse Seines and Other Roundhaul Nets in California. By W. L. Scofield. 1951; 82 p., 37 figs.

No. 82. A Comparison of the Populations of Yellowfin Tuna, Neothunnus macropterus, from the Eastern and Central Pacific. By H. C. Godsil and E. C. Greenhood. 1951; 33 p., 6 figs.

No. 83. Age Composition of the Southern California Catch of Pacific Mackerel 1939–40 through 1950–51. By John E. Fitch. 1951; 73 p., 17 figs.

No. 84. A Racial Study of the Pacific Mackerel, Pneumatophorus diego. By Phil M. Roedel, 1952; 53 p., 5 figs.

No. 85. The Biology of the Dover Sole, Microstomus pacificus (Lockington). By Frederick B. Hagerman. 1952; 48 p., 28 figs.

No. 86. The Commercial Fish Catch of California for the Year 1950 with a Description of Methods Used in Collecting and Compiling the Statistics.) By the Staff of the Bureau of Marine Fisheries. 1952; 120 p., 43 figs.

No. 87. Surveys through 1951 of the Distribution and Abundance of Young Sardines (Sardinops caerulea) . By Julius B. Phillips and John Radovich. 1952. 63 p., 13 figs.

No. 88. A Revision of the Family Embiotocidae (The Surfperches). By Fred H. Tarp. 1952; 99 p., 32 figs.

No. 89. The Commercial Fish Catch of California for the Year 1951, with an Evaluation of the Existing Anchovy Case Pack Requirements. By the Staff of the Bureau of Marine Fisheries. 1953; 68 p., 4 figs.

No. 90. Common Marine Bivalves of California. By John E. Fitch. 1963; 102 p., 63 figs.

No. 91. Common Ocean Fishes of the California Coast. By Phil M. Roedel. 1953; 184 p., 175 figs.

No. 92. Studies on Fish Preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company. By James E. Kerr. 1953; 66 p., 36 figs.

No. 93. The Life History of the Cabezon, Scorpaenichthys marmoratus (Ayres). By Charles P. O'Connell. 1953; 76 p., 40 figs.

No. 94. The Behavior and Reproduction of Salmonid Fishes in a Small Coastal Stream. By John C. Briggs. 1953; 62 p., 5 figs.

No. 95. The Commercial Fish Catch of California for the Year 1952 with Proportion of King and Silver Salmon in California's 1952 Landings. By the Staff of the Marine Fisheries Branch. 1954; 64 p., 7 figs.

No. 96. California Fishing Ports. by W. L. Scofield. 1954; 159 p., 88 figs.

No. 97. A Descriptive Study of Certain Tuna-like Fishes. By H. C. Godsil. 1954; 185 p., 93 figs.

No. 98. The Life Histories of the Steelhead Rainbow Trout (Salmo gairdneri gairdneri) and Silver Salmon (Onorhynchus kisutch) : with Special Reference to Waddell Creek, California, and Recommendations Regarding their Management. By Leo Shapovalov and Alan C. Taft. 1954; 375 p., 32 figs.

No. 99. A Description of Two Species of Bonito Sarda orientalis and S. chiliensis and a Consideration of Relationships within the Genus. By H. C. Godsil. 1955; 43 p., 14 figs.

No. 100. Catch Localities for Pacific Albacore (Thunnus germo) Landed in California. 1951 through 1953. By Harold B. Clemens. 1955; 28 p., 24 figs.

No. 101. Age Determination of the Northern Anchovy, Engraulis mordax. by Daniel J. Miller and Others. 1955; 66 p., 19 figs.

No 102. The Marine Fish Catch of California for the Years 1953 and 1954, with Jack Mackerel and Sardine Yield per Acre from California Waters 1946–47 through 1954–55. By the Staff of the Marine Fisheries Branch. 1956; 99 p., 10 figs.

No. 103. Trolling Gear in California. By W. L. Scofield. 1956; 45 p., 16 figs.

