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ERRATA

- Rawstron, Robert R. 1975. Mortality and growth rates, cost, and relative contribution of two different sizes of silver salmon stocked in Lake Berryessa, California, in 1972. Calif. Fish Game 61(3): 127-132.
- p 129. Darrah Springs Hatchery is located in Tehama County and Mt. Shasta Hatchery in Siskiyou County.
- p 132. Line 6 should read “. . . reach 200 to 250 mm (8 to 10 inches) in 10 to 14 months in the hatchery.”

LIFE HISTORY STUDIES OF THE SACRAMENTO PERCH, *ARCHOPLITES INTERRUPTUS* (GIRARD), IN CALIFORNIA¹

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and

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Aspects of the life history of the Sacramento perch from Lake Greenhaven and Lake Almanor are described. Spawning occurred in May and possibly early June in Lake Greenhaven, and in late May and June in Lake Almanor. Seven age groups, O through VI, were present in each population. Females outnumbered males, particularly at older ages, and grew slightly faster than males in both populations. Greenhaven fish grew faster than Almanor fish. Length-weight relationships and condition factors of the two populations were similar. Food habits analysis of Lake Greenhaven fish indicated that the major food items were chironomid larvae and pupae and zooplankton. Life history characteristics from these populations are compared with those reported for other Sacramento perch populations.

INTRODUCTION

The Sacramento perch (*Archoplites interruptus*), the only native centrarchid west of the Rocky Mountains, is endemic to the lower Sacramento-San Joaquin drainage system and the Pajaro and Salinas River systems of California. The current status of this species is regarded as "depleted" since it has undergone a major decline in distribution and abundance throughout its native range, probably as a result of interactions with introduced centrarchids (Fisk 1972, Aceituno and Nicola 1976). It has been successfully introduced into many waters outside of its original range, especially in Nevada and Nebraska (McCarragher and Gregory 1970). In recent years, due to a growing interest in the conservation of threatened species, the California Department of Fish and Game has attempted to expand the distribution of the Sacramento perch by introducing it into many lakes and ponds within the state (Aceituno and Nicola 1976).

Life history information on this unique species within California is relatively scarce (Murphy 1948, Mathews 1962 and 1965, and Moyle, Mathews, and Bonderson 1974). The present study was conducted to provide information of various aspects of the life history of the Sacramento perch from two California lakes with very different limnological characteristics: Lake Greenhaven, which was re-stocked with Sacramento perch after chemical treatment and lake enlargement in 1965; and Lake Almanor, where Sacramento perch were stocked in 1964.

¹ Accepted for publication April, 1974. This paper is based on a thesis written in partial fulfillment of requirements for the degree of Master of Science at California State University, Sacramento.

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DESCRIPTION OF STUDY AREAS

Lake Greenhaven

Lake Greenhaven, formerly known as Brickyard Pond, has been the primary source of Sacramento perch used by the California Department of Fish and Game for their transplanting efforts in recent years. This 24 ha (59 acre) man-made lake is located in the southwest portion of the city of Sacramento (T8N,R4E) at an elevation of 4.9 m (16 ft) above sea level. The surrounding drainage area (111 ha or 274 acres) consists of commercial and residential developments. Private homes with boat docks and beaches occupy about one-half of the shoreline; no public access is available. No streams enter or leave this lake, which has an average depth of 2 to 3 m (6.5 to 10 ft). The water level is determined by surface runoff from the surrounding area and fluctuation of the ground water table. During rainy periods with heavy runoff, lake water is pumped through a pipe to the Sacramento River nearby. In 1973 the surface level fluctuated less than 0.5 m (1.6 ft). The primary uses of the lake by residents of the surrounding homes are for scenic value, boating, and to a small extent, fishing.

Sacramento perch dominated the fish fauna during the study; other species present were the largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis machrochirus*), white crappie (*Pomoxis annulus*), green sunfish (*Lepomis cyanellus*), mosquitofish (*Gambusia affinis*), channel catfish (*Ictalurus punctatus*), golden shiner (*Notemigonus crysoleucas*), goldfish (*Carassius auratus*), and carp (*Cyprinus carpio*). Aquatic vegetation, mostly sago pondweed (*Potamogeton pectinatus*), was abundant during the summer months. Excessive pondweed growth was controlled periodically by mechanical cutting and by addition of commercial fertilizer.

In general, Lake Greenhaven is a hard-water, eutrophic lake (Table 1). The water was relatively turbid throughout the period of study, as secchi disk readings averaged 34 cm (13.4 inches) due to phytoplankton blooms. Surface water temperatures ranged from 7 C (45 F) in January to at least 23 C (74 F) during the months from April through September.

TABLE 1. Water Quality Characteristics of Lake Greenhaven (June 1, 1973) and Lake Almanor (April 17, 1973).

	Lake Greenhaven	Lake Almanor
pH.....	8.5	7.5
Hardness (ppm).....	146.0	36.0
CO ₂ Alkalinity (ppm).....	18.0	0.0
HCO ₃ Alkalinity (ppm).....	382.0	54.0
Total Dissolved Solids.....	505.0	56.0
Specific Conductance (Micromhos/cm).....	879.0	93.0

Lake Almanor

Lake Almanor is a reservoir on the North Fork of the Feather River in Plumas County (T27/28N, R7/8E) and is surrounded by yellow pine forests. At maximum pool (1385 m or 4544 ft above sea level) the surface area is 10,620 ha (26,242 acres) and the mean depth is 19.7 m (65

ft). It is a clear, soft-water lake, and many of its chemical characteristics contrast sharply from those at Lake Greenhaven (Table 1). The lake freezes over most winters and thermally stratifies during the summer. During the summer months the epilimnion maintains ample dissolved oxygen and has suitable temperatures (20 C or 68 F and above) for growth of warmwater fishes.

In contrast to Lake Greenhaven, where Sacramento perch predominated, tui chubs (*Gila bicolor*), carp, Sacramento squawfish (*Ptychocheilus grandis*), and Sacramento sucker (*Catostomus occidentalis*) dominated the Lake Almanor fish fauna. Other species present were Sacramento perch, largemouth bass, smallmouth bass (*Micropterus dolomieu*), green sunfish, brown bullhead, (*Ictalurus nebulosus*), threadfin shad (*Dorosoma petenense*), kokanee salmon (*Oncorhynchus nerka*), silver salmon (*O. kisutch*), rainbow trout (*Salmo gairdneri*), and brown trout (*S. trutta*). Some aquatic vegetation, including pondweed (*Potamogeton* sp.) and water nymph (*Najas* sp.) was present.

METHODS AND MATERIALS

Water quality analyses were made with a Hach Chemistry Kit (Model 36-AL). The California Department of Water Resources provided additional data on mineral content of the waters.

The Sacramento perch population at Lake Greenhaven was sampled monthly from March 1973 to January 1974. Fish were collected with the following gear:¹ a 30.5 m (100 ft) x 1.8 m (6 ft) bag seine with 2.5 cm (1.0 inch) mesh wings and a 1.3 cm (0.5 inch) mesh bag; a 12.2 m (40 ft) x 1.8 m (6 ft) bag seine with 1.3 cm (0.5 inch) mesh; a 4.5 m (15 ft) x 1.2 m (4 ft) minnow seine with 3 mm (0.1 inch) bobbinet mesh; 1.8 m (6 ft) x .8 m (2.6 ft) fyke nets with 19 mm (0.75 inch) mesh; a 45.6 m (150 ft) x 1.8 m (6 ft) experimental gill net with 15.2 m (50 ft) sections of 19, 25, and 38 mm (0.75, 1.0, and 1.5 inch) mesh; and hook and line. At Lake Almanor, Sacramento perch were collected during May and June with Merwin traps (described by Smith, McCammon, and Fraser 1963) with 2.5 cm mesh in the lead and 1.3 cm (0.5 inch) mesh in the pot, wings, and apron. In August young fish were collected with a 15.2 m (50 ft) bag seine, with 6 mm (0.24 inch) mesh.

All fish captured were measured to the nearest mm, FL. A representative sample from each monthly collection at Lake Greenhaven, and all fish collected at Lake Almanor were preserved in 10% formalin and later transferred to 50% isopropyl alcohol. In the laboratory, each fish was measured to the nearest mm FL; weight to the nearest gram and sex and state of maturity were recorded. Scales were taken from an area on the left side of the fish below the lateral line at the posterior tip of the pectoral fin. Impressions of about 5 scales were made on cellulose acetate slides with the aid of a Carver Laboratory Press. Scales were read with a Bausch and Lomb Microprojector. Stomach samples were taken from 10 to 29 fish captured by seining from alternate monthly collections. Food items were identified to order with the aid of keys in Pennak (1953) and Usinger (1956). Linear regressions for body-scale relationships and length-weight relationships were computed with the aid of a Burroughs 5500 computer.

¹ All mesh sizes listed are square measure.

RESULTS

Observations on Reproduction

At Lake Greenhaven in 1973, sexual dimorphism was apparent as early as April 7; the water temperature was 16 C (61 F). The males were much darker than females, and their dark vertical bands were almost indistinguishable. Spawning occurred during May and possibly extended into early June. Ripe fish were collected on May 12 when the water temperature reached 22 C (72 F). Young-of-the-year, averaging 16 mm (0.6 inch) were first captured on May 26. Some ripe fish were still present in the May 26 collection, but no ripe fish were observed in the June 23 collection. Gonadal development of adults of both sexes was recorded to provide an additional index of time of spawning in Lake Greenhaven. Mean weight of gonads from a sample of 213 fish, expressed as a percentage of body weight, was calculated on a monthly basis from March through November 1973 (Figure 1). Beginning in March gonadal weights increased rapidly. The peak for females occurred in May (2.5%) while the peak for males occurred in April (0.8%).

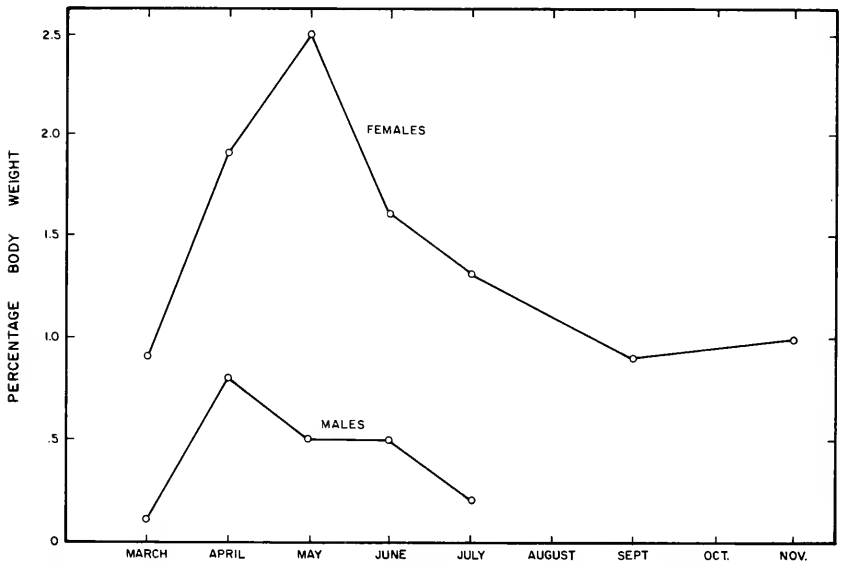


FIGURE 1. Monthly mean gonadal weights, expressed as percentage of body weight, for male and female Sacramento perch at Lake Greenhaven, 1973.

At Lake Almanor ripe Sacramento perch were collected from late May, when the water temperature had reached 20 C (68 F), through June. Young-of-the-year averaging 28 mm (1.1 inch) in length were collected in mid-August.

We could not make any direct observations on Sacramento perch spawning in Lake Greenhaven in 1973 because of high turbidity. How-

ever, in late April of 1974 the water was clearer for a period and some observations could be made. On April 21, males were found over nests located among large rocks of the rip-rapped north shoreline. These rocks were approximately 15 to 30 cm (6 to 12 inches) in diameter, covered with filamentous algae on a sand and gravel substrate. The filamentous algae had been cleared from the inside surface of the rocks and from the substrate in the nests. The males appeared to defend a nest territory of approximately 40 cm (16 inches) in diameter. Other Sacramento perch nests were observed in clay and mud substrates around the lake.

Age and Growth

To determine age composition and growth, scales from 187 Lake Greenhaven and 99 Lake Almanor fish were analyzed. All fish over 200 mm (7.9 inches) in length were included in the scale analysis, while a size-representative sample of the fish less than 200 mm was selected. Although "false annuli" were common on the scales, true annuli could be recognized by applying these two criteria:

- (1) Anastomosis of circuli in both lateral fields, and
- (2) a wide space between circuli in the anterior field.

Annulus formation occurred during the months of March and April in Lake Greenhaven and during May in Lake Almanor.

Body-Scale Relationship

The relationship between anterior scale radius and fork length was judged to be linear and was calculated by the least squares method for each population:

$$\text{Lake Greenhaven: } L = 23.2608 + 1.1423 S$$

$$\text{Lake Almanor: } L = 17.4694 + 1.1095 S$$

where L = fork length in mm

S = anterior scale radius in mm $\times 40$

Growth Histories

Fork lengths at the various annuli were back-calculated on a standard nomograph (Carlander and Smith 1944), using the intercept values of 23 and 17, respectively, for the two populations. Sexes were treated separately for age groups II and older. The growth histories of the six age groups were compiled for each population, and grand weighted mean fork lengths and increments were computed (Tables 2 and 3).

Females were consistently more abundant than males in both populations, with the exception of age group V from Lake Almanor. At Lake Greenhaven no males older than age IV were collected. In both populations females tended to be longer than males, most noticeably at older ages.

To compare growth between the two populations, we combined calculated lengths of the sexes (Figure 2). Lake Greenhaven fish were

larger at all annuli, although the Lake Almanor growth increments of the last 4 years were greater than those from Lake Greenhaven. In Lake Greenhaven the increments for the first 2 years were nearly identical, then dropped abruptly for the third year, and remained fairly constant for the remaining years. In Lake Almanor, annual increments varied less; the largest increment occurred during the second year, and the remaining increments gradually declined with age. The largest fish captured at Lake Greenhaven was a 6-year old, 305 mm (12 inch) female; the largest fish from Lake Almanor was a 6-year old, 285 mm (11.2 inch) female. Growth of Sacramento perch from Lake Greenhaven compared favorably with growth of this species reported for other California waters, but was slightly less than that reported for Nevada waters (Table 4).

A comparison of mean empirical lengths substantiated the larger size of young-of-the-year fish in Lake Greenhaven. In mid-August young-of-the-year perch in Lake Almanor averaged 28 mm (1.1 inches), while the estimated mean length of young-of-the-year in Lake Greenhaven at this time was approximately 46 mm (1.8 inches).

TABLE 2. Mean Calculated Fork Lengths and Annual Increments of Sacramento Perch Collected From Lake Greenhaven in 1973. All Measurements in Millimeters.

Age group	Year class	Sex	No. of fish	Mean FL at capture	Mean calculated fork length at annulus						
					1	2	3	4	5	6	
I.....	1972	--	83	126	88						
II.....	1971	M	26	163	74	156					
		F	41	169	77	157					
III.....	1970	M	6	188	71	152	184				
		F	12	207	80	159	200				
IV.....	1969	M	2	227	89	161	198	221			
		F	15	243	99	187	212	239			
V.....	1968	M	0	--	--	--	--	--			
		F	1	305	132	176	203	238	278		
VI.....	1967	M	0	--	--	--	--	--	--		
		F	1	319	89	221	262	278	294	312	
Grand Mean Calculated Fork Length.....				M	74	155	188	221	--	--	
				F	83	167	208	241	286	312	
				Total	84	163	203	239	286	312	
Mean Annual Increment.....				M	74	81	33	23	--	--	
				F	83	83	28	26	28	18	
				Total	84	82	29	25	28	18	
Number of Fish.....				M	34	34	8	2	0	0	
				F	70	70	29	17	2	1	
				Total	187	104	37	19	2	1	

TABLE 3. Mean Calculated Fork Lengths and Annual Increments of Sacramento Perch Collected From Lake Almanor in 1973. All Measurements in Millimeters

Age group	Year class	Sex	No. of fish	Mean FL at capture	Mean calculated fork length at annulus						
					1	2	3	4	5	6	
I.....	1972	--	14	80	77						
II.....	1971	M	13	145	54	141					
		F	16	139	53	134					
III.....	1970	M	9	176	57	115	173				
		F	23	183	57	112	181				
IV.....	1969	M	5	188	60	105	150	185			
		F	13	214	59	126	173	211			
V.....	1968	M	3	207	53	105	138	172	204		
		F	2	238	48	90	153	176	216		
VI.....	1967	M	0	--	--	--	--	--	--	--	--
		F	1	285	65	129	178	219	252	282	
Grand Mean Calculated Fork Length.....				M	56	124	160	180	204	--	
				F	56	121	177	207	229	282	
				Total	59	122	172	198	217	282	
Mean Annual Increment.....				M	56	68	50	35	32	--	
				F	56	65	61	36	38	30	
				Total	59	66	58	36	35	30	
Number of Fish.....				M	30	30	17	8	3	0	
				F	55	55	39	16	3	1	
				Total	99	85	56	24	6	1	

TABLE 4. Comparison of Sacramento Perch Growth From Different California and Nevada Waters.

Locality	Mean Fork Length at Annulus (mm)								
	1	2	3	4	5	6	7	8	9
California									
Lake Greenhaven.....	84	163	203	239	286	312			
Lake Almanor.....	59	122	172	198	217	282			
Lake Anza.....	86	120	131	138	147	154			
Kingfish Lake ¹	115								
Clear Lake ²	85	171	196	220					
Nevada									
Walker Lake ³	102-127	140-190	190-241	229-299	279-318	305-356			
Pyramid Lake ⁴	76-127	127-190	178-254	229-305	279-343	305-356	324-368	381-394	394-406
Pyramid Lake ¹	99	158	221	261	299	325	346	371	382

¹ Mathews (1962)² Murphy (1948)³ Allan (1958)⁴ Johnson (1958)

Length frequencies of Sacramento perch from Lake Greenhaven were recorded for the months of the largest collections: March, May, and September 1973; and January 1974 (Figure 3). The modes of younger age groups were readily apparent and seasonal growth could be observed. In March age groups I, II, and III, with modes of 70–80 (2.8–3.1 inches), 150–160 (5.9–6.3 inches), and 180–190 mm (7.1–7.5 inches), respectively, were recognizable, while modes of older age groups were not apparent due to growth overlap. In May, young-of-the-year first appeared while modes of age groups II and older were not readily apparent. In September the two youngest age groups were still visible and their seasonal growth apparent: the mode of the young-of-the-year fish had increased from 10–20 to 50–60 mm (.4–.8 to 2.0–2.4 inches), while the yearling mode has increased from 70–80 to 130–140 mm (2.8–3.1 to 5.1–5.5 inches). In January, the modes of these two groups could still be easily observed and had increased in length only slightly from September.

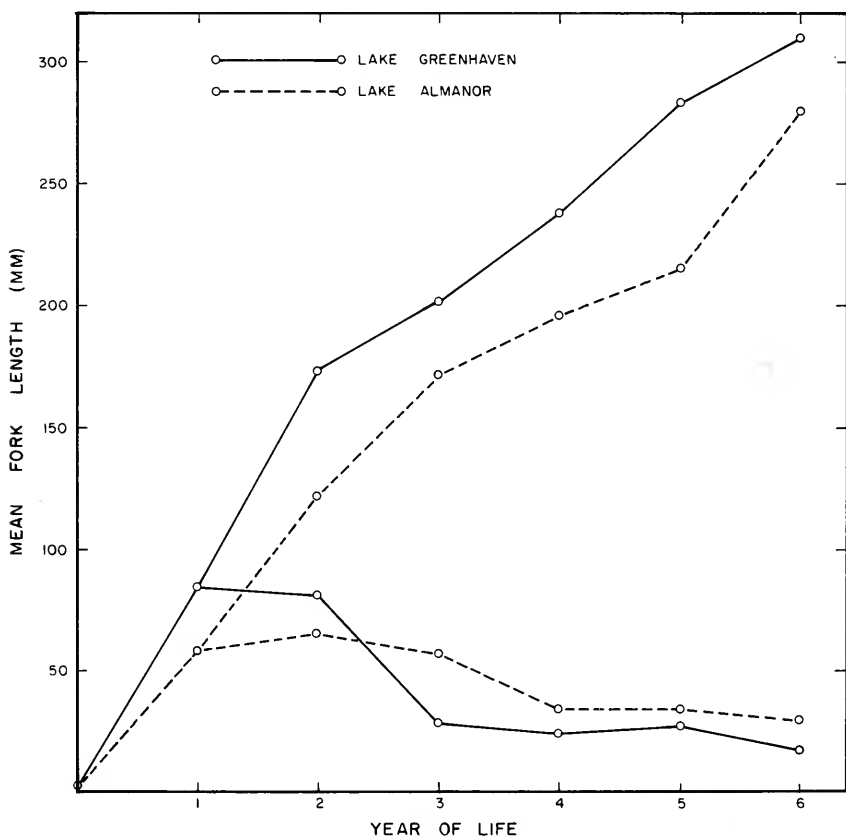


FIGURE 2. Growth of Sacramento perch (sexes combined) in Lake Greenhaven and Lake Almanor. Upper lines represent grand mean calculated fork lengths; lower lines represent mean weighted increments.

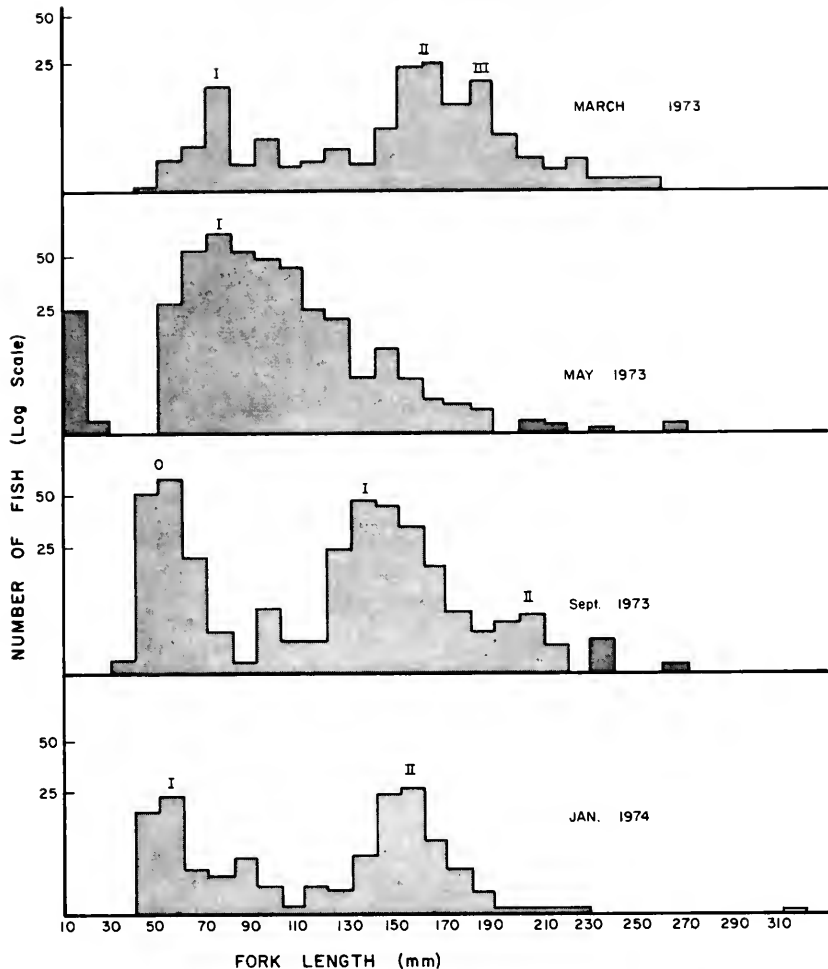


FIGURE 3. Length-frequencies of all Sacramento perch captured at Lake Greenhaven for the months of March, May, and September, 1973, and January, 1974.

The length frequency modes during March, the period of annulus formation in Lake Greenhaven, and January, just prior to the next year's period of annulus formation (Figure 3) agreed reasonably well with the mean calculated fork lengths for the respective year classes (Table 2). A minor difference between these two corresponding values may be observed when comparing the mode of yearling fish in March 1973 (70–80 mm) (2.8–3.1 inches) with the mean calculated length for this year class, which was 88 mm (3.5 inches). This minor discrepancy could be caused by a tendency by us to select larger fish of this age group for scale samples.

Age at Sexual Maturity

On the basis of gonadal inspection, we judged that Sacramento perch at Lake Greenhaven attained sexual maturity in their second year of life. It is not known what portion of the yearling age group actually engaged in spawning activities; most of the ripe fish we collected during the spawning season were age II or older. The smallest ripe fish observed was a yearling 128 mm (5 inches) female. At Lake Almanor, fish did not reach sexual maturity until their third year of life.

Length-Weight Relationship

The length-weight relationship of Sacramento perch from Lake Greenhaven (268 fish) and Lake Almanor (174 fish) were calculated using the squares method:

$$\text{Lake Greenhaven: } \text{Log } W = -4.9593 + 3.1324 \text{ Log } L$$

$$\text{Lake Almanor: } \text{Log } W = -4.9864 + 3.1500 \text{ Log } L$$

The two length-weight relationships were very similar (Figure 4), and analysis of covariance indicated no difference in slope at the 0.05 level.

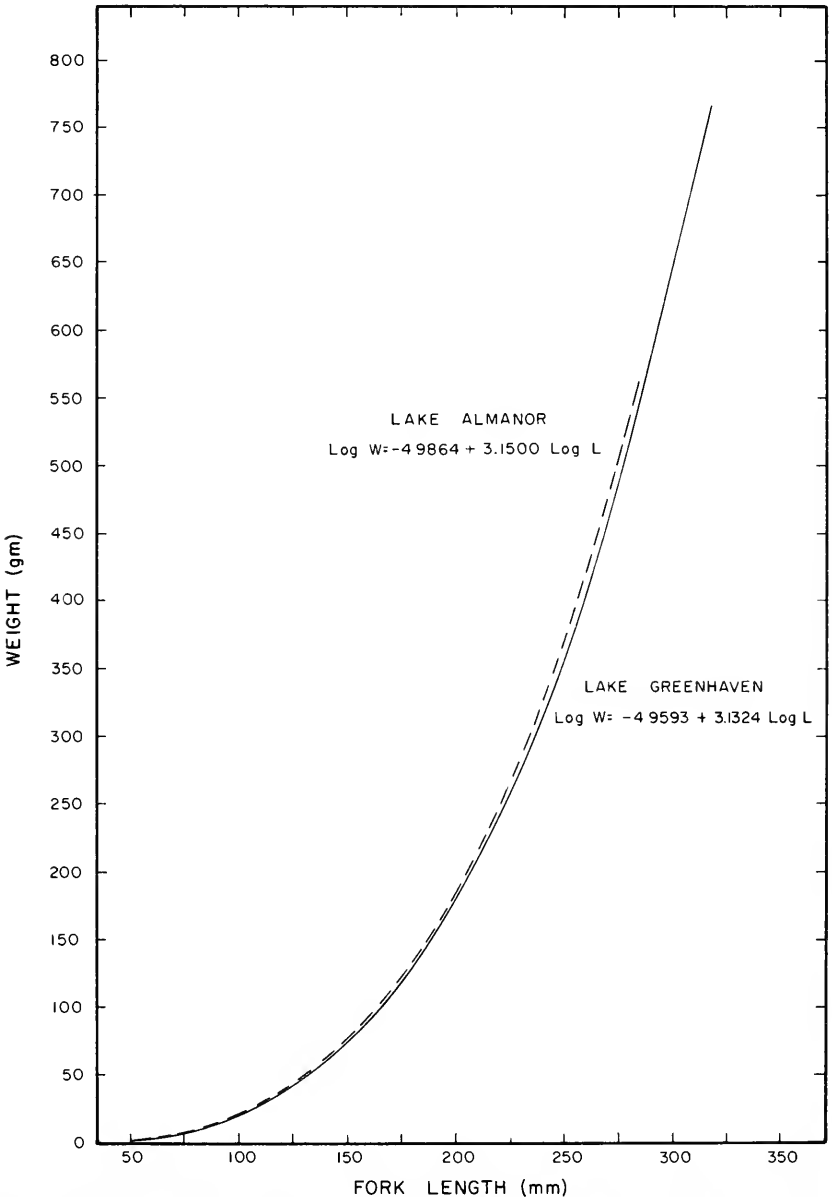


FIGURE 4. Length-weight relationship of Sacramento perch in Lake Greenhaven and Lake Almanor.

Coefficients of Condition

Coefficients of condition ($K = \frac{W}{L} 3 \times 10^5$) were computed for 261 fish from Lake Greenhaven and 174 fish from Lake Almanor. There was no apparent correlation between fork length and condition, other than a tendency for the shortest and longest fish—less than 100 mm (3.9 inches) and a greater than 250 mm (9.9 inches)—to have slightly lower K values. No consistent difference in condition between sexes was observed, although during May and June (the spawning season) female K values averaged slightly higher than males in both populations. Seasonal trend in condition at Lake Greenhaven is illustrated in Figure 5. To reduce variability, only fish between 100 and 225 mm (3.9 and 8.9 inches) were included. The mean monthly K value gradually increased from a low of 2.00 in March until it reached a peak of 2.40 in September. The slight drop between April and May is probably associated with spawning activities. Condition values dropped steadily after September.

Condition factors were available only during the months of May and June from the Lake Almanor population. The mean K value dropped from 2.26 in May to 2.16 in June; this drop is correlated with the June spawning period in this lake.

