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CALIFORNIA FISH AND GAME

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A LIMNOLOGICAL COMPARISON OF THE THREE BASINS OF EAGLE LAKE, CALIFORNIA[1]

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A comparison of the limnological characteristics of the three basins of Eagle Lake, California was conducted during 1971–1972. Light extinction, dissolved oxygen, electrical conductivity, chlorophyll *a* concentration, primary productivity, and plankton were investigated in each basin.

On the basis of morphometry, the north and central basins were expected to be more eutrophic than the south basin. They are shallow, do not stratify, and have smooth, regular shorelines. However, the deeper south basin was less clear, more productive, and had greater populations of plankton. The discrepancy between expected and observed trophic state can best be explained by the additional availability of nutrients in the south basin.

INTRODUCTION

Studies of multi-basin lakes have indicated that separate basins behave like individual lakes due to differences in morphology, geology, land use, etc. (Thomas 1957; Potash, Sundberg, and Henson 1969; Beeton 1969) and may undergo eutrophication at different rates. Rawson (1955) emphasized the importance of morphometric factors, particularly mean depth, in determining the productivity of lakes. More recently Schindler (1971) has suggested that the ratio of catchment area of the lake watershed to lake volume is a good prediction of productivity.

Eagle Lake, California, a large (12,150 ha, 30,010 acre) but little-known lake at 1,557 m (5,100 ft) elevation in the northern Sierra Nevada (Figure 1), is located on a climatic gradient reflected by the neighboring terrestrial vegetation. Although its three basins are at the same elevation, the south basin is surrounded by coniferous forest and the north basin by juniper-sagebrush desert; the central basin straddles the ecotone. The three basins are also quite different in morphometry (Figure 1); the south is irregular in outline, relatively deep (mean depth 13.7 m, max. depth 30.5 m) (44.9 ft and 100 ft) with steeply sloping banks and a generally rocky or sandy bottom down to depths of about 10 m (33 ft). The central and north basins, by contrast, are shallow (mean depth 3.4 m and 3.9 m; max. depth 9.0 m and 5.3 m, respectively) (11.2 ft and 12.8 ft; 29.5 ft and 17.4 ft) with gently sloping banks forming regular, saucer-like depressions. In general, the morphometry of the central and north basins is characteristic of older, eutrophic lakes (Hooper 1969). However, the geology of the area is quite complex; the lake appears to have been modified many times by faulting and vulcanism (Gester 1962) and an accurate description of its history would require deep cores from all three basins.

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[1] Accepted for publication March 1976

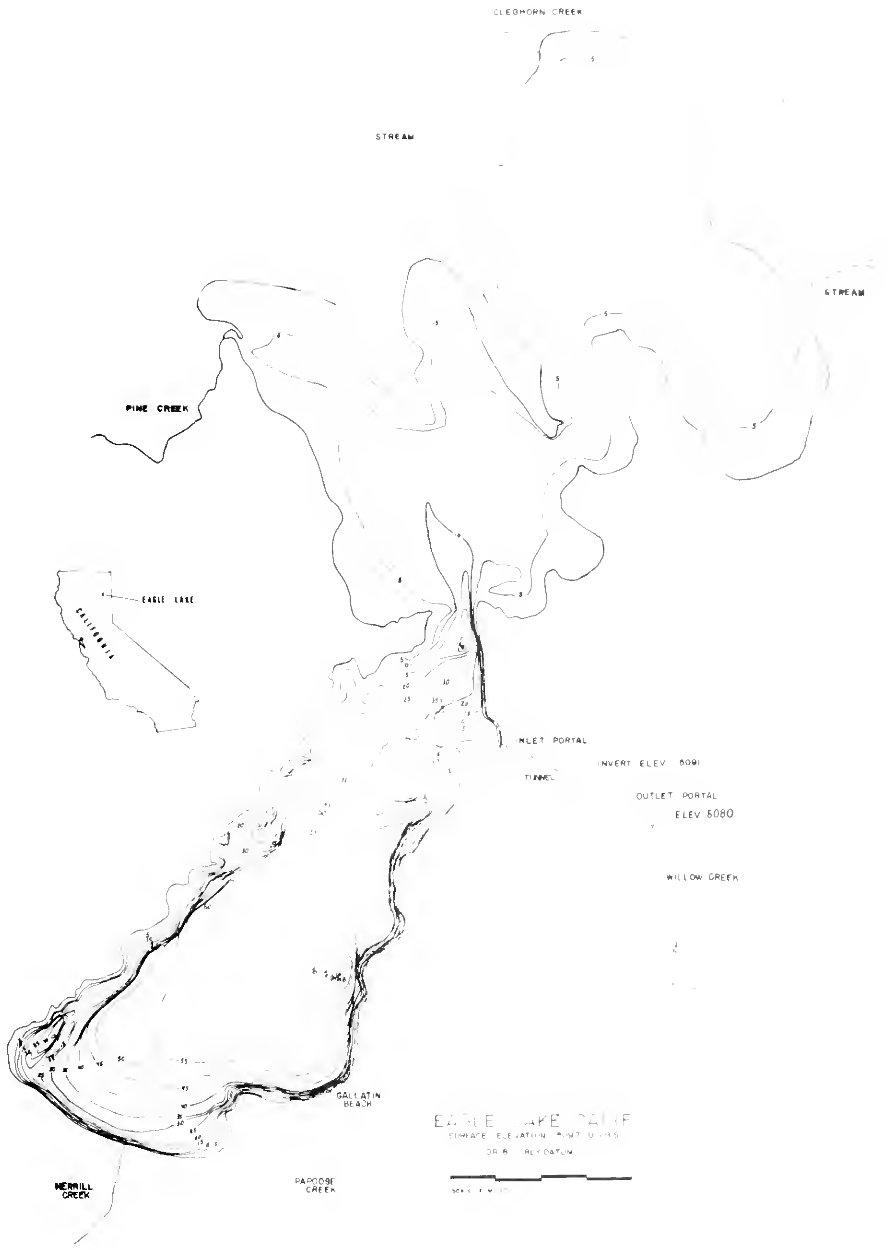

FIGURE 1. Location and morphometry of Eagle Lake, California. Depth contours in feet.

The present study was undertaken to determine if limnological characteristics of the three basins reflect these differences in microclimate and/or morphometry.

METHODS

Vertical profiles for light, dissolved oxygen, temperature, and specific conductance were measured potentiometrically at 12 stations during the period of 10–15 August 1971. Vertical light extinction coefficients were calculated for each station as the slope of the best fitting line to a graph of ln light intensity vs. depth (Hutchinson 1957), excluding measurements within 1 m (3.3 ft) of surface or bottom. During the summer of 1972, weekly measurements of light extinction were made at the 12 sample sites in the lake.

Water from the 12 sites was also analyzed weekly for chlorphyll. Chlorphyll *a* was determined by the trichromatic method (Strickland and Parsons 1968) with the correction for degradation products. Water samples were filtered through glass fiber filters (Whatman GF/C) and the filters ground in a teflon tissue grinder to ensure complete extraction of chlorophyll from the algal cells.

Measurements of phytoplankton production were made at the 12 stations within the lake during the period of 28 July to 17 August 1971. The oxygen light and dark bottle method was used with 24-hour *in situ* incubation of six pairs of bottles at even intervals from top to bottom of the lake.

During the summer 1972, weekly net plankton samples were taken at the 12 sites. Diagonal tows were made from bottom to surface using a number 10 net on a Clark-Bumpus plankton sampler. The sampler was pulled vertically at a constant rate from a slowly moving boat to get a uniformly integrated sample from all depths.

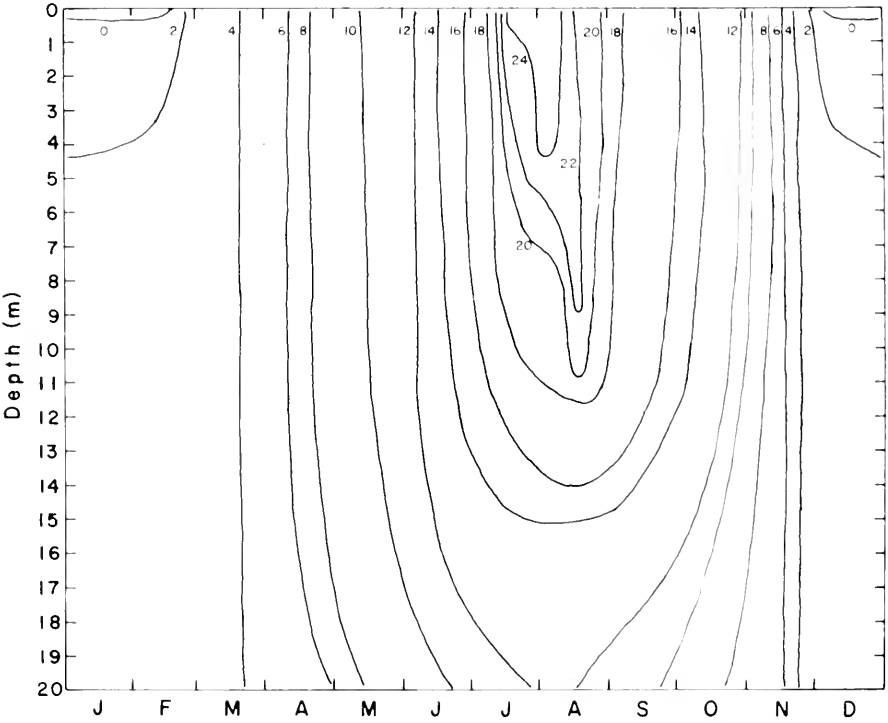

FIGURE 2. Distribution of temperature with depth and time in Eagle Lake's south basin.