No. 104. A Review of the Rockfishes of California (Family Scorpaenidae). By Julius B. Phillips. 1957; 158 p., 66 figs.

No. 105. The Marine Fish Catch of California for the Years 1955 and 1956, with Rockfish Review. By the Staff of the Marine Resources Operations. 1958; 104 p., 9 figs.

No. 106. Age and Length Composition, Pacific Coast Catches, Sardines and Pacific Mackerel 1955–56 and 1956–57 Seasons, and the Northern Anchovy 1954–55 through 1956–57 Seasons. 1958; 72 p.

No. 107. Trout and Salmon Culture (Hatchery Methods). By Earl Leitritz. 1959, Reprinted 1969; 169 p., 58 figs.

No. 108. The Marine Fish Catch of California for the Years 1957 and 1958. By the Biostatistical Section, Marine Resources Operations. 1960; 74 p., 2 figs.

No. 109. The Barred Surfperch, Amphistichus argenteus (Agassiz) in Southern California. By John G. Carlisle, Jr., Jack W. Schott, and Norman J. Abramson. 1960; 79 p., 40 figs.

No. 110. A Study of the Yellowtail, Seriola dorsalis (Gill). By John L. Baxter and a Staff of Associates. 1960; 96 p., 46 figs.

No. 111. The Marine Fish Catch of California for the Year 1959. By the Biostatistical Section, Marine Resources Operations. 1960; 44 p., 2 figs.

No. 112. Relationships of Some Marine Organisms of the Northeast Pacific to Water Temperatures, Particularly During 1957 Through 1959. By John Radovich. 1961; 62 p., 13 figs.

No. 113. The Ecology of the Salton Sea, California, in Relation to the Sportfishery. Edited by Boyd W. Walker. 1961; 204 p., 80 figs.

No. 114. An Evaluation of Stocking Hatchery-Reared Steelhead Rainbow Trout (Salmo gairdnerii gairdnerii) in the Sacramento River System. By Richard J. Hallock, William F. Van Woert, and Leo Shapovalov. 1961; 74 p., 17 figs.

No. 115. The Migration, Age, and Growth of Pacific Albacore (Thunnus germo) , 1951–1958. By Harold B. Clemens. 1961; 128 p., 56 figs.

No. 116. Fitting a Von Bertalanffy Growth Curve by Least Squares, Including Tables of Polynomials. By Patrick K. Tomlinson and Norman J. Abramson. 1961; 69 p.

* No. 117. The Marine Fish Catch of California for the Year 1960. By the Biostatiscal Section, Marine Resources Operations. 1961; 45 p., 2 figs.

* No. 118 California Abalones, Family Haliotidae, By Keith W. Cox. 1962; 133 p., 70 figs.

No. 119. Growth Characteristics of Two Southern California Surffishes, the California Corbina and Spotfin Croaker, Family Sciaenidae. By David C. Joseph. 1962; 54 p., 18 figs.

No. 120. Estimating Absolute Age Composition of California Salmon Landings. By Joseph H. Kutkuhn. 1962; 47 p.

No. 121. The California Marine Fish Catch for 1961. By the Biostatistical Section, Marine Resources Operations. 1963; p. 1–47, 2 figs.

Catch Localities for Dover Sole, Microstomus pacificus (Lockington), Landed in California, 1950 through 1959. By E. A. Best. 1963; p. 48–56, 8 figs.

No. 122. The Kelp Bass (Paralabrax clathratus) and Its Fishery, 1947–1958. By Parke H. Young. 1963; 67 p., 33 figs.

No. 123. The California Oyster Industry. By Elinore M. Barrett. 1963; 103 p., 32 figs.

* No. 124. Artificial Habitat in the Marine Environment. By John G. Carlisle, Jr., Charles H. Turner and Earl E. Ebert. 1964; 93 p., 51 figs.

No. 125. The California Marine Fish Catch for 1962. By the Biostatiscal Section, Marine Resources Operations. 1964; 45 p., 2 figs.

* No. 126. Life History Studies on Ten Species of Rockfish (Genus Sebastodes) . By Julius B. Phillips. 1964; 70 p., 34 figs.

