

# CALIFORNIA FISH AND GAME

"CONSERVATION OF WILDLIFE THROUGH EDUCATION"

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NUMBER 4



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# CALIFORNIA FISH AND GAME

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CALIFORNIA FISH AND GAME

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Editorial staff for this issue consisted of the following:

Marine Resources ..... Robert N. Lea, Ph.D. and Perry L. Herrgesell, Ph.D.  
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## CONTENTS

	Page
Temporal and Spatial Patterns in Sea Otter, <i>Enhydra lutris</i> , Range Expansion and in the Loss of Pismo Clam Fisheries .....	197
Frederick E. Wendell, Robert A. Hardy, Jack A. Ames, and Richard T. Burge	
Aspects of Ecology and Life History of the Woolly Sculpin, <i>Clinocottus analis</i> , from Southern California.....	213
Alan W. Wells	
Ichthyofaunal Composition and Recolonization in a Central California Tidepool .....	227
Ronald H. Matson, C. Ben Crabtree, and Thomas R. Haglund	
Distribution of Major Marine Macrophytes, Seasonal Estimates of <i>Gracilaria</i> Standing Crop, and Spawning Activities of the Pacific Herring, <i>Clupea harengus pallasii</i> , in Elkhorn Slough, California: 1979-1982 ..	232
R. E. Phillips, D. I. Gutoff, J. E. Hansen and J. E. Hardwick	
Observations on the Elasmobranch Assemblage of San Francisco Bay ....	244
David A. Ebert	
Book Reviews .....	250
Index to Volume 72.....	252

## CHANGE OF EDITORSHIP

With this issue Robert N. Lea, of the Marine Resources Division, assumes the duties of Editor-in-Chief of *California Fish and Game*. Dr. Lea's appointment to the editorship follows the Department's policy of rotating the editorship between staff members representing Marine Resources, Inland Fisheries, Wildlife Management, and the Bay-Delta Project.

Dr. Lea has been with the Department for 17 years and has served as Editor for Marine Resources the past five years. He is the co-author of *Guide to the Coastal Marine Fishes of California* and has published over thirty-five scientific papers in various journals and symposia proceedings.

Under his guidance the Journal will continue its policy of presenting the results of scientific investigations as they relate to conservation and management programs of California's fish and wildlife resources. He will strive to maintain the excellent reputation the Journal has achieved during its 72 year history of continuous publication.

Dr. Lea will be assisted in his duties by the following associate editors: Jack A. Hanson—Inland Fisheries; Daniel P. Connelly, Gordon I. Gould, and Douglas R. Updike—Wildlife Management; Peter L. Haaker, Paul N. Reilly, and John P. Scholl—Marine Resources; Kenneth A. Hashagen, Jr., and Arthur C. Knutson, Jr.—Anadromous Fisheries; Donald E. Stevens—Striped Bass, Sturgeon, and Shad; and Kim McCleneghan, Environmental Services.

To Dr. Perry L. Herrgesell, Editor-in-Chief the past four years, we express our deep appreciation for a job well done. *Jack C. Parnell, Director, California Department of Fish and Game.*

## TEMPORAL AND SPATIAL PATTERNS IN SEA OTTER, *ENHYDRA LUTRIS*, RANGE EXPANSION AND IN THE LOSS OF PISMO CLAM FISHERIES<sup>1</sup>

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Two beaches in central California that have been reoccupied by sea otters, *Enhydra lutris*, through a southward expansion of their range once supported major recreational fisheries for Pismo clams, *Tivela stultorum*. Monitoring of recreational fishing and sea otter activity was conducted in these areas to elucidate the sea otter's role in the loss and long term fate of these fisheries. The progressive elimination of sections of beach from the fishery closely corresponded to the southward progression of sea otter foraging activity. Data indicate that once sea otters are established along clam bearing beaches, any future stocks of clams will be fully utilized by sea otters, preventing the return of a fishery.

### INTRODUCTION

Sea otters, *Enhydra lutris*, are predators on benthic invertebrate species which inhabit shallow coastal waters in the North Pacific Ocean. Historically sea otters ranged as far south as Morro Hermoso on the Pacific coast of Baja California. From that southern limit they ranged northward and westward through the Aleutian and Commander islands to the western rim of the North Pacific Ocean (Kenyon 1969). However, there have been major changes in sea otter abundance and distribution associated with their decimation during the fur trade era, 1780 to 1900 (Kenyon 1969) and with the subsequent reoccupation of a portion of their historic range. Considerable debate has existed concerning the effect sea otter predation has on the structure of nearshore communities and on associated shellfish fisheries in the reoccupied area.

Although the effect sea otter predation has on shallow sandy bottom community structure has not been studied directly, the impact on associated shellfish fisheries has received some attention. Miller (1974) noted the loss of the recreational red crab, *Cancer productus*, and rock crab, *C. antennarius*, fishery off the Monterey pier associated with the reoccupation of that area by sea otters. A rapid depletion of the commercial and subsistence dungeness crab, *Cancer magister*, fishery was noted in the Orca Inlet area of Prince William Sound,

<sup>1</sup> Accepted for Publication April 1986.

Alaska, as the sea otter population in that area increased (Matkin 1981 and Kimker 1982). Wild and Ames (1974) noted that Pismo clams, *Tivela stultorum*, were eaten almost exclusively when sea otters initially foraged along Pismo clam bearing beaches in Monterey and Estero Bays, California. Although the extent of the effect on the Pismo clam population was not determined, they indicated it could be substantial. Stephenson (1977) subsequently indicated that sea otters had contributed extensively to the decline of large Pismo clams within his study area in Monterey Bay, California.

The question of the extent of the impact sea otter predation can have on a Pismo clam fishery was first addressed by Miller, Hardwick, and Dahlstrom (1975). Their studies indicated that sea otter foraging along Monterey Bay beaches and at Atascadero Beach near Morro Bay precluded the recreational Pismo clam fisheries in these areas.

Because of the possibility that over-harvest, pollution, or variable recruitment could influence any decline in sport and commercial shellfish catches, it has been suggested that the loss of fisheries cannot be entirely attributed to sea otter predation (Armstrong 1979, Estes and VanBlaricom in press). Most of the published data directed toward clarifying the sea otter's role in the loss of Pismo clam fisheries has not included sufficient historical data to focus on pre-sea otter trends in the fisheries.

Recent sea otter range expansion to the south has occurred along Pismo clam bearing beaches near Pismo Beach (Figure 1). Monitoring of the intertidal portion of that Pismo clam population and the sport harvest of clams has been on going for many years. Data on the fishery and on sea otter distribution and food habits along clam bearing beaches are presented to provide a historical perspective necessary to clarify the sea otter's role in the loss of the fisheries and the long term fate of these fisheries within the established sea otter range.

## MATERIALS AND METHODS

The Pismo clam fisheries located in areas reoccupied by sea otters through a southward expansion of their range were monitored historically by collecting and ageing clams recovered from trench transects. The trench, 15 cm wide by 20 cm deep, was oriented perpendicular to the surf zone and extended into the shallow (ca. 60 cm depth) subtidal during minus tides. In early years, sand was sifted through screens; however, in most years a casting-spreading technique was used. Probing was used to sample inundated portions of the transect. These data were primarily used to assess incoming year-classes for management purposes.

Since 1975 the fishery in the Pismo Beach area has been assessed in a direct manner through interviewing clammers. The basic information obtained during the interviews included the following (i) the number of active clammers in the group, (ii) the time active, (iii) the number of legal-sized clams (114.3 mm, 4.5 in) obtained, and (iv) the number of clams within one inch of legal size which they recalled digging and returning.

Estimates of total effort and total catch for each section of beach were generated from interview data. Analysis incorporated stratification by tide level, day of the week, and section of the beach. Total effort for each sampling day was estimated through an expansion, based on turn-over rates, of the number of active clammers counted during the period from one-half hour before low tide to low tide. The expansion used to estimate total effort was based on the



assumption that the interviewed clammers provided an unbiased sample of the distribution of clamming activity about low tide. The count, therefore, was expanded by the proportion of the interviewed clammers active during the count period (Table 1).

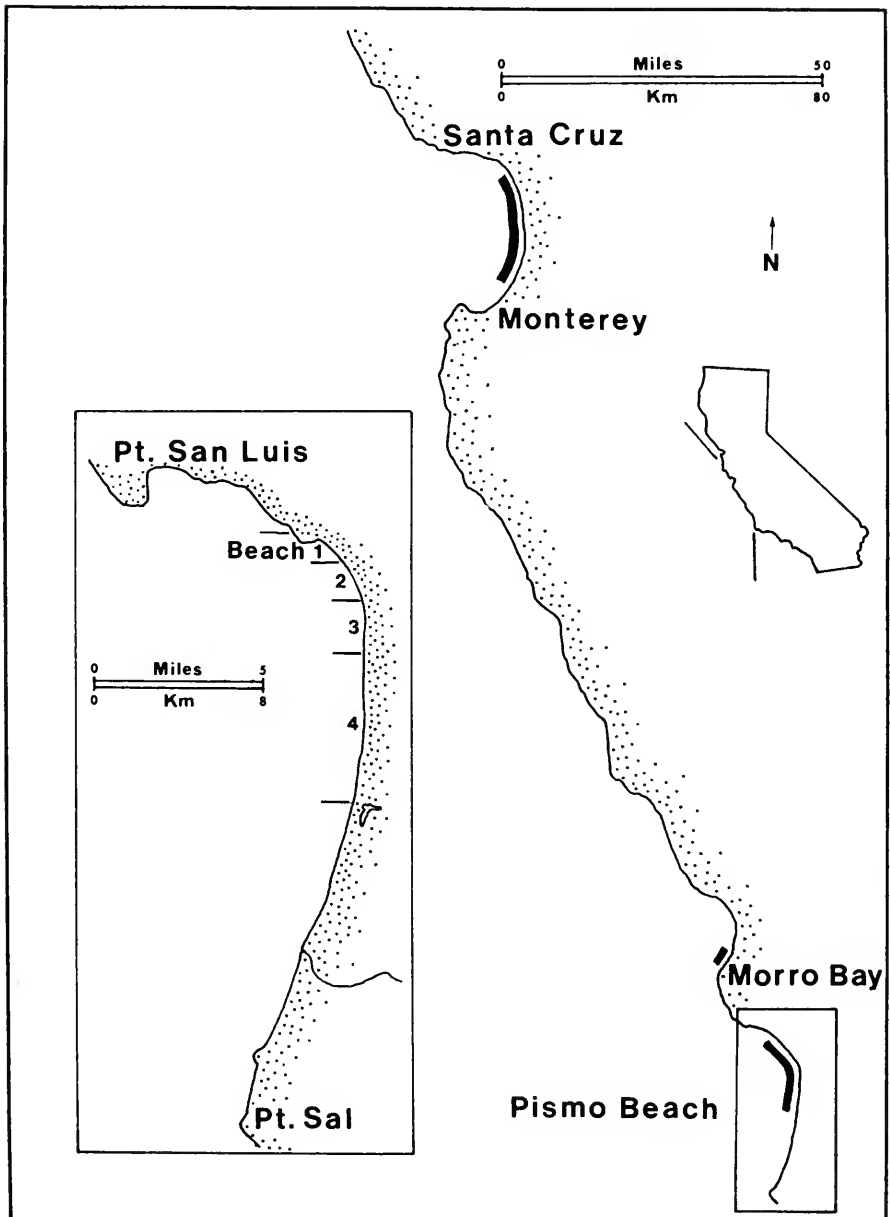


FIGURE 1. Pismo clam bearing beaches (darkened strips) within the sea otter's range. Expanded portion of map delineates relative size and location of sampling sections along Pismo Beach.

**TABLE 1. Proportion of Interviewed Clammers Actively Clamming During the Count Period (from ½ hour before to low tide) for Three Tide Groups (sunrise, daylight, and sunset) by Beach Section.**

	<i>Sunrise</i>	<i>Daylight</i>	<i>Sunset</i>
Beach 1 .....	.68 (n=99)	.80 (n=385)	.94 (n=63)
Beach 2 .....	.63 (n=645)	.85 (n=970)	.81 (n=80)
Beach 3 .....	.72 (n=622)	.88 (n=926)	.76 (n=465)
Beach 4 .....	.65 (n=1031)	.90 (n=2078)	.94 (n=690)

The distribution and relative abundance of sea otters within the Pismo Beach area was determined using both aerial and ground census techniques. Seasonal aerial censuses, conducted since 1976, identified the location and relative abundance of sea otters at the range peripheries. These censuses were supplemented with ground counts in February 1979, south of Point San Luis, when the peripheral male group moved south of the point into the Shell Beach kelp beds. Information on distribution and relative abundance of otters along Pismo clam bearing beaches was also collected while conducting sea otter food habit observations. All ground based observations were made using a 50x–80x Questar telescope.

## RESULTS

### Initial Impact—Pismo Beach

#### Pismo Clams

A summary of transect data was provided by Fitch (1952, 1954, and 1955) for the years 1925 to 1954, by Baxter (1961) for the years 1955 to 1959, and by Carlisle (1966, 1973) for the years 1961 to 1971. These data provide an initial index of density, growth, and survival for clam sets by area. However, with natural mortality and fishing pressure influencing abundance and availability, this sampling method was inadequate to assess these parameters in older cohorts.

Trench transect data, however, have continued to provide information on the density and survival of smaller sub-legal clams (Tables 2–5). The relative number of zero through age 2 clams (an index of recruitment), although apparently reduced, appears to have remained within the range traditionally observed.

Interviews of clammers provide an index of legal-sized Pismo clam availability in the intertidal and shallow subtidal portions of the beach. Over 11,800 interviews have been conducted on 170 interview days since November 1975. The interviews provided catch-per-unit-effort (CPUE) data that were used to generate estimates of the total catch and effort by beach section for tides below 0.0 m (Table 6, Figures 1 and 2). Most beach sections showed considerable fluctuation in the estimated total annual catch and effort as would be expected from a heavily utilized resource based on a species with highly variable recruitment. Clamming conditions, particularly surf height, also contribute to variation in catch and effort. The estimated total annual catch and effort, however, never approached zero for any beach section until 1979 or later.

Average monthly CPUE declined to near zero, beach by beach, from north to south (Figure 2). Beach 1 dropped to near zero in May 1979, while beaches 2, 3, and 4 remained relatively high. Beach 2 followed with a drop to near zero by May 1980. This progression continued until June 1981, when the CPUE was near zero for all beach sections along Pismo Beach. The CPUE has remained essentially zero through 1985.

**TABLE 2. Number of Clams by Age Group from Trench Transects at Atascadero State Beach.**

Year	AGE GROUP									Total
	0	1	2	3	4	5	6	7	8	
1952.....	14	0	0	0	0	0	0	0	0	14
1953.....	0	5	0	0	0	0	0	3	21	29
1954.....	2	0	6	0	0	0	1	0	23	32
1955.....	3	2	0	2	0	1	0	0	5	13
1956.....	0	0	0	0	0	0	0	0	6	6
1957.....	0	0	0	1	0	5	0	0	12	18
1958.....	0	0	0	0	0	0	0	0	2	2
1959.....	0	0	1	0	0	0	0	2	8	11
1960.....	0	1	0	0	0	0	0	1	1	3
1961.....	0	0	2	1	0	0	1	0	0	4
1962.....	0	0	0	2	0	0	0	2	0	4
1963.....	0	0	0	1	4	0	0	0	0	5
1964.....	0	0	1	0	0	0	0	0	0	1
1965.....	1	0	0	1	0	0	0	0	0	2
1966.....	18	2	1	0	0	0	0	0	1	22
1967.....	6	21	3	0	0	0	0	0	1	31
1968.....	-	-	-	-	-	-	-	-	-	-
1969.....	-	-	-	-	-	-	-	-	-	-
1970.....	-	-	-	-	-	-	-	-	-	-
1971.....	0	0	0	0	0	0	0	0	0	0
1972.....	-	-	-	-	-	-	-	-	-	-
1973.....	1	139	0	0	0	1	0	0	0	141
1974.....	1	12	123	0	0	0	0	0	0	136
1975.....	0	3	10	83	0	0	0	0	0	96
1976.....	0	0	3	14	28	0	0	0	0	45
1977.....	2	0	1	2	7	8	0	0	0	20
1978.....	0	3	0	0	3	2	0	0	0	8
1979.....	0	1	0	0	1	0	0	0	0	2
1980.....	0	0	0	1	1	0	0	0	0	2
1981.....	1	0	0	0	0	0	0	0	0	1

### Sea Otters

Observations from shore indicated that the southern peripheral male group had established a rafting site at Cayucos Point (ca. 10 km north of Atascadero Beach) in February 1972. By January 1973, the southern male group was rafting 16 km south of Atascadero Beach at Point Buchon (Wild and Ames 1974). Sea otters, however, were observed foraging along Pismo clam bearing portions of Atascadero Beach in February and March 1973 (Wild and Ames 1974). Between 1973 and 1975 sea otters were frequently observed foraging along Atascadero Beach and a small raft of four to six otters were often seen off Torro Point at the north end of the beach (Burge 1979).

The peripheral male group moved to a rafting site south of Point San Luis at Shell Beach in January 1979. Otters from that raft were first observed foraging along the northernmost portion of Pismo Beach (Beach 1) late in January 1979. Since that time the number of otters observed south of Point San Luis, including areas along clam bearing beaches, has shown a typical seasonal pattern (Figures 3 and 4).

TABLE 3. Number of Clams by Age Group from Trench Transects at Pismo Beach (Beach 1).

Year	AGE GROUP									Total
	0	1	2	3	4	5	6	7	8	
1952.....	19	0	0	0	0	1	4	0	2	26
1953.....	0	49	0	0	0	1	2	13	3	68
1954.....	2	1	20	3	0	0	0	1	4	31
1955.....	3	8	4	16	2	0	0	0	9	42
1956.....	0	2	3	2	35	0	0	0	7	49
1957.....	170	0	0	4	9	13	1	0	7	205
1958.....	6	34	0	0	3	0	7	0	1	51
1959.....	121	25	21	0	0	0	0	7	5	179
1960.....	7	25	17	14	0	1	0	0	1	65
1961.....	4	10	18	13	3	0	0	0	1	49
1962.....	33	12	5	10	15	3	0	0	0	78
1963.....	61	6	11	4	9	4	0	0	1	96
1964.....	111	20	27	10	4	5	1	0	1	179
1965.....	126	97	34	21	0	4	0	0	0	282
1966.....	95	100	78	43	7	1	0	1	0	325
1967.....	11	65	88	69	12	0	0	1	0	246
1968.....	-	-	-	-	-	-	-	-	-	-
1969.....	-	-	-	-	-	-	-	-	-	-
1970.....	-	-	-	-	-	-	-	-	-	-
1971.....	0	14	0	2	2	2	1	0	0	21
1972.....	-	-	-	-	-	-	-	-	-	-
1973.....	-	-	-	-	-	-	-	-	-	-
1974.....	-	-	-	-	-	-	-	-	-	-
1975.....	2	8	20	11	10	4	0	0	0	55
1976.....	0	0	4	2	4	0	0	0	1	11
1977.....	12	18	2	4	4	1	0	0	0	41
1978.....	0	5	13	1	4	0	1	0	2	26
1979.....	3	3	4	1	0	0	0	0	0	11
1980.....	11	2	3	2	0	0	0	0	0	18
1981.....	23	11	4	0	1	0	0	0	0	39

The proportion of otters observed along sandy beaches was relatively low during 1979, the first year the sea otter's range had extended south of Point San Luis. During that year, much of the foraging activity occurred just north of Pismo Beach, in the Shell Beach area. The proportion observed along sandy beaches was noticeably higher in 1980 and 1981. It did not appear at any point that all otters in the area occupied just areas along the clam bearing beaches (Figures 3 and 4). The May 1980 census yielded the highest count to date, 67 sea otters along the sandy beaches and 134 total south of Point San Luis.

Observations of tagged sea otters in the area documented movements between the rafting sites in giant kelp beds, *Macrocystis pyrifera*, off Shell Beach and foraging areas along the Pismo clam bearing beaches. Most sea otters, when along the sandy beaches, foraging or resting offshore, tended to be in loose aggregations and occupied a very limited portion of the nearshore area. Limited radio telemetry research conducted in co-operation with the University of Minnesota also documented movement to and activity along those beaches during the night.

Food habit studies were conducted along the sandy beaches to identify major prey items. Over 500 individual food items were observed being consumed

(Table 7). Pismo clams comprised 96% of those food items. On several occasions tagged sea otters were followed for extended periods during a foraging bout. The longest continuous observation period was slightly under two hours. During that period, the sea otter surfaced with 57 Pismo clams and six unidentified items of which 40 clams and six unidentified items were observed consumed.

**TABLE 4. Number of Clams by Age Group from Trench Transects at Pismo Beach (Beach 3).**

Year	Age Group									Total
	0	1	2	3	4	5	6	7	8	
1952	8	0	0	0	1	0	0	0	0	9
1953	0	28	0	0	1	5	9	50	56	149
1954	1	0	20	5	0	0	8	10	87	131
1955	0	0	1	3	0	1	2	1	65	73
1956	0	0	0	0	7	0	0	0	16	23
1957	470	0	0	0	0	3	0	0	5	478
1958	2	45	0	0	0	0	0	0	1	48
1959	62	27	42	0	0	0	0	0	1	132
1960	10	34	14	17	0	0	0	0	3	78
1961	6	8	13	11	6	0	0	0	0	44
1962	36	18	5	11	7	2	0	0	1	80
1963	14	13	21	6	5	2	0	0	1	62
1964	200	25	16	6	1	1	0	0	0	249
1965	75	141	25	15	1	0	0	0	0	257
1966	36	67	60	24	5	1	0	0	0	193
1967	5	25	40	55	18	2	1	0	0	146
1968	-	-	-	-	-	-	-	-	-	-
1969	-	-	-	-	-	-	-	-	-	-
1970	-	-	-	-	-	-	-	-	-	-
1971	0	8	2	5	2	3	1	0	0	21
1972	-	-	-	-	-	-	-	-	-	-
1973	-	-	-	-	-	-	-	-	-	-
1974	-	-	-	-	-	-	-	-	-	-
1975	2	4	17	15	9	1	0	0	0	48
1976	0	3	6	17	9	0	0	0	0	35
1977	35	1	5	5	6	1	1	1	1	56
1978	0	14	1	0	1	5	1	0	1	23
1979	0	8	22	0	2	2	0	1	3	38
1980	5	2	0	3	0	0	0	0	0	10
1981	6	8	2	0	0	0	0	0	0	16

### Area of Impact

The progression in decline in catch-per-unit-effort for the fishery at Pismo Beach closely corresponded to the southward progression of sea otter foraging activity.