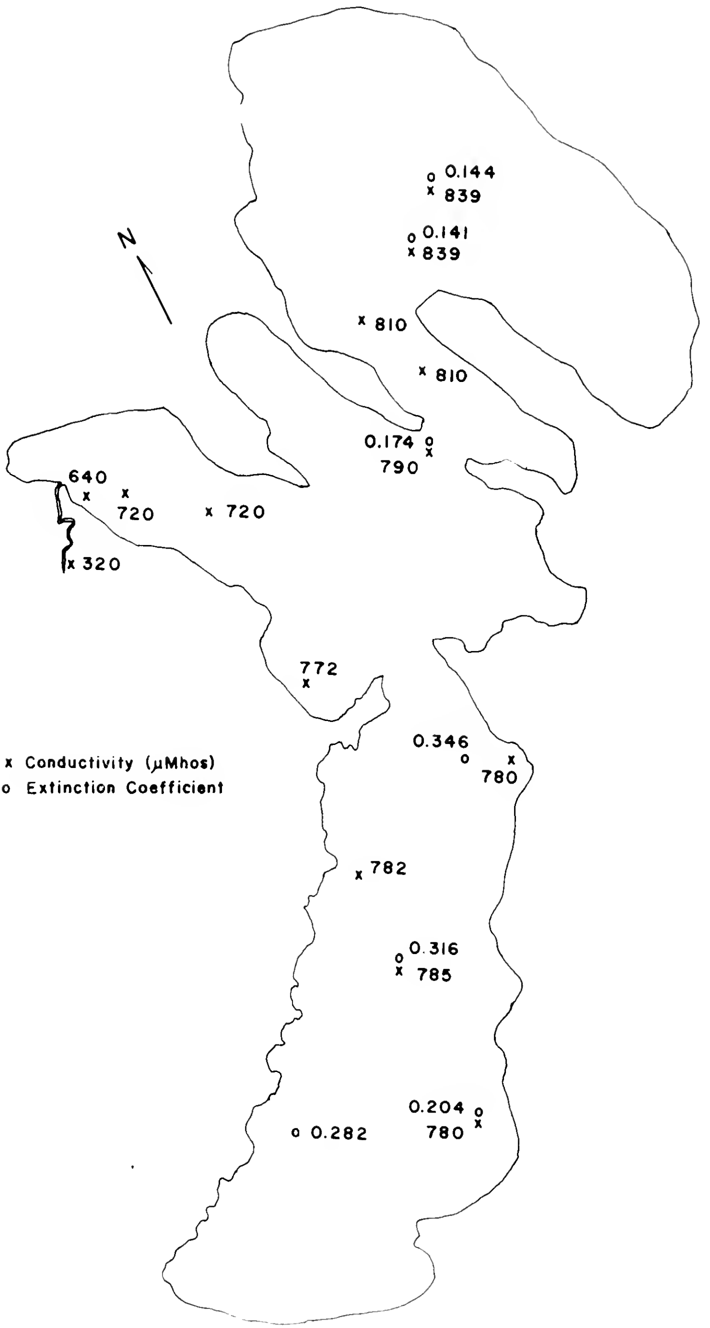

FIGURE 3. Variation in vertical light extinction and conductivity in Eagle Lake during mid-August 1971.

RESULTS

Seasonal isotherms for the south basin show formation of a primary thermocline at 10 to 15 m (33 to 50 ft) about 1 July 1971 (Figure 2). A weak secondary thermocline formed at 4 to 7 m (13 to 23 ft) during a warm, calm period from 17 to 25 July, but disappeared with the return of winds. The basin started to cool in September and the thermocline moved down until the whole basin was isothermal at 6 C (43 F) on 20 November. The basin then continued to cool uniformly.

The shallow north and central basins did not thermally stratify. Temperature gradually increased throughout the water column to 26 C (79 F) by 12 August and cooled to 2 C (36 F) by 20 November 1971. The north and central basins had a complete ice cover by mid-December, while the south basin was only partially covered. By mid-February 1972, ice thickness was 32 cm (12.6 inches) in the north and 25 cm (9.8 inches) in the south basin. Temperature measurements in 1972 showed essentially the same heating and cooling patterns as in 1971.

Variation in electrical conductivity on 12 to 16 August 1971 ranged from 720 to 839 μ Mhos (Figure 3). The central basin, which receives inflow from the major surface tributary, Pine Creek, is the most dilute and shows a strong gradient along the narrow arm leading toward Pine Creek. The other two basins have uniform values of conductivity throughout, with the north basin being most concentrated. Conductivity measurements taken by the California Department of Water Resources during 1971–72 showed the same pattern.

In the summer of 1971 and 1972, the California Department of Water Resources (Bryte Laboratory) analyzed water samples from several stations in the three basin for nitrate-, ammonia- and organic nitrogen and ortho- and total phosphate. All chemical determinations were performed according to approved methods. Concentrations were slightly higher in the south basin in 1971 and 1972 (Table 1). The predominance of organic nitrogen in all basins was similar to conditions generally found in Clear Lake, California during the summer (Calif. Dept. Water Resour. 1972). Nitrates occur in Clear Lake in large quantity only during the colder months when algal activity is low.

TABLE 1. **Average Summer Nutrient Concentrations (ppm) in Eagle Lake, California, 1971–72.**

	NO_3-N	NH_3-N	Organic N	Ortho PO_4-P	Total P-P
North Basin	0.01	0.00	0.85	0.01	0.03
Central Basin	0.01	0.02	0.92	0.00	0.04
South Basin	0.01	0.07	0.91	0.02	0.06

Dissolved oxygen profiles for the south and north basins in mid-August 1971 and mid-July 1972 (Figure 4) indicate that the shallow north basin remained essentially in equilibrium with air. In the hypolimnion of the south basin, oxygen declined to near zero in midsummer, while areas in the lower epilimnion were often supersaturated due to photosynthetic production.

Measurement of primary productivity during late July and early August 1971 (Figure 5) showed that productivity in the south basin was generally higher than that of the north and central basins. The mean productivity per unit volume or per unit area in the south basin was significantly ($P = 0.05$) higher than either north or central basins, which did not differ significantly from each other.

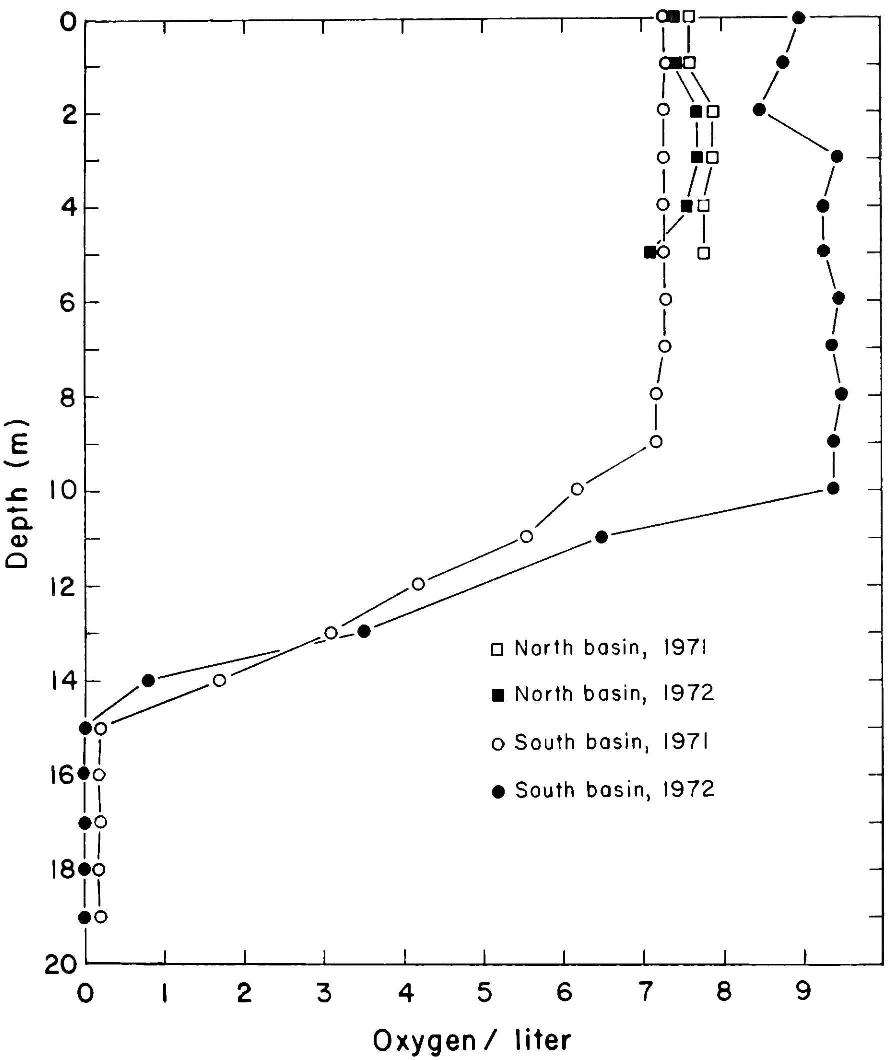

FIGURE 4. Typical dissolved oxygen profiles for Eagle Lake in mid-August 1971 and mid-July 1972.