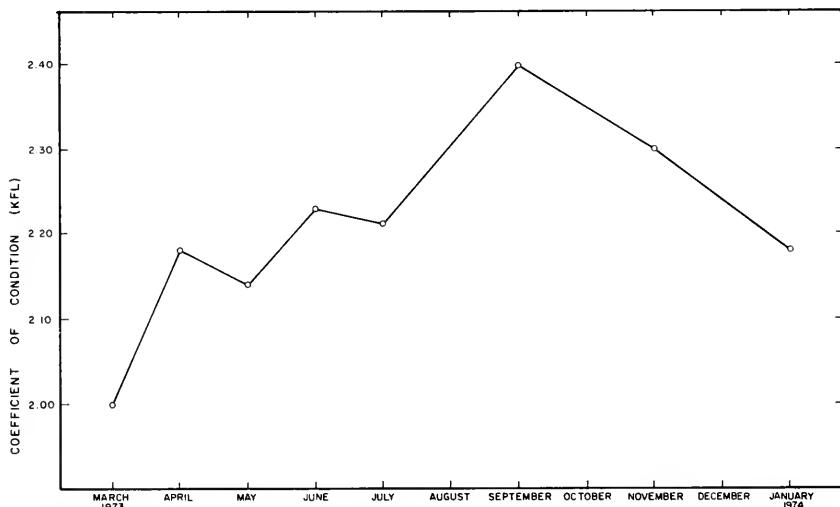


FIGURE 5. Monthly mean coefficients of condition (KFL), March 1973 through January 1974, of Sacramento perch at Lake Greenhaven. Data include both sexes combined.

Length Conversions

Since other workers have used total length (τL) when measuring Sacramento perch, it is useful to know the mathematical relationship between fork length and total length so that growth comparisons can be made. Thirty-four fish from Lake Greenhaven ranging in length

from 106 to 238 mm (4.2 to 9.4 inches) were randomly selected and the fork length to total length ratio was determined for each fish. Since the ratio did not vary with size, one set of conversion factors was computed:

$$FL = 0.978 TL$$

$$TL = 1.022 FL$$

Food Habits

Stomachs were examined from 150 fish from Lake Greenhaven ranging from 50 to 305 mm (2 to 12 inches) FL. Preliminary observations indicated a difference in diet between fingerling and larger fish, so the fish were separated into two categories: i) those between 50 and 100 mm (2 and 4 inches) FL, and ii) those over 100 mm (3.9 inches) FL. In the preliminary analysis, three size groups were used for fish from 100 to 305 mm (3.9 to 12 inches) but these groups were combined when

TABLE 5. Major Food Items of 36 Sacramento Perch 50-100 mm, from Lake Greenhaven, Expressed as Percentage of Total Number of Organisms, Total Volume, and Frequency of Occurrence

Food Item		March- May	July- Sept.	Nov.- Jan.	
Copepoda.....	% No.	63	91	5	
	% Vol.	10	25	5	
	% Freq. Oc.	90	100	59	
Cladocera.....	% No.	6	tr	84	
	% Vol.	1	tr	44	
	% Freq. Oc.	70	22	76	
Ostracoda.....	% No.	tr	tr	4	
	% Vol.	tr	tr	5	
	% Freq. Oc.	10	26	29	
Chironomidae.....	% No.	26	6	4	
	Larvae.....	% Vol.	46	42	37
	% Freq. Oc.	100	78	88	
Pupae.....	% No.	3	1	1	
	% Vol.	15	33	6	
	% Freq. Oc.	60	44	2	
Chaoboridae.....	% No.	tr	0	0	
	Larvae.....	% Vol.	tr	0	
	% Freq. Oc.	10	0	0	
Odonata.....	% No.	tr	0	0	
	% Vol.	13	0	0	
	% Freq. Oc.	20	0	0	
Hemiptera.....	% No.	1	0	0	
	% Vol.	13	0	0	
	% Freq. Oc.	40	0	0	
Ephemeroptera.....	% No.	tr	0	0	
	% Vol.	1	0	0	
	% Freq. Oc.	10	0	0	
Coleoptera.....	% No.	tr	0	0	
	% Vol.	1	0	0	
	% Freq. Oc.	10	0	0	
No. Stomachs Examined.....		9	10	17	

tr = trace (less than 1%)

TABLE 6. Major Food Items of 114 Sacramento Perch 110–305 mm, from Lake Greenhaven, Expressed as Percentage of Total Number of Organisms, Total Volume, and Frequency of Occurrence

Food Item		March- May	July- Sept.	Nov.- Jan.	
Copepoda.....	% No.	3	44	1	
	% Vol.	tr	5	tr	
	% Freq. Oc.	37	57	38	
Cladocera.....	% No.	1	tr	92	
	% Vol.	tr	tr	22	
	% Freq. Oc.	30	2	57	
Ostracoda.....	% No.	0	tr	tr	
	% Vol.	0	tr	tr	
	% Freq. Oc.	0	4	24	
Chironomidae.....	% No.	53	37	6	
	Larvae.....	% Vol.	47	47	35
	% Freq. Oc.	100	98	90	
Pupae.....	% No.	19	19	tr	
	% Vol.	25	30	3	
	% Freq. Oc.	96	95	52	
Chaoboridae.....	% No.	22	tr	tr	
	Larvae.....	% Vol.	9	1	tr
	% Freq. Oc.	70	9	5	
Pupae.....	% No.	2	tr	0	
	% Vol.	1	1	0	
	% Freq. Oc.	22	14	0	
Odonata.....	% No.	tr	tr	tr	
	% Vol.	tr	5	tr	
	% Freq. Oc.	7	27	10	
Hemiptera.....	% No.	tr	1	tr	
	% Vol.	tr	1	tr	
	% Freq. Oc.	22	34	12	
Coleoptera.....	% No.	tr	tr	0	
	% Vol.	tr	tr	0	
	% Freq. Oc.	7	4	0	
Fish.....	% No.	tr	tr	tr	
	% Vol.	5	10	38	
	% Freq. Oc.	11	11	29	
No. Stomachs Examined.....		28	44	42	

tr = trace (less than 1%)

no major dietary differences were apparent. To permit observation of seasonal differences in diet, we segregated the fish into the following groups according to month of capture: March–May; July–September; and November–January. The numerical, volumetric, and frequency methods (Lagler 1956) were used to describe the diet.

The smaller fish fed primarily on copepods, cladocerans, and chironomids (Table 5). Copepods were common in the stomachs during all periods, although they were less frequent in November–January, whereas cladocerans occurred most frequently in the November–January sample. Chironomids formed the greatest bulk of the diet in all seasons, with larvae being somewhat more common than pupae. Several other insect groups, particularly chaoborids, odonotans, hemipterans, and coleopterans were found in fish from the March–May period.

The diet of larger fish differed in that these fish fed on fish to some extent, especially in November–January, and fed less on copepods (Table 6). Like the smaller perch, the larger perch fed heavily on chironomid larvae and pupae in all seasons, and on cladocerans during the November–January period.

DISCUSSION

The Sacramento perch is recognized as a euryhaline species since it has survived and reproduced in waters of widely varying alkalinity and salinity (McCarragher and Gregory 1970). The successful establishment of this species in lakes Greenhaven and Almanor supports the contention that it can survive, grow, and reproduce in environments of contrasting salinity and alkalinity. In addition to major differences in water quality, the fish fauna, the growing season, and the size of these two lakes were considerably different. Introduced centrarchids, which are thought to compete with the Sacramento perch (Moyle *et al.* 1974, Aceituno and Nicola 1976), were not abundant in either lake.

The annual pattern of gonadal development for Sacramento perch in Lake Greenhaven was similar to that reported for this species in Lake Anza by Mathews (1962). The water temperature range at which this species began spawning in Lake Anza and Kingfish Lake (Mathews 1965) was from 21.7 to 23.9 C (71 to 75 F), which approximated those temperatures observed in Lake Greenhaven and Lake Almanor at the onset of spawning. Mathews noted that in 1961 spawning began in early April in Kingfish Lake (a shallow pond which warmed rapidly) and on May 6 in Lake Anza. In Lake Anza, gravid females were present until mid-July. In Clear Lake, the Sacramento perch spawned in May and June (Murphy 1948). In Pyramid Lake, a later spawning season was observed (mid-June through August) due to a slower warming of the water (Johnson 1958). Murphy (1948), Mathews (1965), and McCarragher and Gregory (1970) presented more detailed observations on Sacramento perch reproduction.

Many of the other lakes where Sacramento perch growth parameters have been reported vary considerably with regard to size, water quality characteristics, and fish species composition. Growth and longevity in Nebraska ponds was similar to the Lake Greenhaven population, although calculated lengths at the first three annuli were considerably greater in Nebraska populations (McCarragher and Gregory 1970). The rapid first-year growth in Kingfish Lake, California (Table 4), was probably related to the fact that this was a newly stocked lake and the population density was low (Mathews 1962). In highly alkaline Pyramid Lake, where the fish fauna was very different from other waters reported, growth and longevity reached their greatest expression (Table 4). Johnson (1958) and Mathews (1962) both reported fish as old as 9 years. The largest perch from this lake was a 419 mm (16.5 inch) female reported by Mathews (1962), who felt this rapid growth was related to this species' highly piscivorous diet in this lake. However, as Carlander (1966) pointed out, it is extremely difficult to correlate average growth rates of fish with specific environmental factors, since at a given point in time, growth of individual fish is largely a function of the relationship between the population density and biomass to the environment's carrying capacity. Population density, biomass, and

carrying capacity, particularly the latter, are difficult to measure; such information has not been reported in any of the Sacramento perch growth studies. In Lake Greenhaven, because of the great abundance of the Sacramento perch indicated by our sampling efforts, we judged that this population was at or near its carrying capacity during the time of this study. In spite of the density of the population and the absence of any significant fishing mortality, this population showed no signs of stunting, there has been successful spawning and recruitment over the past several years, and the fish appeared to be in good condition. The addition of inorganic fertilizer to this lake has probably enhanced production of invertebrate food items of the Sacramento perch, and the successful spawning in recent years has provided many young fish which served as forage.

Stunting has been reported for only one population of Sacramento perch. At Lake Anza the maximum length for 6-year old fish was only 160 mm (6.3 inches) (Mathews 1962). Mathews attributed the poor growth in this lake to an insufficient supply of small forage fish.

The length-weight relationships for the Sacramento perch populations in Pyramid Lake and Lake Anza (Mathews 1962) closely approximated those of lakes Greenhaven and Almanor. Comparison with the length-weight data for Sacramento perch in Clear Lake (Murphy 1950) indicated that fish in that population were somewhat lighter in relation to length than either Lake Greenhaven or Lake Almanor fish.

In general the results of our stomach analysis were similar to those reported by Moyle *et al.* (1974) who observed that the Sacramento perch fed on benthic organisms and on mid-water organisms such as zooplankton, fish, and emerging insects. The rarity of adult dipterans and other terrestrial insects in the stomachs from Lake Greenhaven indicates the Sacramento perch is not a surface feeder. Moyle *et al.* noted that in three California ponds Sacramento perch fed heavily on chironomids, but in Pyramid Lake perch over 90 mm (3.5 inches) were almost entirely piscivorous. In Walker Lake, Allan (1958) reported that fish remains were found in most of the 223 Sacramento perch stomachs he examined; other common food items were chironomids and odonatan nymphs, with cladocerans occurring on a seasonal basis. In Nebraska lakes, young Sacramento perch fed almost entirely on invertebrates, while older fish fed on almost equal proportions of invertebrates and fish (McCarragher and Gregory 1970).

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AN ALL-WEATHER, TWO-WAY FISH TRAP FOR SMALL STREAMS¹

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The design and construction of an all-weather, two-way fish trap for small streams are discussed with a description of the study stream. Operation, operational problems, and past history of usage are detailed.

INTRODUCTION

For many years fish migration has been acknowledged as an integral part of many lotic ecosystems. Attempts to study this phenomenon have resulted in several types of fish trap designs.

Downstream traps are usually simpler in design and more effective in operation than upstream traps. Extensive, seasonal runs of anadromous fishes in large, coastal rivers gave rise to the subsampling techniques of scoop traps (Meehan 1964), dip traps (Mason 1966), and fyke nets (Craddock 1959). On small inland and coastal streams, Wolf traps (Wolf 1950) and inclined-screen traps (McLain and Manion 1967) were built to catch all downstream migrants.

Upstream and combination upstream/downstream traps are generally more intricate in design. False waterfalls (Whalls, Proshek, and Shetter 1955), throats (Shetter 1938), anesthetic pools (Kupka 1964), and weirs (Craddock 1958) have all been used to capture upstream migrants.

This paper describes the design of an all-weather fish trap that catches both upstream and downstream migrants simultaneously and discusses the problems and results of its operation.

STREAM SYSTEM DESCRIPTION

The trap is located on Spawn Creek, a small tributary of Temple Fork and the Logan River, approximately 24 km (15 miles) northeast of Logan in northern Utah. The stream drains an area of 1381.8 ha (3412 acres), flowing over a distance of 3.77 km (2.34 miles) at an average width of 2.14 m (7.03 ft). Average watershed elevation is 2314 m (7501 ft), ranging from 1814 to 2749 m (5950 to 9018 ft).

Average annual discharge from the watershed approximates 0.28 m³/sec (10 cfs), ranging from 0.17 to 0.42 m³/sec (6 to 15 cfs) at the trap site. Maximum flow normally occurs during the snowmelt period of May and June, but varies with climatic conditions. Upon completion of snowmelt, the stream drops to a low level and remains low through

¹ Accepted June 1975.

the remainder of the year. High intensity summer and fall thunder-showers may increase discharge for short time periods, but normally have only minor effects.

Climatic conditions at the site are relatively severe. Air temperatures, which can fall as low as -26C (-15F) during the winter months, and water temperatures, which can drop as low as 1.1C (34F), occasionally result in anchor ice formation.

Four fish species inhabit Spawn Creek: cutthroat trout, *Salmo clarki* Richardson; rainbow trout, *Salmo gairdneri* Richardson; brown trout, *Salmo trutta* Linnaeus; and brook trout, *Salvelinus fontinalis* Mitchell.

CONSTRUCTION AND INSTALLATION

All wooden components of the trap in contact with water were built of redwood. The trap superstructure was constructed of 2 inch x 12 inch x 20 ft (5 cm x 30 cm x 6.1 m) redwood planks laid three high for side walls and ten wide for the bottom (Figure 1). An additional 2 inch x 12 inch (5 cm x 30 cm) plank extending beyond the upstream boundary of the trap and past the downstream trap box on each side was later added to the superstructure to prevent splashing over the sides during high flows. A watertight tongue and groove joint between planks was formed by routing a $\frac{1}{2}$ inch (1.3 cm) wide and 1 inch (2.5 cm) deep groove along each long edge and gluing a $\frac{1}{2}$ inch (1.3 cm) redwood strip into the groove between planks.

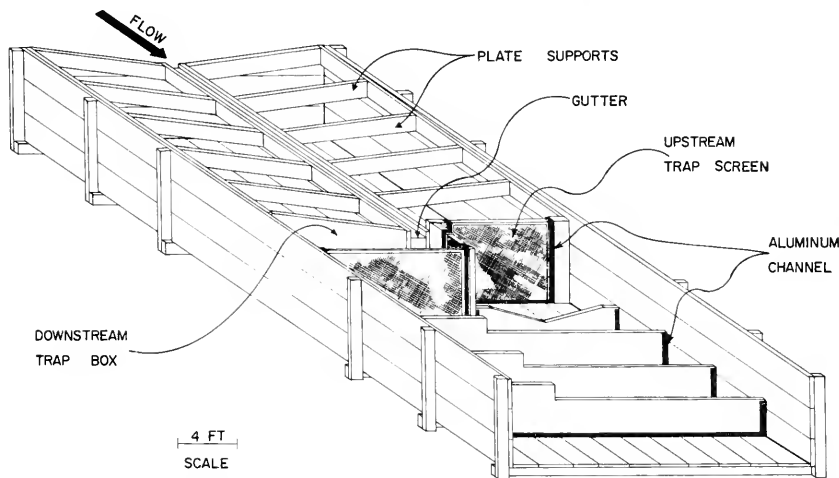


FIGURE 1. Schematic diagram of trap design (metal plates, bracing rods, and tail screen deleted).

A gutter was formed by a 4 inch x 6 inch x 10 ft (10 cm x 15 cm x 3.1 m) beam sided by 2 inch x 6 inch x 10 ft (0.8 cm x 2.4 cm x 3.1 m) boards. Metal plate supports of 2 inch x 6 inch (5 cm x 15 cm) boards, slanted 7.5° toward the gutter and inclined 1° downstream, were connected to the main body by 2 inch x 6 inch x 10 ft (5 cm x 15.2 cm x 3.1 m) boards on each side and supported by a vertical post at the downstream end.

Screens of $\frac{1}{8}$ inch (0.32 cm) hardware cloth (No. 8) with metal frames dimensioned 42 inch x 34 inch (107 cm x 86 cm) and 16 inch x 23 inch (40 cm x 58 cm) formed the downstream and interior

walls, respectively, of the downstream trap box. The upstream and exterior walls were formed of redwood (Figure 1). Bracing rods of $\frac{1}{2}$ inch (1.3 cm) metal attached to the superstructure and the gutter beam from the downstream interior corner of the downstream box prevented lateral and downstream movement of the screens (Figure 2b). The upstream trap screen was formed of $\frac{1}{2}$ inch (1.3 cm) hardware cloth (No. 2 x 2) in a 58 inch x 34 inch (122 cm x 86 cm) metal frame.

A tail screen of $\frac{1}{4}$ inch (0.1 cm) hardware cloth (No. 4) in a pivoting metal frame was located inside the superstructure at the immediate downstream boundary to prevent escape of fish during the trap maintenance (Figure 2c).

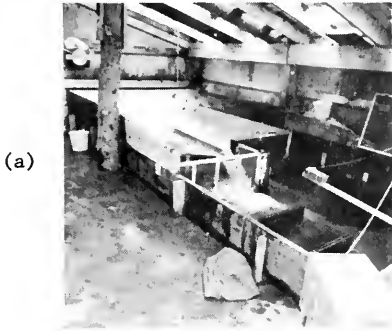


FIGURE 2. (a) Upstream view of trap in operation, (b) downstream trap box, and (c) upstream portion of trap with tailscreen.

Three baffles of 2 inch x 12 inch (5 cm x 30 cm) planks were located equal distances apart in the downstream portion of the trap (Figures 1, 2a, 2c), and were rectangularly notched to widths of 48, 42, and 36 inches (122, 107, and 91 cm) proceeding downstream and depths of 7 and 12 inches (18 and 30 cm) for low and high flow periods, respectively. The baffle dimensions were determined by consideration of hydraulic flow characteristics of the trap. All screens and baffles were positioned in aluminum channels to facilitate easy removal. A series of frames of 2 inch x 4 inch (5 cm x 10 cm) fir lumber were placed around the bottom and sides of the main body for additional support (Figure 1).

The pre-assembled trap was placed into position on a foundation of 9 inch (23 cm) diameter logs placed on the pool bottom and embedded in the stream bank at right angles to the direction of flow. A watertight seal was formed at the upstream end of the trap with clay. A pole-frame building with a wood and translucent fiberglass roof was constructed over the trap assembly to provide adequate work and storage areas (Figure 2a).

OPERATION

The entire streamflow is channeled over the perforated metal plates, and as the water falls through these plates, downstream migrants are forced into the gutter where a minimum continuous flow transports them into the downstream box. The water that has fallen through the metal plates collects in the stilling basin underneath and passes through the upstream screen into the other portion of the trap.

As upstream migrants encounter a barricade, they will hold in the tailwater area for given periods of time (Walburg, Kaiser, and Hudson 1971). The upstream screen provides a barricade while the quiescent sections of the baffled area provide places for migrants to hold. Upon initial access to the trap for fish removal and maintenance, the tail screen should be dropped to deny upstream migrants downstream escape. Fish can be removed from holding areas by dip nets. When the trap is not in use, the upstream screen can be removed and the metal plates can be lifted to allow free passage of migrants.

DISCUSSION

In selection of the type of material for the metal plates, heat conductivity is an important consideration. If the metal will conduct enough heat from the water to keep the temperature of the plates above freezing in the splash zone, the perforations will not freeze shut under most conditions. Relative conductivities of metals may be obtained from Geidt (1957) or any other standard engineering heat transfer text. Selection of a corrosion resistant metal will allow the use of weak acids to remove calcareous sediments from apertures. Decisions as to appropriate materials must be made on an individual basis; weighing the various physical requirements of the site, expected longevity of the facility, and justifiable costs. In construction of the trap superstructure almost any of the usual building materials will do, although a rot-resistant wood (cypress, redwood, etc.) will give a greater adaptability after construction and will better withstand normal, seasonal ground shifts.

If the superstructure extensions begin upstream of the trap mouth, the flow will be more effectively channeled over the metal plates and overflow erosion will be reduced in this area. If these extensions terminate beyond the downstream box, overflow from clogged metal plates will remain within the superstructure. Since the superstructure is butted flush against a natural head formed by a small waterfall, no damming or backing-up of the stream occurs. With little pressure on the forward sections of the superstructure, no heavy, costly buttressing is needed. The baffle that is located furthest downstream should be placed a sufficient distance above the downstream terminus of the superstructure such that the cascading water will fall on the lip of the trap floor. This will eliminate the undercutting component of the current, yet leave the standing wave to facilitate fish entrance.

Operational problems, seasonal and otherwise, which will reduce the period between trap maintenance may be grouped into four categories: ice, detritus, sedimentation, and overflows. Ice will form on any structure where water splashes. This buildup can hinder screen removal and operation of moving parts. Application of a non-stick substance (grease, teflon, etc.) or of heat on trouble areas will reduce this problem (Michel 1971). Detritus will eventually clog all screens and plates unless periodically removed. The selection of aperture sizes in screens and plates just small enough to retain fish of desired size (but no smaller) and the construction of a trash removing device will increase the period of time between maintenance. Unless specially ordered at extreme cost, metal plate pore ratios are dictated by the desired pore size and must be accepted as is from the manufacturer. Sediments will settle into all quiet areas (the downstream box and the baffled areas of the upstream trap) and plug the perforations in the screens and metal plates. These areas may be scooped clean with no long-term impairment of trap efficiency; however, the decreased percentage of holes in the screens and metal plates will reduce trap efficiency significantly. A sediment basin upstream will reduce these problems considerably; the basin should be large enough not only to remove sediments with a diameter the size of the smallest aperture in the trap screens and plates, but also large enough to provide sufficient sediment storage capacity and allow a convenient time interval between basin maintenance operations. Hansen (1973) gives equations for the construction of such facilities. Overflow can occur with freshets and/or the inability of the trap to operate efficiently due to ice, sediment, or detritus build-ups. All of the aforementioned problems as well as freshet overflow can be reduced or eliminated by construction of a facility that is as large as is feasible. The more screen and plate surface area available to plug, the longer the period between trap maintenance.

The trap was placed into use on 21 November, 1973, and one year later had operated successfully for 323 days and had caught 484 migrants. Because extensive spring bedload movement clogged the apertures, the trap was opened for 31 days to allow free passage until an adequate sediment basin could be dug above the trap. Fish censuses which were conducted routinely before and after this period indicated that fish had moved upstream through the trap during this time. Overflow conditions occurred during 11 additional days, and although the trap still caught migrants, their direction of travel could not be ascertained (Table 1).

TABLE 1. Numbers and sizes of migrants in Spawn Creek from November 21, 1973, to November 20, 1974.

	Numbers ¹		Size Ranges (TL mm)	
	Down	Up	Down	Up
Cutthroat Trout.....	335	57	31-324	81-292
Brown Trout.....	37	22	71-265	86-338
Brook Trout.....	5	1	87-223	223-223
Rainbow Trout.....	--	2	--	240-250

¹ When overflow conditions occurred, 13 fish that were caught could not be designated as either immigrants or emigrants, and are subsequently not included in this table.

Trap maintenance schedules varied from a daily pattern at times in the late spring and early fall to a weekly pattern in the winter. Trap-related mortality occurred in the following manner: nine died from entrapment in litter on the metal plates (mostly 0+ age fish), two died by injury from sediments, one died from entrapment in screens and plate joints, and six succumbed from unknown causes. Care must be taken to sift piles of litter that form on the metal plates, as most of the small fish which are entrapped therein are still alive. Table 1 lists the numbers and sizes of the fishes caught.

Since the cutthroat trout is the most abundant and widespread of the fish species in the stream, it constitutes the greatest segment of the migrant population. The brown trout and brook trout populations are segregated in low and high elevations of the watershed, respectively; this arrangement is typical in intermountain streams (Miller 1967). Since the trap was placed at a low stream elevation, the respective proximities of these two populations to the facility partially explains their contributions to the migrant population. Rainbow trout are planted outside the Spawn Creek watershed and occasionally become upstream migrants.

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FISHES COLLECTED BY PIGEON GUILLEMOTS, *CEPPHUS COLUMBA* (PALLAS), NESTING ON SOUTHEAST FARALLON ISLAND, CALIFORNIA¹

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Twenty-four species of marine fishes obtained from nests of pigeon guillemots (*Cepphus columba*) during 1971-1974 on Southeast Farallon Island, California, increase to 42 the number of species of fishes known as prey of pigeon guillemots. Five species are rare: the rockhead (*Bothragonus swanii*), frogmouth sculpin (*Icelinus oculatus*), darter sculpin (*Radulinus boleoides*), an undescribed bathymasterid, and an undescribed cebidichthyid. Sculpins (Cottidae), constituting 52% of the material, indicate that pigeon guillemots forage within the benthic environment; one species has been recorded off California only between depths of 170 and 227 m (93 and 124 fm).

INTRODUCTION

Field work during the summers of 1971-1974 by Ainley has enabled us to record 24 species of fishes collected by pigeon guillemots, *Cepphus columba* (Pallas), nesting on Southeast Farallon Island, California. This island is 37 km (23 miles) SW from Point Bonita at the entrance to San Francisco Bay. Only two of these species have, to our knowledge, been previously recorded as prey of pigeon guillemots.

The capture of fishes by pigeon guillemots breeding on Southeast Farallon Island was mentioned by Bryant (1888), Blankinship and Keeler (1892), and Bent (1919), but none of the fishes was identified.

The specimens of the present collection were found in or near nests of the pigeon guillemots. One species is recorded on the basis of a sight record: a 75-mm (3-inch) fish held in the bill of an adult pigeon guillemot at a distance of about 3 m (10 ft) from the observers (Ainley and Higbee) for some 2 min was recognized as a juvenile ratfish from its silver coloration, large pectoral fins, prominent dorsal "spine," inferior mouth, and attenuate caudal fin.

The material (except the ratfish) is deposited in the Department of Ichthyology, California Academy of Sciences.

For figures and keys for the identification of all fishes represented in this collection (except the two undescribed forms), see Miller and Lea (1972).

FISHES REPRESENTED

The 78 fishes (including the ratfish) collected by the pigeon guillemots represent 24 species, 19 genera, and 10 families (Table 1). Size of the specimens is expressed as standard length (tip of snout to structural base of caudal fin) rather than as total length because many of the specimens are in poor condition and lack the caudal fin.

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TABLE 1. Names, Number, and Length (mm SL²) of Fishes Collected by Pigeon Guillemots on Southeast Farallon Island, California, 1971-1974.

Common name	Scientific name	N ³	Length
Chimaeras	Chimaeridae		
Ratfish.....	<i>Hydrolagus collicii</i> (Lay and Bennett).....	1	±75 ⁴
Scorpionfishes	Scorpaenidae		
Yellowtail rockfish.....	<i>Sebastes flavidus</i> (Ayres).....	1	56
Shortbelly rockfish.....	<i>Sebastes jordani</i> (Gilbert).....	2	59-83
Black rockfish.....	<i>Sebastes melanops</i> Girard.....	1	38
Blue rockfish.....	<i>Sebastes mystinus</i> (Jordan and Gilbert).....	1	46
Canary rockfish.....	<i>Sebastes pinniger</i> (Gill).....	9	51-64
Sculpins	Cottidae		
Scalyhead sculpin.....	<i>Artedius harringtoni</i> (Starks).....	2	56-60
Roughback sculpin.....	<i>Chitonotus pugetensis</i> (Steindachner).....	2	75-113
Brown Irish lord.....	<i>Hemilepidotus spinosus</i> Ayres.....	15	68-116
Frogmouth sculpin.....	<i>Icelinus oculatus</i> Gilbert.....	1	119
Spotfin sculpin.....	<i>Icelinus tenuis</i> Gilbert.....	1	50
Saifin sculpin.....	<i>Nautichthys oculoasciatus</i> (Girard).....	1	98
Snubnose sculpin.....	<i>Orthonopias triacis</i> Starks and Mann.....	8	39-59
Darter sculpin.....	<i>Radulinus boleoides</i> Gilbert.....	1	99
Grunt sculpin.....	<i>Rhamphocottus richardsoni</i> Gunther.....	3	38-61
Cabezon.....	<i>Scorpaenichthys marmoratus</i> Girard.....	6	42-71
Poachers	Agonidae		
Rockhead.....	<i>Bothragonus swanii</i> (Steindachner).....	7	36-42
Pygmy poacher.....	<i>Odontopyxis trispinosa</i> Lockington.....	1	±52
Ronquils	Bathymasteridae		
.....	<i>Rathbunella</i> sp. n. ⁵	1	83
Kelpfishes	Clinidae		
Crevice kelpfish.....	<i>Gibbonsia montereyensis</i> Hubbs.....	2	60-64
Monkeyface-eels	Cebidichthyidae		
.....	Gen. n., sp. n. ⁵	2	65-72
Pricklebacks	Stichaeidae		
Mosshead warbonnet.....	<i>Chirolophis nugator</i> (Jordan and Williams).....	3	67-±94
Gunnels	Pholidae		
Red gunnel.....	<i>Pholis schultzi</i> Hubbs.....	2	79-±83
Lefteye flounders	Bothidae		
Speckled sanddab.....	<i>Citharichthys stigmaeus</i> Jordan and Gilbert.....	5	52-89

² Standard length.³ Number of specimens.⁴ Total length.⁵ To be described by John E. Fitch and Robert J. Lavenberg.⁶ To be described by Carl L. Hubbs.