*Beach 1.* The estimates of total annual catch and effort for this section of Pismo Beach markedly decreased from 1979 to 1980. The highest monthly count of sea otters along this section when superimposed on the mean monthly CPUE showed that the drop to zero in catch for the fishery closely corresponded to that period early in 1979 when sea otters were actively foraging in the area (Figure 5).

**TABLE 5. Number of Clams by Age Group from Trench Transects at Pismo Beach (Beach 4).**

Year	Age Group									Total
	0	1	2	3	4	5	6	7	8	
1952.....	1	0	0	0	0	0	3	1	0	5
1953.....	0	0	0	0	0	6	4	2	2	14
1954.....	0	0	0	0	0	0	0	0	1	1
1955.....	0	2	0	0	0	0	0	0	6	8
1956.....	0	0	2	0	0	0	0	0	8	10
1957.....	13	0	0	2	1	0	0	0	7	23
1958.....	-	-	-	-	-	-	-	-	-	-
1959.....	23	3	0	0	0	0	0	2	6	34
1960.....	32	7	3	1	0	0	0	0	2	45
1961.....	1	7	7	3	0	0	0	0	1	19
1962.....	2	1	6	4	4	1	0	0	0	18
1963.....	4	6	4	5	2	0	0	0	0	21
1964.....	71	8	2	1	7	0	1	0	0	90
1965.....	40	41	14	0	2	1	0	0	0	98
1966.....	61	61	50	6	0	0	0	0	1	179
1967.....	43	26	14	13	17	3	0	0	0	116
1968.....	-	-	-	-	-	-	-	-	-	-
1969.....	-	-	-	-	-	-	-	-	-	-
1970.....	-	-	-	-	-	-	-	-	-	-
1971.....	0	11	3	6	4	3	1	0	0	28
1972.....	-	-	-	-	-	-	-	-	-	-
1973.....	-	-	-	-	-	-	-	-	-	-
1974.....	-	-	-	-	-	-	-	-	-	-
1975.....	32	0	0	3	1	1	0	0	0	37
1976.....	0	14	0	8	1	0	0	0	0	23
1977.....	28	0	2	2	1	0	0	0	0	33
1978.....	0	14	0	2	1	1	0	0	0	18
1979.....	0	4	0	0	0	0	0	0	2	6
1980.....	1	0	2	5	1	0	0	0	0	9
1981.....	3	1	0	0	0	0	0	0	0	4

**TABLE 6. Estimated Annual Catch (C) of Pismo Clams and Annual Effort (E) by Beach Section along Pismo Beach for Tides Below 0.0 m from 1975 to 1983.**

Year	Beach 1		Beach 2		Beach 3		Beach 4		Total	
	C	E	C	E	C	E	C	E	C	E
1975.....	8,107	4,512	12,712	4,486	43,889	9,952	159,439	26,219	224,147	36,209*
1976.....	12,601	3,840	7,142	2,576	28,029	8,551	120,548	25,957	168,320	40,924
1977.....	37,606	10,157	closed		18,191	9,522	156,355	29,137	212,152	48,816
1978.....	26,178	5,550	109,513	16,311	36,173	9,015	171,796	24,660	343,660	55,536
1979.....	4,588	1,853	46,110	9,698	74,135	17,128	106,064	23,310	230,897	51,989
1980.....	22	478	261	1,573	9,979	6,659	137,950	31,188	148,212	39,898
1981.....	1	266	91	616	61	1,358	17,525	10,685	17,678	12,925
1982.....	0	14	0	42	3	158	19	735	22	893
1983.....	0	14	0	0	0	28	0	0	0	42

\* An additional 13,980 (catch) and 3857 (effort) were estimated for tides between +0.5 ft and 0.0 ft during 1975.

*Beach 2.* The estimates of total annual catch and effort for this beach section showed a dramatic increase in response to the management closure of clamming from May 1976 to March 1978. The estimated total annual catch and effort, however, were much lower from 1980 through 1983. The drop to

zero in mean monthly CPUE for that section of beach started late in 1979 which also corresponded to that period when sea otters had shifted their foraging activity to Beach 2 (Figure 5).

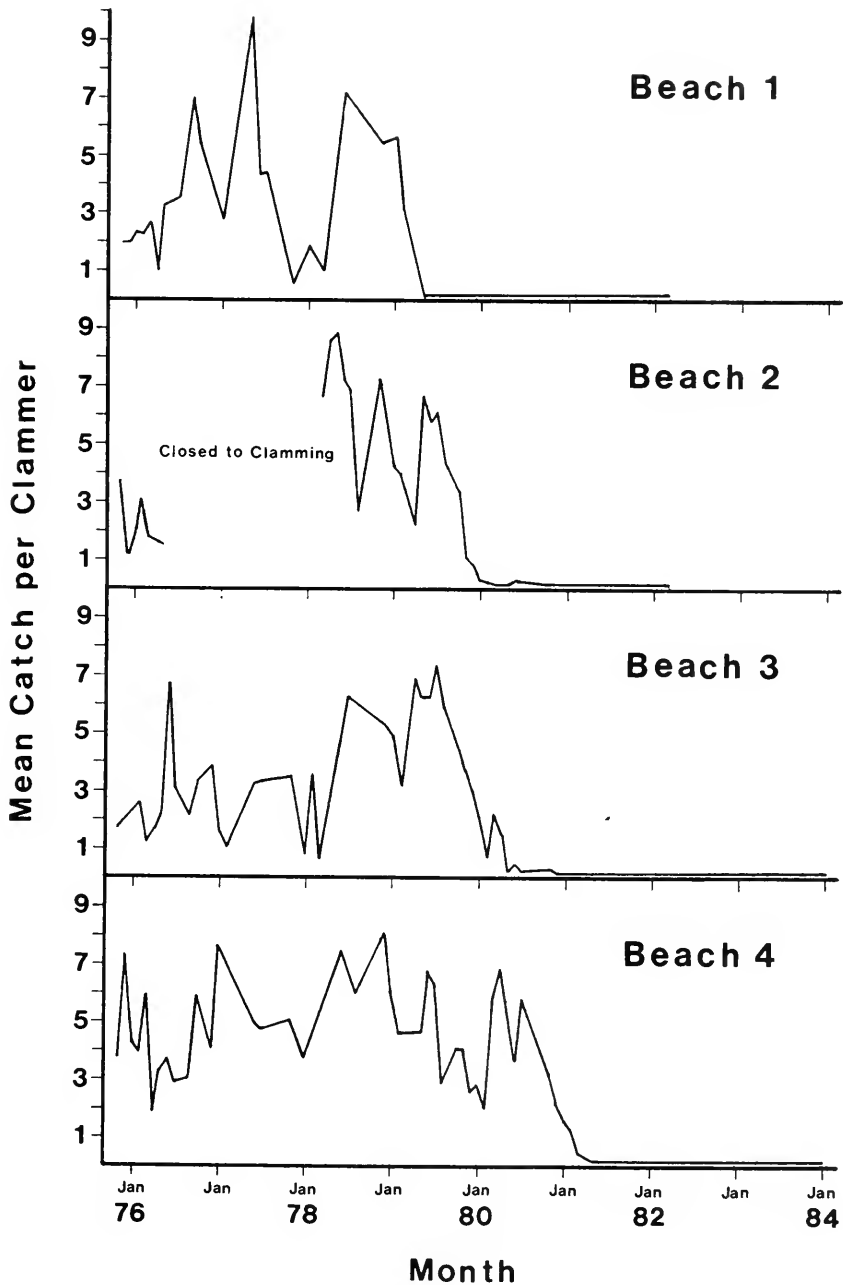


FIGURE 2. Mean daily catch-per-clammer of Pismo clams by month from beach sections 1 through 4, Pismo Beach, between November 1975 and January 1984.

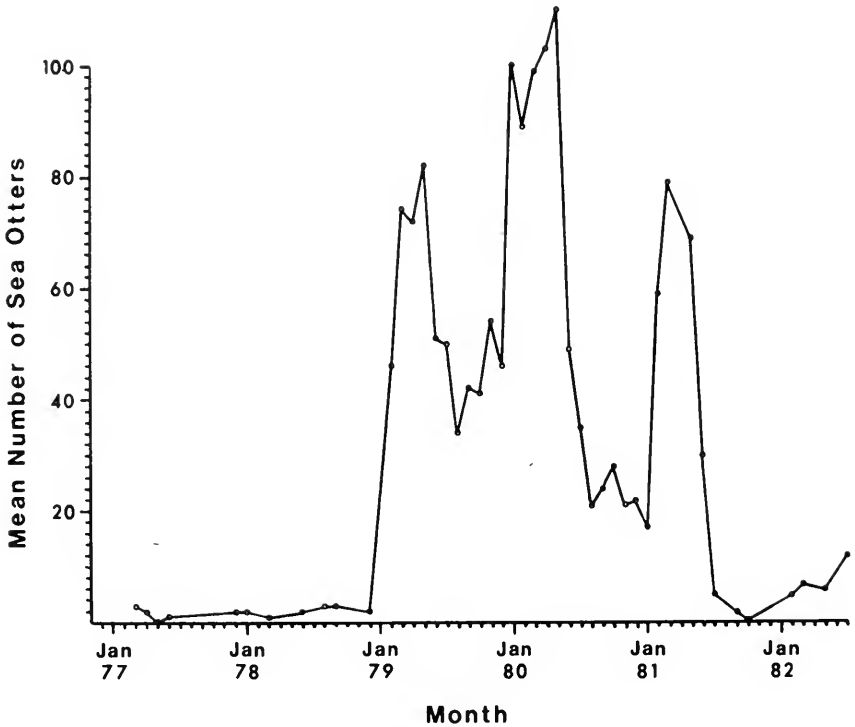


FIGURE 3. Mean number of sea otters by month south of Point San Luis showing the arrival and seasonal fluctuation in numbers of the southern peripheral male group through July 1982.

*Beach 3.* Both the estimates for total annual catch and effort and mean monthly CPUE followed the same pattern observed on Beaches 1 and 2, but occurred slightly later (early 1980, Figure 5).

*Beach 4.* This beach was divided into two sub-units since it was long enough that the influence of foraging activity on CPUE would be masked. Both the estimate of total annual catch and effort and the means monthly CPUE dropped for each sub-unit in 1981, when sea otters had extended their foraging into those areas. There was, however, a noticeable lag in the timing of the decline for the southernmost sub-unit (Figure 5).

CPUE remained high on each beach prior to being foraged upon by sea otters, declined to zero or near zero during concentrated foraging and remained at or near zero after sea otters moved southward.

The Mann-Whitney non-parametric test (Sokal and Rohlf 1969) was applied to CPUE and sea otter census data to determine whether the observed changes associated with sea otter foraging were statistically significant. In all cases, when otters first occupied a section of beach, the CPUE for clams remained relatively high for a limited period of time. The data gathered during the transition from high to low CPUE were grouped with pre-sea otter CPUE data for analysis. The CPUE data were thereby separated into two (pre and post-otter) samples. All beach sections had significantly lower CPUE ( $P > 0.01$ ) by the time sea otters



began foraging on the next beach to the south (Beach 1  $n_1=29$ ,  $n_2=33$ ,  $z=6.74$ ; Beach 2  $n_1=34$ ,  $n_2=34$ ,  $z=4.68$ ; Beach 3  $n_1=24$ ,  $n_2=47$ ,  $z=6.52$ ; Beach 4a  $n_1=10$ ,  $n_2=65$ ,  $z=5.05$ ).

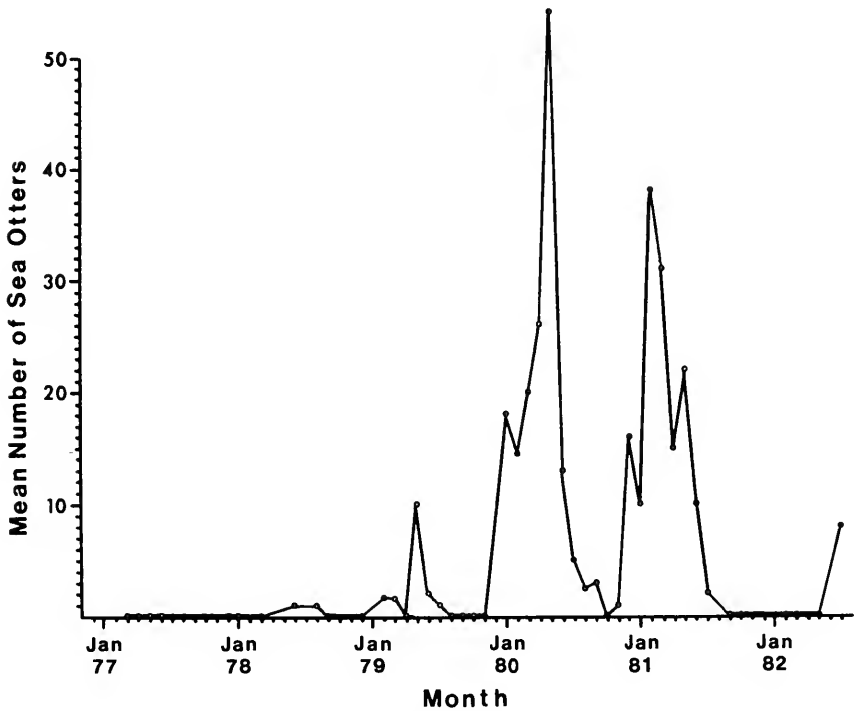


FIGURE 4. Mean number of sea otters by month along the Pismo clam bearing beaches south of Point San Luis through July 1982.

TABLE 7. Number of Prey Retrieved and Observed Consumed by Sea Otters Foraging along Pismo Beach from March 1979 to February 1981.

Food item	Number retrieved	Number consumed
Pismo clams .....	559	505
Unidentified bivalves.....	1	1
Rock crabs .....	1	1
Market crabs .....	1	1
Unidentified crabs .....	1	1
Unidentified food items .....	15	15

### Long Term Impacts—Atascadero Beach

In 1971, the earliest year for which interview data are available for Atascadero Beach, 337 clambers averaged 3.3 clams/h. The southward movement of the peripheral male group 26 km from Point Cayucos to Point Buchon (Figure 1) in January 1973, skipped for a short period, the Pismo clam bearing beaches around Morro Bay, including Atascadero Beach. Sea otters, whether from the peripheral group or from adjacent areas, were observed during that year foraging

along Atascadero Beach on Pismo clams (Wild and Ames 1974; Miller, Hardwick, and Dahlstrom 1975; Wade 1975). Sampling of the Pismo clam fishery indicated that the CPUE for the fishery on Atascadero Beach was zero by December 1973. Sea otters continued foraging along Atascadero Beach after 1973.

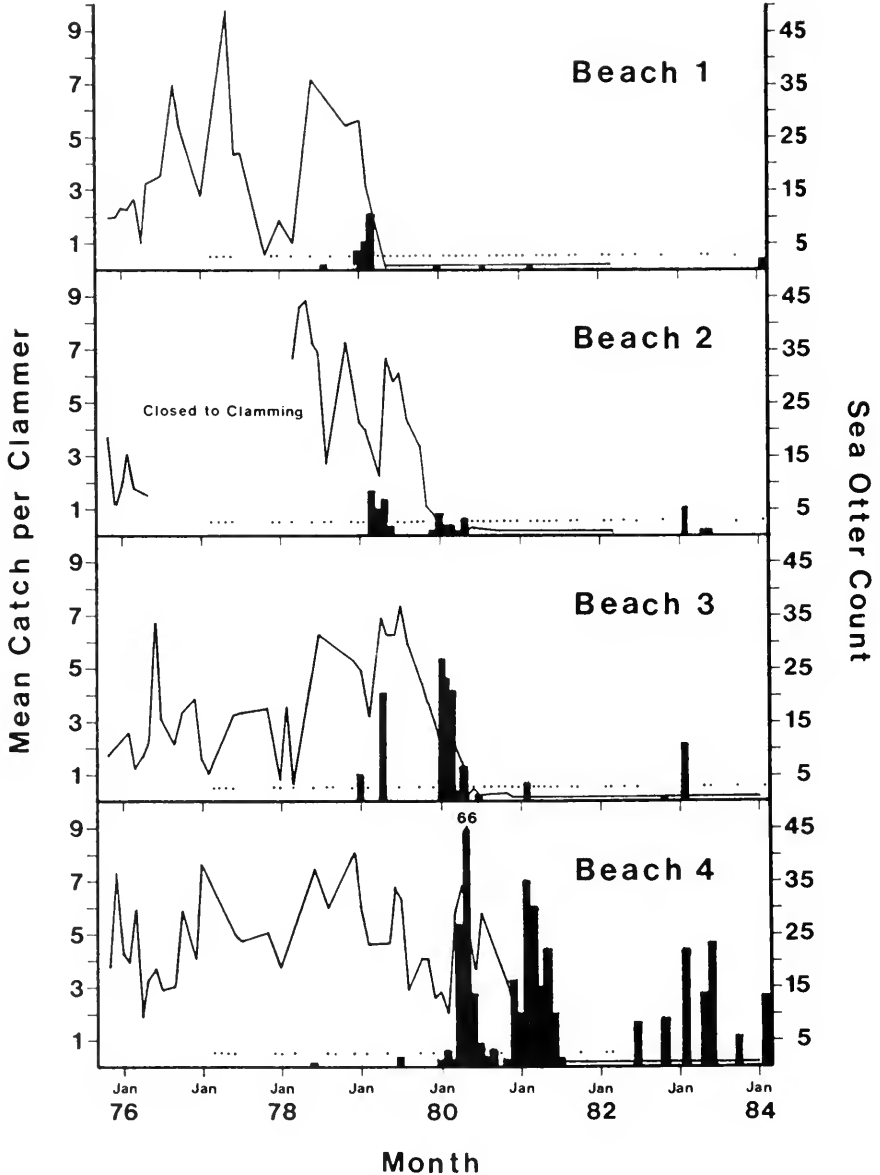


FIGURE 5. High count of sea otters by month (bar) superimposed on a measure of catch-per-unit-effort for the Pismo clam fishery (line) along each beach section from November 1975 through February 1984.

Transect digs in 1973 on that beach identified the 1972 year-class as the best set of Pismo clams in almost thirty years. The 1972 year-class of Pismo clams on that beach showed normal or better than normal survival through at least early 1975 on all three traditional transect locations. During 1975 the observed survival fell below the expected (Tomlinson 1968) (Figure 6). A disparity between the expected (Herrington 1929) and observed growth of the 1972 year-class was apparent after late 1974 (Table 8). This disparity broadened after the beach was closed to sport harvest in March 1975. The 1972 year-class clams were expected to be 7.1 cm and 8.8 cm during the 1975 and 1976 surveys, respectively. Instead the observed average lengths were 6.6 cm and 7.4 cm. This disparity increased through 1978. After 1978 no 1972 year-class clams were found.

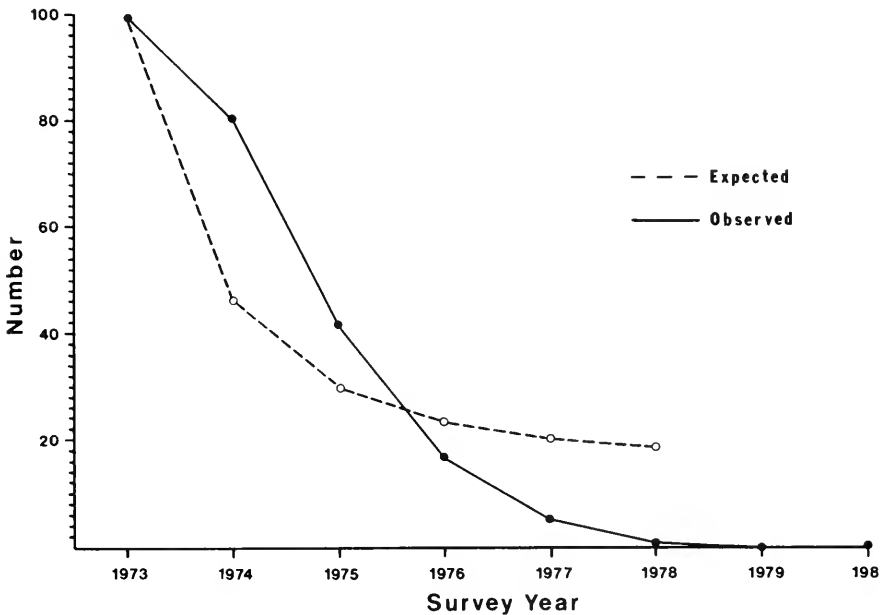


FIGURE 6. Mean number of observed and expected Pismo clams of the 1972 year-class from all traditionally sampled transects (three) on Atascadero Beach.

TABLE 8. Observed and Expected Mean Lengths ( $\pm$  S.D.) of 1972 Year Class Pismo Clams from Atascadero Beach.