The mean Secchi disk visibility in the south basin was 4.6 ± 0.5 m (15.1 ± 1.6 ft) in 1971 and 4.3 ± 0.5 m (14.1 ± 1.6 ft) in 1972. (In the north and central basins the disk can be seen on the bottom in 5+ m (16.4 ft) of water.)

Light extinction coefficients measured at various points in the lake on 14 to 16 August 1971 (Figure 3) shows that the north basin was significantly ($P = 0.05$) clearer than the south but not enough data were available during this time period to evaluate the central basin.

The mean (and 95% Confidence Interval) for extinction coefficients and chlorophyll *a* at 12 sampling stations during the summer 1972 (Figure 6) shows all stations in the north basin were significantly clearer than stations in the central and south basins. Other variations in clarity were

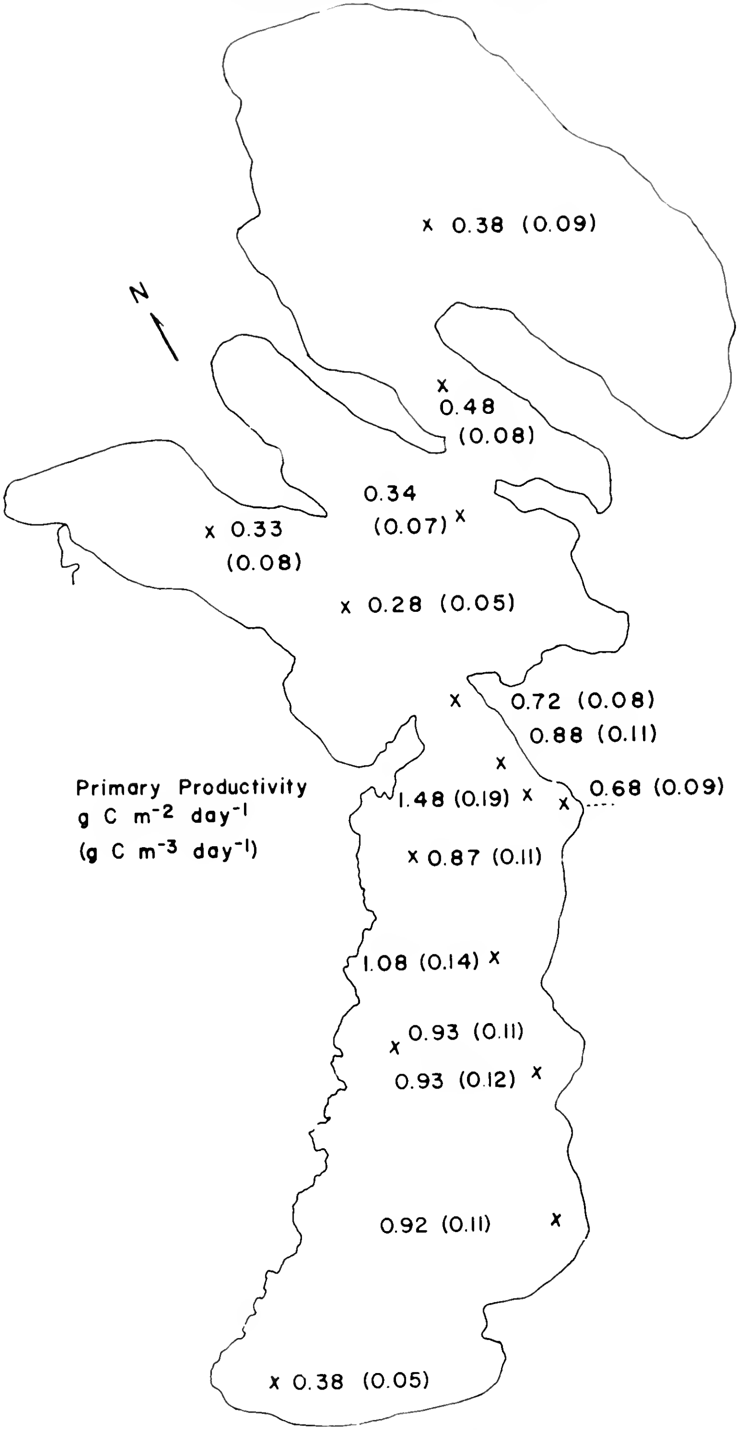

FIGURE 5. Distribution of phytoplankton production in Eagle Lake during mid-July through mid-August 1971.

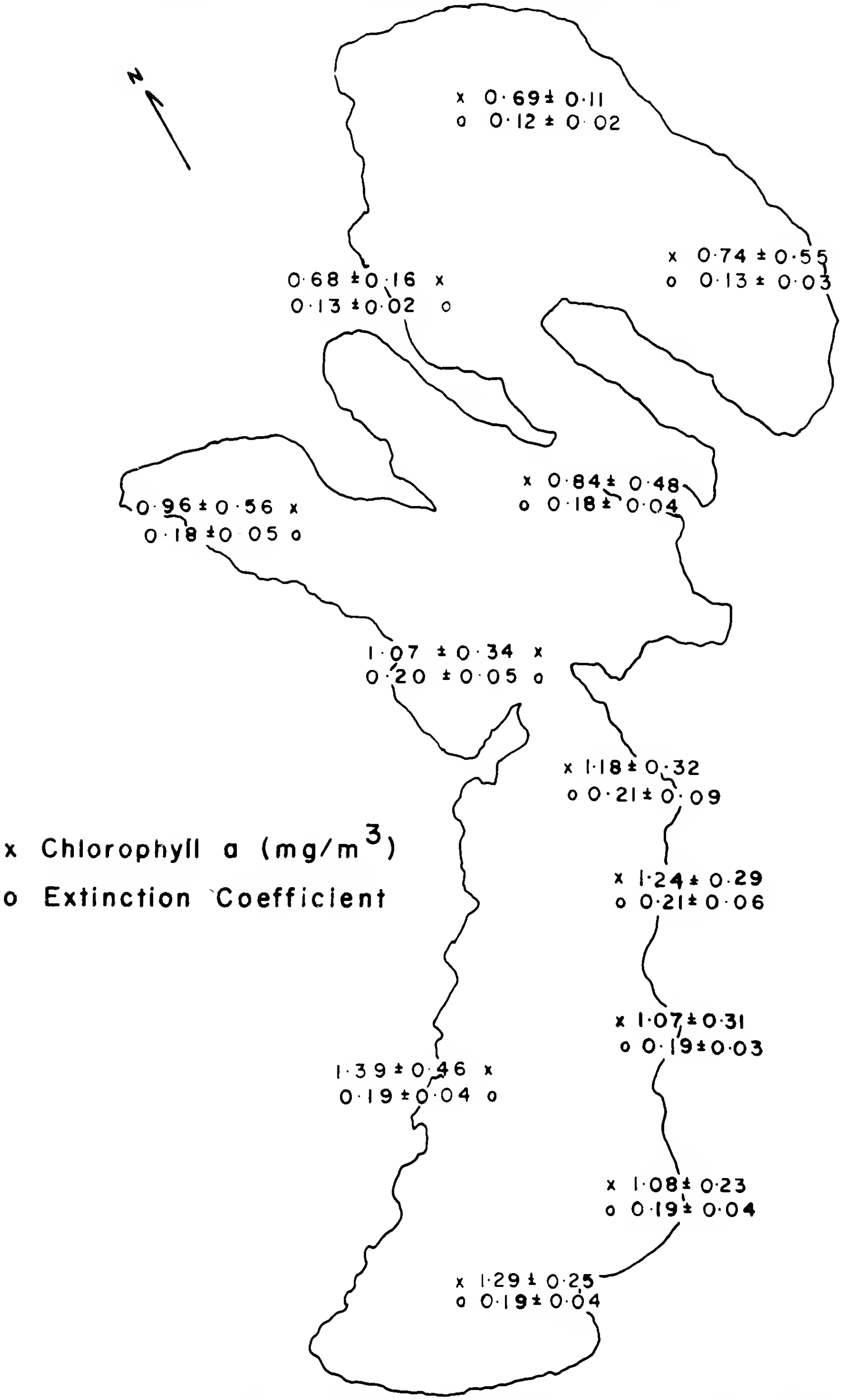

FIGURE 6. Distribution of values for light extinction and chlorophyll *a* in Eagle Lake during the summer of 1972.