No. 127. California "Catchable" Trout Fisheries. By Robert L. Butler and David P. Borgeson. 1965; 47 p., 8 figs.

* No. 128. An Analysis of California's Albacore Fishery through 1961. By Harold B. Clemens and William L. Craig. 1965; 301 p., 176 figs.

* No. 129. The California Marine Fish Catch for 1963. By the Biostatistical Section, Marine Resources Operations. 1965; 45 p., 3 figs.

No. 130. Ocean Sportfish Catch and Effort from Oregon to Point Arguello, California, July 1, 1957-June 30, 1961. By Daniel J. Miller and Daniel Gotshall. 1965; 135 p., 16 figs.

* No. 131. The Structure, Development, Food Relations, Reproduction, and Life History of the Squid, Loligo opalescens Berry. By W. Gordon Fields. 1965; 108 p., 59 figs.

No. 132. The California Marine Fish Catch for 1964. By Edward C. Greenhood and David J. Mackett. 1965; 45 p., 2 figs.

No. 133. Ecological Studies of the Sacramento-San Joaquin Estuary. Part 1. Zooplankton, Zoobenthos, and Fishes of San Pablo and Suisun Bays, Zooplankton and Zoobenthos of the Delta. Compiled by D. W. Kelley. 1966; 133 p., 68 figs.

No. 134. A Management Study of the California Barracuda, Sphyraena argentea Girard. By Leo Pinkas. 1966; 59 p., 18 figs.

* No. 135. The California Marine Fish Catch for 1965. By Edward C. Greenhood and David J. Mackett. 1967; p. 1–42, 2 figs.

California Salmon Landings 1952 Through 1965. By Paul T. Jensen and Phillip G. Swartzell. 1967; p. 43–57.

* No. 136. Ecological Studies of the Sacramento-San Joaquin Delta. Part 2. Fishes of the Delta. Compiled by Jerry L. Turner and D. W. Kelley. 1966; 168 p., 74 figs.

* No. 137. Reproduction, Life History, and Ecology of the Round Stringray, Urlophus halleri Cooper. By John Stanley Babel. 1967; 104 p., 64 figs.

* No. 138. The California Marine Fish Catch for 1966. By Richard F. G. Heimann and Herbert W. Frey. 1968; p. 148, 2 figs.

California-Based Fisheries off the Coast of Mexico for Temperate Tunas, Market Fish, and Sport Fish. By Phillip M. Roedel and Herbert W. Frey. 1968; p. 49–76. 7 figs.

No. 139. Utilization of Kelp-Bed Resources in Southern California. Complied and Edited by Wheeler J. North and Carl L. Hubbs. 1968; 264 p., 84 figs.

* No. 140. The Marine Environment offshore from Point Loma, San Diego County. By Charles H. Turner, Earl E. Ebert, and Robert R. Given. 1968; 85 p., 27 figs.

No. 141. Artificial Destratification of El Capitan Reservoir by Aeration. By Arlo W. Fast. 1968; 97 p., 53 figs.

No. 142. Management of the White Seabass (Cynoscion nobilis) in California waters. By James C. Thomas. 1968; 34 p., 12 figs.

No. 143. Southern California Marine Sportfishing Survey; Private Boats, 1964; Shoreline, 1965–66. By Leo Pinkas, Malcolm S. Oliphant, and Charles W. Haugen. 1968; 42 p., 3 figs.

* No. 144. The California Marine Fish Catch for 1967. By Richard F. G. Heimann and Herbert W. Frey. 1968; 47 p., 2 figs.

No. 145. The California Partyboat Fishery 1947–1967. By Parke H. Young. 1969; 91 p., 16 figs.

No. 146. Man-made Reef Ecology. By Charles H. Turner, Earl E. Ebert, and Robert R. Given. 1969; 221 p., 74 figs.

No. 147. The Northern Anchovy (Engraulis mordax) and Its Fishery, 1965–1968. By James D. Messersmith and a Staff of Associates. 1969; 102 p., 25 figs.