Year	Observed length	n	Expected length	n
1972.....	13.9 (3.5)	64	15.2 (3.4)	139
1973.....	40.8	433	37.0 (4.0)	109
1974.....	49.8 (5.1)	160	55.1 (4.8)	65
1975.....	58.9 (6.3)	154	72.8 (6.7)	41
1976.....	65.0 (6.8)	50	89.2 (9.0)	39
1977.....	74.1	18	105.8 (8.6)	32
1978.....	80.0	2	113.8 (7.2)	17

## DISCUSSION

Human harvest of Pismo clams along Pismo Beach following the fur trade era was sufficient to reduce high density stocks, which had grown as a result of the removal of the otter, to a fully utilized level. A historical account of the changes in regulations governing the Pismo clam fishery reflect this transition (Fitch 1950). Pismo clams show great temporal and spatial variability in recruitment, yet recruitment was sufficient to maintain a sustained long-term harvest. The harvest of legal-sized clams estimated from catch statistics appeared to be, at least for peak use days, the same in 1975 as it was in the late 1940's (Fitch 1950, J. Fitch, Calif. Dept. Fish and Game, pers. comm.). The catch, however, may now be divided among more diggers. The CPUE data, despite rather dramatic fluctuations from 1975 through 1979, suggest that production continued at that same level through 1979. Beginning in 1979, CPUE for the Pismo Beach Pismo clam fishery dropped to zero in a stepwise fashion along the beaches progressing from north to south.

Our observations of the decline of the Pismo Beach Pismo clam fishery, based on otter sightings, clammer censuses, and clam transects, substantiate earlier observations on the Morro Bay and Monterey Bay clam fisheries (Miller, Hardwick, and Dahlstrom 1975) and provide further evidence that sea otters are directly responsible for the loss of these sport fisheries.

Using information available on numbers of otters south of Point San Luis (Figure 3) and assumed consumption rates of Pismo clams (80 clams/otter/day), it is possible to illustrate the impact sea otters had on the Pismo clam resource in the Pismo Beach area. Even after subtracting for a percentage of otters potentially feeding in nearby rocky habitat, the estimated number of clams consumed still exceeded 700,000 in 1980. This number of clams is more than double the highest yearly clammer take at Pismo Beach during the 1975 through 1979 period (Table 6). At this rate, it is easy to understand why the Pismo clam fishery, already being fully utilized collapsed so dramatically and so completely.

What potential is there for a resurgence of a Pismo clam fishery within the sea otter's range in the future? None of the Pismo clam fisheries which once existed in areas now occupied by sea otters currently provide a harvestable resource. However, several alternative views exist on the potential for a resurgence of a fishery in the future (VanBlaricom 1981).

Relatively low adult Pismo clam densities have produced successful sets in the past and could potentially do so in an area occupied by sea otters. If sea otter foraging pressure was low a sufficient number of clams from a major set might survive to support a fishery. Sea otter foraging pressure does decline in an area when the large peripheral male group moves on to new areas.

One major set of Pismo clams has occurred within the sea otters range on Atascadero State Beach in 1972. The data collected on the growth and survival of this year-class strongly support the contention that clam stocks will not reach a high enough level to provide reasonable sport use. The extremely large 1972 year-class of Pismo clams on Atascadero Beach was not available as forage to sea otters, due to the small size of the clams, when the peripheral male group moved through that area. The survival of that year-class of clams appeared excellent until individuals reached a size generally accepted as being available forage for sea otters, at which point survival declined sharply. Coincidentally, a

disparity between observed and expected mean sizes became apparent, indicating that larger individuals were being selectively removed. It should be emphasized that Atascadero Beach was closed to sport clamming from March 1975 to March 1978 and the clam stocks subject to predation by a low density sea otter population. No legal sized clams have been observed in transect digs or clammer interviews since 1973.

Data from trench transects and clammer interviews collected in Monterey Bay through 1986 also substantiate the contention that a sport fishery for Pismo clams cannot coexist with sea otters. No legal-sized clams have been observed from that area (Monterey Bay) since 1976, despite continued clam recruitment and very low densities of sea otters (J. Hardwick, Calif. Dept. Fish and Game, pers. comm.)

Two conclusions can be drawn from these data which have a direct bearing on the debate concerning sea otter-shellfish fishery relationships. Firstly, sea otter foraging, rather than human impact from legal harvest, illegal harvest, pollution, and/or vehicle traffic on beaches, have resulted in the loss of Pismo clam fisheries within the sea otter's range. Secondly, once sea otters are established along clam bearing beach areas, any future harvestable stocks of clams will be fully utilized by sea otters, preventing the return of a fishery.

### ACKNOWLEDGMENTS

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## ASPECTS OF ECOLOGY AND LIFE HISTORY OF THE WOOLLY SCULPIN, *CLINOCOTTUS ANALIS*, FROM SOUTHERN CALIFORNIA<sup>1</sup>

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Approximately 3000 woolly sculpin, *Clinocottus analis*, were captured over a 17-month period at Point Fermin, California, in tidepools from 1.07 m to -0.52 m elevation from Mean Lower Low Water. An average density of 8.5 fish/m<sup>2</sup> and a progressive shift of larger individuals toward lower tidal levels were noted. Spawning was inferred to occur primarily during September through November with peak recruitment to tidepools during November through February. Males grew faster and to a larger size than females; von Bertalanffy growth coefficients  $L_{\infty}$ ,  $k$ , and  $t_0$  were 119.0, 0.71, and -0.10 for males and 96.3, 1.00, and -0.07 for females, respectively. Maximum lifespan was 6 years for females and approximately 8 years for males. All specimens over 60 mm TL appeared sexually mature with batch fecundity described by the linear function  $F = 11.6 TL - 620.6$ . Overall sex ratio was not significantly different than 1:1. Woolly sculpin preyed on copepods, isopods, gammarideans, polychaetes, and mollusks, with the importance of each group changing markedly with fish size. The presence of two parasites, *Opecoelus adsphaericus* and *Ascarophis* sp., was noted.

### INTRODUCTION

The woolly sculpin, *Clinocottus analis*, ranges from Cape Mendocino, California, to at least Punta Ascuncion, Baja California (Miller and Lea 1972). It is also present around Coronado, Guadalupe, San Martin, Cedros and the Channel Islands. Although the woolly sculpin is one of the most abundant intertidal fishes throughout much of its range, only certain aspects of its life history and ecology have been investigated. Eigenmann (1892) and Budd (1940) investigated its larval development, while Hubbs (1966) studied fertilization, early cleavage, and influence of temperature on hatching. Homing was studied by Williams (1957) and Richkus (1968, 1978, 1981). Local distribution and diet were investigated by Mitchell (1953), Johnston (1954), Mollick (1968, 1970) and Yoshiyama (1980). This study attempts to fill some of the gaps in knowledge concerning the life history of this common intertidal fish.

### MATERIALS AND METHODS

The study was conducted 1.5 km northwest of Point Fermin, Los Angeles County, California (lat 33° 42' N, long 118° 17' W). Semi-monthly tidepool collections were made between May 1971 and September 1972. Of the 64 total samples, 51 tidepools were sampled once, 5 were sampled twice, and 1 was sampled three times. Average length and width of each tidepool sampled was recorded as well as an estimate of the degree of cover and tidal elevation. Nearly all tidepools sampled were less than 0.5 m deep.

Collections were made using a solution of 10% quinaldine in ethyl alcohol and anesthetized fish were removed either by hand or small dip net. All fish were

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collected in tidepools with sparse cover; however, in extremely rocky tidepools with numerous crevices, possibly a small proportion of the fish escaped detection. In the laboratory, fish were weighed to the nearest decigram and gonads to the nearest milligram. Total length (TL), to the nearest millimetre, and sex were also recorded. Unless otherwise stated, all lengths are given as TL.

Age was determined by length-frequency analysis (Petersen method) and by counting annuli in otoliths. All otoliths were read twice and any pair of readings not in agreement was disregarded. Von Bertalanffy growth functions were fit using the Program BGC3 (Abramson 1971).

Approximately 20 fish per months of about equal numbers of adults and juveniles, males and females, were chosen for stomach analysis; 248 fish between 15 mm and 170 mm were examined. Both frequency of occurrence and number of individual prey items were recorded. Food volumes per category and an index of stomach fullness (ISF) were estimated since volumes were often too small to be measured directly. An index of relative importance ( $IRI_i$ ), the relative contribution of the  $i$ th food category to total diet, was calculated from:

$$IRI_i = \frac{1}{N} \sum_{i=1}^N (v_{ij} ISF_i) 100$$

where:  $N$  = number of stomachs analyzed in the fish-size category under consideration;  $v_{ij}$  = estimated volumetric proportion of total stomach content of the  $i$ th food category in the  $j$ th individual; and  $ISF_i$  = estimated fractional stomach fullness of the  $i$ th individual.

## RESULTS AND DISCUSSION

### Habitat and Associations

The intertidal zone at Point Fermin consists of shoreward tilted, parallel edges of bedrock with scattered boulders. At a tide of  $-0.55$  m elevation from Mean Lower Low Water (MLLW), 65 m of beach is exposed. Tides are mixed semi-diurnal with maximum high tides about 2.13 m and extreme low tides about  $-0.58$  m.

Tidepool temperatures were extremely variable but generally within  $\pm 3^\circ\text{C}$  of ambient surf temperature. Monthly mean surf temperature ranged from  $12^\circ\text{C}$  in April to  $20^\circ\text{C}$  in August. Although pool temperatures as high as  $27^\circ\text{C}$  were recorded, no woolly sculpin were taken in pools greater than  $22^\circ\text{C}$ . Salinity was fairly constant at 34 ‰ throughout the study. Evaporation in upper tidepools rarely increased salinity more than a few parts per thousand. However, freshwater runoff lowered the salinity of several of them to 24 ‰ on one occasion.

Predominant organisms in the study area were typical rocky shore forms. Periwinkle, *Littorina planaxis*, and turban shell, *Tegula funebris*, were common in higher intertidal zones. Mussels, *Mytilus californianus*, and goose barnacles, *Pollicipes polymerus*, were characteristic of mid-intertidal regions. Boulder surfaces and tidepool bottoms in lower zones were often densely covered with coralline red algae. Several organisms, such as shore crab, *Pachygrapsus crasipes*, and sea anemone, *Anthopleura xanthogrammica*, were found throughout all zones. Fishes commonly associated with woolly sculpin in the intertidal region included: rockpool blenny, *Hypsoblennius gilberti*; juvenile opaleye, *Girella nigricans*; spotted kelpfish, *Gibbonsia elegans*; striped kelpfish, *Gibbonsia*



*metzi*; California clingfish, *Gobiesox rhesodon*; and dwarf surfperch, *Micrometrus minimus*. Species taken on rare occasions in the tidepools included: smooth-head sculpin, *Artedius lateralis*; black perch, *Embiotoca jacksoni*; zebra perch, *Hermosilla azurea*; mussel blenny, *Hypsoblennius jenkinsi*; rosy sculpin, *Oligocottus rubellio*; fluffy sculpin, *O. snyderi*; pile perch, *Rhacochilus vacca*; cabezon, *Scorpaenichthys marmoratus*; and juvenile rockfishes, *Sebastes* spp. Woolly sculpin was numerically the most abundant fish in the intertidal region, outnumbering the second most abundant species, rockpool blenny, by approximately 10 to 1.

### Distribution Within Study Area

Woolly sculpin were collected from tidepools as high as 1.07 m above MLLW, but were occasionally observed above this level. Individuals were taken from all tidepools sampled below 0.91 m to the lowest tidepool sampled at  $-0.52$  m but the region of greatest abundance was from 0.61 m to  $-0.30$  m. Observations made while skin diving suggest a reduced population at tidal levels below  $-0.61$  m. This is consistent with the observation made by Hubbs (1966) at San Diego that baited traps set below this level were seldom effective.

The average population density, excluding newly settled young-of-year, was  $8.5/\text{m}^2$  of tidepool surface but ranged as high as  $27/\text{m}^2$ . Tidepool size, which ranged from  $0.6 \text{ m}^2$  to  $74.3 \text{ m}^2$ , was not significantly correlated with the population density of that pool ( $r = -0.108$ ,  $n = 62$ ,  $P > 0.05$ ). However, those tidepools with moderate to heavy cover (i.e., crevices, rocks, vegetation) appeared to support higher population densities than their lightly covered counterparts. Although no major seasonal shift in intertidal distribution was noted, tidepools high in the intertidal region which lacked fish during summer months contained a few individuals during winter months.

Juvenile woolly sculpin less than approximately 25 mm in length were rarely found in pools inhabited by adults. These young fish were typically found in small, shallow, coralline algae filled pools between 0.45 to  $-0.18$  m. Richkus (1968, 1981) also noted that the distribution of these fish differed from that of larger individuals. He found fish less than 35 mm occurring even in small, sandy depressions that would drain before being resubmerged.

Juvenile and adult woolly sculpin greater than 40 mm in length demonstrated a marked tendency for larger fish to inhabit increasingly lower tidal levels (Figure 1). This trend was also noted by Williams (1957) in the nearby Palos Verdes area.

### Age and Growth

Recruitment of young-of-year into the intertidal region occurred during fall through spring as evidenced by the collection of individuals less than 20 mm in all months from November through May, except April (Figure 2). Peak recruitment, however, occurred during November through February. Based on studies by Budd (1940) on woolly sculpin and Morris (1951) on the closely related species *Clinocottus recalvus*, these 11–25 mm fish were newly settled from the pelagic larval phase and hatched approximately 6–8 weeks prior. By April, the 1971–72 spawned fish averaged approximately 48 mm. Woolly sculpin spawned the preceding year increased from approximately 45 mm in May to about 62 mm in September. The slightly smaller average length in May for the 1970–71 year class as compared to April for the 1971–72 year class is likely the result of sampling error and/or annual variation in growth rate.

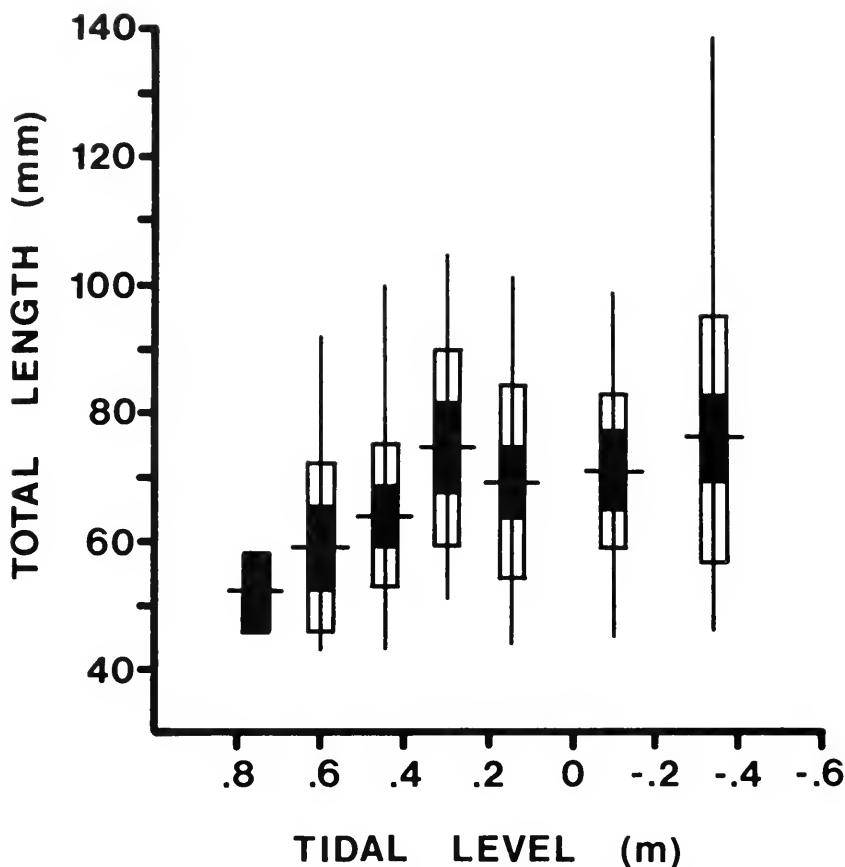


FIGURE 1. Relationship of woolly sculpin total length to tide level during Fall 1971. Mean, range, standard deviation, and two standard errors are indicated.

Mean size at age for fish older than 1 year was determined from otoliths of 182 fish collected March through June 1972. Maximum observed age for females was 6+ while a minimum of seven age classes could be established for males. Age class 1+, 2+, 3+, 4+, 5+, and 6+ females averaged 82.5, 86.5, 93.1, 94.8, 98.3 and 100.0 mm, respectively, while males averaged 87.7, 101.3, 110.6, 112.5, 118.6 and 145.5 mm, respectively (Table 1). The largest fish captured during the study, a 170 mm male, appeared to be at least 8+. The majority of specimens, 88 percent based on November through May length-frequency data, were one year or less in age.

A growth function was calculated by combining monthly mean length for juveniles, estimated from 0+ length-frequency modes, with the mean lengths obtained from otolith analysis. Age was referenced from a presumed 15 September birthday. Since otolith samples were collected during March through June, age was taken as the mid-point of the period, i.e., 1 May. Only otolith ages 1+ through 5+ were included since the sample size for age 6+ and older was small.

Fitted von Bertalanffy functions (Figure 3) were:

Female

$$L_t = 96.3(1 - e^{-1.00(t+0.07)})$$

Male

$$L_t = 119.0(1 - e^{-0.71(t+0.10)})$$

for the general equation:

$$L_t = L_\infty (1 - e^{-k(t-t_0)})$$

$L_t$  = length at time  $t$  in years,  $L_\infty$  = asymptotic length,  $k$  = growth constant, and  $t_0$  = hypothetical age at zero length.

Average growth rate ( $B$ ) at time  $t$  may be obtained from the von Bertalanffy coefficients using Knight's equation (Ricker 1975):

$$B = kL_\infty e^{-k(t-t_0)}$$

From this relationship the average growth rate was 6.1 mm per month during the first month (November) after settling. By the following April this rate had decreased to 4.3 mm per month. In subsequent months the disparity between male and female growth rates become increasingly apparent. At age 1 year the average growth rate for males was 3.2 mm per month while females had slowed to an average of 2.7 mm per month.

It should be noted that these growth estimates, especially for males, likely become increasingly biased low with increasing age. As discussed above, woolly sculpin, with increasing size, tend to inhabit pools at increasingly lower tidal levels. These pools are less often exposed by low tides and typically offer greater cover. Since these fish are, therefore, more difficult to capture, a systematic bias towards slower growing fish is probable.

Growth in weight with length for pooled sexes and juveniles was found to be:

$$W = 0.0000174TL^{2.958} \quad (r=0.997; n=157; P \leq 0.01)$$

where:

$$W = \text{weight in grams.}$$

For males the relationship was,

$$W = 0.0000159TL^{2.988} \quad (r=0.983; n=128; P \leq 0.01)$$

while for females it was,

$$W = 0.0000346TL^{2.793} \quad (r=0.988; n=126; P \leq 0.01).$$

Growth in length or weight with standard length (SL) may be obtained by applying the relationship,

$$SL = 0.15 + 0.81TL.$$

### Reproduction

Sexual maturity for both sexes appears to occur near the end of the first year of life as well-developed gonads were observed in all fish over 60 mm. Mature ovaries were found in all months; however, highest average GSI (gonad wt/body wt  $\times$  100) values occurred in October through November (Figure 4). Peak testicular development was observed during August through November. Lowest average GSI values for both males and females were during February and March. Although it appears that spawning may occur throughout much of the year, peak reproduction, as inferred from GSI values, likely occurs during September through November. This is in reasonable agreement with estimates of

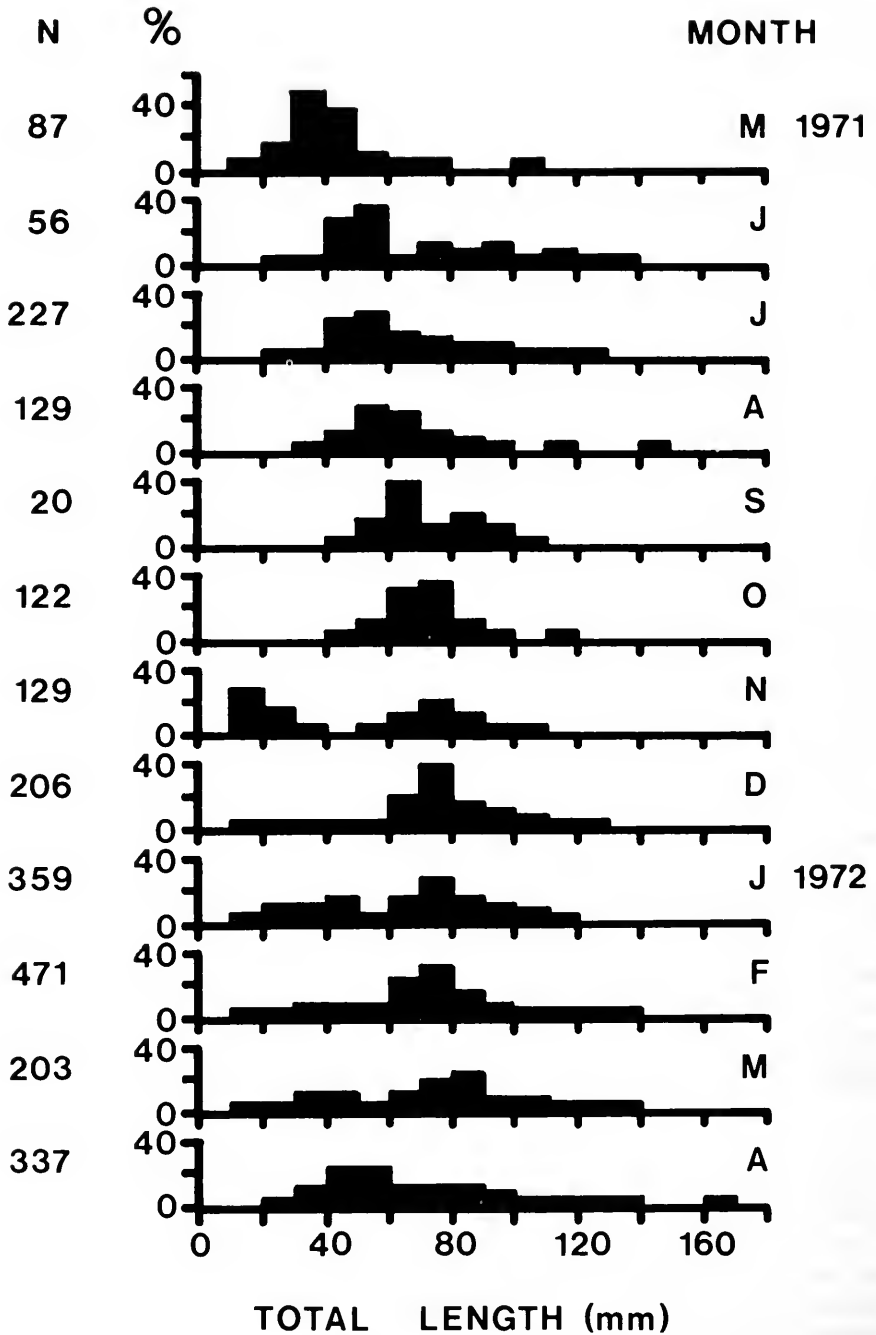


FIGURE 2. Monthly length-frequency distribution for woolly sculpin.

peak spawning deduced from the appearance of young in the tidepools when 3 to 4 weeks for hatching (Hubbs 1966) and 6 to 8 weeks for a pelagic larval phase are allowed. Eigenmann (1892) also indicated spawning over a prolonged period with young occurring in tidepools 2 to 3 months later.