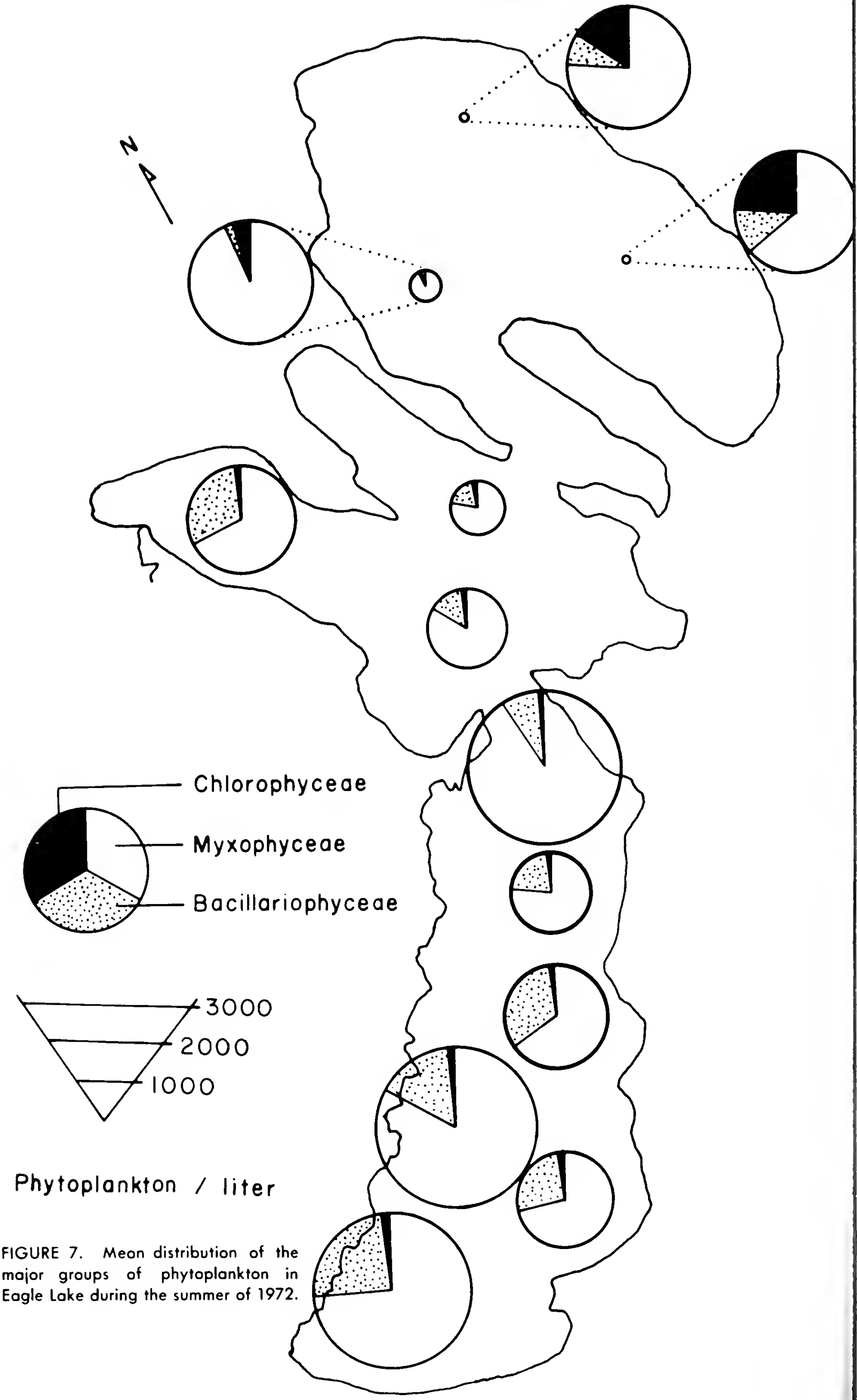

FIGURE 7. Mean distribution of the major groups of phytoplankton in Eagle Lake during the summer of 1972.

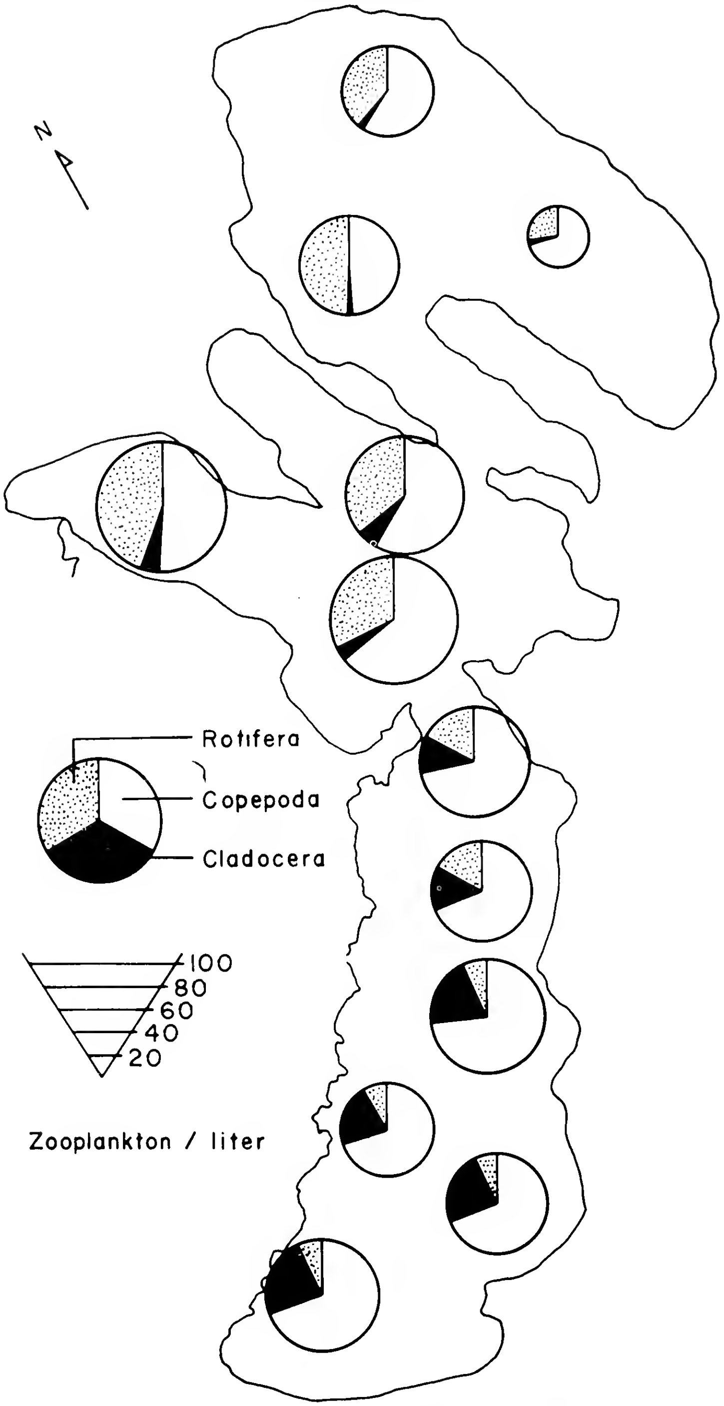

FIGURE 8. Mean distribution of the major groups of zooplankton in Eagle Lake during the summer of 1972.

not significant although the water seemed to be least clear in the north part of the south basin with a gradual trend toward clearer water in any direction from this center. Chlorophyll was considerably more variable than clarity but showed a similar trend: the south basin had more chlorophyll than either of the other basins. While the central basin appeared to have more chlorophyll than the north, the difference was not statistically significant. A statistically significant correlation ($r = 0.8455$, $P = 0.01$) exists between phytoplankton biomass and extinction coefficient.

Net plankton was collected weekly with a Clark-Bumpus sampler at 12 stations throughout the summer of 1972. Although this sampling procedure would not be adequate for nannoplankton, several microscopic analyses of water samples failed to show many nannoplankton. The average distribution of the major groups of net plankton (Figures 7 and 8) show greatest populations were in the south basin. Myxophyceae consisted primarily of one species, *Anabaena flos-aquae.* Also present were *Microcystis* spp., *Oscillatoria* sp., and *Merismopedia tenuissima.* Chlorophyceae included *Spirogyra* sp., *Pediastrum duplex, Staurastrum* sp., and *Planktosphaeria gelatinosa.* The dominant Bacillariophycean was *Fragilaria crotenensis. Gomphonema* sp. was present infrequently.