DISCUSSION

Some of the species represented in this collection may descend only as far as the subtidal zone; others, to various depths between that zone and about 400 m (1,320 ft). Most of them (excepting the deep-water sculpins discussed below, but including the juvenile stages of the rockfishes) may at times be found near the surface or within the intertidal zone. They commonly occur on or over rocky bottom.

Juvenile canary rockfish, 38-45 mm (1.5-1.8 inches) SL (only slightly smaller than those of the present collection) were taken by Follett within the intertidal zone at Trinidad Harbor, Humboldt

County, California, and at Point St. George, Del Norte County, California. Adult canary rockfish were taken at depths of 51.2 and 73.2 m (28 and 40 fm) at Cordell Bank, 43.5 km (27 miles) NW of Southeast Farallon Island (Follett 1952), and this species was said by Phillips (1964) to descend to 201.2 m (110 fm).

Juvenile speckled sanddabs were taken by Follett in a sandy area within the intertidal zone in San Francisco Bay. This species was recorded as the dominant fish in sand-bottom habitat, at depths inside the 50-m (165 ft) contour, near San Diego, California (Hubbs, Kelly, and Limbaugh 1970).

That pigeon guillemots do not forage extensively within the intertidal zone is suggested by the absence from this collection of such cottids as the bald sculpin, *Clinocottus recalvus* (Greeley); rosy sculpin, *Oligocottus rubellio* (Greeley); and fluffy sculpin, *Oligocottus snyderi* (Greeley); all three of which were collected within the intertidal zone on Southeast Farallon Island by Follett.

Absence of such stichaeids as the ribbon prickleback, *Phytichthys chirus* (Jordan and Gilbert); black prickleback, *Xiphister atropurpureus* (Kittlitz); and rock prickleback, *Xiphister mucosus* (Girard); and of such pholids as the rockweed gunnel, *Xererpes fucorum* (Jordan and Gilbert); all four of which were collected at Southeast Farallon Island by Follett, might suggest that these elongate fishes, adept at concealing themselves in rocky crevices, are usually able to elude pigeon guillemots. However, both these species of *Xiphister* were observed among the food materials of pigeon guillemots nesting on islands of the Washington coast (Thoresen and Booth 1958; *Xiphister atropurpureus* recorded as *Epigeichthys*).

Four of the sculpins collected provide some indication of the considerable depths, off California, to which pigeon guillemots may pursue their prey, and the character of the bottom on or over which they sometimes forage. The roughback sculpin has been reported as "common on sandy bottoms in from 20 to 58 fathoms," the spotfin sculpin as "not rare on sandy bottoms in from 18 to 204 fathoms," and the frogmouth sculpin as "taken on soft bottoms in depths between 93 and 124 fathoms" (Bolin 1944); the darter sculpin as taken on a fine gray sand bottom in 146 m (80 fm) (Jordan and Evermann 1898, Townsend 1901).

Among the fishes represented in the present material, the following are rare: The frogmouth sculpin, known only from three specimens taken in California, one in Oregon, and one in British Columbia (McPhail 1969); darter sculpin, known only from two specimens taken in California (Bolin 1944) and two in British Columbia (Hart 1973); rockhead, first recorded from California waters by Haig (1951); the undescribed species of *Rathbunella*; and the undescribed cebidichthyid.

The two species represented in this collection that were previously known as prey of pigeon guillemots are the shortbelly rockfish, taken at Point Lobos Reserve, Monterey County, California (Legg 1954); and the grunt sculpin, taken at Mandarte Island, British Columbia (Drent 1965).

This collection is more diverse in number of species that those previously recorded as prey of pigeon guillemots: 2 species were recorded by Legg (1954), 7 species by Thoresen and Booth (1958), and 11 spe-

cies by Drent (1965). So far as we have found, this collection increases to 42 the number of species of fishes known as prey of the pigeon guillemot.

The 10 species of cottids, represented by a total of 40 specimens, 52% of the present collection, reveal the tendency of pigeon guillemots to forage within the benthic environment.

ACKNOWLEDGMENTS

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STURGEON SPAWNING IN THE SACRAMENTO RIVER IN 1973, AS DETERMINED BY DISTRIBUTION OF LARVAE¹

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To determine the time and location of sturgeon spawning in the Sacramento River, California, sampling was conducted three times per week from March 5 to June 17, 1973 at six locations from the mouth of the Feather River to above Red Bluff. A total of 246 larvae and nine eggs was collected at the mouth of the Feather River, at river km 180 (river mile 112), and at Colusa. Spawning probably occurred from the vicinity of Knights Landing to just above Colusa. Spawning occurred from mid-February to late May, although the majority (93%) was in March and April. Water temperatures during those 2 months ranged from 7.8 to 17.8 C (46 to 64 F). Spawning peaked from April 8 to 17 at a temperature of approximately 14.4 C (58 F). Mean size of larvae increased each month, probably because the growth rate increased with water temperature. Both white sturgeon (*Acipenser transmontanus*) and green sturgeon (*A. medirostris*) occur in the Sacramento-San Joaquin Estuary. While the larvae could not be identified, most were probably white sturgeon since that species dominates the Sacramento River sturgeon fishery.

INTRODUCTION

Information about the spawning of sturgeon in the Sacramento-San Joaquin Estuary, California, is very limited. Until 1965, nothing was known. That year two sturgeon larvae were collected in the Sacramento River near Rio Vista during a striped bass spawning survey. During surveys in 1966, 1967, and 1968, sturgeon larvae were captured in the Sacramento River as far upstream as Verona and in the Sacramento-San Joaquin Delta (Stevens and Miller 1970). During spring 1972 a few larvae were taken as far upstream as Colusa (Jerry Turner, Calif. Dept. Fish and Game, unpublished).

My study was designed to determine the time and location of sturgeon spawning in the Sacramento River by collecting larvae as they moved downstream after hatching.

MATERIALS AND METHODS

Six sampling locations were chosen at 51-64 km (32-40 mile) intervals on the Sacramento River from the mouth of the Feather River to above Red Bluff (Figure 1). Sampling sites were above the mouth of the Feather River at river km (rkm) 129 (river mile [rm] 80); rkm 180 (rm 112); Colusa, rkm 233 (rm 145); Ord Bend, rkm 297 (rm 185); Woodson Bridge, rkm 351 (rm 218); and Bend Bridge, rkm 412 (rm 256). It was necessary to terminate sampling at Ord Bend and sample at Pine Creek, rkm 317 (rm 197), approximately half-way through the survey (Figure 1).

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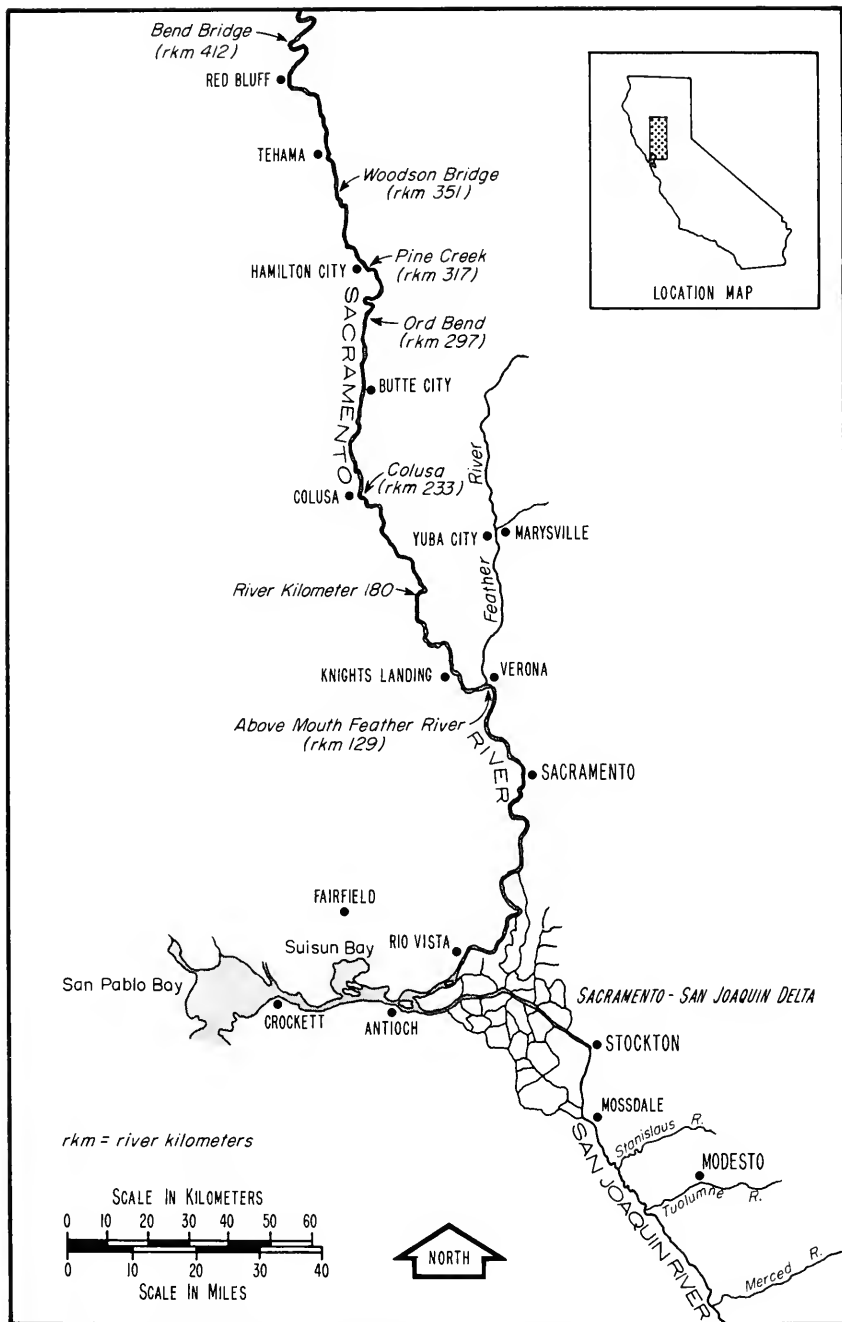


FIGURE 1. Sturgeon larvae sampling sites on the Sacramento River in 1973.

Collections were made three times per week (usually on Monday, Wednesday, and Friday) at each site from March 5 to June 17, 1973. Sampling was occasionally omitted because of equipment failure, dangerous river flows, and silted launching ramps.

Two boats were used for sampling, one for the lower two stations and the other for the upper four.

Larvae were collected with a cone-shaped net constructed of 7.9 mesh/cm (20 mesh/inch) marquisette nylon netting, 3.4 m (11.2 ft) long, and 0.8 m (30 inches) wide at the mouth. This net was attached to an inverted U-shaped frame (1.3 cm [0.5 inch] ID galvanized iron pipe) with a circumference of approximately 2.3 m (7.5 ft). A polyethylene collecting jar was attached to the cod end. A 6 cm by 8 cm (2.4 by 3.1 inch) hole on one side of the jar was screened with 11.8 mesh/cm (30 mesh/inch) stainless steel bolting cloth.

The net was fished from an anchored boat. Two lead weights on each end of the frame held the net near the river bottom. The bottom of the mouth was approximately 10 cm (4 inches) above the substrate. Previous studies demonstrated that sturgeon larvae in the Sacramento River concentrate near the bottom (Stevens and Miller 1970).

Net sets varied from 5 min to 1 h, depending on the amount of debris collected. When sampling time was short, sets were repeated for a cumulative total of at least 30 min. These periods exclude raising and lowering the net.

Surface water temperatures were measured at each station while the net was fishing.

Samples with little debris were sorted in the field and the larvae were preserved in 10% formalin. Samples with large amounts of debris were preserved with 10% formalin containing Rose Bengal dye to stain the larvae. These samples were returned to the laboratory for sorting.

Larvae which were not crushed or deformed during collection were measured to the nearest 0.1 mm (0.004 inch) using a microprojector.

A survey of striped bass spawning occurred in the lower half of the study area between May 1 and June 20, 1973. Sturgeon larvae collected during that survey were also enumerated and measured.

RESULTS

Catch

I collected 246 sturgeon larvae and nine sturgeon eggs. Eleven additional larvae were taken in the study area during the striped bass spawning survey. Sturgeon eggs are demersal and adhesive (Dees 1961; Nikolskii 1961), so the egg catch was expected to be small.

Larvae and eggs were collected only at the lower three stations. A total of 130 larvae and six eggs were captured at Colusa, 102 larvae and two eggs at rkm 180 (rm 112), and 14 larvae and one egg above the mouth of the Feather River (Figure 2). Mean catch per 30 min sample was 2.8 larvae at Colusa, 2.2 at rkm 180 (rm 112), and 0.2 at the Feather River.

Larvae were taken on the first day of sampling at Colusa and rkm 180 (rm 112). Catches peaked at Colusa on April 23 (49 larvae), at rkm 180 (rm 112) on March 19 (19 larvae), and at the Feather River on March 23 (4 larvae) (Figure 2). The last larvae were caught at Colusa on June 3, rkm 180 (rm 112) on May 17, and above the mouth of the Feather River on April 23.

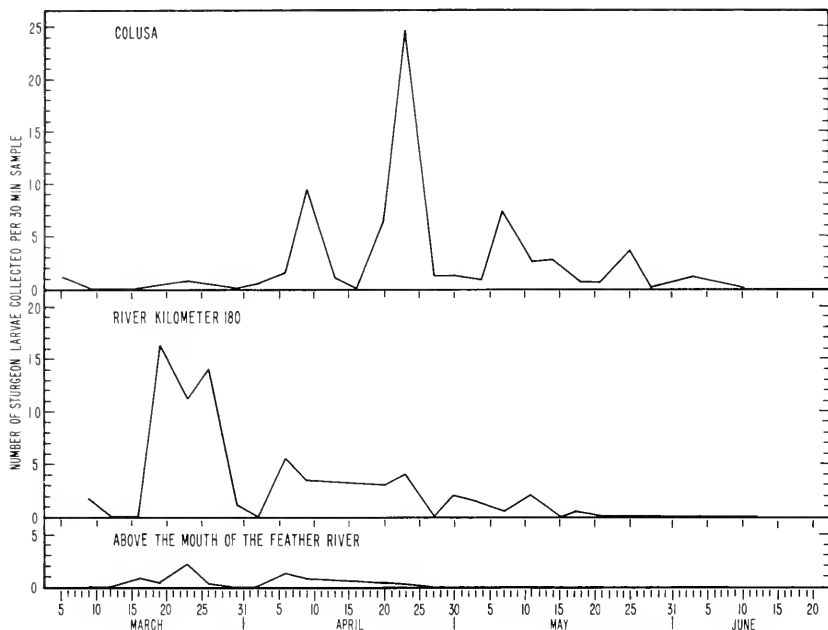


FIGURE 2. Temporal distribution of larval sturgeon caught during the sturgeon spawning survey in the Sacramento River in 1973.

Size

Mean length of the 206 sturgeon larvae measured was 11.6 mm (0.5 inch). One larvae was 5.2 mm (0.2 inch) long; the rest were between 7.2 and 19.5 mm (0.3–0.8 inch). Length frequency distributions were about the same for the three stations and differences in mean lengths between stations were not significant ($F = 0.69$, $P = 0.50$) (Figure 3). Length frequencies in different months were basically similar, but mean size increased slightly each month ($F = 3.75$, $P < 0.05$) (Figure 4), possibly reflecting a direct relationship between growth rate and water temperature.

Spawning Time, Temperature, and River Flow

Larval catches did not provide a direct measure of spawning time due to variable time lags between spawning and capture. To estimate spawning time, I assumed Sacramento River sturgeon developed at rates reported for European and Asiatic species (Cherfas 1956; Nikolskii 1961; Geibel 1966). These rates depend on temperature and are known for the incubation period and for the interval from hatching to active feeding. Only three of the 206 larvae I measured were shorter than 8 mm (0.3 inch) (Figure 4), so I assumed that was the approximate length at hatching. Larvae longer than 18 mm (0.7 inch) had well-developed mouthparts, had absorbed their yolk sacs, and had probably begun to feed. I used regressions of developmental rate on temperature (Figure 5) to estimate larval ages at 8 and 18mm (0.3 and 0.7 inches)

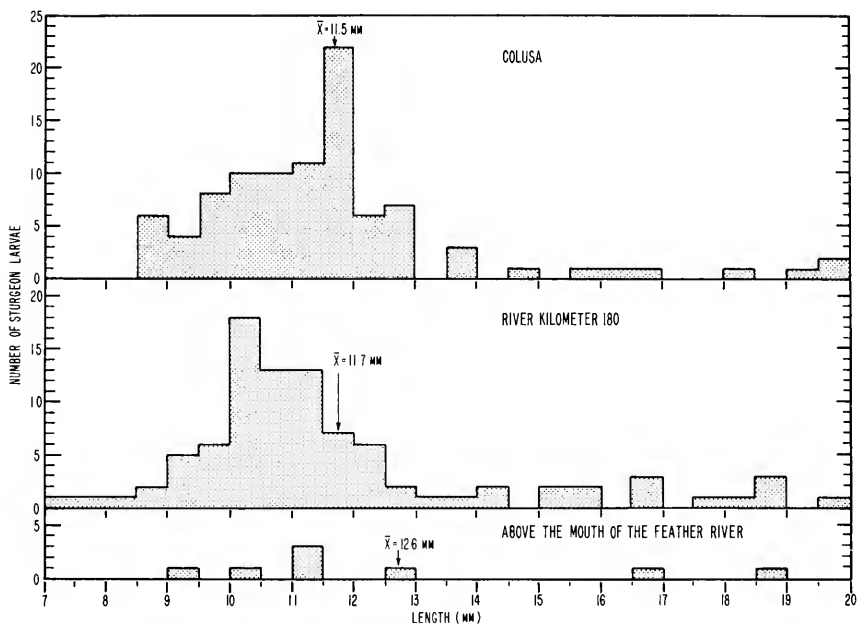


FIGURE 3. Length frequencies and mean lengths of sturgeon larvae collected during the sturgeon spawning survey in the Sacramento River in 1973, arranged by sampling locations.

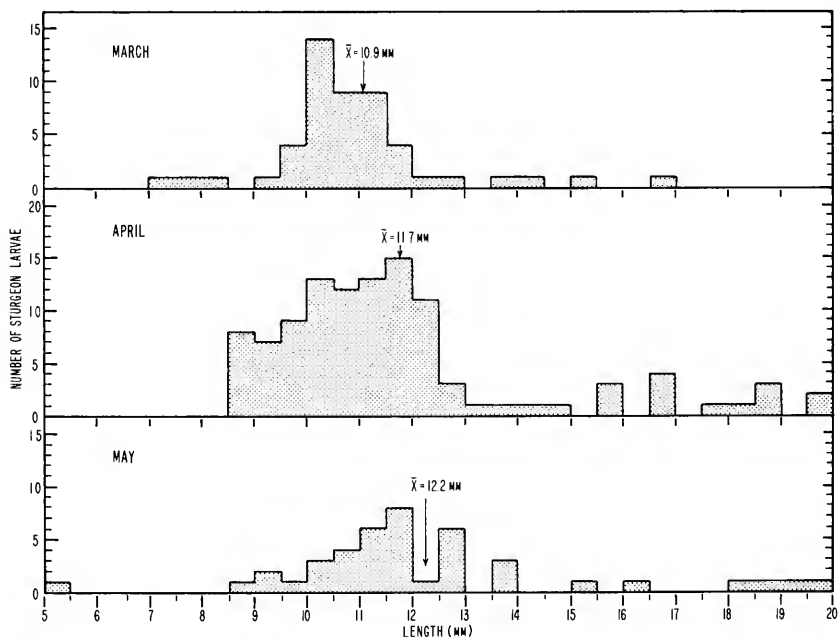


FIGURE 4. Monthly length frequencies and mean lengths of sturgeon larvae collected during the sturgeon and striped bass spawning surveys in the Sacramento River in 1973. June is omitted since only 5 larvae were collected then.

for temperatures observed during spawning and assumed linear growth between these ages (Figure 6). Since larval lengths at capture and approximate water temperature during development were known, the age of each larva (from spawning) could then be interpolated from Figure 6. These ages ranged from 5 to 25 days and averaged 12.4 days. They were subtracted from capture dates to calculate spawning dates.

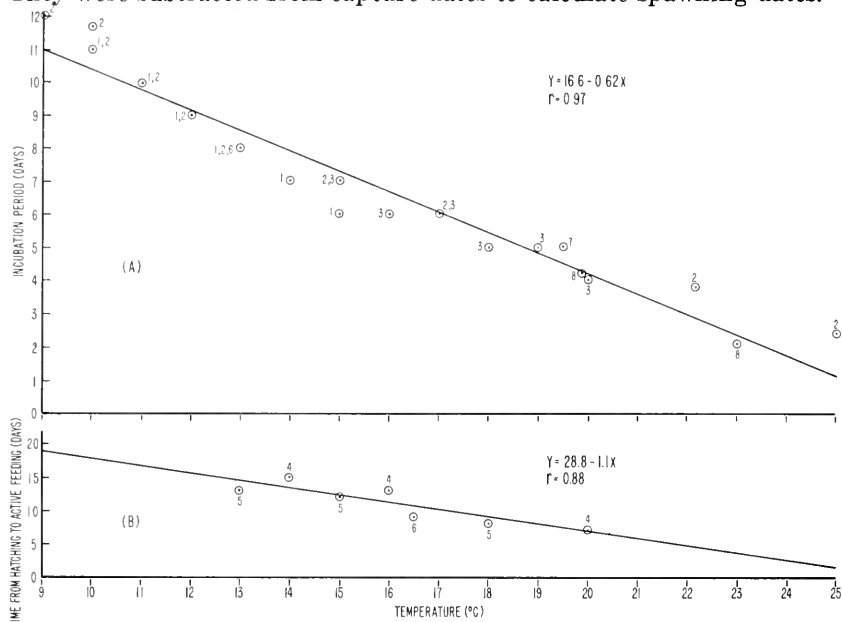


FIGURE 5. Relationship between water temperature and sturgeon larval development, derived from the following sources and species:

Geibel 1966

1. *Huso huso*

2. *Acipenser guldenstadti*

3. *A. stellatus*

Cherfas 1956

4. *A. guldenstadti*

5. *H. huso*

Nikolskii 1961

6. *H. huso*

7. *A. nudiventris*

8. *A. stellatus*

Line (A) was assumed to represent larvae 8 mm long and line (B) was assumed to represent larvae 18 mm long.

Estimated spawning occurred from mid-February to late-May, with 93% between March 3 and May 5 (Figure 7). During this two-month period, water temperature was 7.8–17.8 C (46–64 F). Maximum spawning (April 8–17) occurred at approximately 14.4 C (58 F). Maximum temperature during the spawning period was 22.2 C (72 F). There was no relationship between changing water temperature and spawning intensity.

River flows had no effect on sturgeon spawning intensity. While most spawning occurred during periods of decreasing flows, this is the dominant flow regime during the spring. There was no obvious flow threshold at which spawning was initiated.

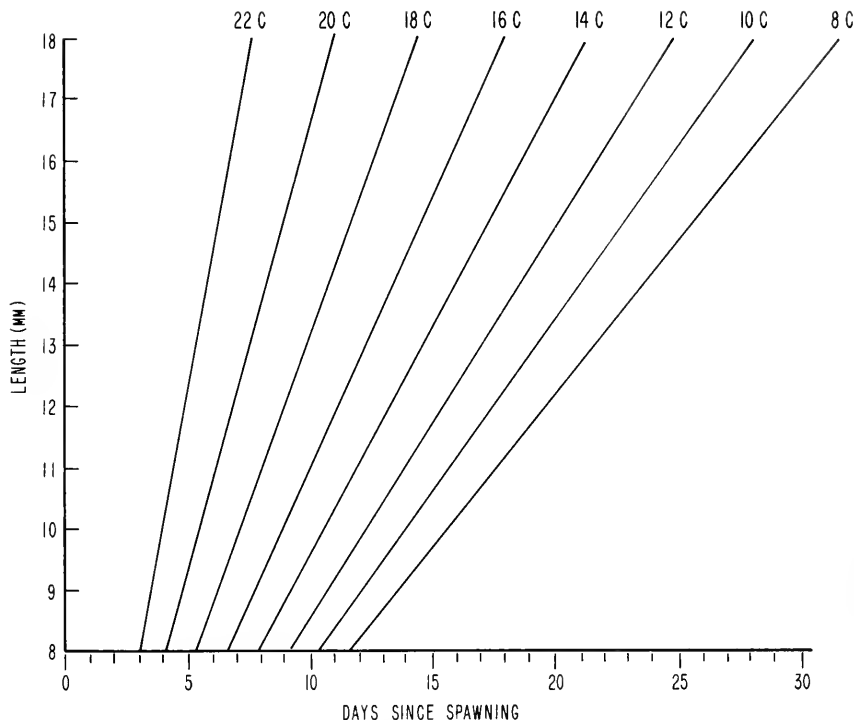


FIGURE 6. Relationship between age (since time of spawning) and length of sturgeon larvae at various water temperatures observed during sampling in the Sacramento River in 1973. These relationships were estimated from the regressions in Figure 5. If larval length and approximate developmental temperature are known, an estimate of larval age can be interpolated from this graph.

DISCUSSION

While small, the catch of 246 larvae provided good information on the location and timing of sturgeon spawning in the Sacramento River in spring 1973. The majority of spawning occurred from the vicinity of Knights Landing upstream to just above Colusa. Spawning was most intense during March and April, but probably began before mid-February since larvae were captured on the first day of sampling.

Information from my study generally agrees with that for other species of sturgeon in other river systems. Spawning dates for many species range from March to early July and spawning temperatures range from 9 to 24 C (48 to 75 F) (Nikolskii 1961; Berg 1962; Geibel 1966; Magnin 1966). Some European sturgeon have two or more races migrating and spawning at different times (Gerbilskii 1951; Nikolskii 1961; Berg 1962). My study was not designed to determine if several spawning races exist in the Sacramento River system; however, the seasonal nature of sport catches (Miller 1972) suggests that the run of sturgeon moving upriver in late winter and spring is the major, if not the only, spawning group.

Sturgeon spawning sites are described as having gravelly or rocky bottoms where currents are moderate to fast (Dees 1961; Nikolskii 1961;

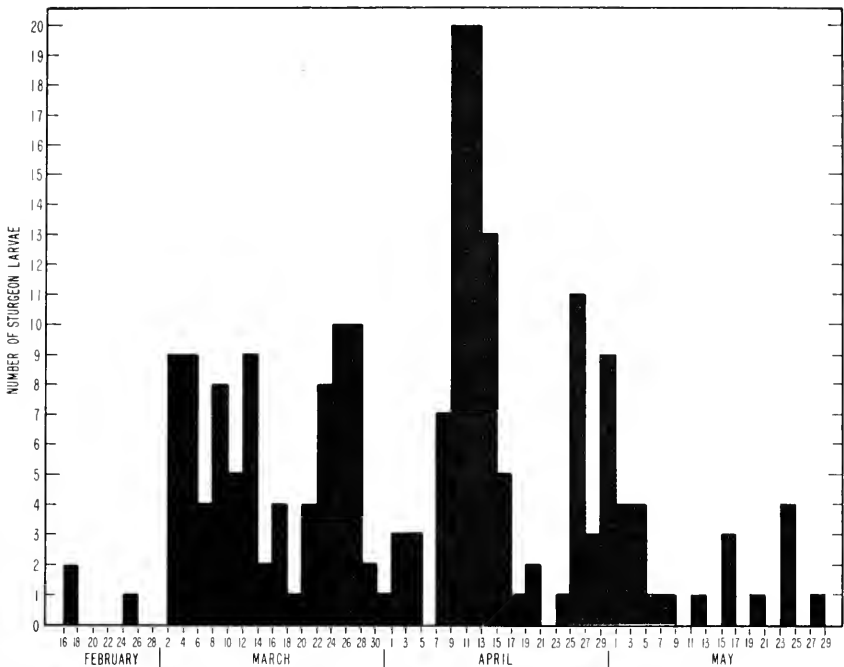


FIGURE 7. Sturgeon spawning periodicity in the Sacramento River in 1973, estimated from larval ages interpolated from Figure 6.

Berg 1962; Geibel 1966; Magnin 1966). Such conditions mainly occur upstream from Colusa in the Sacramento River. Below Colusa the river has a mud and sand bottom and moderate current. Since the spawning area apparently did not extend far above Colusa in 1973, my study disagrees with published descriptions.

Sturgeon probably spawn farther upstream in the Sacramento River than my study suggests. Between June 17 and July 10, 1974, 12 young sturgeon about 25–60 mm (1.0–2.4 inches) were collected at the intake of the Glenn-Colusa Canal near Hamilton City (rkm 330 [rm 205]) (Jerry Wise and Ronald Decoto, Calif. Fish and Game, pers. commun.). Therefore, either sturgeon spawned farther upstream in 1974 than in 1973, or the 1973 survey techniques were inefficient for catching larvae in that section of the river.