TABLE 1. Woolly Sculpin Total Length (mm) at Age Based on Otoliths.

	Age Class					
	1	2	3	4	5	6
Female						
Mean .....	82.5	86.5	93.1	94.8	98.3	100.0
SD .....	4.8	4.6	4.8	7.2	2.6	—
Range .....	70–87	76–92	83–100	87–100	95–102	—
n .....	11	10	14	9	6	1
Male						
Mean .....	87.7	101.3	110.6	112.5	118.6	145.5
SD .....	3.9	9.5	15.5	10.5	10.9	17.6
Range .....	80–93	72–116	84–146	95–130	108–135	124–165
n .....	15	24	21	17	5	4

Frequency analysis of ovarian egg diameter suggests the presence of at least three modal groups of eggs. Generally, there was a single, but distinct, group of eggs greater than 0.7 mm diameter. These eggs averaged approximately 1.24 mm in diameter and, in an unpreserved state, were translucent greenish-yellow to reddish-brown in color. It appears that these are the only eggs released during a spawn. Batch fecundity (F), the potential number of eggs produced during a single spawn, was obtained by direct count of all eggs over 0.7 mm diameter. The linear equation  $F = 11.6 \text{ TL} - 620.6$  ( $r = 0.940$ ;  $n = 45$ ;  $P \leq 0.01$ ) appears to adequately describe the relationship between the number of eggs and fish length (TL in mm) (Figure 5). Logarithmic and semi-logarithmic transformations failed to significantly improve the fit. The largest female examined (110 mm) contained 784 eggs; the mean number was 242 eggs per average reproductive female (74 mm). These fecundity estimates are very similar to those from Pacific Grove specimens and substantially lower than from La Jolla specimens reported by Hubbs (1966).

The total egg production during a single spawning season could not be determined since the number of spawnings per season is unknown. However, the occurrence of several modal groups below 0.5 mm diameter does suggest multiple spawnings. Hubbs (1966) postulated that females lay several complements per season since over half the specimens captured and held in isolation developed ripe eggs within two weeks.

The number of males and females in the population appears to be about equal. During the course of the study, the sex of 1776 adult sculpin was determined. Of these, 865 (48.7%) were male and 911 (51.3%) were female. Chi-square analysis suggests no significant departure from a 1:1 sex ratio ( $\chi^2 = 1.14$ ;  $df = 1$ ;  $P > 0.05$ ). When analyzed by month, the percentage of females ranged from 60.5 in January to 36.7 in August (Table 2). Although sex ratios in January, May, and June departed significantly from 1:1, no consistent or biologically meaningful trend was discernible.

### Food and Feeding

Woolly sculpin appear to feed on a wide diversity of intertidal organisms. In the 248 stomachs examined, at least 33 prey categories could be established

(Table 3). Frequently encountered prey items, those with 25% or greater occurrence, were gammarideans (50.8%), copepods (31.5%), and the isopod *Cirolana harfordi* (26.2%). Clearly, small crustaceans formed the bulk of the diet. Less frequently encountered items, 20–25% occurrence, were polychaetes (23.0%), the tanaidacean *Anatanais normani* (22.2%), and mollusks (21.8%). Algae (19.8%), larvae of the dipteran *Paraclunio* sp. (17.3%), and the polychaete *Phragmatopoma californica* (15.7%) were also commonly encountered.

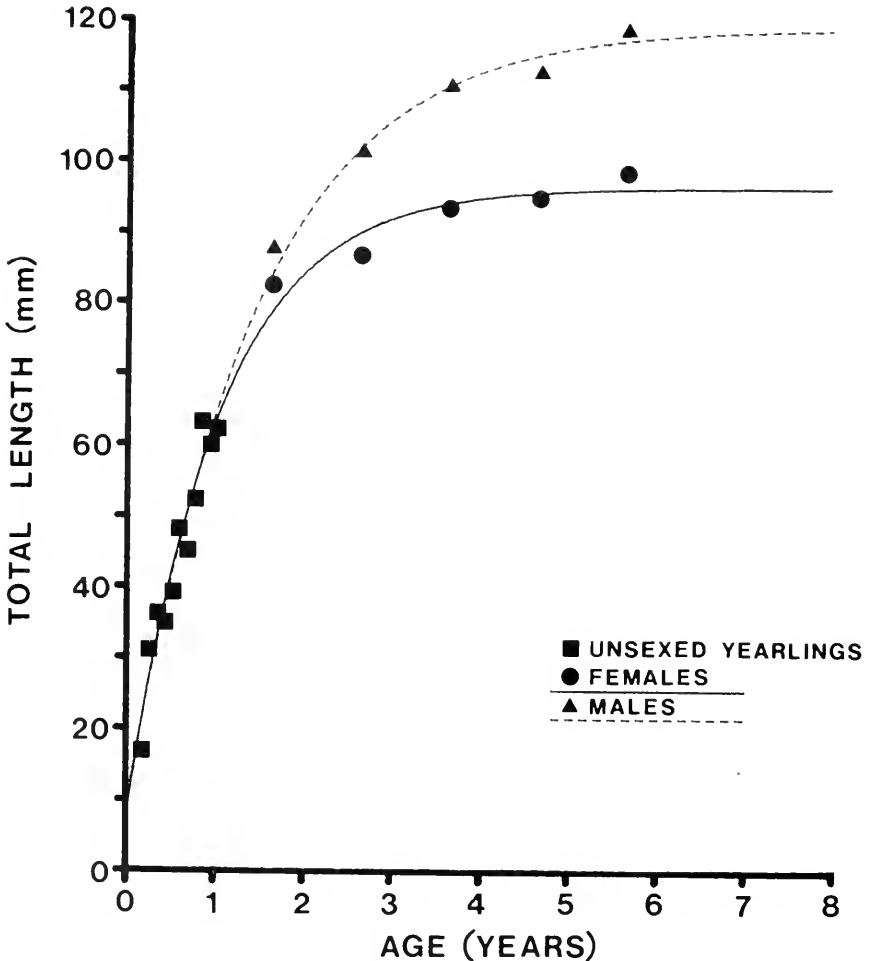
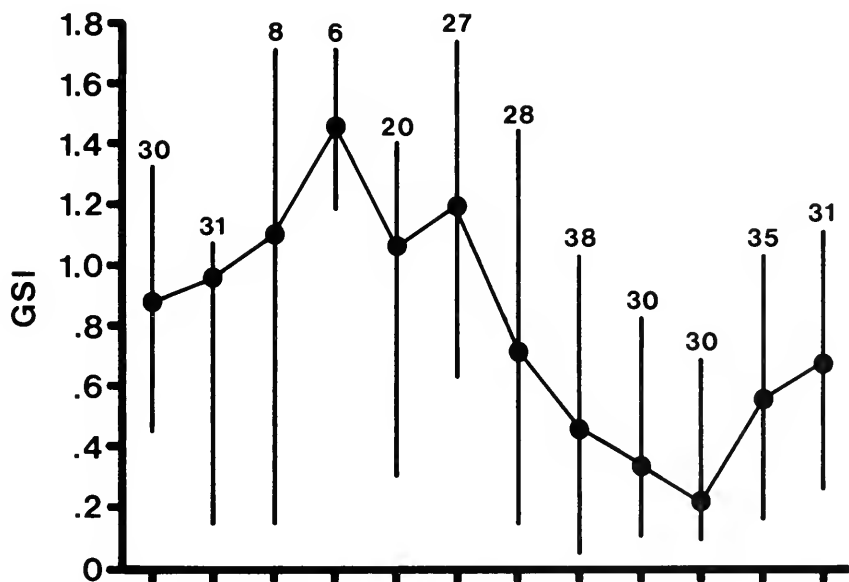


FIGURE 3. Size at age relationship for woolly sculpin at Point Fermin, California.

As measured by the Index of Relative Importance (IRI) diet composition changed markedly with fish size (Figure 6). Approximately 90% of the diet of sculpin under 20 mm was copepods. As fish increased in length (30–100 mm), this percentage decreased and there was increased emphasis on larger items such as amphipods, isopods, and polychaetes. Woolly sculpin over approximately 80 mm, predominantly males, placed increased reliance on relatively

large items such as mollusks, primarily chitons and *Acmaea* spp., and decapods, primarily *Pagurus samuelis* and young *Pachygrapsus crassipes*. The overall pattern of utilization appeared to be one of increasing prey size with increasing body size.

## MALE



## FEMALE

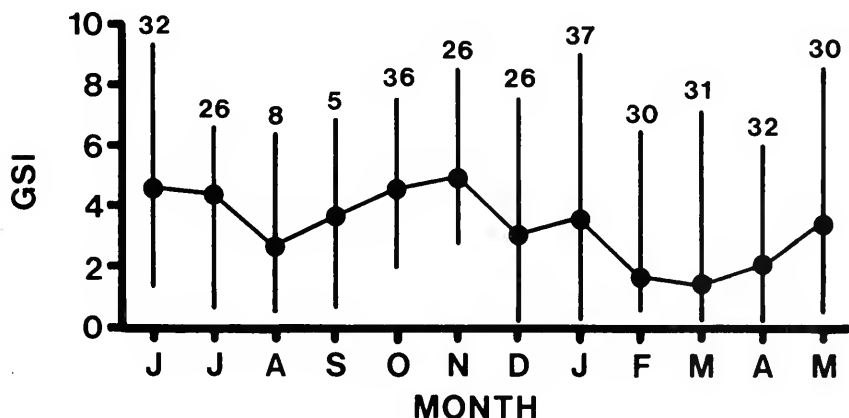


FIGURE 4. Monthly variation in gonosomatic index (GSI) for woolly sculpin. Mean, range, and sample size are indicated.

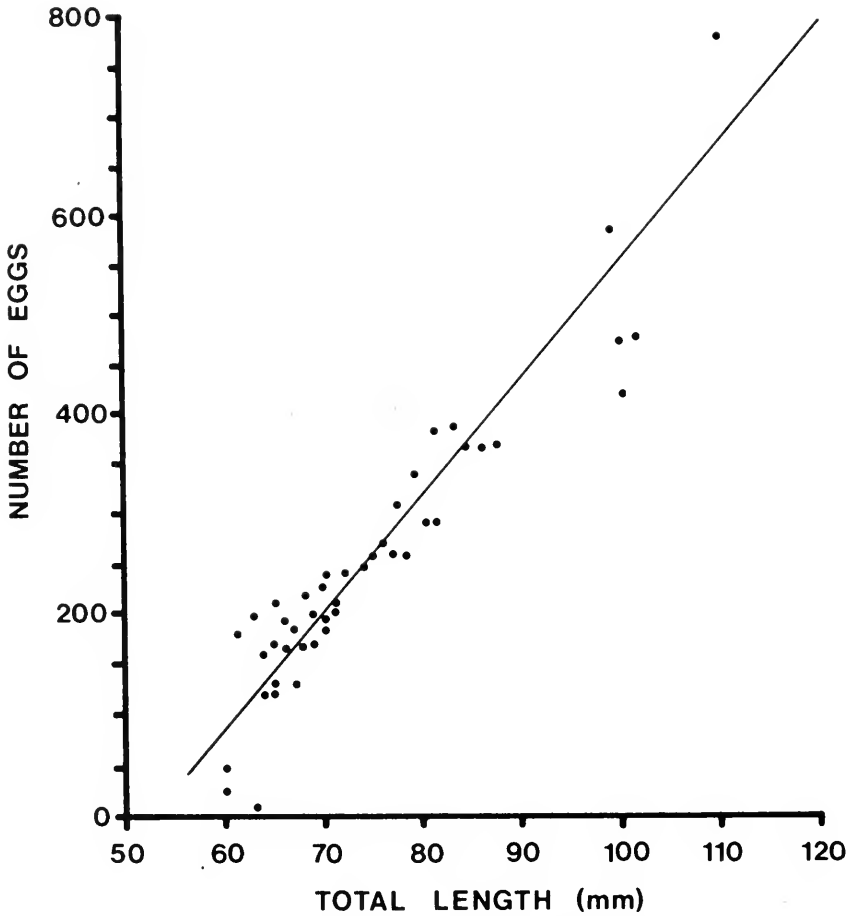


FIGURE 5. Relationship of total length (TL) to number of mature ova in woolly sculpin.

TABLE 2. Adult Woolly Sculpin Population Sex Composition by Month and Chi-Square Test of 1:1 Sex Ratio Hypothesis

Month	Total	Percentage		Chi-square
		Male	Female	
January .....	258	39.5	60.5	10.9**
February .....	385	48.3	51.7	0.4
March .....	105	54.3	45.7	0.6
April .....	103	40.8	59.2	3.1
May .....	141	39.7	60.3	5.6*
June .....	336	57.4	42.6	7.1**
July .....	182	46.7	53.3	0.7
August .....	30	63.3	36.7	1.6
September .....	12	58.3	41.7	0.1
October .....	93	51.6	48.4	0.0
November .....	52	61.5	38.5	2.3
December .....	79	48.1	51.9	0.1
Total .....	1,776	48.7	51.3	1.1

\* $P \leq 0.05$

\*\* $P \leq 0.01$



**TABLE 3.** Diet by Frequency Occurrence, Percent Occurrence, and Number of Organisms of 248 Woolly Sculpin (15–170 mm TL) collected May 1971 through September 1972.

	Frequency	Percent	Number
Protozoa			
Phytomastigophora .....	1	0.4	1
Sipunculida .....	2	0.8	2
Annelida			
<i>Phragmatopoma californica</i> .....	39	15.7	70
Unident. Polychaeta .....	23	9.3	35
Mollusca			
Polyplacophora .....	23	9.3	35
<i>Acaema</i> spp. ....	25	10.1	35
<i>Littorina planaxis</i> .....	2	0.8	2
Unident. Prosobranchia .....	1	0.4	1
Opisthobranchia egg mass .....	1	0.4	1
Arthropoda			
Halacaridae.....	1	0.4	1
Pycnogonida.....	2	0.8	2
Ostracoda .....	15	6.0	24
Copepoda .....	78	31.5	3,700
Cirripedia cirri .....	16	6.5	—
Mysidacea.....	2	0.8	5
<i>Anatanais normani</i> .....	55	22.2	504
<i>Cirolana harfordi</i> .....	65	26.2	160
<i>Exosphaeroma</i> sp. ....	1	0.4	2
Valvifera .....	32	12.9	135
Gammaridea .....	126	50.8	529
<i>Spirontocaris</i> sp.....	2	0.8	2
<i>Bateis</i> sp.....	2	0.8	2
<i>Pagurus samuelis</i> .....	9	3.6	10
<i>Pachygrapsus crassipes</i> .....	10	4.0	10
<i>Cancer</i> sp.....	1	0.4	1
Unident. Decapoda .....	4	1.6	4
Coleoptera .....	3	1.2	3
<i>Paraclunio</i> sp. larvae .....	43	17.3	115
Unident. Diptera .....	2	0.8	7
Echinodermata			
<i>Strongylocentrotus purpuratus</i> tube feet .....	20	8.1	103
Chordata			
<i>Hypsoblennius gilberti</i> .....	1	0.4	1
Fish eggs .....	8	3.2	120
Unident. Algae .....	49	19.8	—
Empty .....	29	11.7	—

Although the normal mode of feeding appears to be that of engulfing whole organisms, woolly sculpin seem to occasionally engage in a browsing-like mode of feeding. This was inferred from the occurrence of such items as barnacle cirri, sea urchin tube feet, and the anterior-most portion of the tube worm *Phragmatopoma californica*.

The findings of this study closely parallel those of several other workers in demonstrating that small crustaceans play an important role in the diet of woolly sculpin. Mitchell (1953) found that decapods, especially the shrimp *Spirontocaris picta*, comprised the bulk of the stomach contents of 12 60–110 mm woolly sculpin examined from the Palos Verdes area. Johnston (1954) found copepods to be the most numerous and most frequently encountered food item in the

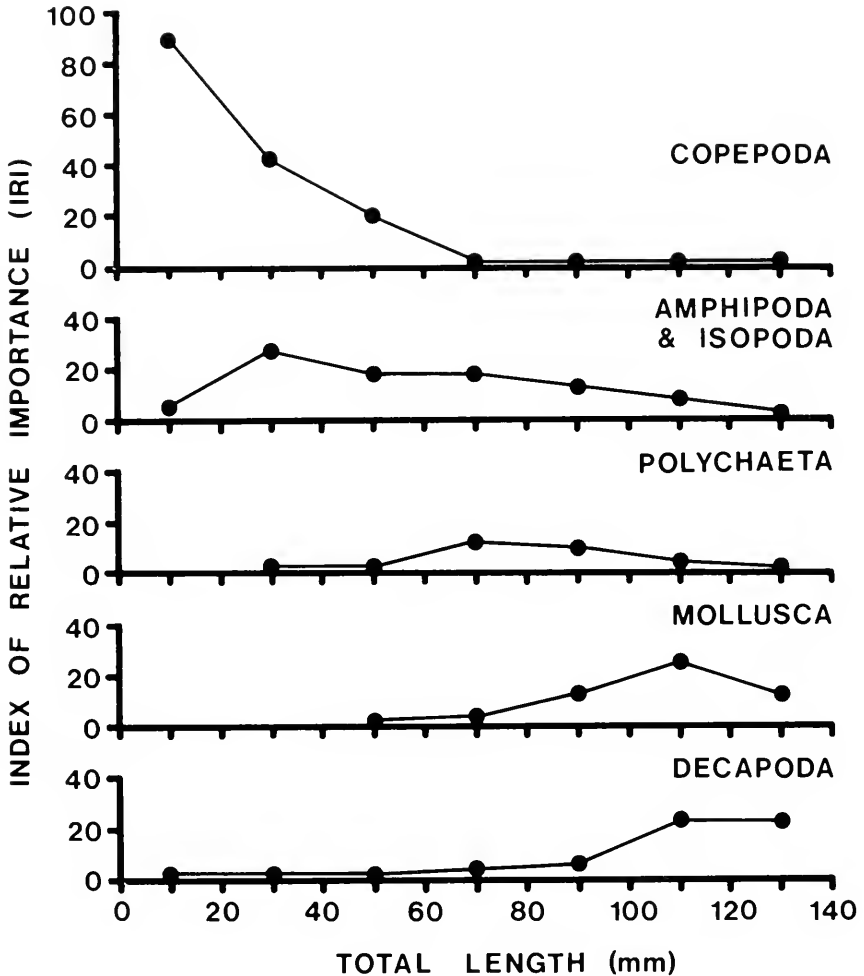


FIGURE 6. Index of Relative Importance (IRI) of selected food items versus total length of woolly sculpin. Points represent mean value for 20 mm size intervals.

summer diet of individuals from Monterey County while Mollick (1968, 1970) found amphipods to be the dominant prey by mean volume and copepods to be the most frequently encountered item during July at Bird Rock, San Diego. Yoshiyama (1980) also found small crustaceans to be the most important category in the diet of woolly sculpin from central California.

Yoshiyama (1980) did report, however, that in central California woolly sculpin consume substantial quantities of algae, a resource exploited by few other rocky intertidal fishes in California. He found algae, primarily *Petalonia*, in 29% of the 62 stomachs analyzed and concluded that the concomitant lack of animal prey in some specimens indicated that algae was not taken incidentally. He also concluded that the exploitation of this food resource served to separate woolly sculpin ecologically from the two more carnivorous sculpin, fluffy sculpin

and smoothhead sculpin, common to the region. He was uncertain as to whether the apparent de-emphasis of algae in the diets of southern California woolly sculpin observed by Mitchell (1953), Johnston (1954) or Mollick (1970) resulted from sampling vagaries, differences in the underlying resource base, or population differences in feeding habits.

A reduction in algae utilization by woolly sculpin in southern California relative to central California might be expected based on the occurrence of potential competitor species. Yoshiyama (1980) found that besides woolly sculpin, the most frequently encountered species were the smoothhead and fluffy sculpins. These two carnivorous species were only rarely encountered during this study. Instead, the most frequently encountered species were the rockpool blenny and juvenile opaleye (30–100 mm *TL*). Both species utilize substantial amounts of algae (Mitchell 1953, Dayneko 1975). Yoshiyama stated that opaleye were not encountered during his study and rockpool blenny do not range north of Point Conception (Miller and Lea 1972). Therefore, a decreased utilization of algae by woolly sculpin in southern California would appear advantageous in lessening interspecific competition.

It should also be noted that the occurrence of algae in the stomach does not necessarily imply utilization. Examination of the posterior gut made during the present study indicated that little, if any, digestion of algae had occurred. This suggests, that while algae is ingested, it may be either coincidental with prey capture or purposeful to obtain organisms associated with it. A concomitant lack of animal prey may result from unsuccessful attempts at capturing prey or differential digestive rates.