Myxophyceae were dominant throughout the lake, although more numerous in the south basin than in the north and central basins. In the north basin the predominant bluegreen was *M. tenuissima,* which appeared late in the summer. Mean density of phytoplankton decreased from the south basin to the north.

Zooplankton consisted of two species of Copepoda: *Diaptomus sicilis* and *Cyclops vernalis;* four species of Cladocera: *Daphnia galeata mendotae, D. schøleri, Diaphanosoma leuchtenbergianum,* and *Leptodora kindtii;* and five species of Rotifera: *Keratella cochlearis, K. quadrata, Filinia terminalis, Trichocerca* sp., and *Hexarthra* sp. Copepods, primarily *D. sicilis,* were the dominant zooplankters in all basins. Rotifers were more numerous in the warmer north and central basins than in the south. Cladocerans were never very numerous and were generally restricted to the south basin.

The central basin had a slightly greater average number of zooplankton per liter than the south basin. However, zooplankton biomass was greater in the south basin since the high percentage of rotifers in the central basin contributed a small amount to the biomass. Also, since the south basin is much deeper than the other basins, both biomass and number of organisms per unit surface area would be considerably greater there.

DISCUSSION

Frequent strong winds, predominantly parallel to the long axis of the lake, insure that thermocline formation will be late and at a relatively great depth, thus preventing the central and north basins from stratifying. These winds might be expected to circulate water from one basin to another but this effect is minimal, due perhaps to the orientation of the straits between basins at a sharp angle relative to the lake's long axis. The variation in conductivity between the three basins and the relatively sharp gradients at basin confluences suggest that the basins are well isolated by circulatory patterns and act effectively as three separate lakes.

Volume and surface: volume ratios dominate the physical limnology of the basins. The northern basins warm and cool more rapidly than the deeper south basin. The relatively warm, shallow north basin has a high evaporation rate but no significant dilution from tributaries, thus it develops a greater salt concentration. Horizontal differences in concentrations of plankton have been attributed to wind action (Langford and Jermolajev 1966). Wind concentration will not explain the greater abundance of both phytoplankton and zooplankton in Eagle Lake's south basin since prevailing winds are primarily from the southwest and observed variations in conductivity indicate that the separate basins do not mix significantly.

Schindler (1971) hypothesized that the quantity of nutrients entering a lake are directly proportional to the catchment area (terrestrial portion of the drainage basin + surface area of the lake = A) and inversely proportional to the volume (V). Thus the level of biological productivity should be proportional to the ratio A/V. A change in morphometry, such as the natural filling of the lake with sediment, would reduce lake volume and increase A/V and the nutrients per unit volume.

The ratio A/V calculated for the three basins of Eagle Lake are: north = 0.802, central = 1.976, and south = 0.010. On this basis the north and central basins of Eagle Lake would be expected to be more eutrophic than the south basin. Shallowness, higher summer temperatures, lack of stratification, and deep organic sediments should all contribute to a higher production and more eutrophic characteristics (Rawson 1960). However, the south basin was significantly less clear, more productive of algae, and had higher densities of plankton, all of which indicate more eutrophic conditions (Edmondson 1970).

The marked discrepancy between expected and observed trophic status can best be explained by the additional availability of nutrients in the south basin. A number of possible nutrient sources exits.

A preliminary hydrologic budget indicates that approximately 40% of inflow enters as groundwater. Chemical analyses show that groundwater in the area has three times the concentration of phosphorus found in surface streams. However, at present the volume of groundwater inflow to the three basins has not been determined and its importance as a nutrient source has not been quantified.

Increased human activity may be contributing nutrients to the south basin. Eagle Lake has just recently been "discovered" in terms of recreational use. Visitor use at Lassen National Forest recreational sites has increased each year except 1969 (Table 2). All campsites are located at the south end of the lake and have pit latrines or septic tank waste disposal. One additional campsite (Bureau of Land Management) at the north end is some distance from the water and relatively unpopular. Boating use has nearly tripled since 1967. Most of the fishing pressure is on the south basin because of the concentration of Eagle Lake's game fish.

TABLE 2. **Use of Recreational Facilities at Eagle Lake, California.**

	Use in Visitor Days				
	1967	1968	1969	1970	1971
Lassen National Forest campgrounds	101,900	113,000	104,300	139,100	141,000
Eagle Lake marina	4,700	8,000	7,100	8,300	11,400

Historically there may have been a greater inflow of nutrients from the more mesic terrestrial communities surrounding the south basin. Logging activities and two large forest fires in the past 50 years have probably increased the amount of nutrient inflow. Also, drainage from the coniferous forests may contribute organic complexes which serve as chelators and thus increase nutrient availability. Studies at the Hubbard Brook Ecosystem have quantified the great effects of deforestation on the export of particulate and dissolved masterials (Bormann *et al.* 1974).

Another possibility is that more efficient nutrient cycling occurs in the south basin. Oxygen depletion in the hypolimnion during thermal stratification may enhance the release of nutrients from sediments. In lakes with long basins and frequent wind disturbance, nutrient enrichment of the illuminated layer may result from incorporation of hypolimnetic water into surface wind drift (Mortimer 1969). Fish and zooplankton may aid in recycling nutrients. During the summer increased water temperature concentrates fish in the hypolimnion, but movement across the thermocline surely occurs. Many genera of planktonic Crustacea and larvae of *Chaoborus,* a common inhabitant of bottom muds, exhibit vertical diurnal migration (Hutchinson 1967).

A similar discrepancy between observed and expected trophic state exists in Clear Lake, California, where the two deeper, semistratified basins are more eutrophic than the shallow one (Horne *et al.* 1972, Horne and Goldman 1972, Calif. Dept. Water Resour. 1972). Nutrient recycling occurs at a slower rate in the shallow basin. While this is partly due to the maintenance of aerobic conditions at the sediment-water interface, a further explanation (which may have great significance for Eagle Lake) is the pattern of sediment deposition in Clear Lake. The upper shallow basin receives most of the sediment inflow. Only the lighter fine particles of inorganic sediments enter the lower basins and this fraction has the greatest capacity to absorb and store nutrients (Hillel 1971). The relatively low nitrogen sediment deposited in the upper basin appears to interfere with nitrogen recycling.

In Eagle Lake the majority of sediment enters the central basin via Pine Creek. An analysis of bottom sediments in the southern basin (Bendixen 1971) shows deposition of large amounts of sand at the northern end of the basin which may have originated in the Pine Creek drainage. Sediments entering the south basin from other sources are transported north by longshore currents. Because of its larger size, sand offers greater resistance to transport and is deposited in the shallow shelf regions. Wave energy erodes and selectively separates out the finer grained sediments, transporting them to the deeper portions of the basin. This silty clay material, which appears as a brownish flocculated ooze, is the predominant textural deposit in the south basin at depths greater than 15 m (50 ft). This suggests that nutrients entering the south basin with sediments are concentrating at depths where anaerobic conditions develop, allowing their release.

Further evidence that morphology is a poor indicator of trophic state has been provided by Brylinsky and Mann (1973) in their analysis of International Biological Program data on 43 lakes and 12 reservoirs. They concluded that variables related to solar energy input were quite important in governing productivity, but morphological factors had little influence. When data from a restricted range of latitude (which would include multi-basin lakes) were considered, factors related to nutrient availability assumed much greater importance.

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DISTRIBUTION AND STATUS OF THE SACRAMENTO PERCH, *ARCHOPLITES INTERRUPTUS* (GIRARD), IN CALIFORNIA [1]

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California's only native centrarchid is virtually nonexistent in its native habitat: the waters of the Central Valley, the Clear Lake basin, and the Pajaro and Salinas rivers. However, it has been introduced and successfully established in a number of artificial environments and natural waters outside of its native range; thus, it is in no danger of becoming extinct. The history of its decline and transplanting is traced.

INTRODUCTION

The Sacramento perch is a unique member of the family Centrarchidae. The only native sunfish west of the Rocky Mountains, it was once abundant in the Sacramento-San Joaquin River system and found in the neighboring Pajaro and Salinas Rivers systems (Figure 1). It is believed to be a relict of an ancient fauna, probably attaining its original distribution during Miocene time, before the formation of the Sierra Nevada and Rocky Mountain ranges (Miller 1946, 1959). The occurrence of fossil *Archoplites* in ancient Lake Idaho, and the fact that the Sacramento perch is the only living member of its genus, suggest a former hydrographic connection between the Snake River, or its antecedent, and the Sacramento River drainage (Miller and Smith 1967). A former connection between the Snake River system and the Mississippi River system is suggested by the occurrence of fossil centrarchids of other living genera in the Lahontan basin (Miller 1959) and elsewhere.

The Sacramento perch is regarded as the most primitive member of the centrarchid family on the basis of the morphological, osteological, and histological components of the centrarchid lateral line system. However, it has become highly specialized through long-continued isolation and is no longer in the direct line of centrarchid evolution (Branson and Moore 1962).