The sturgeon nursery is apparently formed by both the river near and below the spawning area and the Delta and bays downstream. Many larvae are flushed to the Delta and Suisun Bay in years with high runoff, but they are scarce there in years with low runoff (Stevens and Miller 1970). Hence, immigration age to these areas must vary with spring river flow. Spring 1974 flows were high, so the collection of juveniles near Hamilton City that summer and the scarcity of larvae in the Delta when flows are low suggests the river is an important nursery in all years. Although I did not catch sturgeon older than about 16 days, my stationary nets probably did not fish efficiently for them.

My larvae were not developed enough to be identified to species with existing knowledge. Identification requires counts of scutes along the lateral line, gill rakers, or dorsal fin rays (Schreiber 1960). Except for the small size (5.2 mm [0.2 inch]) and dark pigmentation of one sturgeon larva caught during the striped bass spawning survey, the larvae had no obvious features implying more than one species was caught. The predominance of white sturgeon in the system (Miller 1972) suggests that most of the larvae were white sturgeon. The small, dark specimen may have been a green sturgeon. A 60 mm (2.4 inch) juvenile taken at Hamilton City in 1974 was developed enough to be identified as that species, indicating green sturgeon do spawn in the river.

My study made no attempt to determine the existence or extent of sturgeon spawning in the San Joaquin River. Sturgeon larvae have been taken on the San Joaquin side of the Delta, but these could have come from the Sacramento River (Stevens and Miller 1970). Anglers often catch sturgeon in late winter and early spring in the San Joaquin River between Mossdale and the mouth of the Merced River. This migration is probably for the purpose of spawning, but no definitive evidence for this exists.

ACKNOWLEDGEMENTS

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THE ECOLOGY OF THE GAPER OR HORSE CLAM, *TRESUS CAPAX* (GOULD 1850) (BIVALVIA: MACTRIDAE), IN HUMBOLDT BAY, CALIFORNIA¹

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The gaper clam populations of Humboldt Bay, California were studied from June 1969 through July 1973. Recruitments occurred primarily in the early spring of 1970 and 1971 and were not uniform in the clam beds. The beds were dominated by certain age classes but an age class did not necessarily dominate samples. Within samples no correlation existed between the density of established clams and the density of recruits. The spatial distribution generally was either random at low densities or aggregated at high densities. The standing crops for various beds were determined. Growth rates differed significantly between beds and between year classes within a bed. Von Bertalanffy growth equations were generated for various beds. Growth occurred primarily during the late spring and summer. Mortality of recruits was very high in 1970 and 1971 resulting in unsuccessful recruitment. Successful recruitment has not occurred since 1966. Adult mortality was very high in some beds. Predation by the moon snail, *Polinices lewisii*, Dungeness crab, *Cancer magister*, and a sea star, *Pisaster brevispinus*, was observed.

INTRODUCTION

The gaper or horse clam, *Tresus capax* (Gould), ranges from central California to Alaska (Morris 1966). The ecology of the gaper clam is poorly known even though the species is utilized as a sport clam. Its use as a commercial species has been encouraged in British Columbia (Bourne and Smith 1972b). The purpose of this study was to obtain ecological information which will aid in the management of the gaper clam in Humboldt Bay.

MATERIALS AND METHODS

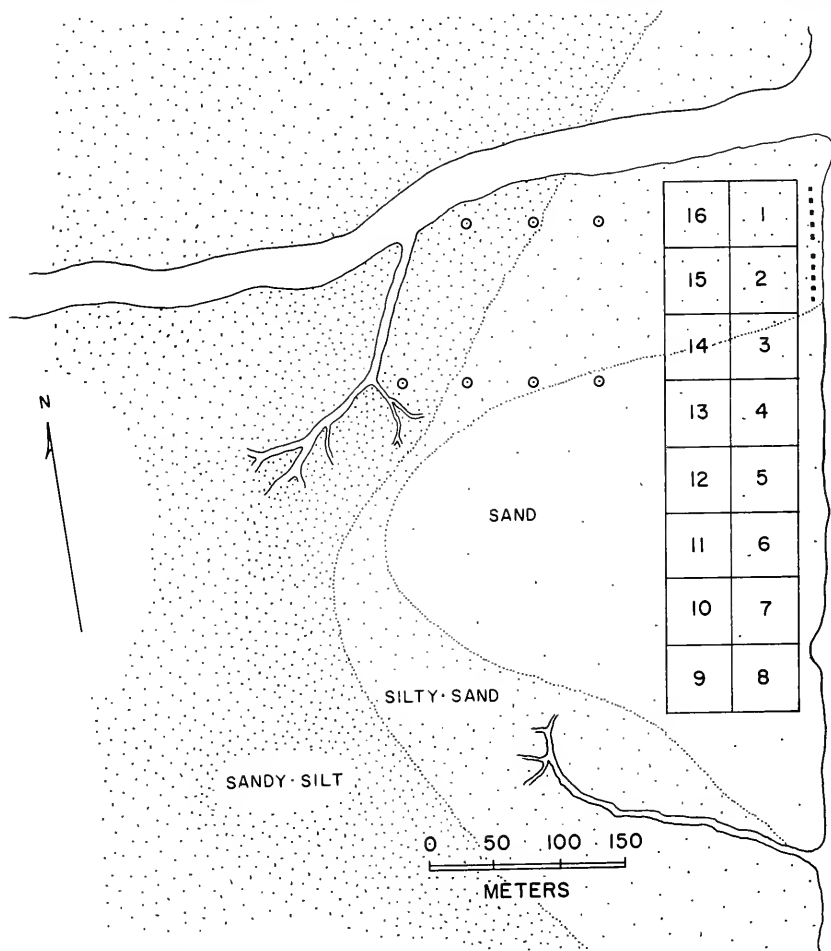
The study areas in Humboldt Bay were below datum and consisted of single or sets of 2500 m² (26,910 ft²) plots (each symbolized by Q), transects, and areas where samples were non-randomly collected. Most of the study was conducted in the Primary Study Area located along the western margin of Southport Channel. This area was divided into 16 contiguous plots (Q₁-Q₁₆) (Figure 1). Additional plots were

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established on Clam Island ($Q_{A, B, C, \text{ and } E}$), Gunther Island (Q_D), and Buhne Point. Supplemental data was collected from Woodley Island, the mouth of Elk River, and four subtidal areas off Clam Island, Buhne Point, and the bay margin of North and South Spit (Figure 2).

The number of samples and methods of obtaining samples varied according to the type of data desired. Sampling quadrats of 0.25 m^2 (2.7 ft^2) were taken for assessing growth, mortality and spatial distribution of recruits. Recruits are clams that entered the fishery during a given year of study. Each 0.25 m^2 sample was screened in the field with standard sieves. Initially, 1-mm (0.04-inch) mesh screens were used to retain young recruits and with their subsequent growth 2-mm (0.08-inch) mesh screens were used. Following collection, the recruits were relaxed in isotonic MgCl_2 , fixed in 10% formalin and preserved in 70% isopropyl alcohol. Study areas were sampled as frequently as tidal conditions allowed in 1970 and 1971. For studying growth and



© transect sampling sites

FIGURE 1. Location of plots (Q 's) of Primary Study Area and of sampling sites east and west of Primary Study Area.

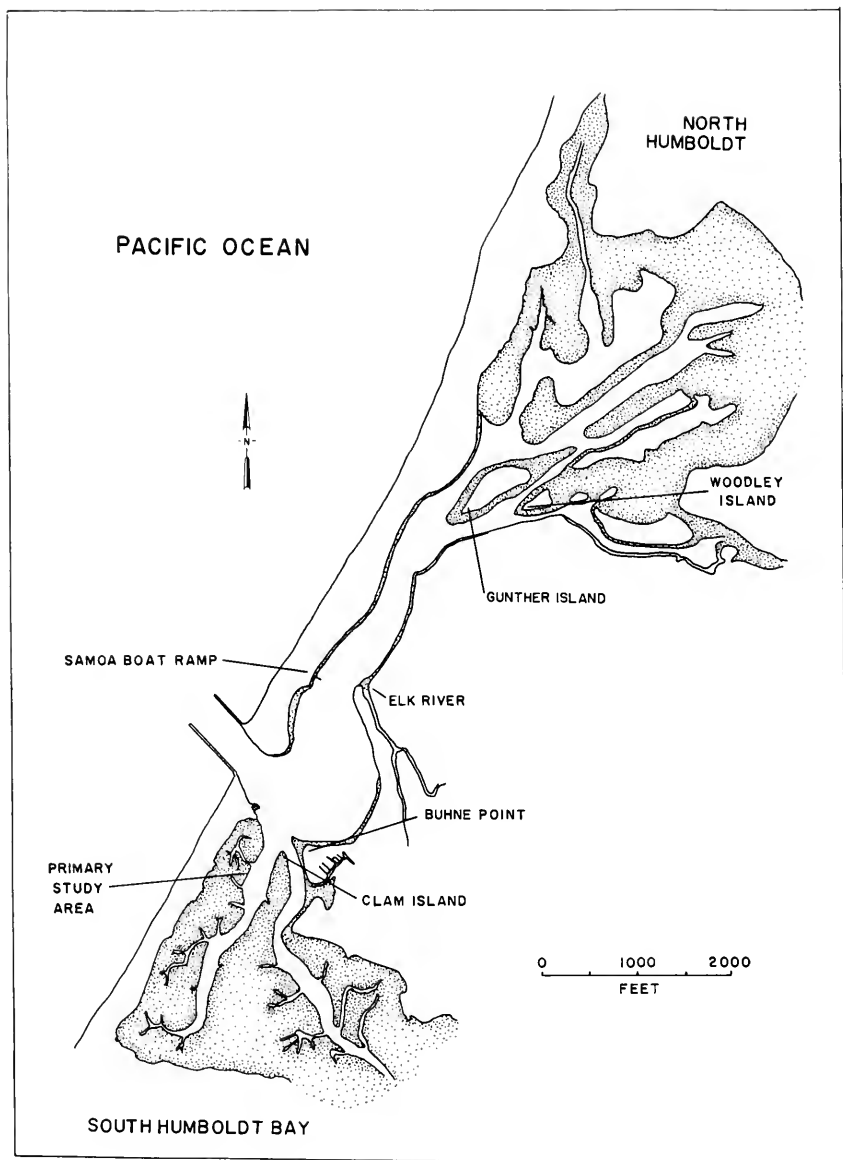


FIGURE 2. Map of Humboldt Bay showing locations of study areas.

mortality of recruits, five random samples were collected from selected plots every 2 or 4 weeks between May 1970 and August 1971. Fifteen random samples were collected from Q_{1, 2, 15} and 16 of the Primary Study Area within a 7-day period for determining the nature of spatial distribution of recruits.

For convenience, clams more than 1 year old will be referred to as adults. Initial sampling for adults took place in the Primary Study Area and consisted of 0.25 m² quadrats. All subsequent intertidal sampling for adults consisted of 0.5 m² (5.4 ft²) quadrats to insure that most samples contained clams. All live clams and shells of recently expired clams were removed from each quadrat and the right valve of each clam, or the left if the right was damaged, was labelled as to sample location and date of collection. A clam was considered recently expired if *in situ* it bore either necrotic tissue or fresh-appearing periostracum. Generally, an annual series of 15 random samples were taken from plots when sampling for adult clams. This sampling began in June 1969 and continued until September 1972. Subtidal regions were sampled by freediving and SCUBA during the summers of 1972 and 1973. Here samples consisted of siphon counts within 0.25 m² quadrats located along transects or chosen non-randomly while diving.

To determine whether the length-width ratio changes with growth, a subsample of 30 recruits from each sampling site were measured to the nearest 0.1 mm (0.004 inch). All valves from adult clams were measured to the nearest mm along the antero-posterior axis and a subsample was taken for measurements of annuli. The wet preserved weight was recorded to the nearest 0.01 g (0.00035 oz) for the 1970 year class recruits. Whole wet body weight and body weight minus shell were also recorded to the nearest 0.1 g (0.0035 oz) for determination of adult length-weight relationships.

RESULTS

Spatial Distribution

Spatial Distribution of Intertidal and Subtidal Adults

Stout (1967) found that gaper clams occurred most abundantly in sand and silty-sand substrates below datum in the intertidal zone of Humboldt Bay. We found that gaper clams also occur subtidally in the bay in similar substrates to a depth of 17 m (56 ft) below datum. Most samples from the major channels of South Humboldt Bay lacked gaper clams and had muddy substrates containing much broken clam shell.

The hypothesis that the spatial distribution of clams within a given intertidal or subtidal bed was random was tested by calculating variance-mean ratios and indices of dispersion (Holme 1950; Hughes 1970). Usually the values obtained were significant ($p < .05$) and indicated aggregated distributions (Table 1). According to Elliott (1971), when organisms exhibit a tendency toward aggregation, the final dispersion pattern depends upon the size of the clumps, the spatial distribution of the clumps and the spatial dispersion of individuals within the clumps.

Very few samples lacked clams. Within a clam bed there usually was a low density pattern with a superimposition of high density clumps

TABLE 1. Summary of Calculations for Determining Randomness of Intertidal and Subtidal Spatial Distributions of Gaper Clams.

Plot location	Quadrat size (m ²)	Mean density	Sample variance	Mean variance	Index of dispersion
Intertidal areas					
Q1 1969.....	0.5	3.73	7.638	2.046*	28.659
Q1 1970.....	0.5	4.33	45.524	10.506	147.088
Q2 1969.....	0.5	7.80	32.743	4.198	58.769
Q2 1970.....	0.5	2.93	3.352	1.143	16.000
Q3 1969.....	0.25	5.93	61.495	10.364	145.101
Q4 1969.....	0.25	1.13	3.124	2.756	38.589
Q5 1969.....	0.25	0.86	0.695	0.802†	11.231†
Q6 1969.....	0.25	0.80	0.886	1.107†	15.500†
Q7 1969.....	0.25	0.46	0.270	0.597†	7.533†
Q8 1969.....	0.25	1.00	4.571	4.571	64.000
Q9 1969.....	0.25	1.46	2.124	1.448†	20.273†
Q10 1969.....	0.25	3.33	12.952	3.836	45.734
Q10 1970.....	0.25	3.46	12.267	3.538	49.539
Q11 1969.....	0.25	3.46	11.838	3.415	47.808
Q12 1969.....	0.25	1.46	3.124	2.129	29.818
Q13 1969.....	0.25	2.06	6.781	2.797	39.163
Q14 1969.....	0.25	4.13	8.981	2.173	30.307
Q15 1969.....	0.5	10.53	25.838	2.453	34.342
Q15 1970.....	0.5	1.60	9.552	5.973	83.625
Q16 1969.....	0.5	10.13	65.981	6.511	91.158
Q16 1970.....	0.5	1.53	2.124	1.385†	19.392†
Q A 1970.....	0.5	26.60	103.429	3.888	103.400
Q C 1970.....	0.5	6.60	45.114	6.835	95.697
Q D 1970.....	0.5	15.66	111.810	7.137	99.915
Subtidal areas					
Buhne Point					
1972.....	0.25	2.79	11.485	4.112	493.413
North Spit					
1972.....	0.25	2.78	5.425	1.950	117.408
South Spit					
1972.....	0.25	3.03	9.308	3.072	168.957
Clam Island.....	0.25	5.50	6.265	1.139*	19.364*

* Significant between 90 and 95%

† Not significant at 90%

or aggregations. Aggregation of clams within a bed is a common phenomenon (Greenway 1969; Hughes 1970; Kristensen 1957) and fits a negative binomial distribution (Elliott 1971):

$$P(x - 1) = \left(\frac{k}{1}\right) \left(\frac{\bar{x}}{\bar{x} + k}\right)$$

The methods used to estimate the parameters \bar{x} and k , and to test the adequacy of fit vary with sample size and distribution of counts. The maximum likelihood method of estimating k (Bliss 1953) was used when the sample size was large enough for the counts to be arranged in a frequency distribution. The moment estimate method was used for small sample sizes ($n = 15$). Agreement with the negative binomial distribution was determined by the procedure outlined by Elliott (1971).

The sampling distributions of areas of high densities fit the negative binomial distribution with one exception and areas of low densities

had samples fitting a random distribution (Table 2). Substantial agreement with a random distribution at low population densities and with the negative binomial distribution at higher densities has been observed with both plant and animal populations (Barnes and Marshall 1951). The subtidal clam bed adjacent to Clam Island had the highest recorded subtidal densities (Table 1). This bed was also exceptional in that the spatial distribution fit a random rather than a negative binomial distribution (Table 2).

TABLE 2. Summary of Calculations for Determining Fit of Intertidal and Subtidal Spatial Distributions to Either Random (R) or Negative Binomial (N) Distribution.

Plot location	Mean sample density (clams/ $\frac{1}{4}$ m ²)	Best fit model	Adequacy of fit
A.....	26.600	N	T = -.685.412* k = 9.2095 (moment est.)
D.....	15.667	N	T = -704.856 k = 2.5530 (moment est.)
Buhne Point (subtidal).....	2.793	N	U = -0.992 k = 0.8057 (max. like. est.)
Buhne Point (intertidal).....	9.133	N	T = -591.735 k = 1.3740 (moment est.)
Q1 (1969).....	3.733	N	T = -10.152 k = 3.5691 (moment est.)
Q1 (1970).....	4.333	N	U = 0.587 k = 0.4495 (moment est.)
Q2 (1969).....	7.800	N	U = 5.917 k = 2.4392 (moment est.)
Q2 (1970).....	2.933	R	Chi square = 4.792 (P < 0.25)
Q5 (1969).....	0.866	R	Chi square = 2.379 (P < 0.25)
Q6 (1969).....	0.800	R	Chi square = 0.364 (P < 0.25)
Q7 (1969).....	0.467	R	Chi square = 1.750 (P < 0.10)
Q9 (1969).....	1.467	R	Chi square = 5.440 (P < 0.25)
Q12 (1969).....	1.467	R	Chi square = 11.480 (P < 0.025)
Q15 (1969).....	10.533	N	T = 52.925 k = 7.1100 (moment est.)
Q15 (1970).....	0.867	R	Chi square = 5.746 (P < 0.10)
Q16 (1969).....	10.133	N	T = -469.762 k = 1.8389 (moment est.)
Q16 (1970).....	1.533	N	T = 1.349 k = 0.3851 (moment est.)

* All T and U values are above the 95% level for acceptance.

For determining the spatial distribution of individuals within dense clumps, the nearest neighbor estimate (Clark and Evans 1954) was used at Q_A (Clam Island), where highest intertidal densities had been measured. This measure of spacing indicates the manner and degree to which

the distribution of individuals within a clump of a given area departs from a random distribution. The distance between an individual and its nearest neighbor, irrespective of direction, provides the basis for this measure. The calculated R value is a ratio of the observed mean distance (R_A) to the expected mean distance (R_E). Under maximum aggregation R equals zero. The obtained R value was 1.48 and departs significantly from random ($p < 0.01$), indicating a uniform distribution of individuals within the dense clumps on Clam Island.

Spatial Distribution of Recruits

Spatial distribution within the Primary Study Area: In 1970 recruitment occurred primarily in the four northernmost plots ($Q_{1, 2, 15 \& 16}$). These plots had a uniform cover of eelgrass, *Zostera marina*, and the substrate was somewhat finer in Q_{15} and Q_{16} , than in Q_1 and Q_2 .

The hypothesis that the densities of the four northernmost plots were the same was tested using the Kruskal-Wallis one-way analysis of variance (Siegel 1956). The hypothesis was rejected ($H = 19.48$, $p < 0.001$) indicating that the densities differed significantly. Plot 1 had the highest density and was the first plot covered by flood tide, thus presenting veligers with the first opportunity to settle. Plot 15 was the last to be inundated and had the lowest density (Table 3).

TABLE 3. Counts of Gaper Clam Recruits/0.25 m² from the Four Northernmost Plots of the Primary Study Area. Samples were collected June 17-24, 1970.

Plot 1	Plot 2	Plot 15	Plot 16
202.....	110	64	67
154.....	79	62	55
114.....	50	60	55
104.....	43	36	54
96.....	42	33	44
93.....	33	29	30
88.....	31	27	26
79.....	28	26	25
75.....	26	24	25
66.....	25	17	24
59.....	24	16	23
52.....	19	16	19
38.....	15	13	16
36.....	12	9	14
26.....	10	5	12
$\bar{X} = 85.5$	$\bar{X} = 36.5$	$\bar{X} = 29.1$	$\bar{X} = 32.6$

For each plot the hypothesis that the spatial distribution of the 1970 recruits was random was tested using the index of dispersion (Holme 1950; Hughes 1970) and rejected in each case ($p < 0.001$) (Table 4). Thus, aggregation is established during the first few months following initial settlement. The possible causes of the observed spatial distributions will be discussed under Recruitment.

Age Class Structure and Dominance

The intertidal gaper clam population of Humboldt Bay is characterized by the dominance of a few age classes (Table 5). Bourne and Smith (1972b) observed that certain year classes dominated gaper clam beds in British Columbia.

TABLE 4. Summary of Calculations for Testing Hypothesis That Spatial Distribution of 1970 Recruits was Random in Each of the Four Northernmost Plots of Primary Study Area.

Plot	Mean density ($\frac{1}{4}$ m ²)	Sum of squares	Density variance	Chi-square	Probability
1.....	85.5	20,196	2156.9	353.2	p < 0.001
2.....	36.5	10,048	717.7	275.3	p < 0.001
15.....	29.1	5,092	363.7	175.0	p < 0.001
16.....	32.6	4,338	309.9	133.1	p < 0.001

Clam Island (Q_A) and Buhne Point, in South Humboldt Bay, were dominated by 1966 year class clams (Table 5). The Primary Study Area contained the 1962, 1963 and 1964 year classes each, accounting for over 20% of all year classes present. Gunther Island (Q_D), in North Humboldt Bay, was dominated by the 1966 year class (Table 5).

The Primary Study Area had several age classes well represented in 1969. The hypotheses that no age class dominance occurred in Plots 4 through 13 were tested using the Kendall Coefficient of Concordance (W) (Siegel 1956). The hypothesis was rejected ($p < 0.005$) and we concluded that age class dominance occurred. Plot 2 had a relatively high density of clams, and the hypothesis that no age class dominance occurred within Q_2 was tested and rejected ($p < 0.05$) (Table 6). Based on the extreme dominance of year class 1966 in other parts of the bay, one might consider that adults probably inhibited recruitment. The hypothesis that no age class significantly dominated the quadrats

TABLE 5. Number of Clams of Each Age Class in Samples Collected From Plot A (Clam Island), Plot D (Gunther Island), Buhne Point, and Plots of Primary Study Area.

Plot	1969	1968	1967	1966	1965	1964	1963 or earlier	Plot total
A (Clam Island).....	36	2	4	117	17	0	202	378
D (Gunther Island).....	0	1	0	176	11	9	2	199
Buhne Point.....	0	5	2	10	1	1	3	39*
1.....	0	3	9	37	5	14	21	89
2.....	0	4	1	25	31	31	48	140
3.....	0	0	0	11	0	16	22	49
4.....	0	0	0	1	0	3	7	11
5.....	0	0	0	0	1	2	3	6
6.....	0	0	0	0	0	5	10	15
7.....	0	0	0	0	0	1	4	5
8.....	0	0	0	0	0	1	8	9
9.....	0	0	0	0	1	2	9	12
10.....	0	0	0	1	0	2	25	28
11.....	0	0	0	0	0	2	29	31
12.....	0	0	0	0	0	1	7	8
13.....	0	0	0	0	0	0	11	11
14.....	0	3	0	2	0	10	21	36
15.....	0	6	1	14	2	21	42	86
16.....	0	0	0	6	2	47	25	80

* dug non-randomly

sampled within Q_2 , a plot dominated by 1962, 1963 and 1964 year classes, was tested and accepted ($p < .05$) (Table 6). This conclusion led us to hypothesize that the presence of adults need not inhibit recruitment.

TABLE 6. Summary of Calculations Used for Testing Hypotheses That No Age Class Dominance Occurred Within Plots or Within Samples of Plot 2 of Primary Study Area.

Area considered	Kendall's W	Chi square	Significance level
Q4-Q13-----	0.5852	40.964	$P_{.005,7df} = 20.277$
Q2-----	0.2760	20.702	$P_{.001,16df} = 20.520$
Q2 (within samples)-----	0.1916	13.415	$P_{.05,5df} = 23.682$

Recruitment

The spatial and temporal distribution of age classes indicated that recruits either do not settle annually on all beds, or if they do, that mortality must be high, resulting in either poor or unsuccessful recruitment for most years.

We first sampled for recruits of the 1970 year class on April 25, 1970 and continued sampling until August 8, 1971. The initial sampling indicated that the year class was not homogeneously distributed. Within the Primary Study Area, the four northernmost plots ($Q_{1, 2, 15, 16}$) were densely populated (>100 recruits/ 0.25 m^2), while the number of recruits was negligible in the southernmost plots ($Q_{7, 8, 9, 10}$).

Recruits of the 1971 year class were first located and sampled on April 25, 1971, and sampling continued until August 8, 1971. The spatial distribution of the 1971 year class differed from that of the 1970 year class. Light densities (50–100 recruits/ 0.25 m^2) occurred primarily in the middle and southern portions of the Primary Study Area. Densities in the four northernmost plots were very low (<50 recruits/ 0.25 m^2). The hypothesis that the number of recruits in the 16 plots of the Primary Study Area were similar in 1970 and 1971 was tested by the Mann-Whitney U-Test (Siegel 1956) and accepted ($U = 111$, $n_1 = 16$, $p > .05$).

Reasons for the difference in recruit distribution between the two years are unknown. Although the southern one-half of the Primary Study Area was characterized by sandy substrate during the summers of 1970 and 1971, patches of silt 5 to 10 cm (2.0 to 4.0 inches) deep were observed overlaying the sand during the spring of 1971. It was in these silty patches that most recruits were found in 1971. Samples in nearby clean sand yielded much fewer recruits. Localization of recruits in this silty layer suggests that either the settling larvae may have possessed an ability to choose a particular substrate or that recruits which did settle in the silt layer were able to maintain their position more easily than recruits in sand. Adults, however, do not frequently occur in silt.

During the lowest tides, a narrow strip approximately 10 m (33 ft) wide existed between the Primary Study Area and Southport Channel

(Figure 1). Five random samples were collected along the channel margin east of Q_1 and Q_2 , and indicated sparse recruitment in this intertidally lower area. The hypotheses that the densities of Q_1 and Q_2 were the same as the areas contiguous and east of them were tested by the Mann-Whitney U-Test. The hypotheses were both rejected (Q_2 and area to east, $U = 0$, $p = 0.004$; Q_1 and area to east, $U = 2$, $p = 0.008$). The densities were significantly higher in the plots of the Primary Study Area. This eastern strip was steep and sandy with a high shell-rubble content, indicating that this area was subjected to runoff and flooding currents.

The region west of the Primary Study Area was sandy and intertidally higher than the Primary Study Area plots and extended approximately 200 m (656 ft) towards South Spit (Figure 1). Live adult gaper clams were rare, although high densities of shells found *in situ* in 0.25 m² quadrats indicated that densities were quite high in the past. On June 9, 1971, five 0.25 m² samples were collected 100 and 200 m (328 and 656 ft) west of Q_{13} and yielded averages of 18.2 and 4.0 recruits/0.25 m² respectively. No recruits were found at 300 m (984 ft). A sample collected in a siltier substrate west of Q_{16} in 1970 yielded no recruits. These data support the contention that optimum settlement occurs close to the channels and in sand and silty-sand substrates in concordance with adult distribution.

The northern end of Clam Island supports high densities of gaper clams and is the area most used by clambers (Figure 2) (Table 1). Plots A, B, C, and E were established in 1970 to obtain information on recruits and adults. Plot A on the north tip of Clam Island was sandy with patches of eelgrass. Plots B and C were of silty sand with heavy eelgrass cover. Plot E was intertidally higher, sandy and lacked eelgrass.

Densities of the 1970 year class were very low in all plots. Average densities/0.25 m² for samples collected between July 2, 1970, and July 18, 1970, were: $Q_A = 3.9$, $Q_B = 2.8$, $Q_C = 1.1$, $Q_E = 0.0$.

Settlement of the 1971 year class on Clam Island was also sparse. On May 15, 1971, five random 0.25 m² samples were collected from Q_C and Q_E . Average densities were 10.2 and 33.6 recruits per 0.25 m², respectively. Sampling in Q_A and Q_B indicated that these plots virtually lacked recruits. As in the Primary Study Area, the highest densities of 1971 recruits occurred in sands just below datum.

Recruitment Versus Established Gaper Clams

Plot A (Clam Island) supported the highest densities of mature gaper clams in Humboldt Bay. The density of older clams was so great that it seemed feasible that older clams significantly affect recruit density. Thus, the hypothesis that the observed densities of recruits were independent of established clams within samples was tested by the Spearman Rank Correlation method (Siegel 1956) for counts of older clams and recruits from Q_A . The hypothesis was accepted ($r_{SP} = 0.138$, $p < 0.05$). Settlement may occur within a well established gaper clam bed.

Kreger (1940) also found that spatfall of the cockle, *Cardium edule*, in the Netherlands was little if at all affected by very high densities

of older cockles. We found that the 1966 year class had a density of 10.2 clams/0.5 m² in Q_A in 1970. Settlement of recruits of this year class must have been very great even though the density of established clams at that time in Q_A must have been somewhat greater than 15 clams/0.5 m² (Table 5).

Buhne Point had a high density of gaper clams (Table 2). Gaper clam recruits were not found in 1970 and 1971.

The Elk River clam bed was divided into two areas by Elk River (Figure 1). The northern bed had a silty-sand substrate. The southern bed was somewhat sandier. Both beds had medium covers of eelgrass. No significant recruitment occurred in 1970. Sampling in 1971 indicated that light settlement occurred, but was not followed.