### Parasites and Predators

Intestines of 21 woolly sculpin (56–116 mm), collected April 1972, were examined for parasites. The diagenetic trematode, *Opecoelus adsphaericus*, was found in 17 (81%), with an average of four trematodes per fish (range 1–15). There is no significant correlation between fish size and number of trematodes ( $r = 0.140$ ,  $n=21$ ,  $P > 0.05$ ).

A nematode, *Ascarophis* sp., occurred in 12% of the 248 (i.e., all) stomachs examined. It appeared most abundant during late winter and early spring. Incidence was highest in woolly sculpin over 60 mm.

Although numerous avian and fish predators of woolly sculpin are suspected, only one was confirmed; a 29 mm woolly sculpin was removed from the stomach of a 140 mm spotted kelpfish. Cabezon and kelp bass, *Paralabrax clathratus*, were common subtidally and were observed in the intertidal region during high tide. Both are reported to prey on sculpins (O'Connell 1953, Smith 1970).

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# ICHTHYOFAUNAL COMPOSITION AND RECOLONIZATION IN A CENTRAL CALIFORNIA TIDEPOOL <sup>1</sup>

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Species composition and age class distribution data were obtained for fishes collected from a tidepool at San Simeon Reef, San Luis Obispo County, California. Two collections, taken in November and December 1983, were made by applying rotenone to the pool. Members of the family Cottidae were the most abundant fishes in both samples and comprised 30% of the 1004 fishes collected. Clinids were second in abundance in the November collection whereas stichaeids were second in December. Brillouin's species diversity index (H) was calculated for the two samples. Comparison (t-test) of diversity indices indicate significant differences between the two samples, suggesting that the time period between collections (43d) was not sufficiently long to allow repopulation. The age class distributions of both samples were similar with the notable exception of *Gobiosox maeandricus*, for which only age class 1 individuals were represented in the second sample.

## INTRODUCTION

The high diversity of the central California rocky intertidal zone and the accessible nature of tidepools has made tidepool fishes model organisms for the study of a number of ecological phenomena. Each species prefers a specific microhabitat within the intertidal zone (Yoshiyama 1980, Barton 1982) and the actual distribution of fishes is influenced by physical factors, such as water temperature (Thomson and Lehner 1976), as well as biotic interactions such as competition and predation (Yoshiyama 1980, 1981; Grossman 1982). Although there is a wide range of environmental fluctuations within the intertidal zone, the assemblage of fishes found here tends to be both persistent and resilient. Thus, even after a major perturbation, the community structure of the tidepool appears to return to its original state (Grossman 1982).

Investigations of the structure of tidepool fish communities often involve experimental defaunation (Williams 1957, Grossman 1982). It is assumed that recolonization of a tidepool is relatively rapid after the application of an ichthyocide and that the time between defaunations is sufficiently long to allow recovery (Grossman 1982). While the effect of defaunation on community structure seems to be minimal in the long term (e.g., Thomson and Lehner 1976, Grossman 1982), the short term effects have not been well documented. If the recovery time is insufficient, these collections will present a biased picture of community structure. Therefore, it is important to have an indication of the minimum time interval needed between such collections. Herein, we describe the ichthyofaunal composition of a central California tidepool and examine the short-term effects of the application of an ichthyocide (rotenone) on its community structure.

## METHODS

The study site is located at San Simeon Reef, roughly 8 km north of San Simeon

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Point, San Luis Obispo County, California (approximately lat 35° 39'N, long 121° 16'W). The tidepool selected was approximately 3 × 5 m with a maximum depth of approximately 0.5 m. It lies in the mid-intertidal approximately 40 m offshore from the mean high tide mark. The substrate was composed primarily of rocks interspersed with patches of sand.

Fishes were collected during low tide on 5 November and 17 December 1983 between 1500 and 1700 h. Water temperature in the tidepool on these two days was approximately 12°C and 16°C, respectively. *Derris* root rotenone was employed as an ichthyocide. Following 10% formalin fixation and preservation in 45% isopropanol, specimens were identified, counted, and standard lengths recorded to the nearest 0.5 mm. Age classes were separated through the use of length frequency histograms (Ricker 1975). Data correlating standard length with age were used for distinguishing age classes (Burge and Schultz 1973; Hart 1973; Fitch and Lavenberg 1975; R. D. Orton, pers. comm.). Where such data were not available, discontinuities in the length frequency were used to assign age class membership.

To assess the effects of defaunation on the structure of the tidepool ichthyofauna, a measurement of species diversity was calculated and compared between the two samples. Brillouin's species diversity index ( $H$ ) was chosen because it ". . . is the preferred index for most problems in applied aquatic ecology" (Stauffer, Reish, and Calhoun 1980, p. 185). This index represents the total recoverable population of fishes within the tidepool, not just a random sample (Thomson and Lehner 1976). Brillouin's index is:

$$H = 1/N \ln (N!/N_1! N_2! \dots N_s!)$$

where  $N$  is the total number of individuals in the sample;  $N_1, N_2 \dots N_s$  the number of individuals in species 1, 2 . . .  $s$ ; and  $s$  the total number of species collected (Pielou 1977). To determine if there was a statistically significant difference between indices obtained for the two samples, a  $t$ -test was performed (Zar 1974, p. 115). A  $G$ -test, using Williams' correction (Sokal and Rohlf 1981), was utilized to determine if there were statistically significant differences in the age class composition of certain species between the two samples. When employing the  $G$ -test on data for *Artemis lateralis*, age class 3 individuals were pooled with age class 2 individuals.

## RESULTS AND DISCUSSION

Species composition of the two collections is provided in Table 1. Cottids were the most abundant fishes in both samples (28.7% and 33.1%, respectively). Clinids were second in abundance in the November collection (21.8%), but stichaeids were second in December (22.2%). The same species were obtained in both collections with the following exceptions: *Xiphister mucosus* was absent from the November sample whereas *Atherniops affinis* and *Micrometrus aurora* were not present in the December sample. Brillouin's species diversity indices for the November and December collections were 2.34 and 2.04, respectively; these values are significantly different ( $t = 7.85$ ,  $df = 197$ ,  $P < 0.05$ ). Alternatively, if the nonresident species, *A. affinis* and *M. aurora* (i.e., species not typically found in the tidepool habitat), are omitted from the analysis, Brillouin's species diversity index for the November sample is 2.19. However, the difference between the values for November and December remains significant ( $t = 3.90$ ,  $df = 187$ ,  $P < 0.05$ ).

**TABLE 1. Species Composition And Relative Abundance Of Fishes Collected In The Two Tidepool Samples. Taxonomy Follows Robins *et al.* (1980).**

Taxa	5 November 1983		17 December 1983	
	Number	Percent	Number	Percent
Gobiesocidae				
<i>Gobiesox maeandricus</i> .....	48	6.8	59	19.5
Atherinidae				
<i>Atherinops affinis</i> .....	16	2.3	-	-
Cottidae				
<i>Artedius lateralis</i> .....	79	11.2	56	18.5
<i>Clinocottus analis</i> .....	112	16.0	38	12.6
<i>Oligocottus rimensis</i> .....	1	0.1	1	0.3
<i>Oligocottus snyderi</i> .....	10	1.4	5	1.7
Kyphosidae				
<i>Girella nigricans</i> .....	36	5.1	18	6.0
Embiotocidae				
<i>Micrometrus aurora</i> .....	87	12.4	-	-
Clinidae				
<i>Gibbonsia metzi</i> .....	97	13.8	52	17.2
<i>Gibbonsia montereyensis</i> .....	56	8.0	1	0.3
Stichaeidae				
<i>Anoplarchus purpurescens</i> .....	46	6.6	31	10.3
<i>Cebidichthys violaceus</i> .....	25	3.6	6	2.0
<i>Xiphister atropurpureus</i> .....	71	10.1	26	8.6
<i>Xiphister mucosus</i> .....	-	-	4	1.3
Pholidae				
<i>Xeropes fucorum</i> .....	18	2.6	5	1.7
Totals: .....	702	-	302	-

Because of the small sample sizes, it was inappropriate to conduct G-tests comparing age classes from both collections for all but three species (Table 2). There were no statistically significant differences in the age class structure of *Artedius lateralis* and *Xiphister atropurpureus* taken from both collections. For *Clinocottus analis* there was a significant difference in the age classes represented in the two collections ( $G = 5.77$ ,  $df = 1$ ,  $P < 0.05$ ) reflecting, in part, an increase in the representation of age class 2 individuals from 26% in November to 47% in December. Three age classes of *G. maeandricus* were found in November, while only age class 1 individuals were present in December. *A. affinis* and *M. aurora* collected in November were represented by only age class 1 individuals (standard lengths ranged between 28–51 mm and 48–89 mm, respectively); these species were not obtained in December.

Our species diversity indices are within the range of those reported for other tidepools of the eastern Pacific (Thomson and Lehner 1976). At the familial level, composition of our tidepool is similar to that reported for other coastal California tidepools (e.g., Yoshiyama 1981). However, our site, which is approximately 120 km south of the San Mateo site of Yoshiyama (1981), has a very different cottid and stichaeid fauna. *Oligocottus snyderi*, which was numerically dominant in the tidepools sampled by Yoshiyama, is replaced by *C. analis* and *A. lateralis* at our site. Yoshiyama (1981) found *Anoplarchus purpurescens* to be most abundant followed by *Cebidichthys violaceus*, while *X. atropurpureus*

was the most abundant stichaeid species at our site. The stichaeid composition of our tidepool also differed from that of Barton (1982), whose Piedras Blancas study site was near ours. He found that *C. violaceus* was most numerous among this group of fishes. Reasons for these faunistic differences between collecting sites are not totally clear (Yoshiyama 1981), although sampling bias may explain some of them (e.g., the absence of *X. mucosus* in the November sample). That fish were captured by different methods (i.e., some investigators employed quinaldine while others used rotenone) may also account for some of the differences between results. Furthermore, Moring (1981), Yoshiyama (1981), and Barton (1982) have demonstrated habitat preference, in terms of vertical distribution within the intertidal, for many of these species. Because we collected only at one level within the intertidal zone during one season, the fact that the species composition of our samples differ from others reported is not unexpected.

**TABLE 2. Numbers Of Individuals In Each Age Class, As Determined From Length Frequency Histograms, Represented In The Two Tidepool Samples.**

Species *	5 November 1983			17 December 1983		
	1 †	2	3	1	2	3
<i>Gobiesox maeandricus</i> (a) ‡	35	9	4	59	0	0
<i>Artedius lateralis</i> (a)	33	40	6	28	28	0
<i>Clinocottus analis</i> (a,b)	83	29	0	20	18	0
<i>Oligocottus rimensis</i>	1	0	0	1	0	0
<i>Oligocottus snyderi</i>	8	2	0	3	2	0
<i>Girella nigricans</i> (c)	35	1	0	18	0	0
<i>Gibbonsia metzi</i> (a)	91	6	0	51	1	0
<i>Gibbonsia montereyensis</i> (a)	47	9	0	1	0	0
<i>Cebidichthys violaceus</i> (a)	5	13	7	0	5	1
<i>Anoplarchus purpureus</i> (a,d)	36	8	2	28	2	1
<i>Xiphister atropurpureus</i> (a,d)	36	35	0	17	9	0
<i>Xerperes fucorum</i> (a)	13	5	0	5	0	0

\* Includes only species taken in both collections.

† Numbers refer to age classes in years: 1(0-1 yr), 2(1-2 yr), and 3(2 yr and older).

‡ References for age/size class data: a) Burge and Schultz 1973, b) Fitch and Lavenberg 1975, c) R. D. Orton, pers. comm., d) Hart 1973.

Our results, which are in general agreement with those of Grossman (1982), indicate that representatives of all age classes are moving into the empty tidepool habitat. *Gobiesox maeandricus* represents a notable exception. Three age classes were represented in the November sample while only younger individuals were taken in the December sample. The absence of larger individuals in the second sample may be an indication of the low vagility of older fishes. Other exceptions are *Xerperes fucorum*, *Gibbonsia montereyensis*, and *Girella nigricans*; however, due to small sample sizes, these observations may be attributable to sampling error.

The statistically significant difference between H values suggests that a period of 43 days is not a sufficient amount of time between artificial defaunations for recolonization to occur such that species diversity is at pre-perturbation levels. This is true even if the nonresident species (*A. affinis* and *M. aurora*) are omitted from the calculation of diversity indices (the chance capture of the two nonresident species may reflect a real biological phenomenon; not in terms of species



composition of tidepool residents, but rather temporal changes in the use of tidepools by these species). Williams (1957) noted that tidepools from which he had removed fish had not fully repopulated within a period of several weeks although Thomson and Lehner (1976) sampled tidepools at intervals as short as three months and found no effect on the community variables which they calculated. Thus, it would seem that a time period between 43 and 90 days is needed to assure recovery and that assumptions of recovery within a shorter time span may not be appropriate. To more accurately document recruitment after defaunation, an expanded sampling strategy needs to be employed. Adjacent tidepools should be sampled over varying time intervals. In any case, caution must be observed when using removal experiments in determining the community structure of tidepools. When samples are taken within short time periods, the total numbers may not only differ, but age class distributions may also be affected.

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## DISTRIBUTION OF MAJOR MARINE MACROPHYTES, SEASONAL ESTIMATES OF *GRACILARIA* STANDING CROP, AND SPAWNING ACTIVITIES OF THE PACIFIC HERRING, *CLUPEA HARENGUS PALLASII*, IN ELKHORN SLOUGH, CALIFORNIA; 1979-1982<sup>1</sup>

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Marine vegetation surveys and Pacific herring spawn assessments were carried out in Moss Landing Harbor and Elkhorn Slough, California for three consecutive herring spawning seasons (1979-80 to 1981-82). The red alga *Gracilaria* sp. and the marine vascular plant *Zostera marina* (eelgrass) are the major macrophyte substrata available for herring spawn deposition. *Gracilaria* standing crops varied considerably among years and locations within the study area. The standing crop of *Gracilaria* in Elkhorn Slough was physically reduced each winter by storm runoff and strong tidal currents. Biomass estimates of spawning herring were calculated from each season's egg deposits. During the 1979-80 season, an estimated 0.4 short ton of herring spawned on *Gracilaria*. Biomass estimates of spawning herring for the 1980-81 and 1981-82 seasons were based on all plant substrata and were 0.1 and 0.6 short tons respectively. The density of herring spawn deposition observed in Moss Landing Harbor and Elkhorn Slough was consistently very light ( $\leq 0.25$  egg layers).

### INTRODUCTION

The Pacific herring, *Clupea harengus pallasii* Valenciennes, has supported a varying portion of the California fishing industry since at least 1916. The history of the herring fishery in California was recently summarized (Spratt 1981). Within the past two decades commercial activities in the fishery have been stimulated by the development of markets for herring roe in Japan.

In 1965 a fishery began in which salt-cured herring eggs-on-seaweed are shipped to Japan where they are a delicacy. In California a comparatively small Asian market exists and the product is served locally in restaurants. Today the California herring eggs-on-seaweed fishery is restricted to San Francisco Bay. From 1965 to 1977 Tomales Bay was also open to the fishery. Harvest quotas

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were set at 5 short tons (wet weight of seaweed and eggs) for each bay, and this quota is still in effect in San Francisco Bay. Harvest quotas have never been reached in either bay. The largest recorded harvest occurred during the 1967–68 season when 6.7 short tons was harvested from both bays combined.

Much larger harvests of herring eggs-on-seaweed occur annually in Alaska and British Columbia (Fuoco 1980, R. Hunt, pers. comm.). The most desirable seaweed substrata from the Pacific Northwest are *Macrocystis integrifolia* Bory and *Laminaria saccharina* (Linnaeus) Lamouroux. An even and heavy herring spawn (approximately 80% eggs by weight) on these seaweeds may bring up to \$17.00/lb wholesale. Other desirable seaweed substrata belonging to the genera *Laminaria*, *Agarum*, *Fucus*, *Ulva*, and *Gracilaria* wholesale for \$2.00 to \$8.00/lb (R. Hunt, pers. comm.). In California the major seaweeds harvested are *Laminaria sinclairii* (Harvey) Farlow, Anderson & Eaton and *Gracilaria* sp. (Hardwick 1973, Spratt 1981).

In 1972 the herring fishery in the Pacific Northwest was further enhanced when Japan removed its import quota on herring. Since 1972 the herring fishery in California has experienced a resurgence. Annual landings for the 1981–82 and 1982–83 seasons (11,615 and 10,611 short tons respectively) were more than twice those recorded for any year prior to 1972 (Spratt 1983).

The recent enhancement of the Pacific herring fishery has prompted investigations of herring spawning activities and spawning biomass in bays and estuaries (Hardwick 1973; Rabin and Barnhart 1977; Spratt 1976, 1981). In California the present herring fishery centers around San Francisco, Tomales, and more recently, Bodega bays. Humboldt Bay and Crescent City support fisheries of 12.5 to 50.0 short tons per year. Recent surveys have estimated the spawning biomass of herring in these areas (Rabin and Barnhart 1977, Spratt 1981).

Monterey Bay, in central California, supports a small spring and summer herring fishery for bait and animal food from 40.0 to 340.0 short tons annually since 1965 (Spratt 1981). Pacific herring have been reported to spawn in Elkhorn Slough, Moss Landing Harbor, and the mouth of the Salinas River in Monterey Bay (Miller and Schmidtke 1956, Nybakken et al. 1977, Spratt 1976, K. Forsyth, pers. comm.). The extent of the herring spawn, an estimate of the spawning biomass, or year to year variability in the Monterey Bay area are not presently known.

This study was part of a collaborative effort between the California Department of Fish and Game and a California Sea Grant project (R/F-58 'Multiple Species Utilization of the Herring Eggs-On-Seaweed Fishery', Abbott and Hansen 1981) to evaluate the potential for integration of two marine fisheries: (i) the existing winter herring eggs-on-seaweed fishery, and (ii) *Gracilaria* mariculture for an agarweed resource. Reported here are distributions of the major marine macrophytes, seasonal estimates of *Gracilaria* standing crop, and spawning activities of the Pacific herring in Moss Landing Harbor and Elkhorn Slough for three consecutive spawning seasons (winters 1979–80 to 1981–82).

## MATERIALS AND METHODS

### Vegetation Surveys and Mapping

At the onset of the 1979–80 herring spawning season, intertidal and subtidal vegetation surveys were conducted throughout Moss Landing Harbor (Lat 36°48.1' N, Long 121°47.9' W) and Elkhorn Slough (Figure 1). The distribution

of each major vegetation type was determined by observations during low tides for intertidal populations (The term 'population' is used here to describe macrophyte beds which are spatially distinct; it does not imply any genetic distinctions.) and by boat using a Miller Aquatic Vegetation Sampler or SCUBA for subtidal populations. A Miller Vegetation Sampler consists of two heavy duty garden rakes (3 tines/10 cm) welded back-to-back and fastened to a line (Miller and Schmidtke 1956, Hardwick 1973).

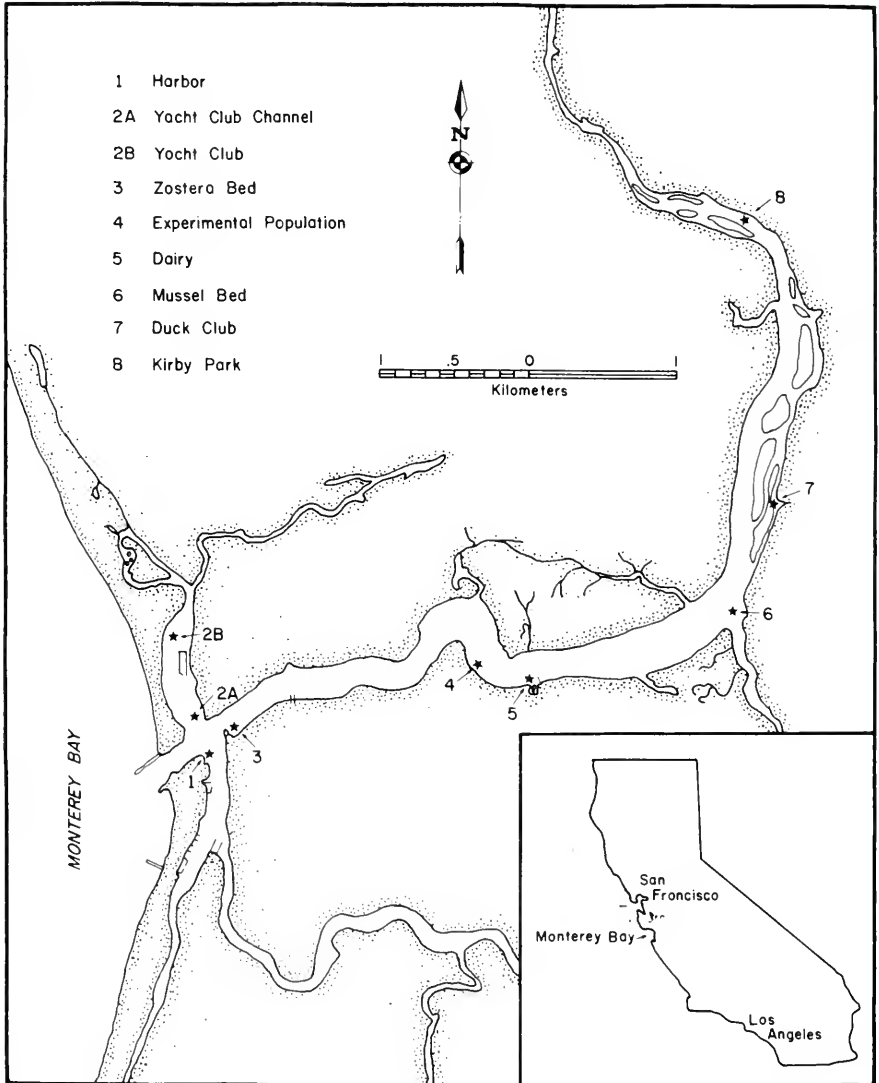


FIGURE 1. Location of sampling stations in Moss Landing Harbor and Elkhorn Slough.