Despite its unique status as California's only native sunfish, the history of the Sacramento perch generally was one of neglect. It was ignored by a majority of anglers and biologists who preferred to harvest and manage the more familiar and widespread exotic centrarchids introduced from the

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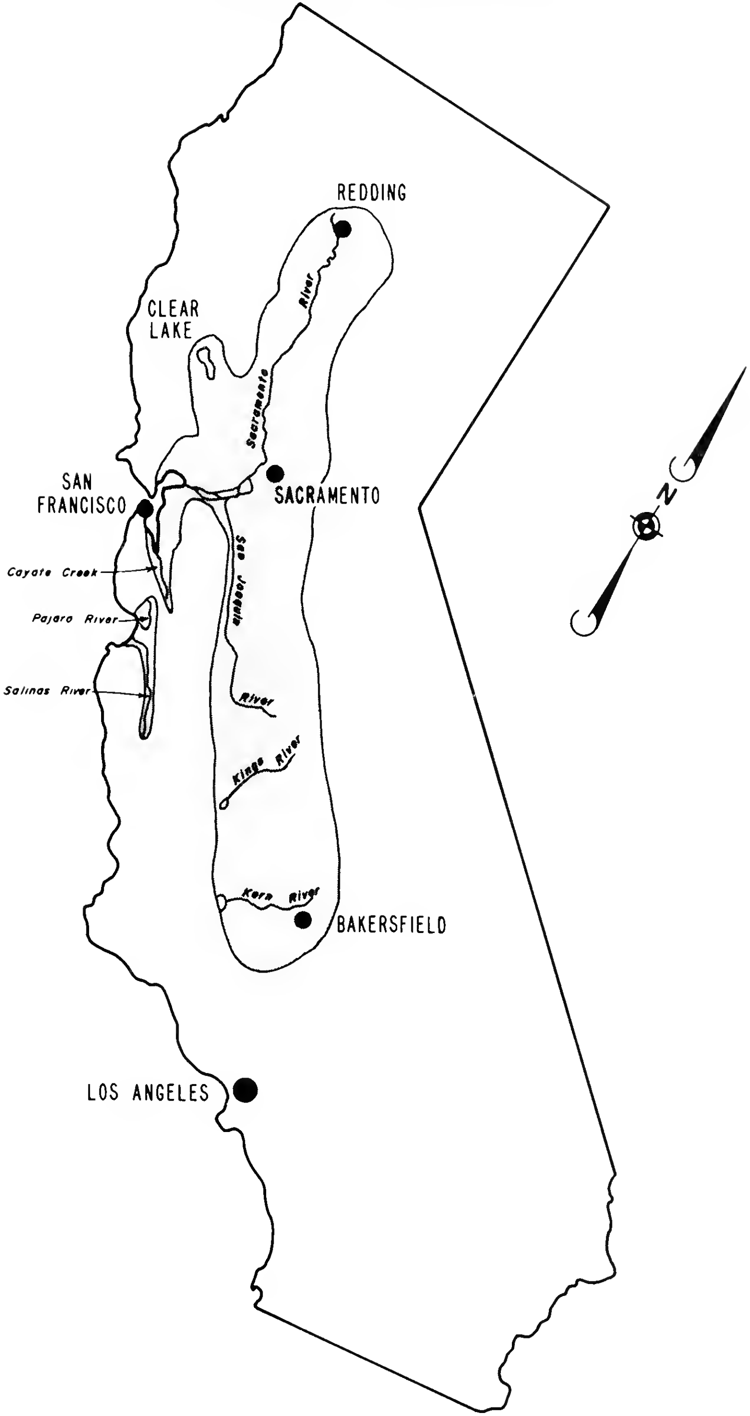

FIGURE 1. Probable range of Sacramento perch prior to settlement of California.

midwest and east. Consequently, little is known of its life history, biology, and habitat requirements (see Aceituno 1974 for summary). Unfortunately, its native habitat has been so irreparably altered that the original ecological role of this species will never be adequately understood. Most populations, both within and outside its native range, now exist in artificial environments.

In recent years there has been a renewed interest in the Sacramento perch both as a game fish and as a candidate for a list of endangered species. In 1973 and 1974, as part of a Master's thesis research project supported in part by the California Department of Fish and Game, the senior author studied several populations of Sacramento perch in order to more fully understand its life history and biology. The results of this investigation have been reported elsewhere (Aceituno and Vanicek 1976). During this period the senior author also attempted to determine the present distribution and status of this species in California. These results are presented here.

PAST DISTRIBUTION

Sacramento perch were first collected from the Sacramento River by Girard (1854). The exact collection locality is not known but it is assumed that it was somewhere in the lower river area, probably near Sacramento. In the same year, speciments obtained at a San Francisco fish market were described by another author (Ayres 1854). These presumably also originated in the lower Sacramento River, or perhaps the San Joaquin River.

Jordan and Gilbert (1895) were the first to collect Sacamento perch from Clear Lake, Lake County, and Snyder (1913) recorded perch from the Pajaro River, a tributary to Monterey Bay. Although Snyder collected extensively in the nearby Salinas River, none were found there until they were collected by Hubbs (1947) from the lower Salinas River in 1946. Hubbs believed their presence in the Salinas was the result of an introduction. Sacramento perch were apparently native to the Salinas River, however, as Follett (1972) found Sacramento perch remains in an excavation at Mission La Soledad (1791–1835) along the Salinas River some 48 km (30 miles) upstream from Monterey Bay.

In the late 1800's, the Sacramento perch was described as "abundant along the lower courses of the Sacramento and San Joaquin Rivers and in all branches of these rivers that permeate the lowlands. . ." (Lockington 1879). Neale (1931) reported that "in the year 1890, or before the introduced fishes became numerous, Tulare Lake in Kings County, Duck, Prospect, and Sycamore sloughs in Yolo County, Butte Creek and many other waters of Sutter County were thickly populated with them."

Walford (1931) listed its distribution as "Sacramento-San Joaquin Basin, Clear Lake, Kern Lake." He also noted that it was "esteemed by anglers," and that commercial fishing for it was prohibited.

Neale (1931) noted that around 1930, 200 Sacramento perch weighing 2½ to 4 lb apiece were rescued from Lake Chabot, Solano County, and transported to two lakes near Sacramento. The names of these lakes were not given. The author also stated that it was his intent and that of W. H. Shebley, in charge of the Bureau of Fish Culture of the then Division of Fish and Game, to "propagate and to endeavor to rehabilitate them by stocking. . ."

Records of early collection localities for the Sacramento perch are summarized by Rutter (1908), Evermann and Clark (1931), and Hopkirk (1973).

Despite the apparent abundance of the Sacramento perch in the mid- and late-1800's, by the turn of the century it was considered uncommon, even though it was still collected in "marketable quantities" in the Sacramento River near Rio Vista (Rutter 1908). Most publications during the first half of the 20th century indicated that the abundance of perch was declining. By the end of the 1940's it was described as "scarce", except in a few isolated localities, and of "minor" importance as a sport fish (Murphy 1948, Curtis 1949).

Apparently sometime during this period it was realized, possibly through the efforts of Mr. Shebley and Mr. Neale, that to save this unique fish it would become necessary to undertake a stocking program. The planting records of the Central Valleys State Hatchery in Elk Grove indicate that stocking of Sacramento perch began in 1941. Between 1941 and 1955, Sacramento perch propagated at the hatchery were planted in as many as six waters per year, primarily in farm ponds and reservoirs. Planted fish were occasionally procured from rescue operations.

In 1955 the records of the Department of Fish and Game indicated that Sacramento perch were present in only 14 localities (Table 1). Of these, all but three (Brickyard Pond, Washington Lake, Clear Lake) were the result of introductions either into artificial environments within its native range, or into natural waters outside of its native range. In addition, Hopkirk (1973) listed a record of Sacramento perch collected during chemical treatment operations by the Department of Fish and Game (Pintler and Johnson 1958) from the Russian River near Ukiah in 1953, presumably the result of an introduction.

TABLE 1. **Known Localities of Sacramento Perch in California in 1955, Based on Records of the California Department of Fish and Game**

Water	County	Source
Alameda Creek	Alameda	Calaveras Reservoir
Alamo River	Imperial	Introduced
Brickyard Pond	Sacramento	Native
Calaveras Reservoir	Alameda/Contra Costa	Introduced
Clear Lake	Lake	Native
Duncan Pond	Mendocino	Introduced
Gravel Pit Ponds near Niles	Alameda	Introduced
Lake Anza	Contra Costa	Introduced
Lassotovich Pond	Fresno	Introduced
Middle Lake	San Francisco	Introduced
Ramer Lake	Imperial	Introduced
Tevis Ponds	Marin	Introduced
Van Vleck Ponds	Sacramento	Introduced
Washington Lake	Yolo	Native

At this time there was no known population of Sacramento perch within the Sacramento-San Joaquin Delta; although in 1950, 300 adult Sacramento perch had been rescued from a small pond on the floodplain of the Sacramento River about ¼-mile above the mouth of Steamboat Slough. It is possible that in the 1950's they were present in the Delta, but in such low numbers that they were rarely encountered.