The southern tip of Gunther Island (Q_D) had an established gaper clam bed of high density in 1971. The hypothesis that the number of 1970 recruits was independent of the number of established clams in Q_D was tested by the Spearman Rank Correlation method. The hypothesis was accepted ($r_{SP} = -0.38$, $p < 0.05$), indicating that the presence of adults need not deter recruitment.

Light recruitment occurred on Gunther Island for both the 1970 and 1971 year classes. Each year the early recruit densities were greater than in Q_A on Clam Island, but less than Q₄ in the Primary Study Area. Fifteen random samples collected on July 19 and 20, 1970, yielded an average density of 6.7 recruits/0.25 m². Five random samples collected on July 25, 1971, yielded an average density of 17.0 recruits/0.25 m².

A small gaper clam bed at the Samoa Boat Ramp (Figure 2) was checked for 1971 recruits. Light recruitment had occurred here. Woodley Island and Bird Island were also checked for recruits in 1970. Recruitment occurred but was unsuccessful. Also, the number of adults was very low and the substrate was very silty, indicating that the area was not prime gaper clam habitat. All other areas examined in North Humboldt Bay appeared uninhabitable because of very high silt content.

Temporal Patterns of Recruitment

The possibility of more than one settlement occurring during 1970 was indicated by samples from Q₁ and Q₄ (Primary Study Area), Q_D (Gunther Island), and Q_A (Clam Island). An analysis of variance (Li 1966) indicated that both Q₁ and Q₄ received recruits concurrently since no significant difference in mean lengths occurred between the two plots on May 9, 1970 ($F = 2.17$, $p > .05$). Comparisons of length frequencies of Q₁ and Q₄ with Q_D, and of Q₁ and Q₄ with Q_A were made (Figures 3 and 4). In the samples of Q₁ and Q₄ taken in July, significant differences in length existed and are attributed to a more rapid growth rate in Q₄. Differences in the length frequency of recruits were also apparent in Q_D and Q₄ (Figure 3). The hypothesis that Q₁ and Q_D had the same mean length was tested by the t-test (Li 1966) ($t = 10.642$, $p < 0.001$) and also rejected. It appears that Q_D and Q_A may have received recruits at the same time by a settlement that occurred later than the one occurring in the Primary Study Area. Some recruits of early and late settlements apparently occurred in all four plots (Figures 3 and 4).

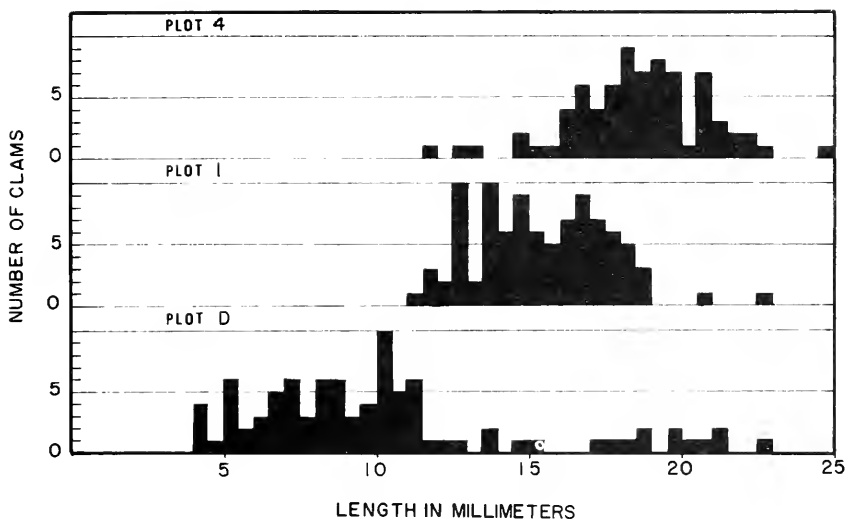


FIGURE 3. Histograms of length frequencies of recruits collected on May 9, 1970 from plots 1 and 4 (Primary Study Area) and lots D (Gunther Island).

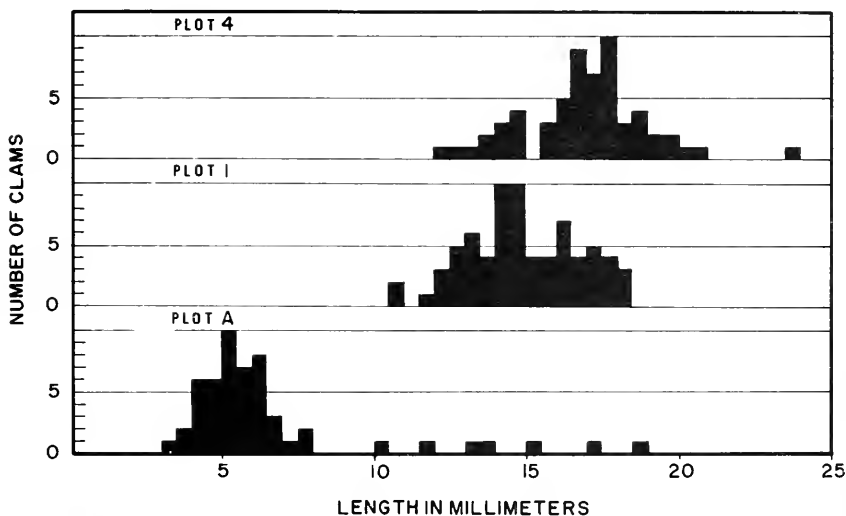


FIGURE 4. Histograms of length frequencies of recruits collected July 2, and August 5, 1970, from plots 1 and 4 (Primary Study Area) and plot A (Clam Island).

The 1971 length-frequency distribution differs from the 1970 distribution. A single, extended period of settlement is indicated for 1971 by the absence of distinct peaks and a broad length interval (Figure 5).

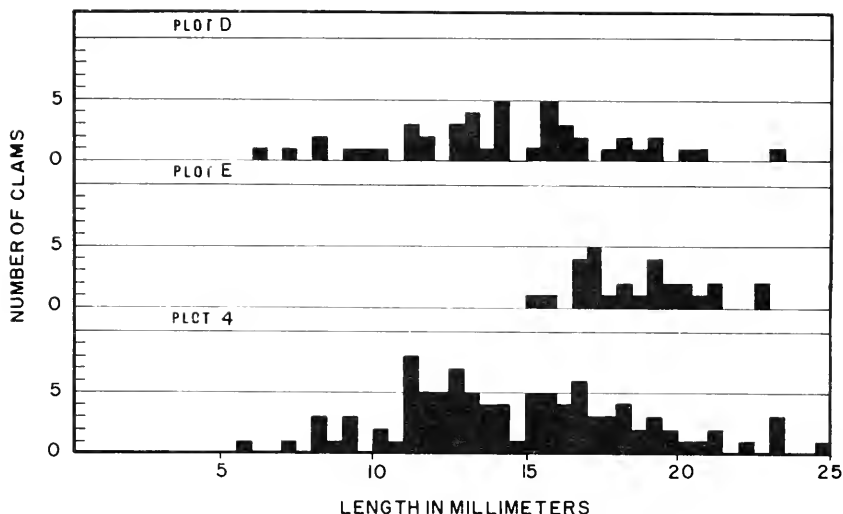


FIGURE 5. Histogram of length frequencies of recruits collected July 9 and 10, 1971, from plot D (Gunther Island), plot E (Clam Island) and plot 4 (Primary Study Area).

Variability in the number of settling peaks from year to year has been recorded for other bivalves. Tegelberg (1964) found that more than one settling peak per year occurred commonly for the razor clam, *Siliqua patula*, at one beach and irregularly at two other beaches in Washington. Hirschhorn (1962) also found unequal settlement dates for razor clams in Oregon.

The gaper clam of the intertidal beds of Humboldt Bay is a winter spawner (Machell and DeMartini 1971). Bourne and Smith (1972a) found that laboratory reared gaper clams remain as planktonic veligers up to 3 weeks. On April 25, 1970 and 1971, recruits averaged about 2.3 mm (0.09 inch) long, and may have settled approximately 1 month earlier. Two settlement peaks were indicated for 1970, allowing for the possibility of either more than one spawning of adult bay clams or of recruiting from outside the bay. However, we presently are unaware of significant gaper clam populations outside the bay.

Recruits greater than 2 mm (0.07 inch) long and adults rarely occur in muddy substrates indicating that recruits may select sandy substrates for settlement. Initial spatial distribution of recruits is unknown; however, by the time they reach 10 mm (0.4 inch) long, they are highly aggregated. Kristensen (1957) found that the recruits of the cockle, *Cardium edule*, when about 1 mm (0.04 inch) long were distributed homogeneously in a clam bed; however, specimens 2 mm (0.07 inch) long were patchy. He attributed the change to a patchy distribution to effects of currents which carry the small recruits but leave large ones which are too heavy and have reached their definitive spatial distribution at about 2 mm (0.07 inch).

Growth

In Humboldt Bay, gaper clam valves usually bear well defined annuli. Bourne and Smith (1972b) used annuli of British Columbia gaper clams to study their growth. We determined that a shell ring usually corresponds to one year's growth by following growth of the 1966 year class and of recruits, observing the formation of the most recent annulus. Valve length (antero-posterior dimension) was a linear function of valve width (dorso-ventral dimension) resulting in isometric valve growth (Figure 6). Valve length was the valve parameter used for studying growth.

Growth of Recruits

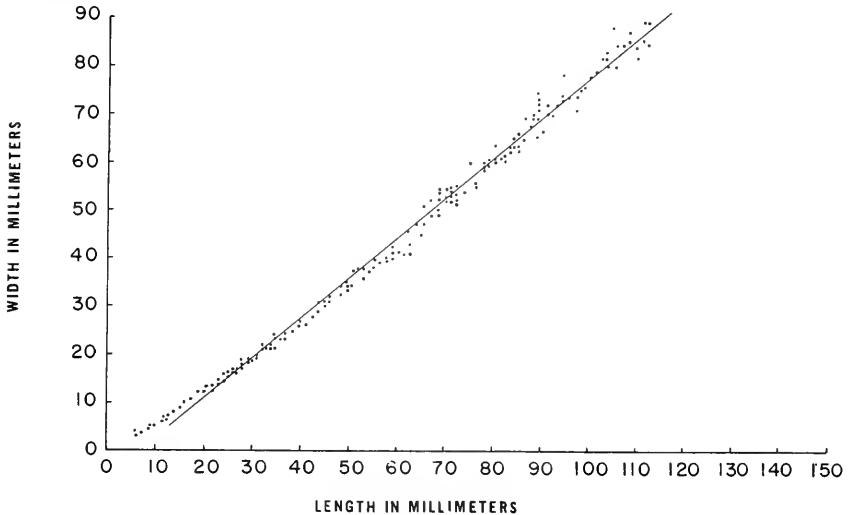


FIGURE 6. Regression line of valve width as a function of valve length. Line is hand-fitted.

Primary Study Area: In 1970, Q_1 and Q_4 had recruit densities high enough for comparing growth rates. For May 9, 1970, the 95% confidence intervals of the mean lengths for Q_1 and Q_4 , respectively, were 3.8 ± 0.3 mm (0.15 ± 0.01 inch) and 4.3 ± 0.4 mm (0.16 ± 0.02 inch), and thus inseparable. The two plots may have received recruits simultaneously. However, on July 5, 1970, the mean lengths of recruits of Q_1 and Q_4 , respectively, were 14.3 ± 0.9 mm (0.56 ± 0.039 inch) and 16.9 ± 1.0 mm (0.67 ± 0.04 inch). Thus, the growth of gaper clam recruits in 1970 was greater in Q_4 than in Q_1 (Figure 7).

Growth of recruits virtually ceased after October 1970 and did not resume until April 1971. Growth rates were high from June through August 1971 and approximated the growth rate of the first year through August (Figure 7). Bourne and Smith (1972b) observed cessation of growth in October for the gaper clams in the Straits of Georgia, British Columbia. Due to the cessation of growth during the late fall and winter months and rapid growth during the late spring and summer months, a distinct annulus was formed on the 1970 year class valves in Humboldt Bay. The annulus was distinct on every specimen of the 1970 year class recovered in 1971. Bourne and Smith (1972b) observed similar first year annuli in the gaper clam.

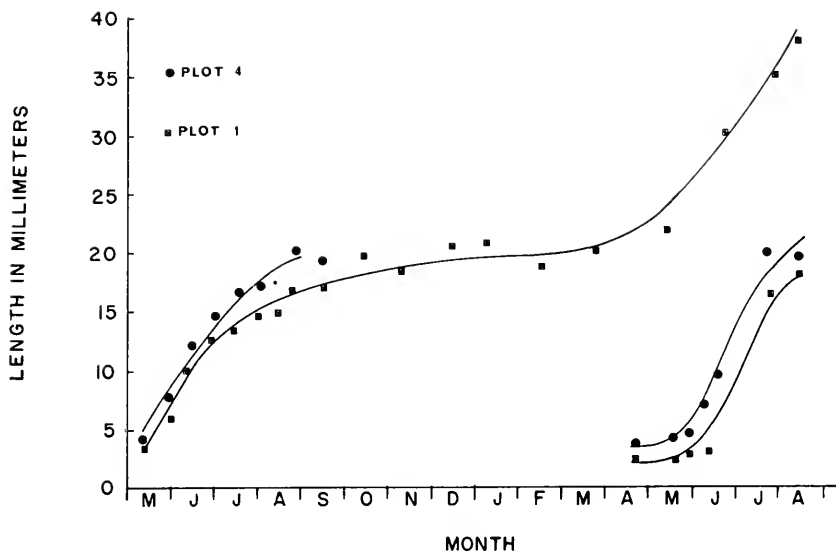


FIGURE 7. Hand-fitted growth curves of mean growth of gaper clam recruits in Primary Study Area.

The growth rate of the 1971 year class in Q_1 and Q_4 approximated the growth rate of 1970 year class (Figure 7). However, the growth of this year class seemed to exhibit a lag phase prior to rapid growth. Between April 25 and May 26, 1971 very little growth of the 1971 year class took place. Rapid growth occurred in June and July. Samples taken on August 9, 1971 indicated that the growth rate had started to decrease.

Growth of the 1971 year class was monitored in four other areas of Humboldt Bay: Clam Island (Q_E), Elk River, Gunther Island (Q_D), and Woodley Island (Figure 1). The form of the growth curve for each area was similar to the form of the growth curves for the plots monitored in the Primary Study Area. The growth rate was slow in each area until late May or early June, was rapid through June and July, and decreased in August (Figure 8).

Growth of adults occurred primarily in the spring and summer. Growth is evidenced by a peripheral annulus which is covered by a fresh and clean periostracum and thin shell margin. Growth rates of adults were determined using annuli of clams from Elk River (1966 year class), Clam Island (Q_A) (1966 year class), and the Primary Study Area (Q_2 and Q_{15}) (1964 and 1966 year classes). Log Transformations of the length-time data were plotted and the slopes compared utilizing analysis of covariance (Li 1966). The slopes or growth rates showed no significant difference between clams of the 1966 year class from Q_2 , Q_{15} , and Q_{16} ($F = 0.5578$, $p > 0.05$). Growth rates were also similar when the 1964 year class was tested by Q_2 and Q_{15} ($F = 2.7775$, $p > .05$). However, a comparison of the 1964 and 1966 year classes within the Primary Study Area indicated a significant difference in the growth rate ($F = 9.9177$, $p < 0.01$). This difference may reflect environmental conditions during the initial two years of growth of the

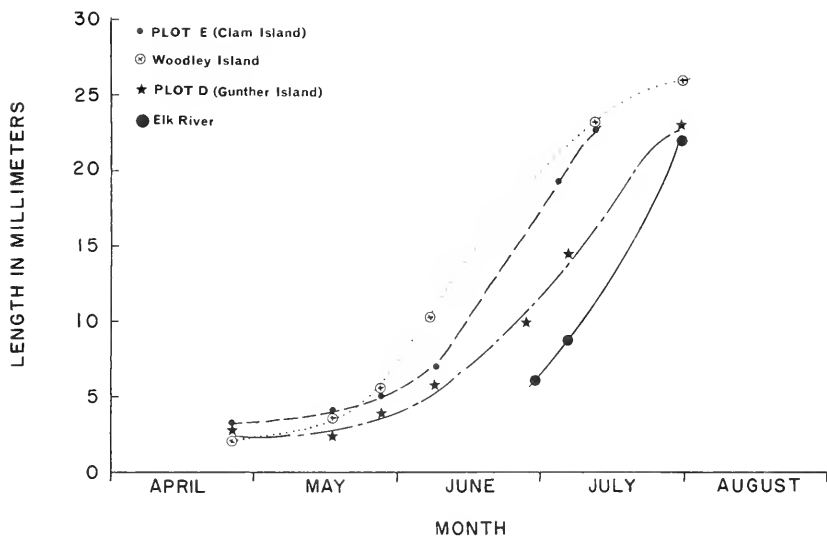


FIGURE 8. Hand-fitted growth curves of mean growth of gaper clam recruits of areas other than Primary Study Area in 1971.

1964 year class since all subsequent growth for both year classes was subjected to the same external conditions. The 1966 year class taken from Elk River and Q_A (Clam Island) had similar growth rates ($F = 1.3321$, $p > 0.05$). When these slopes were compared with the 1966 year class from the Primary Study Area, there was a significant difference ($F = 7.5659$, $p < 0.01$), with the Primary Study Area showing the greatest growth rate.

Growth rate is more variable earlier in life. This trend was shown by a Walford plot for the 1966 year class in Plot D (Gunther Island) (Figure 9). The Spearman Rank Correlation method was used to test the hypothesis that a given year's growth of a clam is independent of the previous year's growth. The results were as follows:

- 1) 2nd year independent of 1st year ($r_{SP} = 0.55$, $p \geq 0.10$)
- 2) 3rd year independent of 2nd year ($r_{SP} = 0.827$, $p \leq 0.01$)
- 3) 4th year independent of 3rd year ($r_{SP} = 0.944$, $p \leq 0.01$)

Thus, with age, growth becomes more uniform. The cause of the great variability, when comparing the second year to the first, may be the recruitment occurring over an extended period. After the first year, growth could be great enough to cancel the variation of the last year's growth. This phenomenon is called growth compensation (Ricker 1958). There is apparently no predictive value of future growth success of recruits based on their first year's growth.

Growth Curves

For clams more than 2 years old, the measurements of annuli were used to generate von Bertalanffy growth equations:

$$l_t = l_\infty (1 - e^{-k(t-t_0)}),$$

where l_t is the length at age t , l_∞ is the theoretical maximum length, and k and t_0 are constants (Ricker 1958).

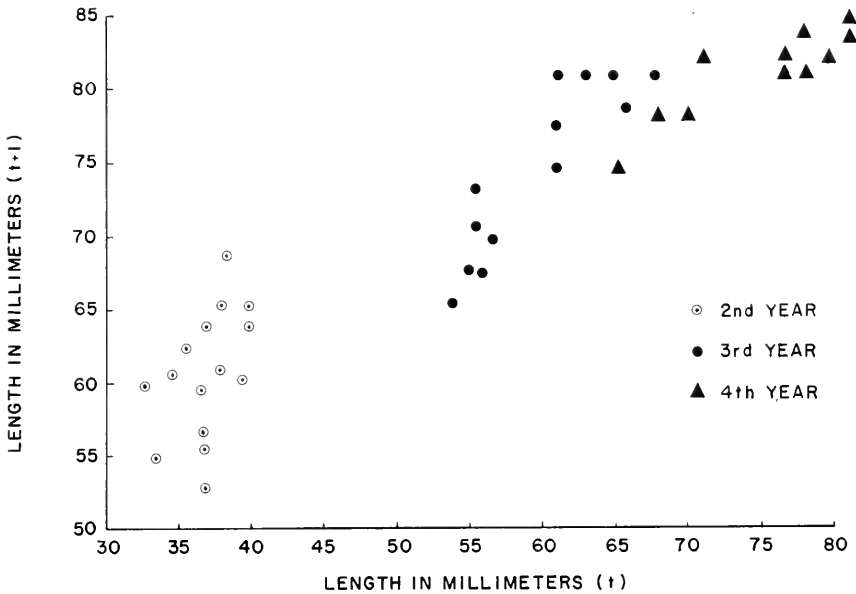


FIGURE 9. Walford plot of gaper clams of 1966 year class collected on Gunther Island in 1971.

Estimates of the three parameters, l_{∞} , t_0 , and k , were obtained by fitting data to a Fortran IV computer program developed by Allen (1966). The program output includes a 95% confidence estimate of the three parameters. The parameters were generated for the Primary Study Area and Clam Island (Table 7).

TABLE 7. Ninety-five Percent Confidence Estimates of Three Parameters of von Bertalanffy Growth Equations for Primary Study Area and Clam Island.

Area	Final L_{∞} (mm)	95% range	Final t_0	95% range	Final k	95% range
Primary Study Area.....	171.3	166.4-176.3	-0.4497	-0.6033- -0.2961	0.1309	0.1210- 0.1408
QA (Clam Island).....	169.5	167.0-172.0	-0.6254	-0.6803- -0.5706	0.1424	0.1377- 0.1472

In various intertidal gaper clam beds, a number of live clams sampled between 140 and 150 mm (5.5 and 5.9 inches) ranged in age from 9 to 13 years. The oldest clam was 16 years and 156 mm (6.1 inches) long. The von Bertalanffy equations indicate that gaper clams may live over 20 years.

It was shown earlier that growth rates differed significantly between the Primary Study Area and Clam Island (Q_A). However, the von Bertalanffy growth parameters are not significantly different at the 95% level. An explanation for the incongruency lies in the fact that the growth rates were compared for clams of year class 1966, while

the growth equations were generated for several year classes. Knight (1968) felt that the parameters should be regarded as descriptive summaries of the data analysis rather than fact.

Weight-Length Relationship

During their first season gaper clam recruits increased their shell length to a greater extent than their body weight. Thereafter, body weight increased more rapidly than length (Figure 10). All weight-length observations of adults were made during the late spring and summer months, thereby reducing the effect of probable seasonal fluctuations in weights of the gonad and digestive gland. For determination of the weight-length relationship in adult clams, the logarithms of length and weight were recorded for individuals taken from several beds in Humboldt Bay. The slope of the line resulting from this plot is the exponent 'n' in the relationship:

$$W = aL^n$$

The values of 'n' obtained from the log transformations ranged between 3.3 and 3.4, indicating little or no difference in the weight-length relationship of the clam beds compared.

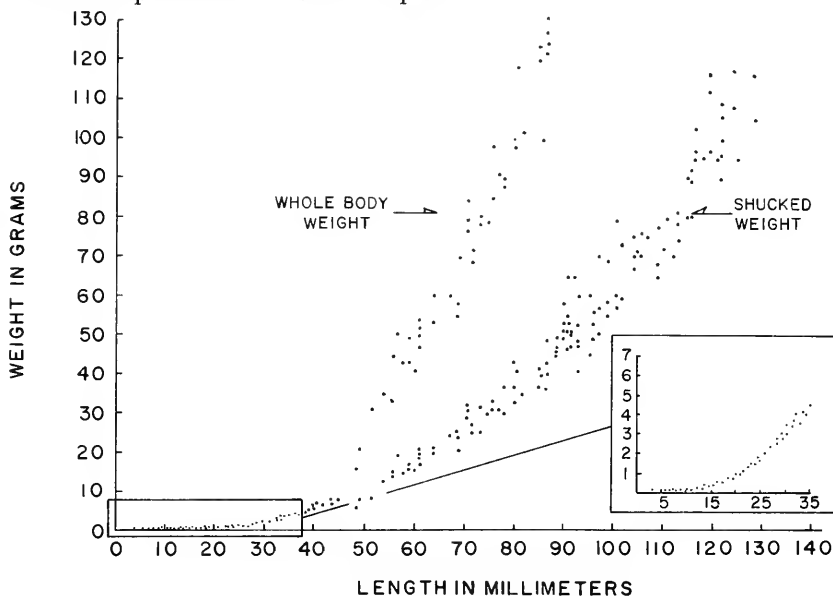


FIGURE 10. Plot of weight as a function of length for gaper clams from Primary Study Area.

Mortality

Large-Scale Mortality of Adults in the Primary Study Area

A large-scale mortality occurred in the four northernmost plots (Q_1 , Q_2 , Q_{15} , & Q_{16}) between September 1969 and June 1970. In June 1970, many recently expired clams occurred *in situ* (Figure 11). The hypothesis that the densities of the live gaper clams in the four northernmost plots *in toto* were the same for 1969 and 1970 was tested using the Mann-Whitney U-test. The hypothesis was rejected ($U = 14$, $p > .05$). The cause of the significant mortality is unknown. However, since live clams still occurred in the plots, smothering appar-

ently was not the cause. Histological preparations were made of some necrotic clams by Ronald Warner of the California Department of Fish and Game. He found no evidence of either protozoan or bacterial infections.

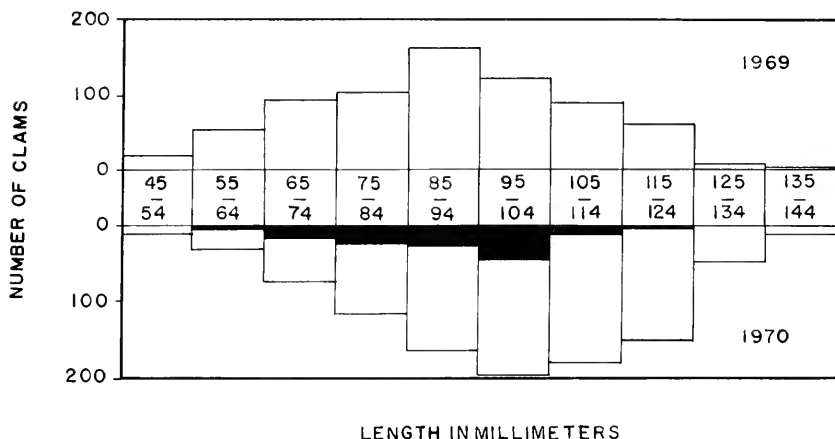


FIGURE 11. Histograms of length frequencies of clams collected during 1969 and 1970 in plots 1, 2, 15 and 16. Solid bars represent live clams; empty bars represent clams that died between summers of 1969 and 1970.

Mortality of Recruits in the Primary Study Area

Comparisons of mortality rates were based on five random samples taken concurrently and semimonthly in Q₁ and Q₄. For each sampling date in 1970, counts of the two plots were compared by means of the Mann-Whitney U-test to test the hypothesis that the densities were the same. Only on May 9, 1970 was the difference significant (U = 4, p < .05) with Q₁ having a higher density than Q₄ (Table 8). By September 1970, the number of 1970 recruits in Q₄ was so low that sampling was curtailed. By April 1971, the density of 1970 recruits in Q₁ had dropped to about one recruit per 0.25 m² and sampling for mortality ceased. Q₁ was sampled for 1971 recruits until May 26, 1971. In 1970, the slope of the mortality curve of Q₁ was steeper than that of Q₄. However, in 1971, Q₄ exhibited a steeper mortality slope than Q₁ (Figure 12). Thus, each year the plot with the greatest initial density had the greatest mortality.

TABLE 8. Calculated Mann-Whitney U Values for Testing Hypothesis That on Each Sampling Date Mean Densities in Plot 1 and Plot 4 Were the Same.

Date	Mann-Whitney U	Probability (of as small as U as observed)
May 9, 1970.....	4	0.048
May 22, 1970.....	5	0.075
June 7, 1970.....	5	0.075
July 5, 1970.....	9	0.274
July 16, 1970.....	7	0.155
July 22, 1970.....	11	0.421
July 31, 1970.....	3	0.028
August 16, 1970.....	13	0.579
September 14, 1970.....	0	0.004

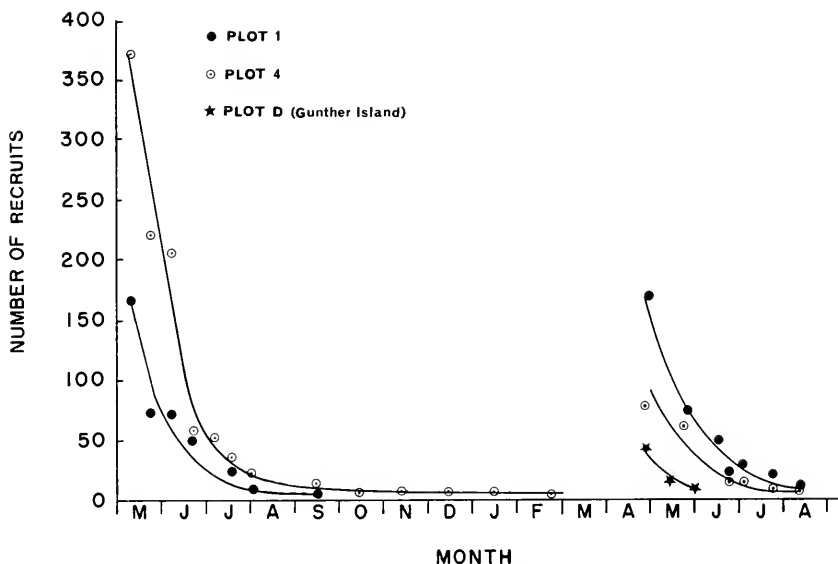


FIGURE 12. Mortality rates of 1970 and 1971 year class gaper clam recruits.

Predation

No quantitative assessment of predation was made. Known gaper clam predators are the moon snail, *Polinices lewisii*; Dungeness crab, *Cancer magister*; sea star, *Pisaster brevispinus*; and the bat ray, *Myliobatis californicus*. The bat ray or indications of bat ray predation were not observed.

The sea star, a known clam predator, is not documented as a gaper clam predator. On two occasions, however, we observed the sea star feeding on large gaper clams, apparently removed from nearby excavated burrows.