Seasonal changes in standing crop within one representative intertidal *Gracilaria* population (approximately 325 m<sup>2</sup>) were measured at Station 4 (Figure 1). The population was mapped and divided into a 0.5 m<sup>2</sup> grid pattern using lines

and permanent anchors. Fifteen new quadrats were chosen randomly once every three months and algal biomass was harvested using sheepshears. Samples were washed in fresh water, cleaned of debris, drained, weighed fresh, and then dried to constant weight at 60°C.

### Herring Spawn Assessments and Estimates of Spawning Biomass

Herring spawn assessments were carried out at eight major populations of intertidal and subtidal vegetation (Figure 1). Vegetation was sampled from these stations every 3–7 days during the 1979–80 and 1980–81 spawning seasons (18 Dec. 1979 – 28 Feb. 1980, 15 Dec. 1980–5 March 1981) and every other day during the 1981–82 season (15 Dec. 1981–29 Feb. 1982). Observations of the mud bottom and other substrata (pilings, shell beds, etc.) indicated that herring in the study area spawn primarily on vegetation, rarely on other substrata.

During the 1979–80 and 1980–81 spawning seasons, intertidal vegetation was assessed for the presence of herring spawn at all stations during low tide periods. When herring spawn was found, samples of the vegetation and spawn were collected and returned to the laboratory for processing. Intertidal spawns were sampled by harvesting the vegetation within several 0.5 m<sup>2</sup> quadrats. The total area of an intertidal spawn was determined from distance measurements around the perimeter of the spawning location. Subtidal spawns were sampled using the Miller Vegetation Sampler. The vegetation sampler was towed along the bottom behind a boat for a distance of approximately 20 m and then retrieved with adherent vegetation. Alternatively, the sampler was tossed from the boat, allowed to sink to the bottom, and then retrieved. The distribution of subtidal spawns was determined by successive bottom tows around the perimeter of the plant population, and the total area of spawn was calculated from distance measurements between sighted landmarks and/or visual estimates of distance.

During the 1981–82 spawning season, herring spawn found on intertidal vegetation was assessed by subsampling the entire station area at low tide. Twenty or more 0.25 m<sup>2</sup> quadrats were chosen randomly and all vegetation within the quadrats was harvested. Subtidal spawns were assessed by randomly sampling a similar number of 0.25 m<sup>2</sup> quadrats using SCUBA. Distance measurements were taken to determine the total area of all spawns.

Each eggs-on-seaweed sample was sorted into major vegetation type and wet weights were determined. Representative subsamples were taken from each vegetation type, wet weighed, and the herring eggs adhering to the subsample were counted. The number of herring eggs/g wet wt of sample and the number of eggs/m<sup>2</sup> of vegetated area were calculated.

Estimates of spawning herring biomass were made based on the number of eggs spawned. The total number of eggs spawned for each season was converted to short tons of herring by multiplying by  $0.966 \times 10^{-8}$ . This factor is derived from studies on Pacific herring fecundity. The calculation assumes a 1:1 sex ratio in the spawning herring population (Hardwick 1973; Rabin and Barnhart 1976; Spratt 1976, 1981).

Data collected during the 1979–80 season did not include quantitative estimates of *Gracilaria* or *Zostera marina* standing crops at all spawning locations. The standing crop of *Gracilaria* at each spawning location was estimated by visual inspection and comparison to the known standing crop at Station 4 (see Vegetation Surveys). The estimates for *Gracilaria* standing crops and the number of eggs/g wet wt of seaweed were used to calculate the number of eggs spawned

on *Gracilaria*. No estimates were made of *Zostera marina* standing crops and, therefore, the total number of eggs spawned on *Zostera* was not calculated.

During the 1980–81 and 1981–82 seasons, plant standing crops were quantitatively determined at each station when a spawn was found. The number of eggs/g wet wt of vegetation was counted for each spawn. Direct calculations of number of eggs/m<sup>2</sup> could then be made.

## RESULTS

### Floristic Studies

In Moss Landing Harbor and Elkhorn Slough the major low intertidal and subtidal flora is composed of the red alga *Gracilaria* sp. and the marine vascular plant *Zostera marina* (eelgrass). The forms of *Gracilaria* that occur in Moss Landing Harbor and Elkhorn Slough are combined in this study. The taxonomy of local *Gracilaria* species is presently under study (I. A. Abbott and M. Hoyle, in prep.). Other algal genera that may contribute ephemeral or minor substrata for spawning herring are *Enteromorpha* and *Polysiphonia*. *Enteromorpha* spp. are especially prevalent on the mud flats of Elkhorn Slough during spring and summer. *Enteromorpha* was sparse during the 1979–80 and 1981–82 spawning seasons but was fairly common during the 1980–81 season. Relatively small populations of the filamentous red alga *Polysiphonia* sp. (predominately *P. mollis* Hooker & Harvey) were also observed among populations of *Gracilaria* sp. and *Zostera marina*.

Populations of *Z. marina* were found in low intertidal and shallow subtidal areas of Moss Landing Harbor and the mouth of Elkhorn Slough (Figure 2). On an area basis, *Gracilaria* was the dominant macrophyte found in the study area. Substantial populations occurred in the intertidal and shallow subtidal areas of the Harbor (Station 1) and the Yacht Club (Stations 2A & 2B). *Gracilaria* was also intermixed with the *Zostera* population at the mouth of Elkhorn Slough (Station 3; Figures 1 and 3). Discrete populations occurred in the upper reaches of Elkhorn Slough along the southern bank (Stations 4,5,6, and 7). These populations were associated with areas that: (i) were semi-protected from strong tidal currents (Station 7), or (ii) consisted of mollusc shell deposits and/or mussel beds (*Mytilus edulis* Linnaeus) (Stations 4,5, and 6; Figures 1 and 3).

The standing crop of *Gracilaria* at most stations varied substantially over the study period. Quarterly biomass estimates for the experimental population at Station 4 (Figure 1) give an indication of the three year seasonal variability for most Elkhorn Slough *Gracilaria* populations. The results (Figure 4) show a dramatic decrease in the standing crop of *Gracilaria* during the 1979–80 herring spawning season. Storm runoff, high tides, and rapid currents (23–25 Dec. 1979 and 15–17 Feb. 1980) were probably responsible for the decline in standing crop. This population had recovered to about 10% of the 1979 standing crop by the beginning of the 1980–81 herring spawning season (Dec. 1980), but again showed a sharp decline by March 1981 (Figure 4). The seasonal trend of regrowth followed by physical removal is also apparent in the 1981 data; however the decline occurred prior to our December 1981 sample. By the beginning of the 1981–82 spawning season, *Gracilaria* biomass was approximately 4% of the standing crop measured in December 1979. The other *Gracilaria* populations in Elkhorn Slough (Stations 5 and 6) displayed similar fluctuations in standing crop, except for Station 7 which is semi-protected from strong tidal currents. Populations in Moss Landing Harbor (Stations 1,2A,2B and 3) were less severely affected by winter storm runoff and tidal currents.

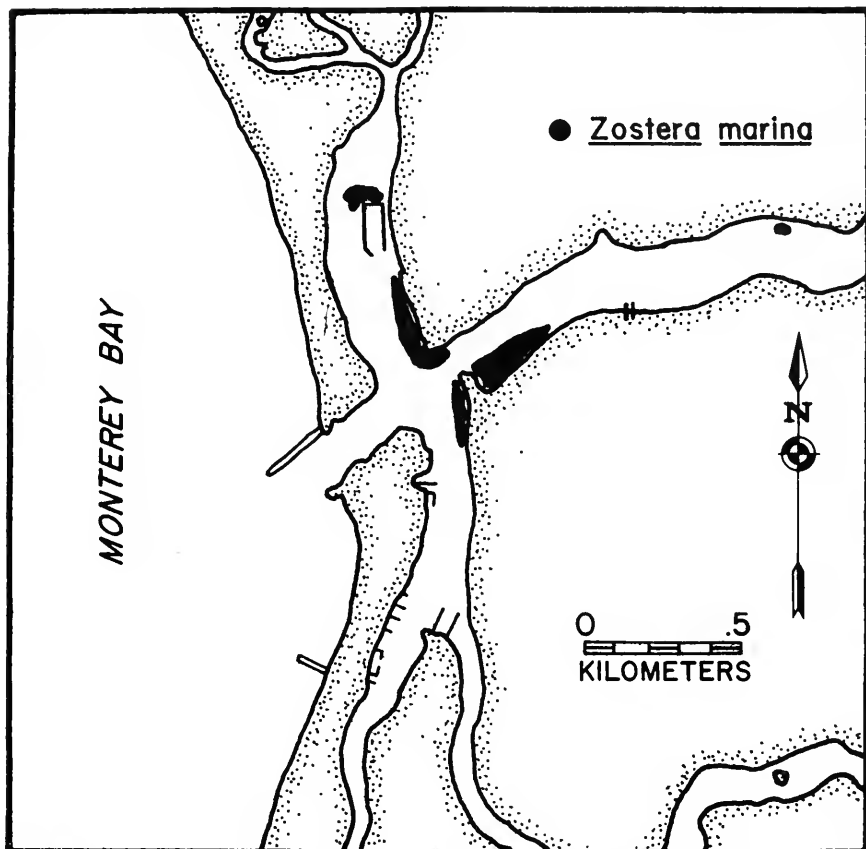


FIGURE 2. Distribution of *Zostera marina* in Moss Landing Harbor and Elkhorn Slough.

*Gracilaria* collected from Elkhorn Slough was predominately non-reproductive; rarely were tetrasporangial plants found. However, cystocarpic plants were common in the adjacent *Gracilaria* populations of Moss Landing Harbor.

#### Herring Spawn Assessments and Estimates of Spawning Biomass

The areas where herring spawns were found during the three-year study period are illustrated in Figure 5. Three discrete herring spawning runs were observed during the 1979–80 season (Table 1). On the basis of vegetated area, the spawns were primarily on *Gracilaria*. Herring spawns were found only in the Harbor, the Yacht Club, and the mouth of Elkhorn Slough (Stations 1, 2A, 2B and 3; Figure 1). Egg deposits were very light and the total spawning area was estimated at 3,730 m<sup>2</sup>. Based on our estimates of *Gracilaria* standing crops, approximately 41 million eggs were spawned on *Gracilaria* by 0.4 short ton of herring.

We were informed that a fourth herring spawn occurred during the 1979–80 season at the head of Elkhorn Slough near Hudson's Landing. We attempted to document this report and found no evidence of herring spawning activity. However, herring eggs hatch in 6–11 days (Hardwick 1973), and we may have been too late.

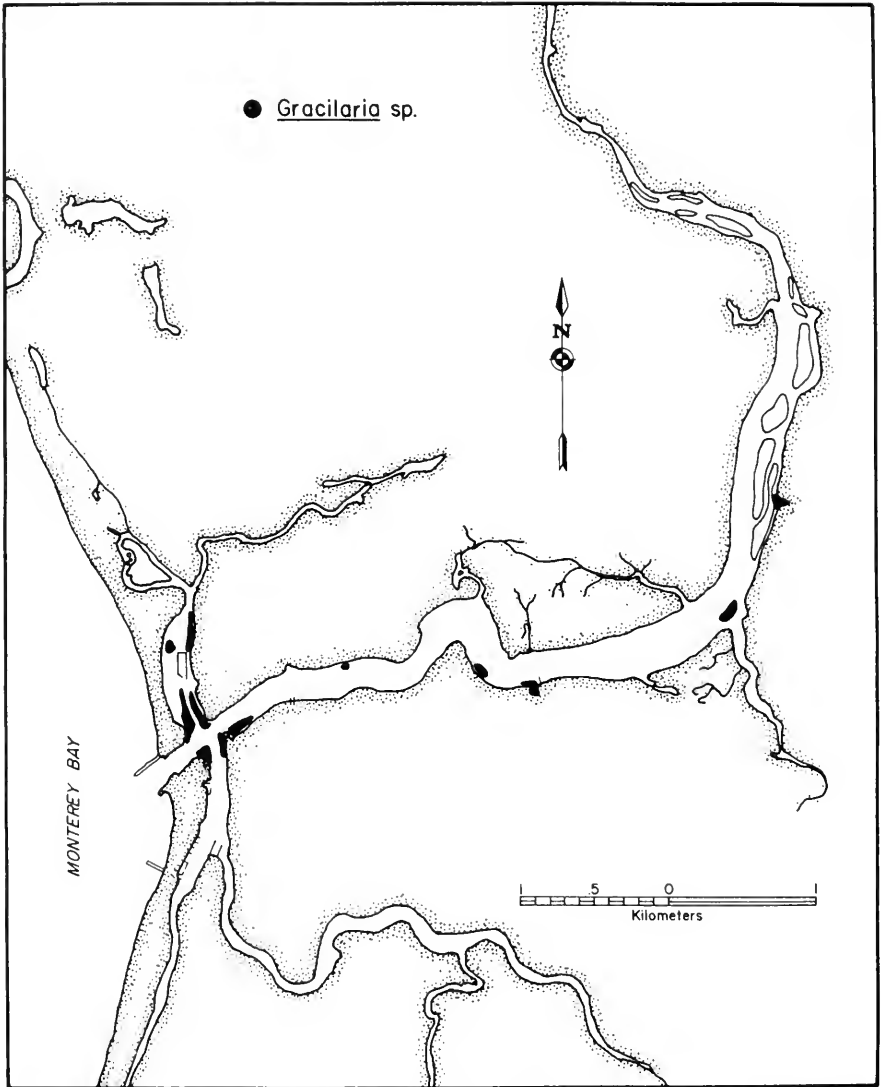


FIGURE 3. Distribution of *Gracilaria* in Moss Landing Harbor and Elkhorn Slough. The maximum area occupied by *Gracilaria* is illustrated.

During the period from 15 December 1980 to 5 March 1981, three herring spawns were recorded in Elkhorn Slough (Table 2). On 15 Dec. 1980 a small herring spawn was found on *Enteromorpha* at Kirby Park (Station 8). All other herring spawns occurred on the *Gracilaria* population at Station 7 (Figure 1). The deposition of herring eggs was generally very light and the total spawning area was estimated to be only 480 m<sup>2</sup>. Estimates from standing crop and egg count data for the 1980–81 season include 6 million eggs spawned on *Enteromorpha* and 4 million eggs spawned on *Gracilaria* (Table 2). The meager total for the 1980–81 season was 10 million eggs spawned by 0.1 short ton of herring.



Seven herring spawns were recorded in Moss Landing Harbor and Elkhorn Slough during the 1981–82 spawning season (Table 3). Herring spawned on an estimated 80,118 m<sup>2</sup> of vegetated area, including nearly all of the *Gracilaria* and *Zostera* populations. The deposition of herring eggs was very light for all spawns. Based on standing crop and egg count data, total estimates for the 1981–82 season include 58 million eggs spawned on vegetation by 0.6 short ton of herring.

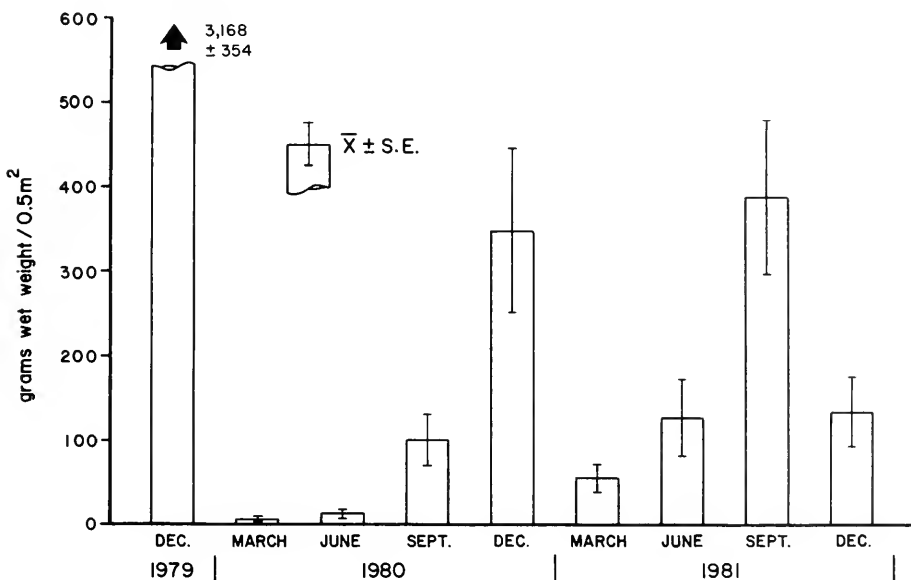


FIGURE 4. Seasonal variation in the standing crop of *Gracilaria* at Station 4.

## DISCUSSION

We consider our estimates of spawning herring biomass to be conservative. Predation on herring eggs by birds and fishes can be quite extensive within the first several days after a spawn (Hardwick 1973; Spratt 1976, 1981). Bird predation (predominantly gulls) was noted on several intertidal spawns in Elkhorn Slough. We have not included egg loss via predation in our calculations of total eggs spawned per season. It is also possible that our estimates of spawning herring biomass are low due to: (i) herring spawns which occurred before or after our survey periods, and (ii) small spawns which were not detected.

The results of our surveys show that a very small biomass of herring ( $\leq 0.6$  short ton) was responsible for the egg deposits observed in Moss Landing Harbor and Elkhorn Slough during the 1979–80, 1980–81, and 1981–82 spawning seasons. Compared to the results of other spawning surveys performed in California (Spratt 1981) and British Columbia (Humphreys and Hourston 1978), the egg densities found in our study area were consistently very light ( $\leq 0.25$  egg layers). While the desirable herring eggs-on-seaweed species *Gracilaria* provided abundant substratum for herring spawn deposition, the very light egg densities were below commercial standards.

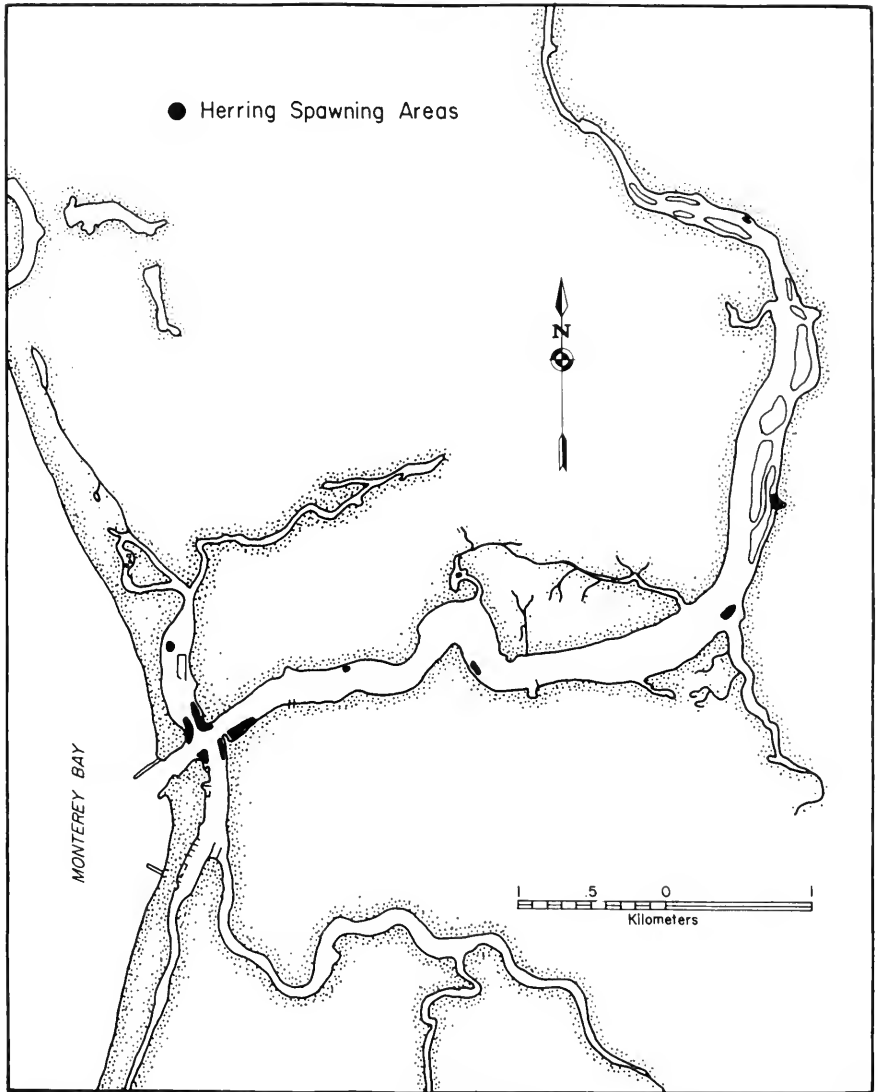


FIGURE 5. Location of herring spawn deposition in Moss Landing Harbor and Elkhorn Slough during the 1979-80, 1980-81, and 1981-82 spawning seasons.

Based on our estimates of spawning herring biomass it appears that a large portion of the herring caught in Monterey Bay during spring and summer must come from spawning grounds other than Moss Landing Harbor and Elkhorn Slough. However, the consistent year-to-year presence of spawning and larval herring populations in Moss Landing Harbor and Elkhorn Slough is indicative of the historical importance of this area as a herring nursery grounds.

TABLE 1. Spawn Dates, Locations, Substrata, and Estimates of Total Eggs Spawmed During the 1979-80 Season.