Thus, by 1955 the range of the Sacramento perch had been reduced from one that occupied virtually all waters of the Sacramento and San Joaquin valleys, the Clear Lake basin, and the Pajaro and Salinas rivers (Figure 1), to one that consisted of disjunct populations in two valley floodplain lakes (Brickyard Pond and Washington Lake), Clear Lake, several artificial lakes and farm ponds mostly in the Central Coast area, two waters in the Salton Sea area, and possibly the Sacramento-San Joaquin Delta and Russian River. Except for some of the waters where it was introduced, it was probably nowhere abundant. Pintler (1957) presented evidence from the Clear Lake sport fishery that shows the Sacramento perch was no longer abundant there in 1955.

PRESENT DISTRIBUTION

In 1973, the senior author examined the records of the California Department of Fish and Game and determined that the Sacramento perch could be found at that time in 34 waters in the State (Table 2). Only four of these contained Sacramento perch in 1955: Alameda Creek, Calaveras Reservoir, Clear Lake, and Brickyard Pond, now known as Lake Greenhaven. The latter two localities are among the three natural waters within its native range known to contain Sacramento perch in 1955. The third, Washington Lake, Yolo County, was lost as Sacramento perch habitat when it was extensively altered during construction of a port and turning basin for ocean-going ships. However, a recent collection of two Sacramento perch in the lower Sacramento River by the Department of Fish and Game, and the collection of one perch by students of the University of California at Davis in the Yolo Bypass (Dr. Peter B. Moyle, U.C.D., pers. commun.), indicates a residual population may still exist in the lower Sacramento River and upper Delta area. The Clear Lake population apparently has been able to maintain itself despite its small numbers. Puckett (1972) noted that it was still taken occasionally by sport fishermen, and Moyle (pers. commun.) saw two perch in the catch of a commercial fisherman at Clear Lake in 1974.

TABLE 2. **Known Localities of Sacramento Perch in California in 1973, Based on Records of the California Department of Fish and Game**

Water	County
Abbots Lagoon	Marin
Alameda Creek	Alameda
Alta Sierra Ranch pond	Nevada
Bisset Ranch pond	Mariposa
Calaveras Reservoir	Santa Clara
Clear Lake	Lake
Clear Lake Reservoir	Modoc
Crowley Lake	Mono
Fowler Farm pond	Madera
Hamilton Farm pond	Fresno
Hedgpeth Farm pond	Fresno
Honey Lake Wildlife Management Area	Lassen
Lake Almanor	Plumas
Lake Greenhaven (Brickyard pond)	Sacramento
Lester B. Hard Ranch pond	Napa
Little Lake	Inyo
Lost River	Modoc
Martin Ranch pond	Fresno
Merle Collins Reservoir	Yuba
Moon Lake Reservoir	Lassen
Oca Tathum Farm pond	Fresno
Pleasant Valley Reservoir	Mono
Ruth Lake	Merced
Sacramento River	Sacramento
San Joaquin Experimental Range pond	Madera
San Luis Reservoir	Merced
Sherwood Lake	Ventura
Shive Farm pond	Fresno
Sterling Ranch pond	Sonoma
Tara Mobil Estate pond	Kings
Upper Owens River	Mono
Visalia City Park ponds	Tulare
West Valley Reservoir	Lassen
Woodward Park ponds	Fresno

The spread of Sacramento perch to additional waters throughout the State since 1955 has been largely the result of transplant efforts of the Department of Fish and Game. From March 1964 through May 1966 Sacramento perch were planted 23 times in 15 different waters. Since 1967 planting has been much less intense.

Of the 34 known localities of Sacramento perch populations, 11 (32%) are in lakes and ponds in the San Joaquin Valley, 8 (24%) are in waters of the northern California foothills and mountains, 6 (18%) are in waters of the Central Coast counties, and 4 (12%) are in waters east of the Sierra Nevada. The only waters where Sacramento perch were not deliberately transplanted by Fish and Game personnel are those on the east side of the Sierra Divide: Crowley Lake, Owens River, Pleasant Valley Reservoir, and Little Lake. These populations are probably the result of unauthorized transplanting by private citizens, the original source possibly being Walker Lake, Nevada.

As these data show, virtually all of the waters where Sacramento perch now exist in California are artificial waters (farm ponds, reservoirs) or natural waters into which they have been introduced by man. Although small populations may persist in Clear Lake and the Sacramento River, the species is virtually nonexistent in its native range. During a 1973 survey of endemic fishes in the Sacramento and San Joaquin valleys, no Sacramento perch were found in 196 collections from streams tributary to the Sacramento and San Joaquin rivers, oxbow lakes along the Sacramento River, and waters of the Sacramento-San Joaquin Delta (California Department of Fish and Game, unpublished data).

In addition, no Sacramento perch have been found during recent intensive collecting by the University of California at Davis in the Pajaro River, nor in a small number of collections from the Salinas River (Moyle, pers. commun.).

THE DECLINE OF SACRAMENTO PERCH IN ITS NATIVE HABITAT

Predation, habitat alteration, interspecific competition for food and space, as well as a reduction in the abundance of native cyprinids have all been suggested as possible causes for the decline of the Sacramento perch (Jordan and Gilbert 1895; Neale 1931; Dill and Shapovalov 1939; Murphy 1948; Mathews 1962; Hopkirk 1973; Moyle, Matthews, and Bonderson 1974).

That the original habitat of the Sacramento perch has been altered is an inescapable fact. Probably no other natural ecosystem in California, except the Los Angeles plain, has been more intensively disrupted by man's actions than the Central Valley. The clear Sacramento River of a century-and-a-half ago has been transformed to a permanent murky brown. Floods are now controlled, artificial flow regimes have been created, and floodplains engineered out of existence.

How these changes have affected the Sacramento perch is unknown. Being a sight-feeding predator, it may have been adversely affected by a loss of water clarity. Sight-feeding predators such as the striped bass (*Morone saxatilis*), largemouth bass (*Micropterus salmoides*), crappies (*Pomoxis* spp.), and Sacramento squawfish (*Ptychocheilus grandis*), however, are able to exist under these conditions. Perhaps channelization and the elimination of flooding deprived the perch of spawning and nursery habitat. However, nonnative centrarchids, with apparently similar spawning habitat requirements, are able to successfully maintain themselves throughout the Central Valley.

We believe a more probable explanation for the demise of the Sacramento perch in its native habitat is the establishment of exotic centrarchids. Murphy (1948) indicated that predation on Sacramento perch eggs by introduced species, including centrarchids, was responsible for its decline. It is not likely that this factor alone, however, is responsible; many native species, such as sculpins (*Cottus* spp.), probably served as efficient predators on Sacramento perch eggs before any exotic species were introduced. The inefficient nest constructing and the ineffective guarding behavior of Sacramento perch observed by Murphy (1948) and others is indicative of its general lack of territoriality, aggressiveness, and pugnacity which are characteristic of its eastern cousins. These features must place this species at a serious competitive disadvantage with introduced centrarchids for food and space in all phases of its life history. Moyle et al. (1974) have shown that the food of Sacramento perch is similar to that of bluegill (*Lepomis macrochirus*) and have suggested that bluegill are responsible for the decline of perch in Clear Lake.

To test this "competitive interaction" hypothesis, we attempted to correlate the abundance of Sacramento perch in 14 waters with that of other species present in the same waters. This included 10 waters listed in Table 2, plus 4 waters where it had been introduced but had not become established. Ratings of relative abundance of all fish species present were based on field collections by the senior author, and/or on data provided by California Department of Fish and Game. The categories of fish abundance were ranked on a scale from 1 to 7 and defined as follows:

1 = Absent: once present but no longer caught, even with great effort.
2 = Rare: caught infrequently and with great effort; only one year class evident.
4 = Common: occurs often in the catch; two or more year classes present.
6 = Abundant: occurs in nearly every sample; several year classes present.
7 = Dominant: occurs in every sample and comprises over 75% of the catch.

Ratings of 3 or 5 were assigned to species which were judged to be intermediate between rare and common, and common and abundant, respectively.

Correlation coefficients were calculated for the abundance of Sacramento perch compared to that of each of 37 other species. The abundance of 24 species was negatively correlated with Sacramento perch abundance. Those species that occurred in at least four locations with Sacramento perch are listed in Table 3. Only the black crappie had a significant correlation value ($r = -0.5946$) at the 95% level of confidence. Other species with high, although not statistically significant, negative correlations were the largemouth bass, bluegill, and hitch. Total abundance of Sacramento perch versus all other centrarchids combined was negatively correlated ($r = -0.36397$). In 5 of 6 waters where Sacramento perch had been stocked at one time, but were now absent or rare, at least one other centrarchid species was now dominant.