Burrowing Behavior

Burrowing time and depth are important in determining the effects of physical stresses such as temperature and salinity. Larger recruits are found in deeper burrows (Figure 13). However, an increase in size significantly decreased burrowing ability (Figure 14). Clams older than two years 75 mm (3.0 inches) do not reburrow. Pohlo (1964) found a progressive loss of burrowing ability in larger forms of the horseneck clam, *Tresus nuttalli*.

Mortality of recruits is apparently highest following spring settlement and through early summer. Early mortality may be due to physical factors such as salinity and temperature stress and to predation. Deeper burrowing, with age, reduces the effects of physical and biological stress. After reaching an age of 4 to 5 months, a most critical stage of the life history is passed, and the probability of survival increases greatly (Figure 12). An optimum time to consider artificial seeding of beds would be in late summer when recruits can readily reburrow to deep substrate.

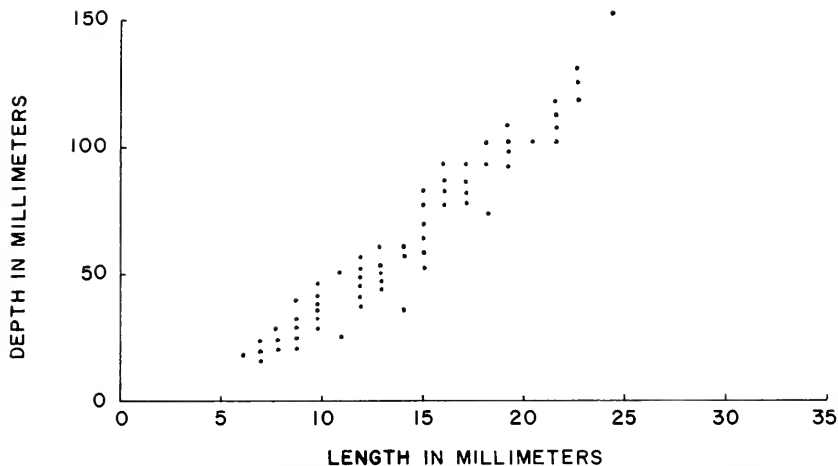


FIGURE 13. Depth of burrowing of gaper clam recruits as a function of shell length in sand and silty-sand substrate.

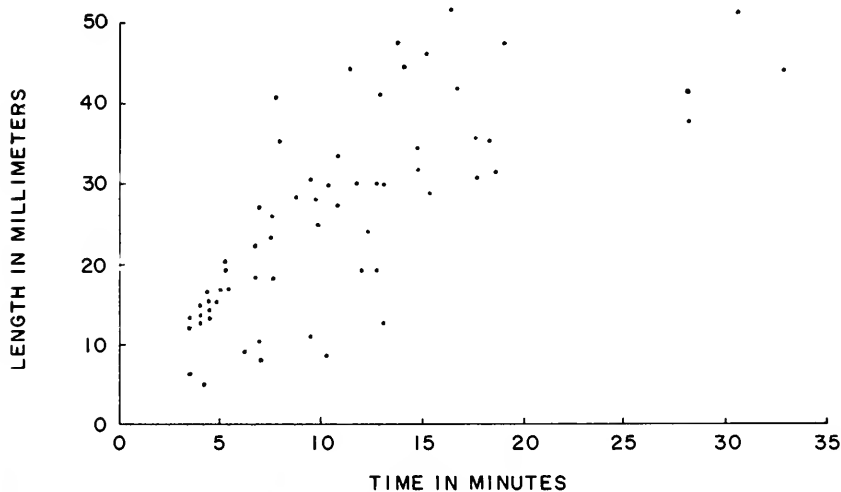


FIGURE 14. Reburrowing times as a function of shell length of gaper clam recruits.

Standing Crop Estimate

Primary Study Area

Standing crops were estimated for all plots sampled during the summer of 1969, and for Q_1 , Q_2 , Q_{15} and Q_{16} sampled in 1970 and 1972 (Table 9). The selected plots were the only ones resampled due to a large mortality in the remaining plots. The high density plots were typified by having a high fine sand content and a heavy cover of eelgrass. Plots of clean sand (Q_5 - Q_{12}) had very low densities (Table 9).

TABLE 9. 95% Confidence Intervals of the Geometric Mean Densities and Standing Crop Estimates for Intertidal and Subtidal Gaper Clam Beds.

Plot location	Date	Geometric mean	95% confidence interval	Standing crop estimates (/2500m ²)
Intertidal				
A.....	1970	24.62/0.5m ²	19.32-31.37	96,600-156,850
A.....	1972	12.37/0.5m ²	6.97-21.94	34,850-109,700
C.....	1970	4.70/0.5m ²	2.59- 8.54	12,930- 42,695
D.....	1970	12.37/0.5m ²	6.52-18.64	32,605- 93,200
D.....	1971	2.50/0.5m ²	1.94- 3.23	9,700- 16,150
D.....	1972	2.78/0.5m ²	1.59-48.50	7,950- 24,250
Q1.....	1969	3.98/0.5m ²	2.80- 5.66	14,005- 28,305
Q1.....	1970	3.15/0.5m ²	1.80- 5.48	9,020- 27,390
Q1.....	1972	2.40/0.5m ²	1.81- 3.20	2,434- 15,900
Q2.....	1969	5.16/0.5m ²	2.83- 9.44	14,125- 47,185
Q2.....	1970	3.46/0.5m ²	2.53- 4.72	12,665- 23,610
Q2.....	1972	2.71/0.5m ²	1.91- 3.84	9,550- 19,200
Q3.....	1969	4.46/0.25m ²	2.66- 7.46	26,550- 74,590
Q4.....	1969	1.66/0.25m ²	1.14- 2.43	11,350- 24,310
Q5.....	1969	1.71/0.25m ²	1.34- 2.18	13,420- 21,750
Q6.....	1969	1.60/0.25m ²	1.22- 2.10	12,180- 21,020
Q7.....	1969	1.38/0.25m ²	1.13- 1.68	11,340- 16,840
Q8.....	1969	1.50/0.25m ²	1.03- 2.18	10,300- 21,820
Q9.....	1969	2.11/0.25m ²	1.53- 2.91	15,330- 29,070
Q10.....	1969	2.27/0.25m ²	1.39- 3.11	13,960- 31,120
Q11.....	1969	3.33/0.25m ²	2.11- 5.24	21,120- 52,350
Q12.....	1969	1.99/0.25m ²	1.38- 2.88	13,760- 28,760
Q13.....	1969	2.38/0.25m ²	1.60- 3.55	16,020- 35,450
Q14.....	1969	4.12/0.25m ²	2.71- 6.25	27,110- 62,350
Q15.....	1969	9.44/0.5m ²	7.21-12.36	36,030- 61,800
Q15.....	1970	1.62/0.5m ²	1.21- 2.17	6,070- 10,855
Q15.....	1972	1.92/0.5m ²	1.33- 2.76	6,650- 13,800
Q16.....	1969	7.72/0.5m ²	4.42-13.51	22,075- 67,550
Q16.....	1970	2.19/0.5m ²	1.62- 2.97	8,085- 14,830
Q16.....	1972	1.59/0.5m ²	1.17- 2.17	6,850- 10,850
Subtidal				
Buhne Point.....	1972	2.85/0.25m ²	2.50- 3.24	366,000-473,250
North Spit.....	1972	3.05/0.25m ²	2.66- 3.50	237,000-312,600
South Spit.....	1972	3.34/0.25m ²	2.75- 4.07	10,980- 16,300

Clam Island (Q_A)

This area is the most heavily utilized by clammers and had the highest standing crop estimates for the whole bay. In 1970 the standing crop estimate of Q_A was very high, but decreased greatly in 1972 (Table 9).

Gunther Island (Q_D)

Plot D had the second highest standing crop estimate in 1970. A drastic reduction was indicated by our 1971 and 1972 sampling, but not significant at the 95% level (Table 9).

As this study progressed the standing crop of gaper clams markedly decreased twice in all beds sampled. The fact that successful recruitment has not occurred since 1966, coupled with reduction in standing crops due to mortality, predation and other factors, indicates that the fishery needs continuous monitoring.

SUMMARY

Gaper clams occurred primarily in intertidal and subtidal sand and silty-sand substrates in Humboldt Bay. Within these strata the spatial distribution varied from random, at low mean densities (<3 clams/0.5

m²), to aggregated, at higher mean densities. Samples from areas of higher densities usually fitted a negative binomial distribution. Within an area of very high mean density (12.4 clams/0.5 m²), the clams constituting aggregations were uniformly distributed.

Gaper clam beds were dominated by certain age classes. Some beds had only one or two dominant age classes. Although beds may be dominated by an age class, or age classes, samples need not be.

Recruitment began in the early spring. There was evidence of more than one settlement and of settlement over an extended period. Settlement was densest in areas containing established clams. By the time recruits were 4 mm (0.16 inch) long they had an aggregated distribution. No rank correlation existed between densities of recruits and adults within samples indicating that adults did not deter recruitment.

Growth, as indicated by increase in shell length, occurred primarily in the spring and summer. Growth rates of 1964 and 1966 year classes differed significantly in one clam bed. The growth rates of the 1966 year class in three separate beds differed significantly. Von Bertalanffy growth equations were generated for three major clam beds and did not differ significantly ($p > .05$) even though growth rates did. However, the trends of the growth equations and growth rates of a given bed were in agreement. The von Bertalanffy equations indicated a theoretical maximum age of over 20 years. Based on field observations, an average longevity of around 15 years seems reasonable.

The densities of two major gaper clam beds were found to decrease significantly during the study. The cause of the decline was undetermined, but not attributable to clamming. Mortality of the 1970 and 1971 recruits was very great after settlement but slight by late summer. The densities of recruits were too low for future sustenance of the fishery. Certain predators were identified and included the market crab, moon snail, sea star, and bat ray.

Standing crops were determined for two years on major beds during 1969-1973. Standing crops were in a general decline on three major intertidal beds.

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ESTIMATES OF POPULATION SIZE FOR TIDEPPOOL SCULPINS, *OLIGOCOTTUS MACULOSUS*, AND OTHER INTERTIDAL FISHES, TRINIDAD BAY, HUMBOLDT COUNTY, CALIFORNIA

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Intertidal fishes were marked and recaptured during a 12-month study, December 1968 to December 1969. Three adjacent zones of a relatively undisturbed intertidal area in Trinidad Bay, California, were used in the experimental work. A total of 1124 fishes was marked and 69 were recaptured (6.1%). Schnabel, Modified Schnabel, and Schumacher-Eschmeyer population estimates were computed for the total population, and for the most common species, *Oligocottus maculosus*. Several modified estimates were derived for the intertidal environment to eliminate the effects of seasonal fishes and recruitment of young cottids. Indications of the sizes and densities of the seasonally fluctuating fish populations are given for spring, summer, fall, and winter. There was no evidence of significant lateral movement of *Oligocottus maculosus* or other species. The ecological implications of the study are discussed.

INTRODUCTION

Accurate population analysis of intertidal fish populations is difficult because of the diverse nature of the environment, differing habitat requirements for fishes, seasonal availability of certain species, and difficulty in sampling. The most common resident intertidal fish from northern California to Alaska is the tidepool sculpin, *Oligocottus maculosus*. The life history and some behavioral patterns of this species have been previously described (Gersbacher and Denison 1930; Atkinson 1939; Green 1971). However, virtually no studies are available concerning population estimate techniques for this cottid, or other fishes in the complex intertidal zone.

In this study, I have applied some basic methods of population estimation to intertidal fish populations, particularly *Oligocottus maculosus*, in Trinidad Bay, California. Trinidad Bay not only has unexploited tidepool areas, but also some that have been heavily collected and others that are largely destroyed. Base line population estimates of "natural" areas should provide an indication of the extent of destruction in heavily collected tidepool regions.

STUDY AREA

Baker Tidepools, an isolated, rocky intertidal area 275 m (900 ft) north of Sotsin Point in Trinidad Bay was selected for study. Trinidad Bay is located approximately 22.5 km (14 miles) north of Humboldt Bay, and is characterized by rocky shores and scattered tidepools (Figure 1).

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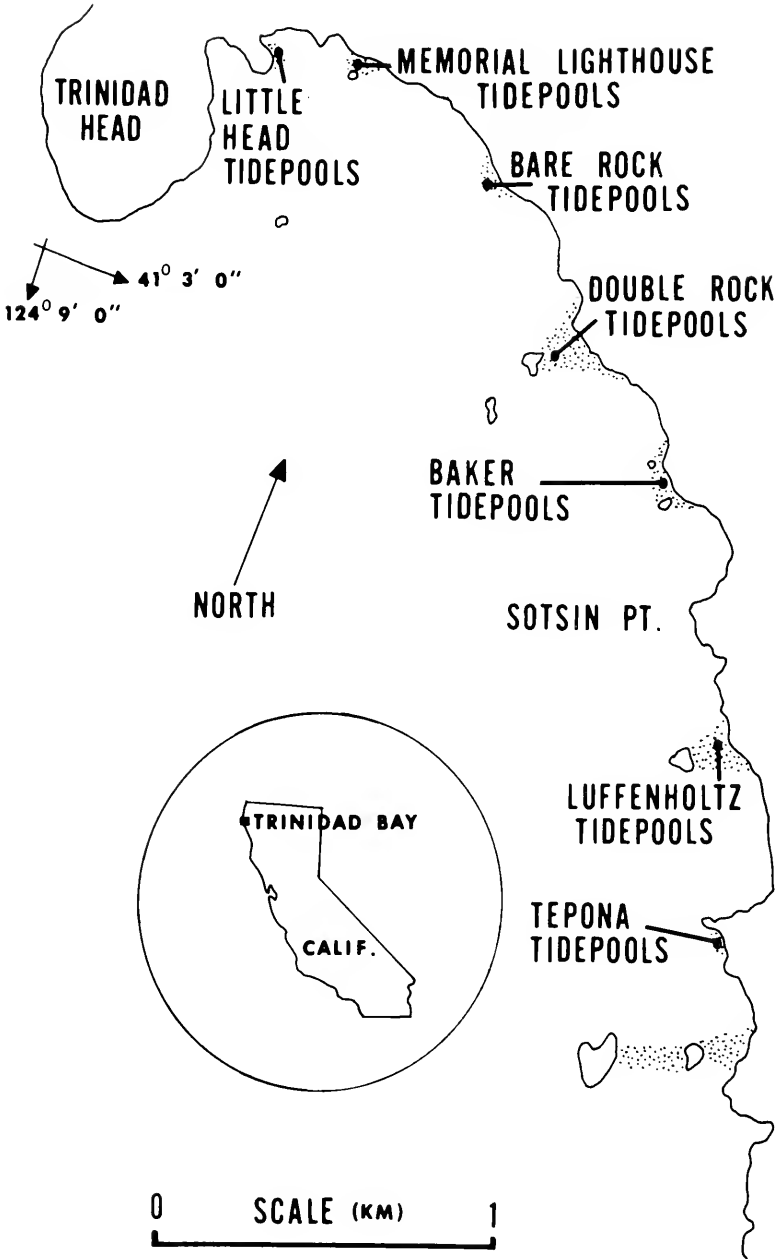


FIGURE 1. Trinidad Bay, California: the Baker Tidepools were the scene of intertidal fish population studies, 1968-1969.

The topography of the study area, principally rock headlands, divides this intertidal region into three separate zones at low tide. At high tide, much of the three zones is under water. The environmental features of the three zones are as close to being untouched as possible. At the time of the study, the area had been exposed to only limited collecting and disruption, as it was not easily accessible during much of the year. The three zones will hereafter be referred to as the South Zone, Central Zone, and North Zone. This reflects their relative position along the coast.

An effective sampling area (ESA) was determined for each zone. Not all of the area at low tide is suitable for fish life. Much of the region is exposed rocks, with isolated tidepools between (Figure 2). Intertidal fishes of the Families Cyclopteridae, Pholidae, Stichaeidae, and Gobiocidae may be found beneath rocks; while members of the Bothidae and Pleuronectidae are generally found under sand or mud at the bottoms of tidepools. Fishes of other families may be found exposed in pools or camouflaged near rocks or in crevasses.



FIGURE 2. Part of the intertidal area of the Baker Tidepools. The effective sampling area (ESA) includes exposed and submerged rocks as well as pools. Photograph by David Misitano.

The South Zone has an almost east-west alignment, and is effectively protected from direct wave assault. It is the largest of the three zones, with an ESA of approximately 2270 m² (24,434 ft²). This zone contains the most diverse habitats. In three locations there are sand bottomed tidepools, while other areas are predominately gravel or rock bottomed. There are several large, deep tidepools, whereas most other pools are relatively shallow.

The Central Zone has an ESA of 1700 m² (18,299 ft²). It is more aligned with direct wave assault, and life in the lower tidal levels is subject to heavy surf and wave action. There is a minimum of habitat

variation. Most tidepools are shallow pockets of trapped water, and few are large.

The North Zone is the smallest of the three zones, with an ESA of 1055 m² (11,356 ft²). It is subject to direct wave assault. There is some diversity in habitat within the North Zone, but most tidepools are relatively shallow.

METHODS

Marking

With many of the intertidal fishes, particularly *Oligocottus* spp., the pectoral fins serve as a principal means of propulsion and support while on the bottom. However, in a series of laboratory tests prior to field studies, it was found that partial fin clipping of the right or left pectoral, or clipping of a portion of the caudal, resulted in no unusual mortalities or loss of mobility over an extended period. A separate mark was assigned to fish from each intertidal zone.

Collection

Sampling was limited to low tidal periods, due to surf conditions in the area. Much of the sampling was by hand implements, a process both slow and relatively inefficient.

Intertidal fishes were collected from the three population study zones from December 17, 1968 to December 7, 1969. Thirty collection-marking trips were made during this period, with 10 trips to each zone. Fishes were collected in only one zone each date. Collection periods averaged approximately 80 min in duration. All fishes were sampled at low tides, ranging in height from -0.7 m to +0.3 m (-2.3 to +1.1 ft), and averaging -0.06 m (-0.2 ft). Collection was intended to be random, with fishes captured at scattered tidepools throughout a zone. An attempt was made to capture all fishes encountered, while still sampling throughout a collection zone. Fish were anesthetized with quinaldine in a manner previously described (Moring 1970).

Measurement and Recovery

All fish were measured in millimeters total length (TL). Each fish received a fin clip corresponding to the collection zone. Young fish less than 20 mm (0.8 inch) TL were measured and returned to tidepools. It was felt that fin clipping could be detrimental to survival for these small fishes. After measurement, or measurement and clipping, fish were revived and randomly returned to zone tidepools. All fishes returned were checked for recovery so they would not be overly susceptible to predation.

Recaptures

All recaptured fish were noted, measured, and returned to zone tidepools. Recaptured fishes were easily recognizable, even with partial fin regeneration.

RESULTS

During the 12-month study period, 1124 fishes were marked and released within the three zones. Fourteen species were marked, although at least 20 intertidal species are found in Trinidad Bay (Moring 1972). A total of 69 fishes was recaptured, for a recapture percentage of 6.1%. The most common species, *Oligocottus maculosus*, accounted for 853 of the fish marked (75.9%) and 64 of the recaptures (92.8%). The

other species recaptured were the fluffy sculpin, *O. snyderi*, (2 recaptures) and juvenile black rockfish, *Sebastes melanops*, (3 recaptures). The latter species occurred only seasonally from May to August.

Basic population estimates were computed following the methods of Ricker (1948 and 1958). Three types of population estimates were derived: Schnabel (Schnabel 1938), Modified Schnabel (Chapman 1952), and Schumacher-Eschmeyer (Schumacher and Eschmeyer 1943). Because of the strong homing patterns of *Oligocottus maculosus* and many other intertidal species, it was felt the best estimates should follow the procedures for lake and enclosed watershed population estimates. Poisson 95% confidence limits were computed for both Schnabel and Modified Schnabel estimates.

Only *Oligocottus maculosus* was recaptured in sufficient numbers to provide reliable population estimates for an individual species. The Modified Schnabel estimate, with its confidence limits, was considered to be the most accurate. Modified Schnabel population estimates were 2066, 2779, and 2014 in the South, Central, and North Zones respectively, for a combined estimate of 6859 *O. maculosus*. Using the measurements of effective sampling areas, these figures reflect densities of 0.91, 1.63, and 1.91 fish per m² respectively. The combined average density was 1.36 *O. maculosus* per m² of total intertidal area (pools and exposed rocks).

There was one recaptured *O. snyderi* each in the Central and North Zones. The small number of recaptures results in unreliable population estimates. Two *Sebastes melanops* were recaptured in the South Zone, and one was recaptured in the Central Zone. This seasonal juvenile was available for marking and recapture only during 4 months.

Combined population estimates for all species were derived for the entire experimental area. Gulland (1966) and others consider combined estimates of stratified areas to be better indications of population size than cumulative estimates. This involves summing each zone estimate to achieve a combined estimate for the experimental area. The result is less variance and bias within strata than if the entire intertidal area were treated as one zone. Combination of zonal Modified Schnabel estimates results in a total estimate of 11,258 fishes (Table 1). This reflects a total density of 2.24 fish per m² of effective sampling area.

TABLE 1. Synopsis of Schnabel, Modified Schnabel, and Schumacher-Eschmeyer Population Estimates for Intertidal Fishes in Zones of a Mark and Recapture Experiment, December 17, 1968 to December 7, 1969.

Study area	Method	Population estimate	Poisson 95% confidence limits	Density per ESA (Fish/m ²)
South Zone:-----	Modified Schnabel.....	3724	2622-5473	1.64
	Schnabel.....	3862	2732-5943	--
	Schumacher-Eschmeyer....	5567	--	--
Central Zone:-----	Modified Schnabel.....	4520	2757-7812	2.66
	Schnabel.....	4868	2963-9458	--
	Schumacher-Eschmeyer....	6292	--	--
North Zone:-----	Modified Schnabel.....	3014	2166-4447	2.86
	Schnabel.....	3118	2209-4746	--
	Schumacher-Eschmeyer....	3905	--	--

DISCUSSION

No marked fishes were recaptured in adjacent zones of the experimental study area. There is no evidence for significant lateral movement of the 14 intertidal species marked in this mark-recapture study. The results tend to support previous data on the stability of individual members of intertidal fish populations, particularly resident cottids (Gersbacher and Denison 1930; Williams 1957; Green 1971).

In this study, no attempt was made to tag individual fish and trace them to individual tidepools. At flood tides, all three zones constituted a single submerged area of less than 300 m (985 ft) in length, with the maximum length of any one zone 110 m (360 ft). There was no evidence that *O. maculosus* or other tagged fishes moved from one zone to another, establishing new "home" tidepools.

For the combined experimental area, the density of all intertidal fishes was 2.24 per m². The figure for tidepool sculpins alone was 1.36 per m², or 60.7% of the fish. During actual collection in the population estimate study, tidepool sculpins accounted for 75.9% of the marked fish. For a 5-year collecting period in Trinidad Bay (May 1965 to May 1970), 68.0% of the fishes collected were tidepool sculpins. However, several intertidal areas in the Bay can be considered disrupted, and not suitable for less hardy species.

Of the 20 species of intertidal fishes in Trinidad Bay, several occur only seasonally. Population estimates are increased by the presence of seasonal fishes. When these fishes leave the area, the population estimates do not decline, but are computed as if the seasonal fishes are still part of the total population subject to recapture. The final population estimates are high due to this type of emigration. The effect of seasonal fishes in the population can be included in the population estimate during late spring and summer months, and eliminated during other times. Similarly, it is advantageous to know when young tidepool sculpins and fluffy sculpins enter the sampled population, as (in this study) these species comprised 82.8% of the fishes examined. For both species, records show the peak frequency of young fishes in the population occurred in August and September. This recruitment factor can also be utilized in individual monthly seasonal estimates.

As a result of the influences of seasonal fishes and young cottids entering the population, three types of population estimates were derived (Table 2): (i) a calculated population estimate, computed with the Modified Schnabel formula, representing the results of the 12-month mark and recapture study; (ii) a seasonally adjusted estimate, which eliminates the effects of immigration and emigration of strictly seasonal species; (iii) a "basic" population estimate which accounts for the entry of young cottids into the sampled population by disregarding their appearance in calculations for certain peak months.

A spring population estimate (May) will include the resident fishes, a low number of young cottids of the year (proportionately), and few seasonal fishes. The true estimate is close to the derived "basic" estimate (9,313, a density of 1.85 fish per m²). The summer population estimate (July), however, reflects the presence of resident fishes, few young cottids, but numerous seasonal fishes (primarily young rock-

TABLE 2. Formulation of Seasonal (P_s) and "Basic" (P_b) Population Estimates, Illustrating the Effect of Seasonal Fish Immigration and Emigration, and the Entry of Young Cottids (Expressed as Modified Schnabel Estimates).

Study area	P_s Calculated estimate	P_s Seasonal estimate*	P_b "Basic" estimate†	Fish per m ² for P_s , P_s , P_b
South Zone.....	3,724	2,963	2,709	1.64, 1.31, 1.19
Central Zone.....	4,520	4,469	4,253	2.66, 2.63, 2.50
North Zone.....	3,014	2,822	2,351	2.86, 2.67, 2.23
Combined total for all zones.....	11,258	10,254	9,313	2.24, 2.07, 1.85

* After eliminating the effects of seasonal fish immigration and emigration.

† After eliminating the effects of young cottid recruitment.

fishes). The actual calculated Modified Schnabel estimate is the best indicator of the population at this time (11,258, a density of 2.24 fish per m²).

The fall population estimate (September) reflects the presence of resident fishes and large numbers of small cottids of Age Group O entering the collections by this time. Few seasonal fishes remain, but they are still statistically considered part of the resident population. Eliminating the effects of seasonal fishes marked prior to September, the seasonal estimate gives the best indication of the actual population size (10,377, a density of 2.07 fish per m²). The winter population estimate (December) represents the presence of resident fishes, the statistical presence of seasonal fishes, and the decreasing proportion of young fish in the population. The "basic" population estimate gives the best indication of the population size at this time. The estimate of 9,313 falls within the Poisson 95% confidence limits of the calculated Modified Schnabel value of 11,258. The minimal density with this population drops to 1.85 fish per m² of intertidal area. In this case, the estimated proportion of tidepool sculpins is very similar to that found during actual collecting from 1965 to 1970.

In effect, the "basic" estimate should be considered a yearly minimum estimate of the fluctuating intertidal fish population. Theoretically, this basic population size should remain essentially stable, barring disruption of the ecological balance within the intertidal zone. The normal seasonal adjustments in population numbers vary most from the norm during late spring and summer months, and return to a minimum level by early spring.

The results indicate one potential hazard for further collection. Extensive collection, pollution, or other disruption of the ecology of a restricted intertidal area may dramatically reduce intertidal fish populations. The results of this study, and those of Williams (1957) and Green (1971) indicate re-population of intertidal cottids, via lateral movement, is minimal. This is an indication that the delicate ecology of the intertidal, when upset, is quite slow in returning to "normal". In Trinidad Bay, at least two important areas show the effects of extensive collecting (Luffenholtz Tidepools and Memorial Lighthouse Tidepools). The "basic" population densities in these areas are lower than

in relatively untouched areas. Population estimates in such areas are difficult, as fishes, invertebrates, and marine algae are responding to changing, stressed conditions. However, comparison with base line estimates from "natural" areas can provide an index of deterioration.

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THE ROCK WRASSE, *HALICHOERES SEMICINCTUS*, AS A CLEANER FISH¹

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What may have been one individual rock wrasse, *Halichoeres semicinctus*, was observed over 10 months cleaning other fishes at Santa Catalina Island. Cleaning is an insignificant activity for rock wrasse in general, but was a major activity of the individual involved in each of these observations. Cleaning activity of the rock wrasse is similar in most respects to that of its relative, the señorita, *Oxyjulis californica*.

INTRODUCTION

The rock wrasse, *Halichoeres semicinctus*, which is numerous over algal-covered substrata in shallow near-shore waters off southern California, looks much like another wrasse, the señorita, *Oxyjulis californica*, which is even more numerous in the same area. Although the señorita is the predominant cleaner fish in California (Limbaugh 1961; Hobson 1971), the rock wrasse has not been known to clean.

Cleaning, or removing by mouth, ectoparasites and other deleterious materials from the bodies of other animals (Feder 1966), cannot be a major activity of the rock wrasse. During an 18-month field study of cleaning symbiosis at La Jolla, California (Hobson 1971), I failed to see this species clean. Nor did I see it clean during extensive incidental observations over 12 years (1961 to 1973) in areas frequented by this fish. Occasionally I saw other fishes respond to an approaching rock wrasse by hovering motionless in the manner of fishes that solicit cleaning (Feder 1966), but always they were unsuccessful in eliciting service. Furthermore, in other accounts of cleaning symbiosis in California (e.g. Limbaugh 1955; Gotshall 1967) the rock wrasse has remained unimplicated in cleaning symbiosis, either as cleaner or as a client.

Recently, however, I observed the rock wrasse cleaning other fishes, including members of its own species, near Isthmus Cove, Santa Catalina Island. The activity was witnessed on four occasions over 10 months at a single location in 5 m (17 ft) of water along the inner margin of a kelp, *Macrocystis*, forest.

My feeling is that all these observations involved the same individual cleaner. I cannot be positive of this, but two facts lead to this impression. First, the cleaner each time was an adult male, about 150 mm (6 inches) long, and, although the species was numerous throughout the area, males differ markedly in coloration with size, and only a relatively few resembled the cleaner. Second, despite being widespread and frequently observed, this species has only been seen cleaning at this one spot, a circumstance that seems best explained by the one-individual hypothesis.