Date	Station	Substratum	Area of spawn (m <sup>2</sup> )	$\bar{X}$ Biomass of substratum (Kg wet wt/m <sup>2</sup> )	$\bar{X}$ # of eggs per kg substratum	Total # of eggs/m <sup>2</sup>	Total # of eggs ( $\times 10^6$ )
17-20 Jan. 1980	1	Gracilaria	400	0.32	16,000	5,120	2.05
	2A	Gracilaria	320	0.10	35,700	3,570	1.14
	2A	Zostera	300	nd*	23,100	nd	nd
	3	Gracilaria	130	0.07	15,000	1,050	0.14
13-15 Feb. 1980	3	Zostera	130	nd	nd	nd	nd
	1	Gracilaria	400	0.32	103,300	33,056	13.22
	2A	Gracilaria	200	0.10	8,800	880	0.18
25-28 Feb. 1980	1	Gracilaria	450	0.32	99,300	31,776	14.30
	2A	Gracilaria	250	0.10	38,500	3,850	0.96
	2A	Zostera	250	nd	25,600	nd	nd
	2B	Gracilaria	300	1.59	14,500	23,055	6.92
	3	Gracilaria	200	0.07	38,100	2,667	1.60
	3	Zostera	400	nd	62,100	nd	nd
Total 1979-1980		Gracilaria	2,650				40.51
		Zostera	1,080				nd
		Total	3,730				nd

\* nd = no data

TABLE 2. Spawn Dates, Locations, Substrata, and Estimates of Total Eggs Spawned During the 1980-81 Season.

Date	Station	Substratum	Area of spawn (m <sup>2</sup> ) (Kg wet wt/m <sup>2</sup> )	$\bar{X}$ Biomass of substratum (Kg wet wt/m <sup>2</sup> )	$\bar{X}$ # of eggs per kg substratum	Total # of eggs/m <sup>2</sup>	Total # of eggs ( $\times 10^6$ )
15 Dec. 1980	8	Enteromorpha	75	2.41	32,300	77,843	5.84
31 Jan. 1981	7	Gracilaria	5	0.60	101,900	61,140	0.31
5 Feb. 1981	7	Gracilaria	400	1.08	8,400	9,072	3.63
Total 1980-1981		Enteromorpha Gracilaria TOTAL	75 405 480				5.84 3.94 9.78

TABLE 3. Spawn Dates, Locations, Substrata, and Estimates of Total Eggs Spawned During the 1981-82 Season.

Date	Station	Substratum	Area of spawn (m <sup>2</sup> )	$\bar{X}$ Biomass of substratum (Kg wet wt/m <sup>2</sup> )	$\bar{X}$ # of eggs per kg substratum	Total # of eggs/m <sup>2</sup>	Total # of eggs ( $\times 10^6$ )
16 Dec. 1981	1	Gracilaria	892	0.15	2,500	1,130	1.00
22 Dec. 1981	6	Gracilaria	4,301	0.23	2,900	657	2.82
28 Dec. 1981	1	Gracilaria	892	0.80	2,700	2,267	2.02
5 Jan. 1982	5	Gracilaria	3,646	0.11	50	15	0.06
	3	Gracilaria & Zostera	4,570	0.25	4,900	1,122	5.13
7 Jan. 1982	2A	Gracilaria	3,394	0.99	10,300	9,323	31.65
17 Jan. 1982	2A	Gracilaria & Zostera	7,803	0.06	4,100	347	2.71
22 Feb. 1982	3	Gracilaria & Zostera	1,300	0.09	900	219	0.30
	3	Gracilaria & Zostera	26,660	0.04	3,100	131	3.49
TOTAL 1981-1982			80,118				58.44

## ACKNOWLEDGMENTS

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## OBSERVATIONS ON THE ELASMOBRANCH ASSEMBLAGE OF SAN FRANCISCO BAY<sup>1</sup>

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**Elasmobranchs were collected over a 19 month period using several types of fishing gear. The information gathered suggests a possible shift in the elasmobranch species composition in San Francisco Bay when compared with previous data. A difference in the sex ratios of some species was also noted. The population of at least one species appears to have declined.**

### INTRODUCTION

An increasing interest in elasmobranch fishes as a food source has raised concern about the stability of this fishery, primarily because most elasmobranchs are slow growing and have a low reproductive rate. A problem with managing this growing fishery is the lack of information concerning their population structure. The shark and ray population of San Francisco Bay is one of the few elasmobranch fisheries where historical data, albeit limited, is available concerning species abundance.

Herald and Ripley (1951) reported on the abundance of sharks and rays in San Francisco Bay based on studies by the California Department of Fish and Game and catch records from annual shark derbies. They presented their data as a preliminary working basis for future population studies in the bay. Later, de Wit (1975) reported possible changes in the shark species composition of south San Francisco Bay. With an increasing interest in elasmobranchs as a food source more current information is required to better assess their populational status. The objective of this research was to investigate the elasmobranch assemblage in San Francisco Bay and to compare these data with historical catch records.

### METHODS AND MATERIALS

During the course of a study on the biology of the sevengill shark, *Notorynchus maculatus*, (Ebert in press) I gathered data on the elasmobranch fishes that were caught in San Francisco Bay. Sampling was conducted between the Richmond-San Rafael Bridge and the San Mateo Bridge (Figure 1).

Shark samples were collected by several methods, including gill net (3.1 m x 275 m x 20 cm), long-line (6 to 335, 12/0 hooks per set), and rod-and-reel (one 12/0 hook-per-pole). Shark fishing was conducted year-round using long-line and rod-and-reel. Gill nets were used only during the winter months.

Data were recorded monthly for all species and used to provide an estimate of the species composition. Catch-per-unit-effort (CPUE), using catch per hook-hour, was calculated for long-line and rod-and-reel. Gill net CPUE was calculated by catch-per-hour.

<sup>1</sup> Accepted for publication May 1986.

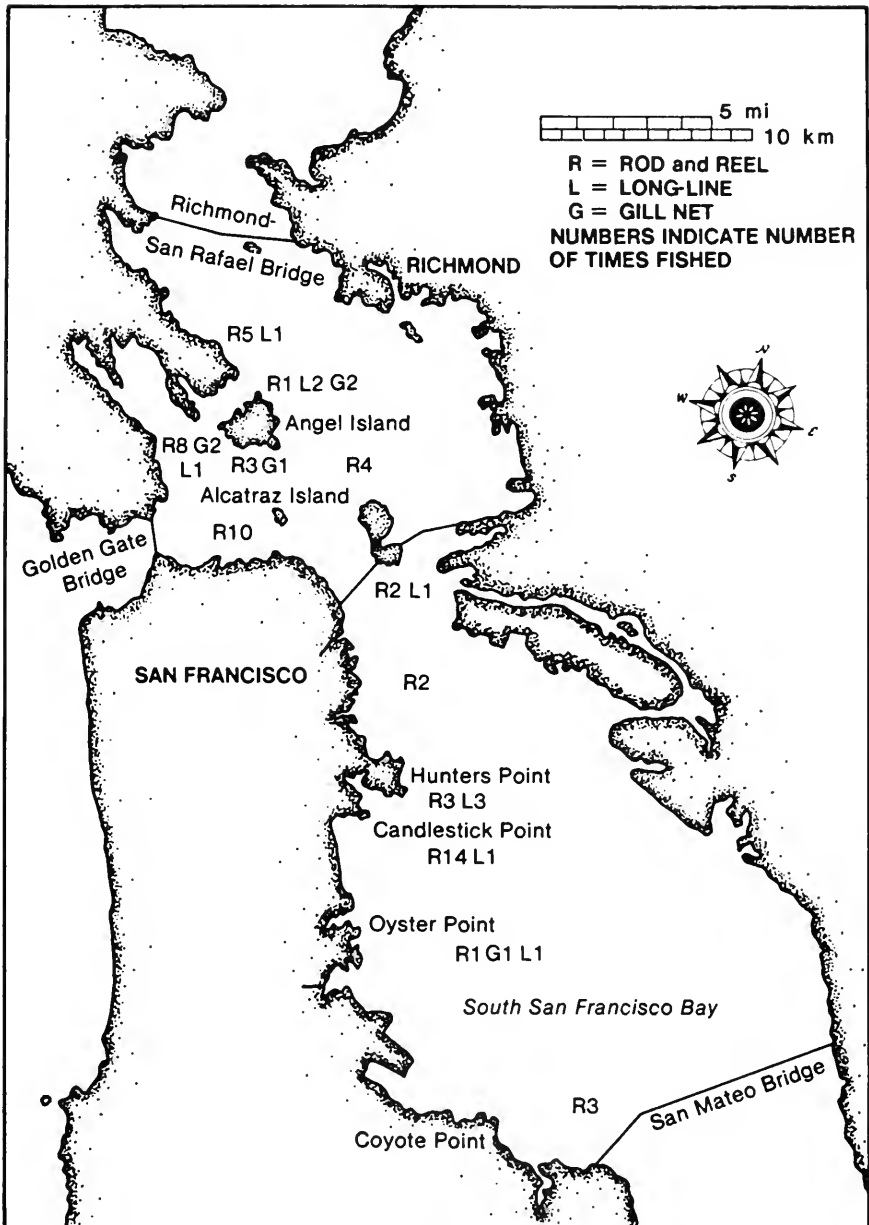


FIGURE 1. Map of San Francisco Bay showing gear type and areas fished.

## RESULTS

Using all gear combined, a total of 441 sharks and rays, representing seven species, was caught in San Francisco Bay from November 1981 through May 1983. These species included: the brown smoothhound shark, *Mustelus henlei*; leopard shark, *Triakis semifasciata*; soupfin shark, *Galeorhinus zyopterus*; spiny

dogfish, *Squalus acanthias*; sevengill shark, *Notorynchus maculatus*; bat ray, *Myliobatis californica*; and big skate, *Raja binoculata*.

The type of fishing gear employed was dependent on commercial fishing practices; and rod-and-reel was the most prevalent and effective method (Table 1). Long-line gear was too time consuming and expensive (bait) for the yield. One fishermen who long-lined exclusively was financially forced to suspend operations. Winter storms limited my use of gill netting to only six sets between December 1982 and March 1983.

The most productive fishing months for all elasmobranch species using rod-and-reel in San Francisco Bay were May through October 1982 and May 1983 (Table 2). There was no fishing effort reported for February through April 1982, and February and April 1983 (Table 2). Fishing during these months was precluded by inclement weather.

**TABLE 1. Elasmobranch Catch-and-Effort Data, According to Gear Type, From San Francisco Bay.**

Gear type	No. hooks	No. sets	Hours fished	Catch
Set line (range 6-335 hooks per set) .....	1736	10	63	44
Gill net .....	-	6	32	8
Rod-and-reel (one 12/0 hook per pole) .....	158	57	125	389

Leopard shark were the most abundant elasmobranch caught in San Francisco Bay and represented 40% of the rod-and-reel catch (Table 3). Brown smoothhound and spiny dogfish also ranked high representing 23% and 22% of the elasmobranch catch, respectively. The soupfin shark was the least abundant species caught, representing 1%.

The rod-and-reel catch categorized according to sex revealed that the sevengill shark was the only elasmobranch caught in which males outnumbered females. The sevengill shark was caught at a 1.1:1 (male:female) sex ratio. Females dominated in the remaining elasmobranch catch, with ratios ranging from 1:2 for leopard shark to 1:4.5 for bat ray.

## DISCUSSION

Results of this study indicate that the dominance of leopard shark in San Francisco Bay suggests that a shift may have occurred in the elasmobranch assemblage, at least between two major species. Herald (1953) and de Wit (1975) both reported the brown smoothhound as being the most abundant elasmobranch in the bay, comprising over 41% of the recorded catch. I found the brown smoothhound to represent only 23% of the elasmobranchs caught, while the leopard shark accounted for 40%. De Wit (1975) reported the brown smoothhound as being most numerous in the catch from June through September 1972, while I found them to be dominant in the catch only during August and October 1982 (Table 2). My data represents only a rough estimate of the elasmobranch assemblage in San Francisco Bay and any observed differences may reflect a bias in the various sampling methods employed. However, the common denominator in Herald's (1953) and de Wit's (1975), and my own sampling methods was that the fishing gear (gill nets, long-line, and rod-and-reel) employed was specifically targeted toward elasmobranchs. Furthermore, although de Wit (1975) conducted his study south of the San Mateo Bridge, his



TABLE 2. Rod-and-Reel Catch—Effort Data by Month for All Elasmobranch Species in San Francisco Bay, November 1981 through May 1983.

Year/month	Hours fished	No. hooks	Effort	N.m. catch/cpue	T.s. catch/cpue	S.a. catch/cpue	M.h. catch/cpue	C.z. catch/cpue	M.c. catch/cpue	R.b. catch/cpue	Total catch/cpue
1981/Nov.	5.5	6	33.0	0	1/0.03	2/0.06	0	0	0	0	3/0.09
Dec.	6.25	6	18.7	2/0.11	3/0.16	1/0.05	0	0	0	0	6/0.32
1982/Jan.	5.67	12	17.0	0	0	0	0	0	0	0	0
Feb.	No Effort	No Effort									
Mar.	No Effort	No Effort									
Apr.	No Effort	No Effort									
May	18	16	59.5	10/0.17	20/0.34	0	15/0.25	2/0.03	2/0.03	0	49/0.82
Jun.	16.08	16	45.4	2/0.04	27/0.06	8/0.13	14/0.24	0	0	0	51/1.12
Jul.	6.83	8	17.5	1/0.06	4/0.23	19/1.09	3/0.17	0	0	1/0.06	28/1.6
Aug.	9.75	7	26.0	5/0.19	3/0.12	10/0.39	10/0.39	0	0	0	28/1.08
Sep.	10.7	22	43.4	5/0.12	31/0.71	0	20/0.46	0	16/7.8	0	72/1.66
Oct.	2.17	4	8.6	1/0.12	2/0.23	7/0.81	16/1.84	0	1/0.5	0	27/3.0
Nov.	3.42	4	6.8	0	0	0	0	0	0	0	0
Dec.	12.98	19	34.0	0	1/0.03	11/0.32	0	0	0	3/0.09	15/0.44
1983/Jan.	4.16	8	8.3	0	0	0	0	0	0	0	0
Feb.	No Effort	No Effort									
Mar.	2.92	21	20.4	0	3/0.15	0	0	0	0	1/0.05	4/0.2
Apr.	No Effort	No Effort									
May	19.59	31	41.0	6/0.15	61/1.49	10/0.24	11/0.27	0	14/0.34	4/0.1	106/2.58

**TABLE 3. Number, Percent, and Sex for Seven Elasmobranch Fishes Caught in San Francisco Bay on Rod-and-Reel, November 1981 through May 1983.**

Species	Male		Female		Total	
	No.	%	No.	%	No.	%
leopard shark .....	53	34	103	66	156	40
brown smoothhound .....	28	31	61	69	89	23
spiny dogfish .....	17	25	51	75	68	18
sevengill shark.....	17	53	15	47	32	8
bat ray .....	6	18	27	82	33	8
big skate.....	4	44	5	56	9	2
soupin shark.....	0	0	2	100	2	1

results compared favorably to those of Herald (1953) whose sample area was similar to mine (Figure 1).

The sex ratios I found for some species were different from that reported by Russo and Herald (1968), who based their estimate on a shark mortality that occurred along the east bay. I found the male-female sex ratio for brown smoothhound to be 1:2.2. Russo and Herald (1968) reported that the brown smoothhound had a sex ratio of 1:4.5 (male : female). Susan Smith (National Marine Fishery Service, Tiburon, Calif., pers. comm.) found a 4:1 male-female ratio for brown smoothhound from a long-line study conducted near Hunter's Point in September 1979. Herald and Ripley (1951) noted a similar reversal in the sex ratio of sevengill sharks between 1943 and 1950, but could offer no explanation. I also found a difference in the sex ratio of leopard shark (1:2, male:female) and bat rays (1:4.5) compared to what Russo and Herald (1968) reported which was 1:1 for both species. I recorded a 1:1.6 male-female sex ratio for leopard shark at a San Francisco Bay shark derby held in September 1983. Therefore, these differences between Russo and Herald (1968), Susan Smith (pers. comm.), and my own data may not be significant due to differences in sampling methods.

There may be a general population decline of several elasmobranch species occurring in San Francisco Bay. Particularly evident was the low abundance of soupfin shark when compared to that reported by Herald (1953), Russo and Herald (1968), and Smith and Kato (1979). The reasons for this apparent change are unclear, but may be related to: (i) a combination of lower salinities in San Francisco Bay from large amounts of rainfall (Reilly and Moore 1982) and unusually warmer open coastal waters (Smith 1983) that caused sharks to seek a cooler, more suitable habitat, or (ii) over-exploitation. Increased fishing pressure was evident in San Francisco Bay during the mid- to late 1970's (L.J.V. Compagno, Tiburon Center for Environmental Studies, pers. comm.) and although the California Department of Fish and Game obtains commercial shark catch data, the principal take of elasmobranchs is by recreational fishermen. Catch data are not available for this type of fishing. Due to time constraints I was unable to measure size frequency, but it appeared that most sharks caught were at the minimum size for maturity. Further evidence for this came from the 1983 shark derby where I recorded total length (TL) measurements for leopard shark. I found the mean TL for male (98.9 cm TL) and female (106.9 cm TL) leopard shark to be under the approximate size of maturity (males—107 cm TL and females—118 cm TL). This derby had a minimum check-in size of 70 cm TL. The soupfin shark fishery in California collapsed from overfishing (Ripley 1946).

Holden (1974) cites other instances where over-exploited elasmobranch fisheries have collapsed. If the reduction in shark numbers in San Francisco Bay is due to reduced salinity or warm water then the decline may be temporary. However, if the decline is due to over-exploitation this may have long term effects and a management program should be implemented to sustain this fishery.

### ACKNOWLEDGMENTS

I would like to thank the following persons for their time and consideration throughout this research. D. Kittredge and B. Van Gorp for their fishing efforts. G. Cailliet, E. Ebert, R. Lea, M. Foster, J. McCosker, and S. Smith for their many helpful suggestions and comments in reviewing this manuscript. L. Compagno provided many helpful ideas and suggestions. M. Kittridge for illustrating the figure. General assistance in various portions of this study was given generously by T. Ebert, K. Hauge, and S. Willis.

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## BOOK REVIEWS

### ARIZONA WETLANDS AND WATERFOWL

By David E. Brown. Illustrations by Bonnie Swarbrick Morehouse. University of Arizona Press, 1985. 169 p. \$24.95 cloth.

It is difficult to characterize this book. Too general to be considered a reference work, it has too few color illustrations (only seven species covered) to make a good "coffee table" book. It is directed at the general public, amateur naturalists and waterfowl hunters who are most interested in waterfowl and wetland matters as they pertain to Arizona conditions.

The book is divided into five chapters with an additional section of reference materials (appendices and a bibliography). The introduction includes material on early history, uses and users and the need for wetland and waterfowl conservation. A chapter entitled "Environmental Setting" covers in detail the wetlands and waterfowl resources of the main physiographic regions or Arizona, both historically and as they exist today. The chapter on Waterfowl Biology discusses taxonomy, anatomy (including molts and plumages), life history, migration, foods, sexual dimorphism and sex ratios, and diseases (including lead poisoning). Much data on Arizona situations are presented in this chapter.

Chapter four focuses on waterfowl management, beginning with an historic overview of hunting and early conservation laws. This is followed by discussions of the refuge system (both state and federal), banding and the flyway concept, surveys and bag checks, regulating the harvest, species identification by the hunter and habitat enhancement. The remainder of the book almost a third of it, is devoted to species accounts, which are thorough and informative. They cover distribution and status in Arizona, descriptions, habitat preferences and miscellaneous information "of interest to the waterfowler and habitat manager".

The author's style is relaxed and easy to read, there is an absolute minimum of typographical and technical error and a large variety of subject matter covered, though not in great depth. The book will probably prove attractive and useful to Arizona residents and those non-residents with a special interest in Arizona wetlands and waterfowl management. Others may well wish to send the \$25 on one of the recent works by Paul Johnsgard or Frank Bellrose.—*Bruce E. Deuel*

### HUMMINGBIRDS: THEIR LIFE AND BEHAVIOR

By Esther Q. Tyrrell, with photographs by Robert A. Tyrrell; Crown Publishers, Inc., New York City; 1985; 224 p; \$35.00.

"Nature has favored the Americas with a sparkling bird whose jewellike colors and fascinating aerial acrobatics make it unique." So begins the first chapter, "An Introduction to Hummingbirds", in this oversized book whose subtitle is "A Photographic Study of the North American Species." At first glance one might believe that this is another coffee table book. However, a closer look finds much scientific detail to accompany the 235 full-color photographs. The photographs themselves may be worth a good deal of the price of the book. Many stop-action pictures are found throughout the third through ninth chapters, which cover the topics of anatomy, feathers, flight, courtship and nesting, food and metabolism, behavior, and wildflower pollination.

In the second chapter, "A Portfolio of North American Hummingbirds", the 16 hummingbirds which breed in the United States are each described on a two-page spread with two color photographs and a discussion of field marks,

range, nesting period, migration times, and habitat. This book definitely is oriented toward U.S. breeding species. The authors do list the additional seven hummers which have been recorded in the U.S. north of Mexico, and provide a list of the 338 species (in 116 genera) of hummingbirds in the world.

The most fascinating part of the book to this reviewer is the chapter on wildflower pollination. Illustrated with many photographs of hummingbirds at flowers and showing pollen on the bills, crowns, and chins of the birds, this chapter discusses that group of plants known as hummingbird flowers, since they are pollinated only by these birds. At least 129 of these species of plants are known from the American southwest, and 20 others are in the northeast. There is even a discussion of the hummingbird flower mites, which live, mate, and reproduce in the flowers but are transported between flowers in the nostrils of hummingbirds. A list of hummingbird-pollinated wildflowers by family is included.

The authors, a husband and wife team, claim to have traveled over 30,000 miles in several years to find hummingbirds to photograph. They depended on a number of birders to guide them to appropriate sites. The text of the chapters was submitted to knowledgeable ornithologists for verification.