No. 148. Effects of Artificial Destratification on Distribution of Bottom Organisms in El Capital Reservoir. By Inland Fisheries Branch. 1970; 30 p., 17 figs.

* No. 149. The California Marine Fish Catch for 1968 and Historical Review 1916–1968. By Richard F. G. Heimann and John G. Carlisle, Jr. 1970; 70 p., 2 figs.

* No. 150. A History of California's Fish Hatcheries, 1870–1960. By Earl Leitritz. 1970; 92 p., 55 figs.

No. 151. Migrations of Adult King Salmon Oncorhynchus tshawytscha in the San Joaquin Delta. As Demonstrated by the Use of Sonic Tags. By Richard J. Hallock, Robert F. Elwell and Donald H. Fry, Jr. 1970; 92 p., 22 figs.

No. 152. Food Habits of Albacore, Bluefin Tuna, and Bonito in California Waters. By Leo Pinkas, Malcolm S. Oliphant, and Ingrid L. K. Iverson. 1971; 105 p., 50 figs.

No. 153. The California Marine Fish Catch for 1969. By Leo Pinkas. 1970; 47 p., 2 figs.

* No. 154. California Marine Fish Landings for 1970. By Robert R. Bell. 1971; 50 p., 2 figs.

* No. 155. Population Size, Mortality Rates, and Growth Rates of Northern California Ocean Shrimp, Pandalus jordani, 1965 Through 1968. By Daniel W. Gotshall. 1972; 47 p., 9 figs.

No. 156. The Venom Apparatus of California Rockfishes (Family Scorpaenidae). By Edward T. Roche and Bruce W. Halstead. 1972; 49 p., 45 figs.

No. 157. Guide to the Coastal Marine Fishes of California. By Daniel J. Miller and Robert N. Lea. 1972; 235 p., illus.

No. 158. Summary of Blue Rockfish and Lingcod Life Histories; a Reef Ecology Study; and Giant Kelp, macrocystis pyrifera, Experiments in Monterey Bay, California. By Daniel J. Miller and John J. Giebel. 1973

No. 159. California Marine Fish Landings for 1971. By M. S. Oliphant and Marine Fisheries Statistics Staff. 1973; 49 p., 2 figs.

No. 160. Observations on Fishes Associated With Kelp Beds in Southern California. By Howard M. Feder, Charles H. Turner, and Conrad Limbaugh. 1974; 144 p., 76 figs.

No. 161. California Marine Fish Landings for 1972. By Leo Pinkas. 1974; 53 p., 2 figs. And Designated Common Names of Certain Marine Organisms of California. By Doyle E. Gates and Herbert W. Frey. 1974; 36 p.

No. 162. Pelagic Fish Surveys in the California Current. By Kenneth F. Mais. 1974; 79 p., 28 figs.

No. 163. California Marine Fish Landings for 1973. By Robert McAllister. 1975; 53 p., 2 figs.

No. 164. Trout and Salmon Culture (Hatchery Methods). By Earl Leitritz and Robert C. Lewis. 1976; 193 p., 94 figs.

No. 165. The Marine Resources of Anaheim Bay. Edited by E. David Lane and Cliff W. Hill. 1975; 195 p., 56 figs.

No. 166. California Marine fish Landings for 1974. By Robert McAllister. 1976; 53 p., 2 figs.

No. 167. Climatic Variation and Exploitation in the Pacific Mackerel Fishery. By Richard H. Parrish and Alec D. MacCall. 1978; 110 p., 27 figs.

No. 168. California Marine Fish Landings for 1975. By Leo Pinkas. 1977; 55 p., 2 figs.

No. 169. Biological, Oceanographic, and Acoustical Aspects of the Market Squid, Loligo opalescens Berry. Edited by Conrad W. Recksiek and Herbert W. Frey. 1978; 185 p., 64 figs.

No. 170. California Marine Fish Landings of 1976. By M. S. Oliphant. 1979; 56 p., 2 figs.