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OBSERVATIONS

June 1973

I first observed the rock wrasse cleaning during midafternoon in June 1973. After recognizing that this individual was a cleaner, I followed it for 30 min as it circled slowly back and forth within an area about 10 x 40 m (33 x 132 ft), 1 to 2 m (3 to 7 ft) above the sea floor, and then finally lost contact with it amid the kelp. During the observations, it approached, inspected, and then frequently cleaned, the external body surfaces of a succession of fishes of several species (recounted below). Between cleaning bouts, the cleaner swam slowly from one part of its operating range to another, and during these times picked at drifting debris four times and once inspected an algal-covered rock. Mostly, however, it appeared alert for cleaning opportunities.

Repeatedly during its leisurely meandering, the cleaner abruptly changed course and swam with accelerated movements directly toward a fish that was as much as 5 m (17 ft) away. Individuals of several species were thus approached, all of them at the time active in ways characteristic of their kind. Every time the cleaner neared they abruptly assumed the hovering attitude of fishes that solicit cleaning. The cleaner then swam to each one, made a close visual inspection, and then frequently plucked one or more times at their body surfaces.

During this period, when cleaning was clearly its major activity, the rock wrasse serviced individuals of three species: opaleye, *Girella nigricans*; halfmoon, *Medialuna californiensis*; and black perch, *Embiotoca jacksoni*. Of eight opaleyes approached and inspected, it cleaned four, plucking at their bodies one to three times. It cleaned both halfmoons that it approached and inspected, plucking at each more than 10 times. Of two black perch approached and inspected, it cleaned one, plucking at its body twice.

Several other incidents during the observation period are noteworthy. Once the cleaner swam close to another rock wrasse, which paused and erected its dorsal fin as if to solicit cleaning, but the cleaner then passed by without apparent interest. Another time a garibaldi, *Hypsypops rubicundus*, swam up alongside the cleaner as it attended a halfmoon, and, although the garibaldi hovered head down in soliciting fashion just a few cm away, the cleaner gave no overt response.

August 1973

During my next visit to the same location, 1 month later, I again saw a rock wrasse cleaning. This time the cleaner was attending another member of its own species that hovered in a regular horizontal attitude, except that its dorsal fin was erected. The cleaner plucked at the base of this fin once, then swam off. Immediately it moved to another rock wrasse nearby, but, though this one stopped swimming and erected its dorsal fin, the cleaner passed by after only a brief inspection. Two more essentially identical encounters followed in succession, seconds apart, each with a different rock wrasse. Then the cleaner approached a garibaldi, which failed to respond, and then a kelp bass, *Paralabrax clathratus*, which also failed to respond. At this point, only 4 min after the observations had begun, I lost track of the cleaner amid a stand of kelp. Although I searched the area for an additional 25 min, I saw no further cleaning.

February to March 1974

Six months later, on February 14, 1974, James R. Chess (Tiburon Laboratory, National Marine Fisheries Service) was diving in the same location and saw a male rock wrasse about 150 mm (6 inches) long cleaning a garibaldi (pers. commun.). This prompted me to follow up the observations I had made during the previous summer. The earlier observations had been incidental to other work, but now I visited the same area once during each of the following 5 weeks specifically to look for cleaning by the rock wrasse. On the first visit (1200 hr, February 26), underwater visibility was so reduced by suspended material that the effort was abandoned after 10 min of fruitless search.

On the next visit (1300 hr, March 4), conditions were better and after only 5 min in the water I spotted a rock wrasse cleaning a garibaldi. During the next 17 min, I followed the cleaner as it meandered over a relatively large area, about 20 x 75 m (72 x 248 ft) swimming about 1 m (3 ft) above the sea floor. Its course brought it within about 5 m (17 ft) to 16 garibaldis, and every time but once the cleaner swam to the garibaldi, which then invariably assumed the attitude of a fish soliciting cleaning. After a brief visual inspection, the cleaner plucked at the body of each garibaldi 1 to 3 times, then continued on its way. During this time, the cleaner passed close to many other fishes (including individuals of all species previously noted being cleaned by the rock wrasse), but failed to show interest in any of them. Three times it plucked at drifting debris, and once it inspected, but did not pluck at the benthos; otherwise, it seemed interested only in cleaning garibaldis. Finally, I lost contact with the cleaner amid benthic vegetation.

The remaining visits were less fruitful. I looked unsuccessfully for the cleaner on the third and fifth visits (1430 to 1500 hr on March 11, and 1215 to 1245 hr on March 20), even though visibility underwater exceeded 15 m (50 ft). However, after 15 min in the water on the fourth visit (1300 to 1345 hr on March 14), I spotted a rock wrasse inspecting a garibaldi. This time I carried a camera, intending to photograph the activity. As I approached to within close range, however, the rock wrasse, still inspecting the garibaldi, abruptly withdrew without cleaning. I kept the rock wrasse in view for 6 min before losing contact, and during this time it approached and inspected 5 garibaldis. As it closed in on each of these fish, I approached closely for the photo, and each time the rock wrasse broke away without cleaning, probably in alarm at my close approach. Although it did not actually clean, it approached only garibaldis, showing no overt interest in the many other species present.

REMARKS

Cleaning as a Characteristic of Only Certain Individuals

Whether or not one shares my feeling that just one individual cleaner performed during these events, the observations complement, and to an extent suggest modifying, some of my previous thoughts on cleaning symbiosis in California.

My earlier report on California cleaners (Hobson 1971) distinguished between habitual and incidental cleaners. Cleaning is a widely acknowledged major activity of all those species considered to be habitual

cleaners. In citing the señorita as an example, I pointed out that while most señoritas apparently do not clean, at least not at any given time, those that do are nevertheless relatively numerous and widespread. On the other hand, the species considered to be incidental cleaners have only rarely been seen cleaning, even though they are well-equipped to pluck tiny organisms from a substrate, and include some of the most frequently observed fishes in southern California. Among species considered incidental cleaners were pile perch, *Damalichthys vacca*, rainbow perch, *Hypsurus caryi*, and white perch, *Phanerodon furcatus*. These species had been identified as cleaners by Limbaugh (1955, 1961), Gotshall (1967), and Hobson (1971). Sightings of cleaning by these species have been rare, it was reasoned, because to them cleaning is just an infrequent incidental adjunct to their regular foraging. Based on the cleaning activity of the rock wrasse, however, the infrequency of these observations may relate, at least in some instances, to there being relatively few cleaning individuals among these species, rather than to the species members in general cleaning infrequently. Far from being an occasional, incidental event, cleaning may at times be the major activity of these particular individuals, as important to them as to any of those others earlier distinguished as habitual cleaners.

One wonders how many frequently practiced activities of individuals are in fact uncharacteristic of other members of their species. The cleaning rock wrasse was noticed apart from other rock wrasse only because cleaning is so obvious. It seems probable that every individual exhibits certain behaviors, perhaps more subtle than cleaning, that set it apart from others of its kind, a fact that deserves more attention.

Some Comparisons With The Señorita

Cleaning interactions involving señoritas and rock wrasse generally are initiated by the cleaners. We might wonder why fishes that receive this cleaning fail to seek out the cleaners, just as many fishes seek out cleaners on tropical reefs (Feder 1966). Obviously señoritas and rock wrasse are welcomed as cleaners, judging from the way fishes that receive them promptly hover motionless with fins erected. It is unlikely these fishes would assume such vulnerable attitudes unless they benefited from the cleaner's actions. Why then do fishes cleaned by señoritas and rock wrasse always wait for the cleaners to identify themselves by making the first move? The explanation offered for situations involving the señorita (Hobson 1971) would seem even more applicable to the rock wrasse. That is, fishes probably are unable to distinguish cleaning rock wrasse from among the many more non-cleaning rock wrasse around them. The tropical fishes that routinely initiate encounters with cleaners generally approach highly specialized forms like the Hawaiian cleaner wrasse *Labroides phthiophagus* (Losey 1971). Generally, these cleaners center their activity around well-defined stations, so that fishes know precisely where to go for service; furthermore, because most individuals of the cleaning species are themselves cleaners, even random attempts to solicit service from individuals in the population at large would have a reasonably good chance for success. This would be untrue of random attempts to solicit cleaning from either the rock wrasse or señorita.

Cleaning señoritas tend to clean members of just one species during a given period of activity (Hobson 1971). In attempting to explain this situation, I pointed out that because the señorita generally initiates its cleaning encounters it can select its clients. Each potential client-species differs in appearance and behavior, so that each presents a distinctive target to the approaching cleaner. Although these differences often seem subtle, they probably influence the cleaner's choice of clients.

Applying the same reasoning to the cleaning rock wrasse, it is not surprising that during February and March the rock wrasse approached and cleaned only the bright-orange garibaldi, a fish readily distinguished from all others in its habitat. During the previous June, however, the rock wrasse had cleaned several species in succession: opaleye, half-moon and black perch. These three species are similar, all being deep-bodied, dark-hued fish that often swim close above the sea floor, and so they may be a measure of the extent the cleaner generalizes when selecting clients. Perhaps significantly, the garibaldi that solicited cleaning at this time was ignored. During the August observations, the rock wrasse showed interest in a more diverse assortment of fishes, although only other members of its own species responded to this interest. The significance of this apparent inconsistency is difficult to assess, however, because the session was so brief (4 min).

Although observations made since my 1971 report continue to support the contention that cleaning señoritas tend to clean members of just one species during an undetermined period of time, I have seen a few señoritas clean several dissimilar species in succession. Apparently, the extent to which señoritas generalize in selecting clients, like the incidence of cleaning, varies between individuals.

If, in fact, one individual rock wrasse performed all the cleaning described in the present report, then the observations indicate that, although its concept of a cleaning target remained unchanged over at least 1 month (February 14 to March 14), there had been a change between the previous June and August, and another between August and February.

In the guts of señoritas, ectoparasites that presumably had been taken by cleaning frequently occur in blocks sharply delimited from foods obviously unrelated to cleaning (Hobson 1971). I consider this evidence that these individuals had cleaned intensively for a while, abruptly shifted to other modes of feeding, and then later returned to cleaning. It remains unknown whether or not the cleaning rock wrasse similarly alternates between protracted bouts of cleaning and non-cleaning modes of feeding.

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NOTES

TAXONOMIC STATUS OF PERCINA IN CALIFORNIA

Examination of over two hundred *Percina* specimens collected from the Sacramento River and the Sacramento-San Joaquin Delta indicates that they are not the logperch, *P. caprodes* (Rafinesque), previously reported (McKechnie 1966; Farley 1972; Moyle, Fisher, and Li 1974). Meristic and morphological analysis of 20 specimens collected from seven localities for detailed comparison reveal that the California *Percina* fit the description of the bigscale logperch, *P. macrolepida* Stevenson.

Principle characteristics used to distinguish the two species are (i) banding patterns, (ii) existence of scales on the prepectoral, breast, and head areas, and (iii) numbers of horizontal scale rows (Tables 1, 2). Ranges for these characters of California *Percina* lie within the ranges for the bigscale logperch listed by Stevenson (1971). However, the mean number of lateral line scales was higher and scales on the supraoccipital region were present on only 10% of the specimens analyzed. Stevenson (1971) indicates that Texas populations have from 2 to 9 supraoccipital scales. These differences may result from the presumably small numbers originally introduced.

TABLE 1. Comparison of *Percina caprodes* and *Percina macrolepida* from the southwestern United States, and *Percina macrolepida* from California.

Character	<i>P. caprodes</i> *	<i>P. macrolepida</i> *	California <i>Percina</i>
Snout.....	Conical and fleshy	Pointed, not fleshy	Pointed, not fleshy
Head pigmentation.....	Sparse	Heavy, especially on preopercle	Heavy, especially on preopercle
Vertical subocular bar.....	Present, but variable in intensity	Usually absent	Indistinct
Horizontal bar beneath orbit....	Absent or faint	Distinct	Distinct
Vertical bars along body.....	Wide, irregular, often mottled	Regular, narrow, not mottled	Narrow, regular, not mottled
Vertical peduncle bars.....	Rarely meet ventrally in adults	Last two usually meet ventrally	Two or more meet ventrally (65%); one or more (95%)
Scales on breast.....	Absent	Present	Present (95%)
Scales on top of head.....	Absent	Present, but variable in number	Variable
Pigmentation in first dorsal fin....	Yellow band present	No yellow band, irregularly dusky	No yellow band, fin pigmented distally
Exposed scales on edge of preopercle.....	Absent	Present	Present (100%)

* Stevenson (1971).

TABLE 2. Meristic data from California populations of *Percina macrolepida* and Guadalupe River, Texas populations of *Percina macrolepida* and *Percina caprodes*.

Character	<i>P. macrolepida</i> California n = 20			<i>P. macrolepida</i> * Texas n = 41			<i>P. caprodes</i> * Texas n = 55		
	Range	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.
Standard length (mm)-----	50-95	71.6	113.94	53.7-87.1†	--	--	62.2-110.4†	--	--
Scales on nape-----	0-20	9.6	5.18	Fully scaled	--	--	Fully scaled	--	--
Scales on supraoccipital region-----	0-2	0.2	0.49	2-9	--	--	--	None	--
Scales on breast-----	0-85	42.4	19.69	Many	--	--	--	None	--
Prepectoral scales-----	5-38	20.8	8.87	Many	--	--	--	None	--
Lateral line scales-----	82-90	86.5	2.56	79-88	82.8	1.57	83-92	86.6	2.85
Scale rows from origin of anal fin to first dorsal fin-----	22-26	23.8	1.03	20-27	23.0	--	25-32	28.7	--
Scale rows from origin of second dorsal fin to anal fin-----	19-21	19.9	0.79	17-22	19.6	--	21-28	24.3	--
Number of whole bars-----	13-16	14.8	0.89	14-16	ca. 15†	--	9-10	ca. 9‡	--
Number of bars meeting ventrally-----	0-6	2.5	1.67	--	ca. 2	--	Rarely any	--	--

* Stevenson (1971).

† (n = 20).

‡ For 15 juveniles of each species (less than 60 mm).

Bigscale logperch have been collected in California in still or slow moving, generally turbid waters with silt or clay bottoms (Sturgess and Hobbs, unpublished data). Stevenson (1971) found that *P. macrolepid*a in Texas prefer less turbulent waters than *P. caprodes*.

Bigscale logperch were accidentally introduced with a shipment of largemouth bass and bluegill to Beale Air Force Base, Yuba County, in 1953 (McKeehnie 1966). The federal hatchery on the Trinity River near Ft. Worth, Texas, was apparently the source for this introduction although their records show the date as "Spring, 1954" (Stevenson, letter to P. B. Moyle, 19 February 1975).

The native range of *P. macrolepid*a includes the Colorado and Guadalupe River systems, Brazos, Trinity and San Jacinto drainages, Devil's Lake (Devil's River), Lake Nasworthy (Concho River), and Lake Texoma (Red River), all in Texas and Oklahoma. Specimens have also been collected from the Río San Carlos, Mexico (Stevenson 1971).

ACKNOWLEDGEMENTS

Michael Stevenson, Tulane University, confirmed the identification. Specimens were collected with the assistance of Roderick Hobbs, Mark Caywood, and William Tippets. Peter Moyle and Hiram Li, University of California, Davis, suggested the logperch as a study species and reviewed the manuscript.

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FREQUENT MOWING INCREASES TURKEY MULLEIN ON CALIFORNIA FOOTHILL RANGELAND

Turkey mullein (*Eremocarpus setigerus*) seed is an important food for dove and quail. Yet information about its management is singularly scarce. A major food of dove (Browning 1962), turkey mullein is often eaten by quail (Emlen and Glading 1945; Glading et al. 1940; Jepson 1923). Shields and Duncan (1966) and Duncan and Shields (1966) found that the plant was somewhat less important in the fall-winter diet of quail in studies made during a series of rather dry years. In a study of quail food in a wet year, Duncan (1968) found that it ranked second only to legume seeds in the diet.

In 1965, a range study was started at the San Joaquin Experimental Range near Coarsegold, California to determine the effects of different mowing rates on forage plant composition. The purpose of mowing was to simulate livestock grazing. As a byproduct of the research, data was collected that should help game managers, ranchers and others to obtain a better supply of preferred game bird food, and attract more birds, by increased growth of turkey mullein plants. A dramatic response in the growth of turkey mullein to frequent mowing was found.

STUDY AREA AND METHODS

The Experimental Range, in the Sierra Nevada foothills, is maintained by the Pacific Southwest Forest and Range Experiment Station. On that range turkey mullein is considered one of the few "summer" annuals that reaches full growth after most of the other, earlier-maturing annual plants have completed their growth. Its general abundance in any year seems closely related to available soil moisture. Most of the growth of turkey mullein occurs after the rainy season. In general, turkey mullein on the Experimental Range is more common in the swales, where the soil (Visalia series) is deeper and holds more moisture. The data reported in this paper are not from a swale site, but from plots on a gentle slope, where the soil is Ahwahnee coarse sandy loam, mostly 50.8-91.4 cm (20-36 inches) deep.

Two blocks were set up each consisting of four 24.4 by 6.1 m (80-by-20 ft) plots. Within each plot were 1.2 m (4-ft) buffer strips on two sides. The rest of the plot was divided into four .91 m (3-ft) sampling strips that were randomly designated A, B, C, and D. The buffer strips were labeled E.

The study consisted of two replications (blocks 1 and 2) of four treatments: (i) mowing every 2 weeks during main growing season (roughly January or February through April or May); (ii) mowing every 3 weeks; (iii) mowing every 4 weeks; and (iv) no mowing (approximates grazing during dry-forage season or no grazing). Mowing was done with a heavy-duty rotary mower, which left a stubble height of about 3.8 cm (1½ inches).

At the end of the growing season, each treated strip was sampled and the rest of the herbage harvested. Litter in excess of 362.9 to 453.7

kg (800 to 1,000 lb) per acre was removed. None of the activities seemed to affect turkey mullein. The plants made practically all of their growth after treatments were completed.

In 1965, the A strips in each plot were left unmowed; the remaining sampling strips were mowed at designated intervals, according to treatment. In 1966, the B strips were unmowed; in 1967, the C strips were left unmowed.

In the first year of the study, 49.9 cm (19.65 inches) of rain fell during the growing season. This amount was only slightly higher than average but more than 12.7 cm (5 inches) fell in March and April. After all the other plants had matured and been sampled turkey mullein plants began to grow.

The abundance of these plants posed a definite problem because it was not intended to study them originally. If they had been allowed to reach maturity, sampling of the plots would have been very difficult the next year. The mowed portions of the area would have been almost a solid mat of turkey mullein plants. So all the plants were pulled and counted.

1966 was a dry year—rainfall in the growing season totaled only 32.5 cm (12.81 inches), 3.4 cm (1.32 inches) of it falling after March 1. Conditions were unfavorable so turkey mullein plants were scarce, and they were not counted. Areas outside the test plots showed a similar condition.

By pulling out all the plants before they matured in 1965, had the seed source been eliminated? Or were the dry conditions in 1966 responsible for an almost complete lack of turkey mullein with viable seed still in the soil? How long would the seed remain viable?

It was a long wait for some of the answers; 1967 was a wet year. Of the 71.1 cm (28 inches) during the growing season, half fell after March 1, and 22.8 cm (9 inches) in April was a record for that month. For the first time in many years, annual-herbage species that develop earlier than turkey mullein matured in a soil with abundant moisture, and grew longer than usual. All of these developments produced a bumper crop of turkey mullein.

On September 7, 1967, all turkey mullein plants more than 2.5 cm (1 inch) high were pulled and tallied. Because of the many plants and our lack of time, the plants on only one block were counted.

The year 1968 proved to be similar to 1966 for turkey mullein. Rainfall totaled only 30.3 cm (11.93 inches); that for April was only 1.2 cm (0.46 inch). Again, no counts were made because of the few plants in the plots.

RESULTS AND DISCUSSION

There was a close relationship between intensity of mowing and the number of turkey mullein plants counted on August 9, 1965 (Table 1). Plots mowed every 2 weeks during the growing season of plants which mature earlier had twice as many turkey mullein plants as those mowed every 3 weeks, four times as many as those mowed every 4 weeks, and 20 times as many as the unmowed plots. All data are total plant counts, not a sample.

TABLE 1. Number of *Eremocarpus setigerus* Plants After Three Intensities of Mowing During the Growing Season of Other Species, San Joaquin Experimental Range, 1965 and 1967

Treatment no.	Frequency of mowing	No. of plants		No. of plants per .099m ²	
		*1965	†1967	*1965	†1967
1.....	Every 2 weeks	1,364	4,061	0.43	2.54
2.....	Every 3 weeks	777	2,657	0.24	1.66
3.....	Every 4 weeks	375	2,076	0.12	1.30
4.....	None	57	459	0.02	0.29

* Two replications counted in August.

† One replication counted in September.

When the mowing frequency was every 2 weeks, the number of plants in 1965 was 1,364; that in the unmowed plots was 57 (Table 1). The results in 1967 were equally startling: 4,061 in the plot mowed every two weeks; 459 in the unmowed plot. Outside the study area many turkey mullein plants germinated, but relatively few grew in the dense stand of other earlier-maturing annuals.

MANAGEMENT IMPLICATIONS

Ranchers and range and game managers have long noted that more turkey mullein will grow when grazing has been heavy or the soil has been disturbed. This study showed a marked response by the plant to mowing treatments. Frequent mowing resulted in many times more turkey mullein plants than less frequent mowing or no mowing.

From the manager's viewpoint, the implications are clear. If a site is suited to growth of turkey mullein and the seed is there, the manager may be able to increase the number of plants by mowing or by grazing practices.

Results of this study point to the effects of weather. There was an almost complete absence of turkey mullein in 1966 and in 1968—both dry years. In contrast, abundant stands grew in 1965 and 1967—both wet years.

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PREY REMAINS AT A GOLDEN EAGLE, *AQUILA* *CHRYSAETOS*, NEST NEAR HOPLAND, CALIFORNIA

In 1974 golden eagles were observed nesting near Hopland, Mendocino County, California at a site inactive at least since 1968. Late in August 1974, after the birds had left, we gathered the prey remains from the nest and vicinity for analysis. The nest was 14 m (46 ft) above ground in a large Oregon oak (*Quercus garryana*) on a north facing slope at approximately 305 m (1,000 ft) elevation about 1.6 km (1 mile) east of the Russian River. Predominant vegetation at the nest site was oak woodland (*Quercus* spp.) with annual grass (*Bromus* spp. and others) understory.

The nest was approximately 2 m (6 ft) in diameter with a shallow central depression lined with wool, feathers, bay (*Umbellularia californica*) and black oak (*Q. kelloggii*) leaves, arboreal lichens (*Ramalina reticulata* and *Usnea* spp.), moss, annual grasses, oak bark, and Douglas fir (*Pseudotsuga menziesii*) and knobcone pine (*Pinus attenuata*) needles, twigs, and cones. Conifer needles comprised about 30% of the nest lining even though coniferous trees do not occur within 1 km (0.6 mile) of the nest. The nest site, on privately owned land, commands an

TABLE 1. Prey Remains from a Golden Eagle Nest Near Hopland, California in 1974

Prey items	Number of individuals	Weight air dry (g)
Deer (small fawns)..... <i>Odocoileus hemionus columbianus</i>	6	2,105
Grey squirrels..... <i>Sciurus griseus</i>	30	1,902
Jack rabbits..... <i>Lepus californicus</i>	16	1,638
Domestic sheep (small lambs)..... <i>Ovis aries</i>	2	180
Ground squirrels..... <i>Citellus beecheyi</i>	5	105
Crows..... <i>Corvus brachyrhynchos</i>	2	11
Brush rabbit..... <i>Sylvilagus bachmani</i>	1	5
Unidentified bone fragments.....	--	19
Totals.....	62	5,965

unobstructed view of several hundred acres to the south and west. A vineyard 1 km south of the nest was worked by as many as five men during the spring and the nest area was grazed by cattle throughout the nesting season. These activities did not prevent successful nesting by the eagles.

All animal remains from the nest, nest tree, and surrounding ground were collected and taken to the University of California, Hopland Field Station laboratory for analysis. Skeletal remains were identified by comparison with museum specimens at the Hopland Field Station and by the keys and diagrams of Ingles (1965) and Hildebrand (1974).

The eagle prey remains consisted mostly of black-tailed deer (*Odocoileus hemionus columbianus*) fawns, grey squirrels (*Sciurus griseus*), and jack rabbits (*Lepus californicus*) (Table 1). On two of the fawn carcasses the molariform teeth were covered with dried membrane, suggesting that the animals were either stillborn or died shortly after birth. Small lambs (*Ovis aries*) occurred in the prey remains even though the nearest sheep were about 1 km north of the nest site. Relatively few ground squirrels were found, as expected from the rancher's observation of fewer ground squirrels in 1974 than in previous years.

ACKNOWLEDGEMENTS

We thank Charles Moon and Richard Ruddick for bringing the nest to our attention. Charles Ozanian assisted in collecting prey remains.

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NEST SITE AND ACTIVITY OF AN INCUBATING COMMON MERGANSER IN NORTHWESTERN CALIFORNIA

Common mergansers (*Mergus merganser*) have been reported nesting in cliffs, under bridges, in tree cavities, under the roots of trees, in old buildings, under brush, among boulders, on hawk nest platforms, and in nest boxes. The common element in these reports is that the sites were dark, cavitous and inconspicuous. White (1957) reported that mergansers in eastern Canada usually nest in the hollow of a tree. In the western states there are few reports of actual nest sites. Bent (1923) reported a nest in Oregon in a crevice in a cliff above the Umpqua River found on May 26, 1895. Griffiee (1958) reported a set of 11 eggs collected on April 12, 1958 from a nest box on the Umpqua River. Dawson and Bowles (1909) reported a nest "near Puget Sound in a decayed fir stub at a height of over a hundred feet."

On May 19, 1973, while observing merganser activity on the Klamath River just east of the confluence of the Trinity River in Humboldt County, California, I saw a female circle over the river and enter a cavity in a living Douglas fir (*Pseudotsuga menziesii*). Subsequent observations of her activity revealed a nest site. The cavity was approximately 30 m (100 ft) above the ground. The top of the tree was broken off about 2 m (6 ft) above the nest entrance. The entrance, barely large enough for her to enter, appeared as though it could have been made by a large woodpecker. The hole opened toward the river at about 10 degrees west of north. The base of the tree was about 12 m (40 ft) from the river's edge on a moderately sloping, vegetated bank. The tree had a base diameter of about 3 m (10 ft). The surrounding trees were primarily Douglas fir, Pacific madrone (*Arbutus menziesii*) and Oregon white oak (*Quercus garryana*).

The nest was observed for 26.3 hr over a 4-day period, Table 1. Departure from the nest began with the appearance of the merganser's face at the hole with just the bill protruding. Within a few seconds, she wiggled her head and breast into the opening. After gazing about for several seconds, she launched out, swooping downward to gain flying speed. She flew directly up the river out of sight; her activities away from the nest were not observed.

Her return to the nest was preceded by several flights 183 m - 274 m (200-300 yards) up and down the river past the nest site. On the final approach she glided downward and then swooped upward to the nest cavity. Reaching stalling speed at the entrance, she stretched her feet forward, grasped the lower rim of the hole and entered her head and breast up to the wings on the last flap. After several wiggles, she disappeared through the tight-fitting hole.

Since I saw a downy brood near this site only 10 days later (May 31) and saw no further activity at the nest, I believe that the female was incubating rather than egg laying.

TABLE 1. Nest Departure and Return Times for an Incubating Female Common Merganser, Northwestern California, 1973.

Date	Observation times		Departure time	Return time	Duration absent (min)
	Times	Hours			
May 17.....	1100-1300	2.0	?	1113	?
May 18.....	0630-0930	3.0	?	0910	?
May 20.....	0600-2100	15.0	0957	1232*	155
May 21.....	0600-1220	6.3	0919	1123	124

* At 1150 hours the female flew up to the nest cavity but turned away just before entering in pursuit of a passing female merganser.

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OBSERVATIONS ON THE INSHORE POPULATION OF DUNGENESS CRAB IN BODEGA BAY

INTRODUCTION

Sampling by the California Fish and Game Department of the Dungeness crab, *Cancer magister* Dana, population in Bodega Bay, California, indicates that the bay is an important nursery area for newly settled post-larvae and juvenile crabs (Dahlstrom 1956; Poole 1965). We sampled the crab population on three different occasions during the summer and early fall of 1973 to investigate its status.