Photographer Robert Tyrrell states that "The largest problem I encountered while attempting to photograph hummingbirds was 'stopping' their wings." The photos in the book attest to his success in overcoming the problem. Hummingbirds are the jewels in the avian crown, and this book illustrates that superbly. I recommend the book also for its scientific fact. The price is not prohibitive in today's book market.—*JOHN R. GUSTAFSON*

## INDEX TO VOLUME 72

## AUTHORS

- Ames, Jack A.: see Wendell, Hardy, Ames, and Burge, 197-212
- Asson-Batres, Mary Ann: The Feeding Behavior of the Juvenile Dungeness Crab, *Cancer magister* Dana, on the Bivalve, *Transennella tantilla* (Gould), and a Determination of Its Daily Consumption Rate, 144-152
- Barnhart, Roger A.: see Rabin and Barnhart, 4-16
- Barrett, Reginald H.: see Gogan, Thompson, Pierce, and Barrett, 47-61
- Bartonek, James C.: see Gilmer, Hicks, Bartonek, and McCollum, 132-143
- Becker, Dennis: see Botti, Warenycia, and Becker, 62-63
- Blahm, Theodore H.: see Emmett, Miller, and Blahm, 38-46
- Botti, Fred, Dee Warenycia, and Dennis Becker: Utilization by Salt Marsh Harvest Mice, *Reithrodontomys raviventris halicoetes*, of a Non-pickleweed Marsh, 62-63
- Bowyer, R. Terry: Habitat Selection by Southern Mule Deer, 153-169
- Burge, Richard T.: see Wendell, Hardy, Ames, and Burge, 197-212
- Compagno, Leonard J.V.: see Seigel and Compagno, 172-176
- Crabtree, C. Ben: see Matson, Crabtree, and Haglund, 227-231
- Cross, Jeffrey N.: Epidermal Tumors in *Microstomus pacificus* (Pleuronectidae) Collected Near a Municipal Wastewater Outfall in the Coastal Waters off Los Angeles (1971-1983), 68-77
- Dinnel, Paul A., and Christopher W. Rogers: Northern Range Extension for California Tonguefish, *Symphurus atricauda*, to Washington State, 119-121
- Ebert, David A.: Observations on the Elasmobranch Assemblage of San Francisco Bay, 244-249
- Emmett, Robert L., David R. Miller, and Theodore H. Blahm: Food of Juvenile Chinook, *Oncorhynchus tshawytscha*, and Coho, *O. kisutch*, Salmon off the Northern Oregon and Southern Washington Coasts, May-September 1980, 38-46
- Gilmer, David S., Jane M. Hicks, James C. Bartonek, and Earl H. McCollum: Waterfowl Harvest at Tule Lake National Wildlife Refuge, 1936-41, 132-143
- Gogan, Peter J.P., Steven C. Thompson, William Pierce, and Reginald H. Barrett: Line-Transect Censuses of Fallow and Black-tailed Deer on the Point Reyes Peninsula, 47-61
- Graham, T.W.: see Lavoipierre, Graham, Walters, and Howarth, 78-82
- Gutoff, D.I.: see Phillips, Gutoff, Hansen, and Hardwick, 232-243
- Haglund, Thomas R.: see Matson, Crabtree, and Haglund, 227-231
- Hansen, J.E.: see Phillips, Gutoff, Hansen, and Hardwick, 232-243
- Hardwick, J.E.: see Phillips, Gutoff, Hansen, and Hardwick, 232-243
- Hardy, Robert A.: see Wendell, Hardy, Ames, and Burges, 197-212
- Herder, Michael: see Stein, Herder, and Miller, 179-181
- Hicks, Jane M.: see Gilmer, Hicks, Bartonek, and McCollum, 132-143
- Howarth, J.A.: see Lavoipierre, Graham, Walters, and Howarth, 78-82
- Juarez, Stephen M.: see O'Farrell, Juarez, and Uptain, 187-189
- Langenwaller, Paul E. II: Indigenous Muskrats, *Ondatra zibethicus*, in Coastal Southern California, 121-122
- Lavoipierre, M.M.J., T.W. Graham, L.L. Walters, and J.A. Howarth: The Occurrence of Two Nematodes, *Spirocerca lupi* and *Dirofilaria immitis*, in Wild Canids of the Lake Berryessa Area, Northern California, 78-82
- Lea, Robert N., and Lawrence F. Quirolo: First Record of *Hemirhamphus bolini*, the Bigmouth Sculpin, from Californian Waters, 117-119
- Littrell, E.E.: Mortality of American Wigeon on a Golf Course Treated with the Organophosphate, Diazinon, 122-124
- Littrell, E.E.: Shell Thickness and Organochlorine Pesticides in Osprey Eggs from Eagle Lake, California, 182-185
- Matson, Ronald H., C. Ben Crabtree, and Thomas R. Haglund: Ichthyofaunal Composition and Recolonization in a Central California Tidepool, 227-231
- Matthews, Kathleen R.: Movement of Two Nearshore, Territorial Rockfishes Previously Reported as Non-Movers and Implications to Management, 103-109
- McCollum, Earl H.: see Gilmer, Hicks, Bartonek, and McCollum, 132-143
- Miller, David R.: see Emmett, Miller, and Blahm, 38-46
- Miller, Kathy: see Stein, Herder, and Miller, 179-181

- O'Farrell, Michael J., Stephen M. Juarez, and Curt E. Uptain: An Addition to the Known Range of Stephens' Kangaroo Rat, *Dipodomys stephensi*, in San Diego County, California, 187-189
- Phillips, R.E., D.I. Gutoff, J.E. Hansen, and J.E. Hardwick: Distribution of Major Marine Macrophytes, Seasonal Estimates of *Gracilaria* Standing Crop, and Spawning Activities of the Pacific Herring, *Clupea harengus pallasii*, in Elkhorn Slough, California; 1979-1982, 232-243
- Pierce, William: see Gogan, Thompson, Pierce, and Barrett, 47-61
- Rabin, Douglas J., and Roger A. Barnhart: Population Characteristics of Pacific Herring, *Clupea harengus pallasii*, in Humboldt Bay, California, 4-16
- Raquel, Paul F.: Juvenile Blue Catfish in the Sacramento-San Joaquin Delta of California, 186-187
- Rogers, Christopher W.: see Dinnel and Rogers, 119-121
- Roletto, Jan, and Robert Van Syoc: The Occurrence of *Lepas anatifera* on *Zalophus californianus* and *Mirounga angustirostris*, 124-126
- Seigel, Jeffrey A. and Leonard J.V. Compagno: New Records of the Ragged-tooth Shark, *Odontaspis ferox*, from California Waters, 172-176
- Sikkel, Paul C.: Intraspecific Cleaning by Juvenile Salema *Xenestius californiensis* (Pisces: Haemulidae), 170-172
- Stein, Janet L., Michael Herder, and Kathy Miller: Birth of a Northern Fur Seal on the Mainland California Coast, 179-181
- Sunada, John S.: Growth and Reproduction of Spot Prawns in the Santa Barbara Channel, 83-93
- Swift, Camm C.: First Record of the Spotted Scorpionfish, *Scorpaena plumieri*, from California: The Curtain Falls on "A Comedy of Errors.", 176-178
- Thompson, Steven C.: see Gogan, Thompson, Pierce, and Barrett, 47-61
- Uptain, Curt E.: see O'Farrell, Juarez, and Uptain, 187-189
- Walters, L.L.: see Lavoipierre, Graham, Walters, and Howarth, 78-82
- Warencycia, Dee: see Botti, Warencycia, and Becker, 62-63
- Welker, Heather J.: Fawn Mortality in the Lake Hollow Deer Herd, Tehama County, California, 99-102
- Welker, Heather J.: Fawn Rearing Habitat of the Lake Hollow Deer Herd, Tehama County, California, 94-98
- Wells, Alan W.: Aspects of Ecology and Life History of the Woolly Sculpin, *Clinocottus analis*, from Southern California, 213-226
- Wendell, Frederick E., Robert A. Hardy, Jack A. Ames, and Richard T. Burge: Temporal and Spatial Patterns in Sea Otter, *Enhydra lutris*, Range Expansion and in the Loss of Pismo Clam Fisheries, 197-212
- White, James R.: The Striped Bass Sport Fishery in the Sacramento-San Joaquin Estuary, 1969-1979, 17-37
- Winter, Brian D.: A Method for the Efficient Removal of Juvenile Salmonid Otoliths, 63-64
- Zielinski, William J.: Relating Marten Scat Contents to Prey Consumed, 110-116

## SUBJECT

- Bass, striped: Sport fishery in the Sacramento-San Joaquin estuary, 1969-1979, 17-37
- Behavior, feeding: Of the juvenile Dungeness crab, *Cancer magister* Dana, on the bivalve *Transennella tantilla* (Gould), and a determination of its daily consumption rate, 144-152
- Catfish, blue: Juvenile, in the Sacramento-San Joaquin Delta of California, 186-187
- Clam, Pismo: Temporal and spatial patterns in sea otter range expansion and in the loss of, fisheries, 197-212
- Cleaning: Intraspecific, by juvenile salema, 170-172
- Censuses, line-transect: Of fallow and black-tailed deer on the Point Reyes Peninsula, 47-61
- Crab, Dungeness: The feeding behavior of the juvenile, on the bivalve, *Transennella tantilla* (Gould), and a determination of its daily consumption rate, 144-152
- Deer, black-tailed: Line-transect censuses of fallow and, on the Point Reyes Peninsula, 47-61
- Deer, fallow: Line-transect censuses of, and black-tailed deer on the Point Reyes Peninsula, 47-61
- Deer: Fawn mortality in the Lake Hollow, herd, Tehama County, California, 99-102
- Deer: Fawn rearing habitat of the Lake Hollow, herd, Tehama County, California, 94-98
- Deer, southern mule: Habitat selection by, 153-169
- Elasmobranch: Observations on the, assemblage of San Francisco Bay, 244-249
- Growth: And reproduction of spot prawns in the Santa Barbara Channel, 83-93
- Habitat: Selection by southern mule deer, 153-169
- Habitat: Fawn rearing, of the lake Hollow deer herd, Tehama County, California, 94-98
- Herring, pacific: Distribution of major marine macrophytes, seasonal estimates of *Gracilaria* standing crop, and spawning activities of the, in Elkhorn Slough, California, 1979-1982, 232-243

- Herring, Pacific: Population characteristics of, in Humboldt Bay, California, 4-16
- Lepas anatifera*: The occurrence of, on *Zalophus californianus* and *Mirounga angustirostris*, 124-126
- Life history: Aspects of ecology and, of the woolly sculpin, *Clinocottus analis*, from southern California, 213-226
- Macrophytes, marine: Distribution of major, seasonal estimates of *Gracilaria* standing crop, and spawning activities of the Pacific herring, in Elkhorn Slough, California, 1979-1982, 232-243
- Marten: Relating, scat contents to prey consumed, 110-116
- Mice, salt marsh harvest: Utilization by, of a non-pickleweed marsh, 62-63
- Muskrats: Indigenous in coastal southern California, 121-122
- Nematodes: The occurrence of two, in wild canids of the Lake Berryessa area, northern California, 78-82
- Organophosphate, Diazinon: Mortality of American wigeon on a golf course treated with, 122-124
- Osprey, eggs: Shell thickness and organochlorine pesticides in, from Eagle Lake, California, 182-185
- Otoliths, salmonid: A method for the efficient removal of juvenile, 63-64
- Otter, sea: Temporal and spatial patterns in, range expansion and in the loss of Pismo clam fisheries, 197-212
- Pesticides, organochlorine: Shell thickness and, in osprey eggs from Eagle Lake, California, 182-185
- Population characteristics: Of Pacific herring, in Humboldt Bay, California, 4-16
- Prawns, spot: Growth and reproduction of, in the Santa Barbara Channel, 83-93
- Rat, Stephens' kangaroo: An addition to the known range of, in San Diego County, California, 187-189
- Recolonization: Ichthyofaunal composition and, in a central California tidepool, 227-231
- Reproduction: Growth and, of spot prawns in the Santa Barbara Channel, 83-93
- Rockfishes: Movement of two nearshore, territorial, previously reported as non-movers and implications to management, 103-109
- Salama: Intraspecific cleaning by juvenile, 170-172
- Salmon, chinook: Food of juvenile, off the northern Oregon and southern Washington coasts, May-September 1980, 38-46
- Salmon, coho: Food of juvenile, off the northern Oregon and southern Washington coasts, May-September 1980, 38-46
- Scat: Relating marten, contents to prey consumed, 110-116
- Scorpionfish, spotted: First record of the, from California: The curtain falls on "A Comedy of Errors.", 176-178
- Sculpin, bigmouth: First record of, *Hemitripterus bolini*, from Californian waters, 117-119
- Sculpin, woolly: Aspects of ecology and life history of the, from southern California, 213-226
- Seal, northern fur: Birth of, on the mainland California coast, 179-181
- Shark, ragged-tooth: New records of the, from California waters, 172-176
- Shell thickness: And organochlorine pesticides in osprey eggs from Eagle Lake, California, 182-185
- Tonguefish, California: Northern range extension for, to Washington state, 119-121
- Tumors, epidermal: In *Microstomus pacificus* (Pleuronectidae) collected near a municipal wastewater outfall in the coastal waters off Los Angeles (1971-1983), 68-77
- Waterfowl: Harvest at the Tule Lake National Wildlife Refuge, 1936-41, 132-143
- Wigeon, American: Mortality of, on a golf course treated with the organophosphate, Diazinon, 122-124



## SCIENTIFIC NAMES

- Acanthogobius flavimanus*: 17  
*Acmaea* spp.: 221  
*Agarum*: 233  
*Aix sponsa*: 133  
*Ammodytes hexapterus*: 41, 42, 43  
*Anas acuta*: 134  
*Anas americana*: 122–124  
*Anas clypeata*: 134  
*Anas platyrhynchos*: 123, 134  
*Anatanais normani*: 220  
*Anoplarchus purpurescens*: 229  
*Anser albifrons*: 134  
*Anthopleura xanthogrammica*: 214  
*Aquila chrysaetos*: 47  
*Artemis lateralis*: 215, 228, 229  
*Ascarophis* sp.: 225  
*Atherinops affinis*: 171, 228, 229  
*Atylus tridens*: 41, 42, 43  
*Aves*: 111, 113, 114  
*Axis axis*: 48  
*Aythya americana*: 133  
*Aythya collaris*: 140  
*Aythya* spp.: 134  
*Aythya valisineria*: 133  
*Bos taurus*: 47  
*Branta canadensis*: 123  
*Branta canadensis hutchinsii*: 134  
*Branta canadensis minima*: 134  
*Branta canadensis* spp.: 134  
*Bucephala albeola*: 133  
*Bucephala* spp.: 134  
*Callorhinus ursinus*: 179  
*Cancer antennarius*: 197  
*Cancer magister*: 41, 42, 43, 119, 144–152, 197  
*Cancer oregonensis*: 41, 42, 43  
*Cancer productus*: 197  
*Canis latrans*: 47, 78, 100, 155  
*Canis lupus*: 110  
*Capra* spp.: 47  
*Carcinus maenas*: 150  
*Cebidichthys violaceus*: 229, 230  
*Cerastoderma edule*: 150  
*Cervus elaphus*: 47  
*Chen rossii*: 133  
*Cirolana harfordi*: 220  
*Cirripedia*: 42, 43  
*Clinocardium nuttali*: 145, 146, 148, 149, 150  
*Clinocottus analis*: 213–226, 229  
*Clinocottus recalvus*: 215  
*Clupea harengus pallasii*: 4–16, 41, 42, 43, 232–243  
*Crangon* sp.: 17  
*Cryptomya* sp.: 149  
*Dama dama*: 48  
*Dipodomys stephensi*: 187–189  
*Dirofilaria immitis*: 78–82  
*Dorosoma petenense*: 17  
*Embiotoca jacksoni*: 215  
*Engraulis mordax*: 17, 41, 42, 43  
*Enhydra lutris*: 197–212  
*Enteromorpha*: 236, 238  
*Equus caballus*: 47  
*Eutamias* spp.: 111, 113, 114, 115  
*Felis concolor*: 47, 100  
*Fucus*: 233  
*Fulica americana*: 123  
*Galeorhinus zyopterus*: 245  
*Gibbonsia elegans*: 214  
*Gibbonsia metzi*: 214, 229  
*Gibbonsia montereyensis*: 229, 230  
*Girella nigricans*: 171, 214, 229, 230  
*Glaucomys sabrinus*: 111, 112  
*Gobiesox maeandricus*: 229, 230  
*Gobiesox rhessodon*: 215  
*Gracilaria*: 232–243  
*Haliaeetus leucocephalus*: 47  
*Hemitripteris bolini*: 117–119  
*Hemitripteris marmoratus*: 117  
*Hemitripteris marmoratus*: 117  
*Hermosilla azurea*: 171, 215  
*Heterostichus rostratus*: 170  
*Hippoglossoides elassodon*: 74  
*Hyperoche medusarum*: 42, 43  
*Hypsoblennius gilberti*: 214  
*Hypsoblennius jenkinsi*: 215  
*Ictalurus furcatus*: 186  
*Laminaria*: 233  
*Laminaria saccharina*: 233  
*Laminaria sinclairii*: 233  
*Lepas anatifera*: 124–126  
*Leptocottus armatus*: 17  
*Lepus californicus*: 114  
*Limacina* sp.: 41, 42, 43  
*Littorina planaxis*: 214  
*Lynx rufus*: 155  
*Macoma* sp.: 149  
*Macrocystis integrifolia*: 233  
*Macrocystis pyrifera*: 202  
*Martes americana*: 110–116  
*Martes pennanti*: 116  
*Micrometrus aurora*: 228, 229  
*Micrometrus minimus*: 215  
*Microstomus pacificus*: 68–77, 117  
*Microtus* spp.: 111, 113, 114, 115  
*Mirounga augustirostris*: 124–126  
*Morone saxatilis*: 17–37  
*Mustela nivalis*: 115  
*Mustela putorius furo*: 110  
*Mustelus henlei*: 245  
*Myliobatis californica*: 246  
*Mytilus californianus*: 214  
*Mytilus edulis*: 236  
*Nautilus pompilius*: 124  
*Neomysis kadiakensis*: 42, 43  
*Neptunea pribilofensis*: 118  
*Notorynchus maculatus*: 244, 246  
*Odocoileus hemionus*: 47–61, 94, 99  
*Odocoileus hemionus californicus*: 167  
*Odocoileus hemionus columbianus*: 94–98, 99–102, 167  
*Odocoileus hemionus fuliginatus*: 153  
*Odocoileus hemionus hemionus*: 167  
*Odontaspis ferax*: 172–176  
*Odontaspis herbstii*: 173  
*Oligocottus rimensis*: 229  
*Oligocottus rubellio*: 215  
*Oligocottus snyderi*: 215, 229  
*Oncorhynchus kisutch*: 38–46  
*Oncorhynchus* spp.: 38  
*Oncorhynchus tshawytscha*: 38–46  
*Ondatra zibethicus*: 121–122

- Ondatra zibethicus bernardi*: 121  
*Ondatra zibethicus mergens*: 121  
*Opecoelus adspheericus*: 225  
 Osmeridae: 41, 42, 43  
*Ovis aries*: 47  
*Oxyjulus californica*: 170, 171  
*Oxyura jamaicensis*: 133  
*Pachygrapsus crassipes*: 214, 221  
*Pagurus samuelis*: 221  
*Pagurus* spp.: 41, 42, 43  
*Pandalus borealis*: 89  
*Pandalus jordani*: 42, 89  
*Pandalus platyceros*: 83-93  
*Pandion haliaetus*: 182  
*Paraclunio* sp.: 220  
*Paralabrax clathratus*: 171, 225  
*Paralichthys californicus*: 34  
*Parathemisto pacifica*: 42, 43  
*Parophrys vetulus*: 74  
*Peromyscus*: 114  
*Peromyscus maniculatus*: 111, 112, 113  
*Petalonia*: 224  
*Phragmatopoma californica*: 220, 223  
*Pinnixa* spp.: 43  
*Platichthys stellatus*: 74  
 Pleuronectidae: 42  
*Pollicipes polymerus*: 214  
 Polysiphonia: 236  
 Porcellanida: 41, 42, 43  
*Raja binoculata*: 246  
*Reithrodontomys raviventris halicoetes*: 62-63  
*Reithrodontomys raviventris raviventris*: 62  
*Rhacochilus vacca*: 215  
*Sagitta* sp.: 42  
*Salicornia pacifica*: 62  
*Salmo gairdneri*: 63  
*Sardinops* sp.: 17  
*Scapanus*: 114  
*Scapanus latimanus*: 115  
*Scorpaena*: 176  
*Scorpaena guttata*: 176, 177  
*Scorpaena histrio*: 176  
*Scorpaena mystes*: 176  
*Scorpaena plumieri*: 176-178  
*Scorpaenichthys marmoratus*: 215  
*Sebastes*: 103, 118  
*Sebastes carnatus*: 103-109  
*Sebastes chrysomelas*: 103-109  
*Sebastes* sp.: 34  
*Sebastes* spp.: 41, 42, 43, 173, 215  
*Seriola lalandi*: 171  
*Sorex* spp.: 113, 114  
*Spermophilus lateralis*: 111, 113, 114  
*Spirinchus thaleischthys*: 42  
*Spirocercia lupi*: 78-82  
*Spirontocaris picta*: 223  
*Squalus acanthias*: 246  
*Sus scrofa*: 47  
*Symphurus atricauda*: 119-121  
*Tamiasciurus*: 114, 115  
*Tamiasciurus douglasii*: 111, 113  
*Tegula funebris*: 214  
*Thomomys*: 114  
*Thomomys monticola*: 113, 115  
*Thyssanoessa spinifera*: 41, 42, 43  
*Tivela stultorum*: 198  
*Transennella tantilla*: 144-152  
*Triakis semifasciata*: 245  
*Ulca bolini*: 117  
*Ulca marmorata*: 117  
*Ulva*: 233  
*Urocyon cinereoargenteus*: 78  
*Ursus americana*: 100  
*Ursus arctos*: 47  
*Vibilia cultripes*: 42  
*Vulpes vulpes*: 47, 110  
*Xenistius californiensis*: 170-172  
*Xerorpes focurum*: 229, 230  
*Xiphister atropurpureus*: 229  
*Xiphister mucosus*: 228, 229, 230  
*Zalophus californianus*: 124-126  
*Zostera marina*: 5, 235, 236, 237

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