SAMPLING PROCEDURES

Trawls were taken in Bodega Bay with a 7.6 m (25 ft) otter trawl on August 7 and 27, and October 16, 1973. The first of two trawls taken on August 7 was approximately 300 m (1000 ft) off Doran Beach at a depth of 6 m (20 ft) for 15 min. The second was about 2.0 km (1.2 miles) southeast of Doran Beach at a depth of 21 m (70 ft) for 15 min. The August 27 trawls were taken at approximately the same locations and of similar duration as those of August 7 (Figure 1). Five trawls

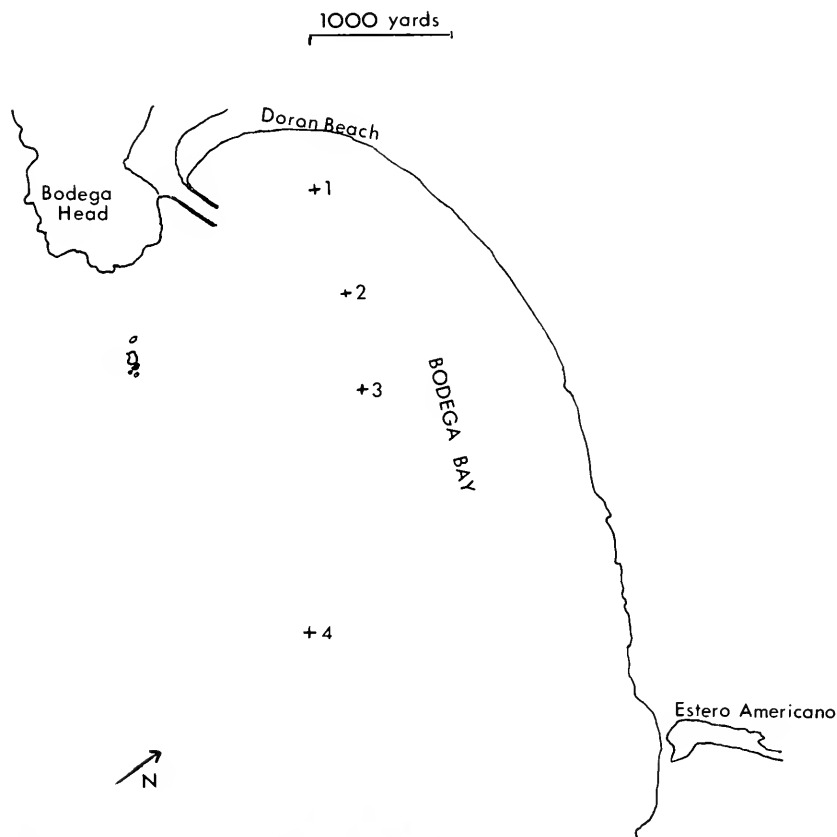


FIGURE 1. Trawl locations in outer Bodega Bay.

were taken on October 16: (i) Trawl #1 was 300 m (1000 ft) off Doran Beach at a depth of 6 m (20 ft) for 15 min.; (ii) Trawl #2 was about 450 m (1500 ft) off Doran Beach at a depth of 9 m (30 ft) for 15 min.; (iii) Trawl #3 was approximately 1500 m (1 mile) southeast of Doran Beach at a depth of 15 m (50 ft) for 15 min.; (iv) Trawls 4 and 5 were each approximately 2.0 km (1.2 miles) southeast of Doran Beach at a depth of 21 m (70 ft) for 25 min each. All specimens of *Cancer magister* obtained were measured with metric calipers across the carapace just anterior to the tenth antero-lateral spine.

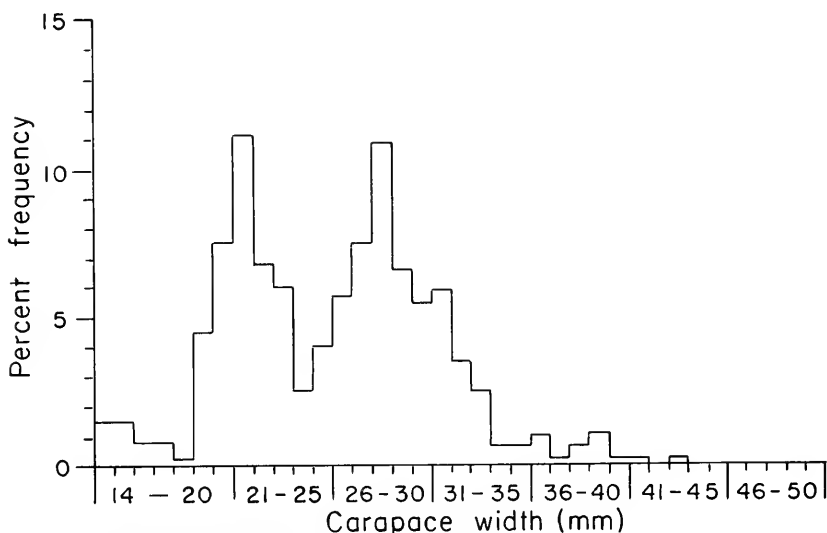


FIGURE 2. *Cancer magister* Size-Frequency Distribution:
August 7, 1973

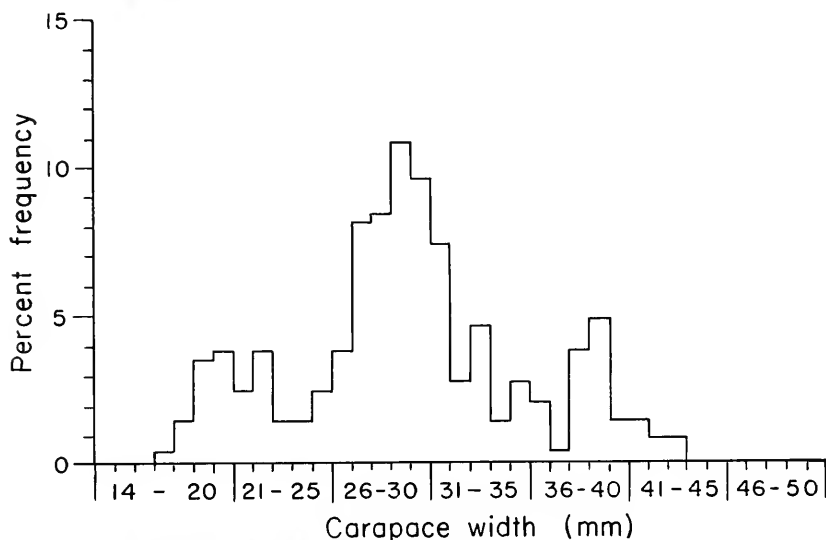


FIGURE 3. *Cancer magister* Size-Frequency Distribution:
August 27, 1973

RESULTS

Three hundred fifty-one juvenile *C. magister* of the 1973 year class were obtained in the first trawl on August 7. No *C. magister* were captured during the second trawl. Two hundred eighty-six juvenile *C. magister* were obtained in the first trawl on August 27. Again, no crabs were obtained in the second trawl. The October 16 trawls resulted in the following: (i) Trawl #1—105 juvenile *C. magister*; (ii) Trawl #2—no *C. magister*; (iii) Trawl #3—17 juvenile *C. magister*; (iv) Trawls 4 and 5—411 juvenile *C. magister*. Other *Cancer* species were obtained during the trawling with *C. gracilis* comprising slightly less than half of all crabs caught. Carapace widths were measured to the nearest mm and size-frequency distribution histograms were prepared (Figures 2, 3, and 4).

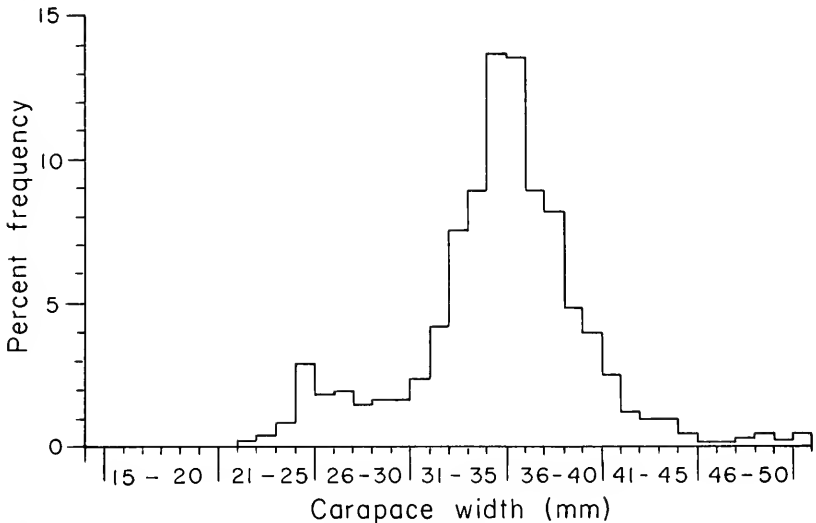


FIGURE 4. *Cancer magister* Size-Frequency Distribution: October 16, 1973

DISCUSSION

Aside from one adult male *Cancer magister* with a carapace width of 150 mm (5.9 inches) all *C. magister* obtained were 1973 year class animals with carapace widths ranging from 14 to 51 mm (0.6 to 2.0 inches). The size-frequency histograms show the typical discontinuous growth pattern of crustacea with modes at 21, 28, and 35 mm (0.8, 1.1, and 1.4 inches) corresponding respectively to instars 4, 5, and 6 as established by Poole (1967).

The 1973 year class in Bodega Bay seems to indicate a highly successful settlement of young crabs. Samples of young of the year in Bodega Bay in the past have shown large variations. Poole estimated the population of juvenile crabs in Bodega Bay in 1961 to have been in excess of 20 million. He reported a yield of 56,000 crabs in a single 3 m (10 ft) beam trawl of 20 min duration (Poole 1967). Other investigators have found in certain years very low numbers of newly settled crabs. In 1957 the California Fish and Game Department found

only 53 juveniles in eight 20–30 min trawls with a 2.4 m (8 ft) beam trawl (Dahlstrom 1957) and only 30 juvenile crabs in several trawls in 1972 (Collier 1972).

The magnitude of the variations in larval success points toward larval success as being an important component in the eventual success of the fishery; however, there are too few samples to correlate young of the year abundance with fishery yield three to four years hence.

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SIZE AND STAGE OF DEVELOPMENT OF LARVAL ENGLISH SOLE, *PAROPHRYS VETULUS*, AT TIME OF ENTRY INTO HUMBOLDT BAY

INTRODUCTION

English sole, *Parophrys vetulus*, are distributed along the Pacific Coast of North America from San Cristobal Bay in Baja California northward and westward to Unimak Island, Alaska. Spawning occurs offshore and the young are transported by water currents from spawning grounds to nursery grounds in the intertidal zone, bays, and estuaries (Hart 1973). Most of the juveniles move out of the nursery area into deeper water September through November of their first year (Ketchen 1947, Westrheim 1955).

Spawning season for this species off California is prolonged, but the peak appears to occur in January and February (Jow 1969). Fertilized eggs float near the surface and drift with the currents. Orsi (1968) reported hatching in 98 to 100 hr at 10.6 C (51 F). Development of the embryo causes the egg to sink prior to hatching. Ketchen (1956) estimated the total time spent drifting in the pelagic stage as egg and larvae to be 6 to 10 weeks before settling on the nursery grounds.

The objective of this study was to determine the stage of development and body size of young English sole entering Humboldt Bay, California nursery ground. Although benthic stages of English sole are abundant in Humboldt Bay, the size and stage of development at the time of initial entry has not been documented. Research in the southern portion of Humboldt Bay by the California Department of Fish and Game (Daniel W. Gotshall and J. Gary Smith, Calif. Dep. Fish and Game pers. commun.) shows immature English sole are one of the three most abundant species. Young sole as small as 26 mm (1.0 inch) total length (TL) were captured by trawling. The largest specimen recorded was 177 mm (7.0 inches). Length frequency data indicate that most young sole leave the Bay by the time they reach 150 mm (5.9 inches).

Ketchen (1956) reported male English sole do not become sexually mature until approximately 250 to 295 mm (2 years of age for males and 3 to 4 for females). The absence of sexually mature individuals in Humboldt Bay rules out any possible spawning and recruitment from within the Bay. Recruitment into the nursery area must, therefore, occur from ocean spawning grounds. If English sole are entering the Bay in the pelagic state, sampling of the water column during the peak spawning period with plankton nets should yield a number of larvae. I sampled the water column during December 1969 and January through March 1970 to obtain data on size and stage of development of English sole.

METHODS

Plankton sampling began on December 12, 1969, and was terminated April 23, 1970. These dates were selected to insure that the sampling period would cover the probable peak spawning period for English sole. Two sampling methods were utilized. A 0.75 m (2.5 ft) plankton net with #0 (0.02 mm) mesh was towed during daylight hours about every 2 weeks. A total of 30 tows was conducted: 3 during December 1969; 11 in January 1970; 4 in February 1970; 10 in March 1970; and 2 in April 1970. Five-minute oblique tows were made in a 5 m (16.5 ft) long boat, powered by an 18-hp outboard. A 0.9 m (3 ft) Isaacs-Kidd midwater trawl was also utilized to attempt the capture of more advanced larval stages. This net was towed by the RV *Seagull*, an 11 m (33.3 ft) long salmon troller converted for research. Fifteen-minute tows in January, April, and May were conducted at night to reduce possible net avoidance. All sampling was conducted in the northern portion of the Bay (lat. 40°46'N, long. 124°12'W) near the mouth on flooding tides. Beach seining was also conducted intermittently in shallow water to confirm entry.

Larval terminology in this paper follows Shelborne's (1957) description of developmental stages:

Stage I	Yolk present.
Stage II	Yolk resorbed but notochord straight.
Stage III	Eyes symmetrical and notochord upturned.
Stage IV	Eyes asymmetrical but not to edge of head.
Stage V	Eyes on or over edge of head.

Identification of Stage I and II larvae in this study was aided by utilizing descriptions of Budd (1940) and Orsi (1968). More advanced stages which are ossified were stained as described by Clothier (1950). This staining technique enables identification by comparing the meristics listed for Pleuronectids in Norman (1934).

RESULTS

Sampling with the 0.75 m (2.5 ft) net captured only two Stage II larvae, one on Dec. 6 and one on Mar. 8; both were 6 mm TL. Regular sampling with this net was discontinued in early April about 3 weeks after several metamorphosed juveniles, 26 to 34 mm (1.0 to 1.3 inches) long, were captured in the small beach seine, March 12.

A total of 17 tows were taken with the midwater trawl. Five tows were taken during the night on January 20 and captured no larvae. Five tows were taken during the night on April 23 and captured 32 Stage IV and V larvae. Seven tows taken on May 19 were the most productive. Three tows in the afternoon captured a total of four larvae, one tow at dusk captured no larvae, and three tows during the night captured a total of 82 Stage IV and V larvae.

Size of larvae ranged from 19 to 26 mm (0.8 to 1.0 inch). The modal length was 21 mm (0.8 inch) (Figure 1). In most individuals 20 mm (0.8 inch) TL, the migrating eye was slightly to the left of the midline; for those larvae 22 mm (0.9 inch) TL however, migration of the eye

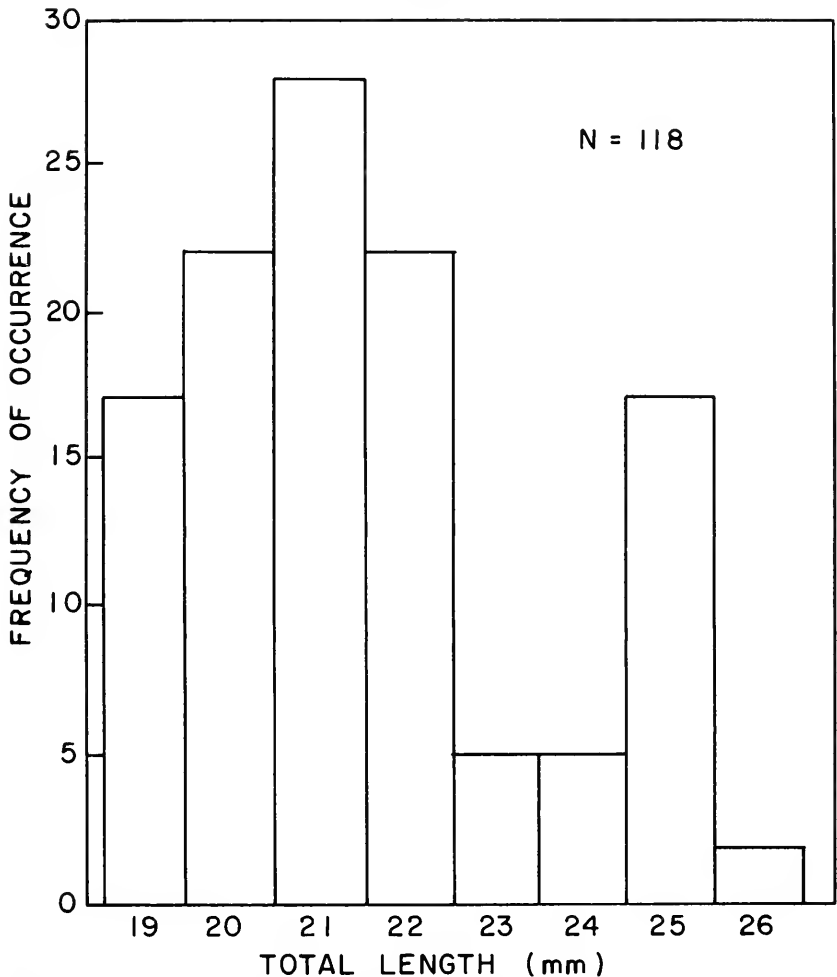


FIGURE 1. Frequency distribution of larval English sole, *Parophrys vetulus*, in Humboldt Bay. Larvae were captured with a 0.9 m (3 ft) Isaacs-Kidd midwater trawl during April and May 1970.

was usually complete (Figure 2). The degree of development, was found to vary slightly with some individuals. A few larvae 23 mm (0.9 inch) TL had the eye to the left of the midline while the eyes of others 20 mm (0.8 inch) TL had completed their migrations.

DISCUSSION

Only two Stage II larval English sole were captured in Humboldt Bay during the spawning season. Eldridge and Bryan's (1972) catch of these early stages were also low; only one specimen, 7mm (0.3 inch) TL, was captured during their 1-year larval fish survey of Humboldt Bay. My capture of 118 Stage IV and V individuals indicates that entry is accomplished at later stages of development, at body lengths of 19 to 26 mm (0.8 to 1.0 inch) TL. The modal length of 20 to 22 mm

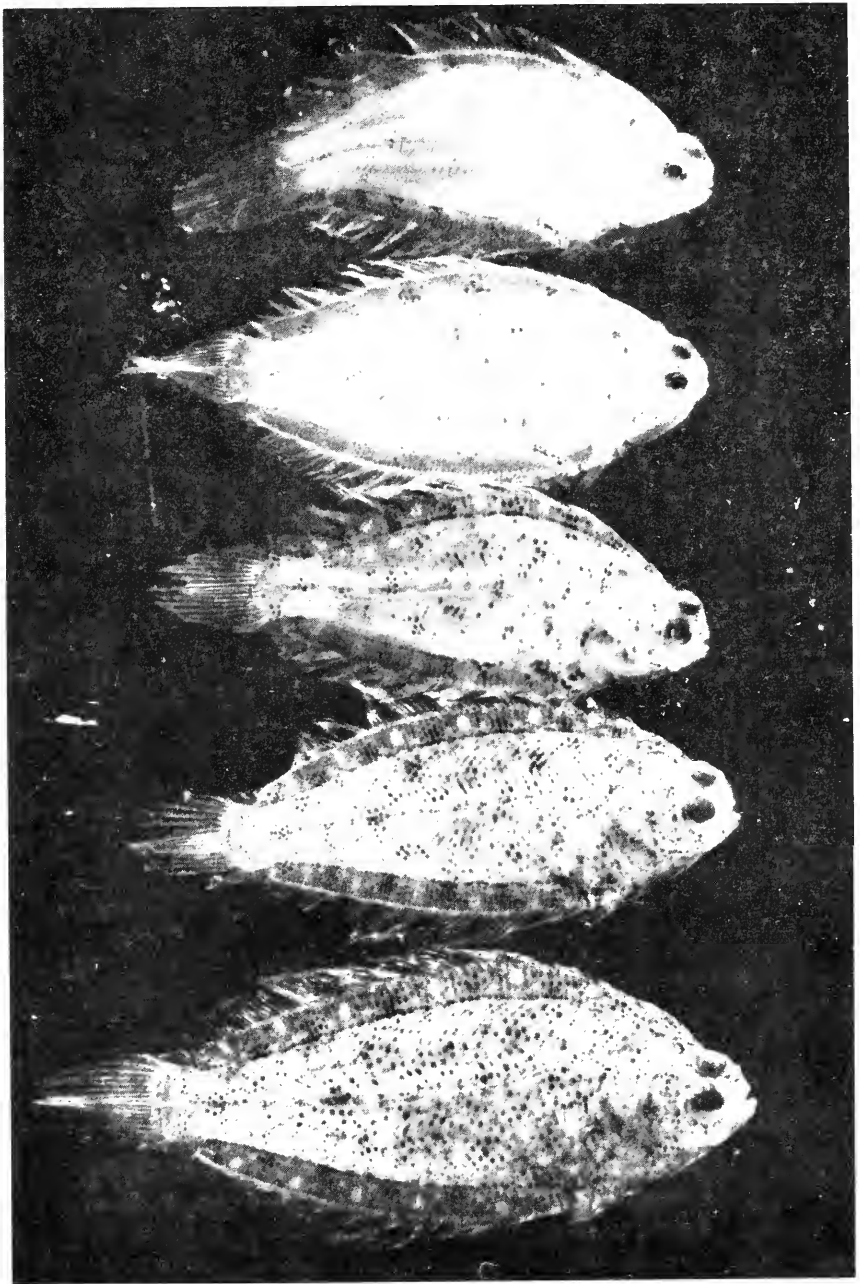


FIGURE 2. English sole larvae captured in an Isaacs-Kidd midwater trawl at the time of entry into Humboldt Bay. The total lengths from top to bottom are 20, 21, 22, and 26 mm.

(0.8 to 0.9 inch) TL at the time of entry appears to coincide closely with the completion of metamorphosis and the start of bottom dwelling habits. These captures, however, do not rule out the possibility of additional recruitment into the Bay by metamorphosed benthic stages from shallow coastal waters. The results clearly indicate that massive recruitment of English sole of Stages I through III did not occur in Humboldt Bay.

In May, catches increased during the night from one larva per tow in daylight to 27.3 larvae per tow during the night. It is not certain if these results are due to increased net avoidance by larvae during daylight or if migration shoreward is actually more pronounced at night. Similar findings in other species of flatfishes have been noted by other workers. Bridger (1956) captured more plaice, *Pleuronectes platessa*, larvae at night than by day. His lowest night catches were greater than the highest day catches. He attributes this difference to increased net avoidance during daylight. Bregnballe (1961) also experienced this day-night variation while beach seining for zero age-class plaice. He feels that net avoidance does not fully explain increased catches at night and cites the work of others who experienced maximum catches at midnight and had another peak in catches at dawn. Increased catches after dark could be explained by a diurnal rhythm of plaice. Bregnballe's observations on two age groups of plaice, 8 to 11 cm (3.2 to 4.3 inches), demonstrated that during daylight they remained buried, at dusk they emerged swimming in short bursts, and at night they swam actively in the water column.

ACKNOWLEDGEMENTS

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—David A. Misitano, National Marine Fisheries Service, Northwest Fisheries Center, 2725 Montlake Boulevard East, Seattle, Washington 98112. This study was supported by the California Cooperative Fisheries Unit at California State University, Humboldt, Arcata, California 95221. Accepted July, 1975.

REVIEWS

Check-list of the Fishes of the North-eastern Atlantic and of the Mediterranean. Volumes I and II.

Edited by J. C. Hureau and Th. Monod; Unesco, Paris, 1973. Vol. I: xxii + 683 p. Vol. II: 331 p. \$70 (paperbound).

These two volumes (abbreviated *Clofnam* I and II) evolved from the establishment in 1965 of a "Panel of Experts for a Catalogue of Fishes of the North-eastern Atlantic and the Mediterranean . . . to develop an extensive generic listing of fish in European waters." Toward that end, 62 authorities in only 8 years produced this check-list involving 221 families, 645 genera, and 1,248 species and subspecies. The area of coverage, very roughly, includes those marine waters lying between latitudes 30° and 80°N (a level of the Azores on the south and uppermost Greenland on the north) and longitudes 30°W and 65°E (east shore of Greenland and west coast of Novaya Zemlya, including the Baltic and White Seas). There was no bathymetric restriction, so many deep-water families are also included.

Volume I covers all the taxa (677 p.) and includes a 3-page list of contributors. The arrangement of taxa follows that of the "Pisces" section of *Zoological Record* of a decade ago. Within each family, the generic and specific presentations follow a rather rigid format: a formal taxonomic synonymy is given for each generic listing and the generic gender is noted. In listing the species, the taxonomic synonymy also notes the location of type specimen(s), when known. The list of synonymies for each species is followed by reference citations to published information on: eggs, larvae, and young stages; otoliths; habitat, distribution, and abundance; and common names. There is also a heading (usually) entitled "complementary iconography."

Volume II contains 159 pages of bibliography (complete literature citations to the references listed in Volume I by author and date only); indexes of common (26 p.) and scientific (122 p.) names; and addenda concerning nine of the families covered in *Clofnam* I (4 p.), additional references (5 p.), and a very valuable set of "editors notes" (5 p.).

One new generic name, *Svetovidovia*, is introduced (as a replacement name for *Gargilius*, a morid), as is one new specific name, *Lepidotrigla dieuzeidei*.

Generally, the taxonomic coverage is excellent, but I did find occasional omissions in the sections concerning development, environments, otoliths, etc. It is unfortunate that these volumes are so expensive as, in my opinion, they are indispensable to any serious-minded fishery biologist, ichthyologist, or ichthyo-paleontologist regardless of geographic placement.—*John E. Fitch*

Thinking Like A Mountain

By Susan L. Flander; University of Missouri Press, Columbia, Missouri, 1974; 284 pp., illustrated. \$12.50.

Aldo Leopold is recognized as one of the fathers of the concept of wilderness protection in the United States, the father of the science and art of wildlife management in this country, as well as a pioneer in conservation and ecology. His book, *SAND COUNTRY ALMANAC*, which distills his philosophy has become a classic among conservationists and ecologists.

This book traces the development of Leopold's philosophy and the experiences which led to the formation of this philosophy. It is a fascinating book in that it portrays how Leopold, the questioning scientific observer, was testing his ideas against the field situation. He was always looking for the broad overall picture. Of particular interests is the evolution of his ideas from providing protection through enforcement of hunting laws and refuges and control of predators toward production in the wild and encouragement of the habitat by the land holder.

This book gives an excellent background of development of science of wildlife management in this country. It goes beyond wildlife management and treats broad ecological concepts. Leopold felt there was a relationship between the ecological diversity of an area and the health of the land. As Susan Flander states in her book: "All of Leopold's thinking was shaped by the land itself and his changing perception of it."

This book is well written and draws extensively on resource documents which are annotated. I found particularly interesting sections relating to deer and the deer controversies, as well as the changing attitude toward the role of predators in the ecology of an area. This book should be a must in the library of wildlife biologists. I would highly recommend it to anyone with an interest in conservation, wilderness and ecology.—*Wallace G. Macgregor*

The California Sea Otter Trade 1784-1848

By Adele Ogden; University of California Press, 1975, 263 p., \$12.75.

The California Library Reprint Series has reissued this historical account of the early Spanish, Mexican, Russian and Yankee harvest and trade in sea otter pelts. First published in 1941 the book has been out of print for several years. Ogden's book contains valuable information for persons interested in sea otters or early California history. The author has researched a great number of historical documents in the preparation of this work giving the reader an insight into a phase of California history often overlooked. In addition, the book gives an indication of the historical distribution and relative abundance of sea otters and the influence of hunting on their population.—*David Zeiner*

This Living Reef—by Douglas Faulkner

Quadrangle/The New York Times Book Co., 1974; 179 p., illustrated in color—\$27.50.

In his second photo-essay Douglas Faulkner concentrated his camera and narrative on that portion of the Micronesian Islands commonly known as Palau. Utilizing local geographical names, his discussion begins with the legends of the origins of Belau (Palau). The narrative then turns to a synopsis of coral biology and coral reef development and evolution that will be easily understood by the non-scientist. Faulkner ends his narrative with descriptions of his experiences and feelings during one day of diving in one of the marine lakes.

Most of the book is devoted to the 107 color plates detailing seascapes and marine life associated with the outer reefs, passes, lagoons, caves and marine lakes. The majority of the photographs are excellent, both in terms of composition as well as exposure and sharpness. However, I feel that there are some that could have been deleted. For example: Plates 10, 11, 12, 14, 15, 22 and 23 are all photos of similar groups of ascidians, sponges and small corals. One or two photos would have served to describe this type of micro-community. Also, plates 29 and 65 are both of the same species of lizardfish. Out of the 25,000 photos taken for this book, surely there must have been good photographs of additional species.

The narrative could have been improved by placing the map within the text rather than at the back of the book. I would also have preferred to see the excellent comments (many which verge on the poetic) for each plate, placed adjacent to the plate rather than grouped at the back of the book.

On the positive side, in addition to the beautiful color plates, I particularly enjoyed Faulkner's discussion of coral biology and his minimal use of anthropomorphisms.

Divers and non-divers interested in tropical marine ecology and photography should find this beautiful book an expensive but worthwhile addition to their libraries.—*Daniel W. Gotshall*



INSTRUCTIONS TO AUTHORS

EDITORIAL POLICY

The editorial staff will consider for publication original articles and notes dealing with the conservation of the fauna and flora of California and its adjacent ocean waters. Authors may submit two copies, each, of manuscript, tables, and figures for consideration at any time.

MANUSCRIPTS: Authors should refer to the *CBE Style Manual* (third edition) for general guidance in preparing their manuscripts. Some major points are given below.

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3. *Abstracts*—Each paper will be introduced by a short, concise abstract. It should immediately follow the title and author's name and be indented at both margins to set it off from the body of the paper.
4. *Abbreviations and numerals*—Use approved abbreviations as listed in the *CBE Style Manual*. In all other cases spell out the entire word.

TABLES: Each table should be typewritten double-spaced throughout with the heading centered at the top. Number tables with arabic numerals and place them together in the manuscript following the references. Use only horizontal rules. See a recent issue of *California Fish and Game* for format.

FIGURES: Submit figures at least twice final size so they may be reduced for publication. Usable page size is $4\frac{3}{8}$ inches by $7\frac{3}{8}$ inches. All figures should be tailored to this proportion. Photographs should be submitted on glossy paper with strong contrasts. All figures should be identified with the author's name in the upper left corner and the figure number in the upper right corner. Markings on figures should be in blue pencil or grease pencil, as this color does not reproduce on copyfilm. Figure captions must be typed on a separate sheet headed by the title of the paper and the author's name.

PROOF AND REPRINTS: Galley proof will be sent to authors approximately 60 days before publication. Fifty reprints will be provided free of charge to authors. Additional copies may be ordered through the editor at the time the proof is submitted.

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