These data lend support to the hypothesis that the demise of the Sacramento perch is the result of the introduction of exotic centrarchids. This is not to say the environmental degradation has not affected the Sacramento perch. It is our contention that this has not been the major factor. It should be pointed out that since the arrival of European settlers in California, only one species of fish appears to have become extinct in the

TABLE 3. **Correlation Coefficients of Abundance Ratings of Sacramento Perch and Some Selected Fishes From 14 Waters in California**

Species	Correlation coefficient
Black crappie (*Pomoxis nigromaculatus*)	−0.59455[1]
Largemouth bass (*Micropterus salmoides*)	−0.38413
Hitch (*Lavinia exilicauda*)	−0.30959
Bluegill (*Lepomis macrochirus*)	−0.25781
Rainbow trout (*Salmo gairdneri*)	−0.20177
Brown bullhead (*Ictalurus nebulosus*)	−0.10884
Golden shiner (*Notemigonus crysoleucas*)	−0.05411
Threespine stickleback (*Gasterosteus aculeatus*)	−0.04631
Green sunfish (*Lepomis cyanellus*)	0.01224
Brown trout (*Salmo trutta*)	0.13458
Carp (*Cyprinus carpio*)	0.13579
Sacramento squawfish (*Ptychocheilus grandis*)	0.18887
Tui chub (*Gila bicolor*)	0.22294
Western sucker (*Catostomus occidentalis*)	0.30648
Total centrarchid abundance	−0.36397
Total fish abundance	0.35481

[1] Significant at $p = 0.05$.

Central Valley. The thicktail chub (*Gila crassicauda*) has not been seen since a single specimen was collected in the Sacramento-San Joaquin Delta in 1957.[3] Although most native species probably have declined in distribution and abundance from presettlement levels, all indications are that most have remained relatively widespread and abundant.

Hopkirk (1973) suggested that the decline of the Sacramento perch may have been due to the decline of the thicktail chub, if the latter were the major prey species of the perch. As he stated, this hypothesis cannot be tested; but given the general lack of diet specialization and characteristic opportunism of most temperate zone piscivorous fishes, this hypothesis would seem to have little merit, particularly in view of the demonstrated ability of this species to adapt to a variety of alien habitats.

STATUS

Although the Sacramento perch may be near extinction in its native habitat, it has become successfully etablished in a number of waters, not only in California but in other states as well (McCarraher and Gregory 1970).

In California, Sacramento perch are abundant or common in a number of waters (e.g., lakes Greenhaven, Crowley, and Ruth), and are at least maintaining viable populations in others (e.g., Lake Almanor, Clear Lake Reservoir, and several farm ponds). Thus, this species would not qualify for classification as rare or endangered under California law (California Department of Fish and Game 1973). Although federal law permits a species to be classed as endangered over any significant portion of its range, such as the Central Valley or Clear Lake, it is unlikely that significant populations of Sacramento perch could ever become reestablished in these habitats.

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[3] Another species, the Sacramento tui chub (*Gila bicolor formosa*), has not been recorded since 1875. There is some question as to its taxonomic validity.

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ASSESSMENT OF OCEAN SHRIMP[1] MANAGEMENT IN CALIFORNIA RESULTING FROM WIDELY FLUCTUATING RECRUITMENT

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The ocean shrimp fishery off California has experienced large variations in annual landings and catch rates that apparently result from fluctuations in recruitment rather than from changes in availability. These fluctuations occur frequently and with a magnitude such that the establishment of a constant annual catch quota is undesirable, while fluctuating catch quotas are difficult to determine accurately. However the occurrence of large numbers of 1-year-old females in most year classes combined with the low exploitation rates on 1-year-olds should insure an adequate spawning stock, under present conditions in the fishery, should the catch quota be eliminated.

INTRODUCTION

In the early 1950's, the California Department of Fish and Game discovered and explored several ocean shrimp, *Pandalus jordani,* beds off of central and northern California. In 1952, regulations governing the potential shrimp fishery were established; during the same year, the first commercial landings of ocean shrimp were made in California (Dahlstrom 1973). Since then, shrimp landings have been sampled during all fishing seasons yielding an excellent series of catch data. In addition, several research cruises have been made to obtain population estimates (Abramson 1968; Gotshall 1972). With this data, the California Department of Fish and Game attempted to manage the ocean shrimp resource on a sustainable yield basis. Present regulations include an annual catch quota, minimum mesh size, and a closed season.

The California Fish and Game Commission set an annual quota each year since 1952 (Dahlstrom 1961, 1970, 1973). In early years of the fishery, quotas were set for each area at one-fourth of the estimated shrimp biomass on each bed. Despite the rather conservative fishery, landings fluctuated wildly on all but the Area A bed (Figure 1). This is the largest bed and consistently produces the bulk of the shrimp landed in California (Dahlstrom 1973).

The extreme fluctuations in landings that have occurred in three of the four areas have been attributed to natural variations in shrimp abundance which indicated that equilibrium yields were unrealistic for smaller beds. As a result, quotas have remained at the 1962 levels in all areas except Area A (Dahlstrom 1973).

In Area A, considerable effort has been directed at applying the Schaefer stock production model (Schaefer 1954) to the shrimp fishery. Abramson and Tomlinson (1972) obtained what appeared to be a satisfactory fit of the model using catch and effort data through 1969, and proposed a management scheme based on this model. However, this management scheme has broken down as data from the last few years has become available. As a consequence, we undertook a detailed review of the Area

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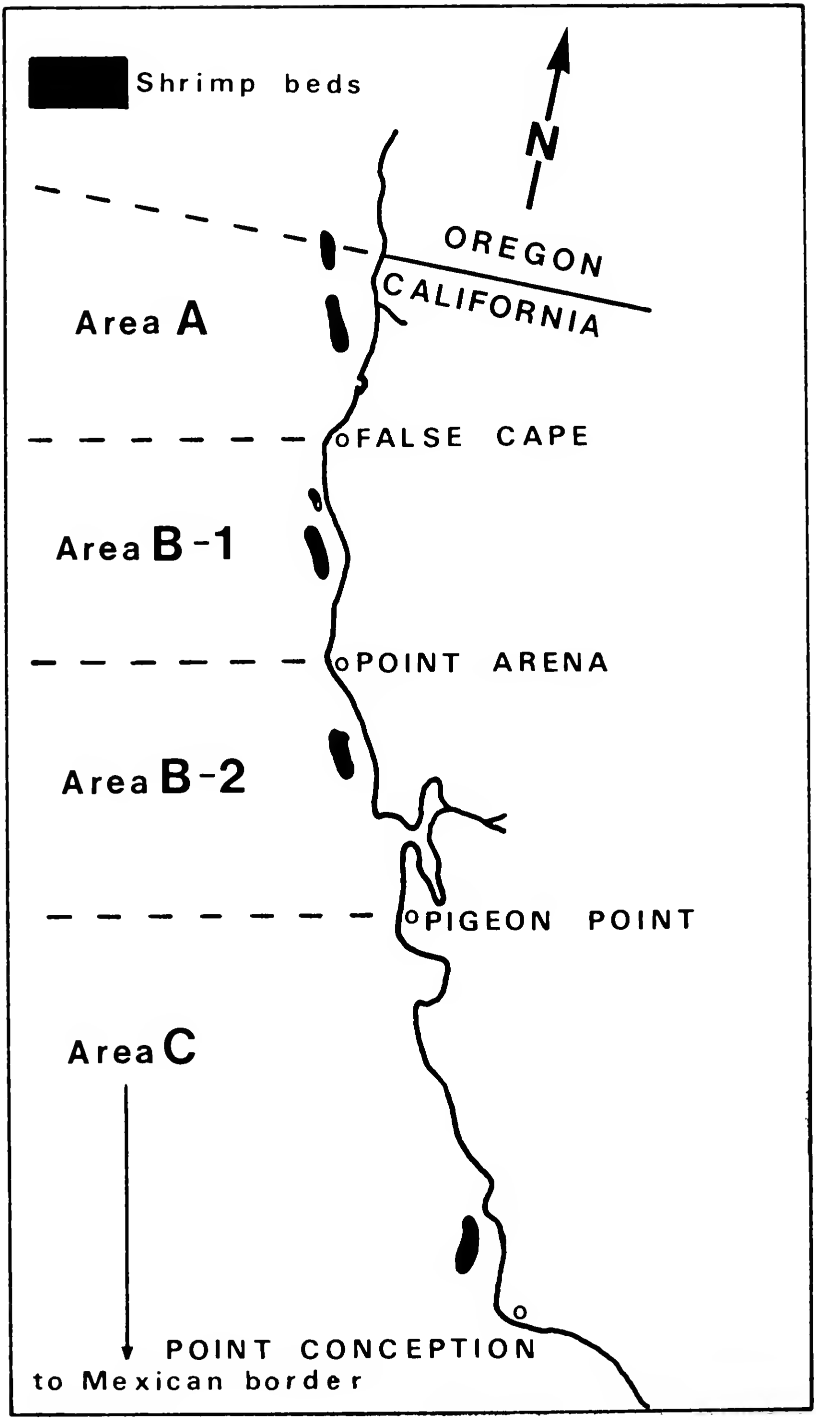

FIGURE 1. Ocean shrimp regulated areas and location of shrimp beds.

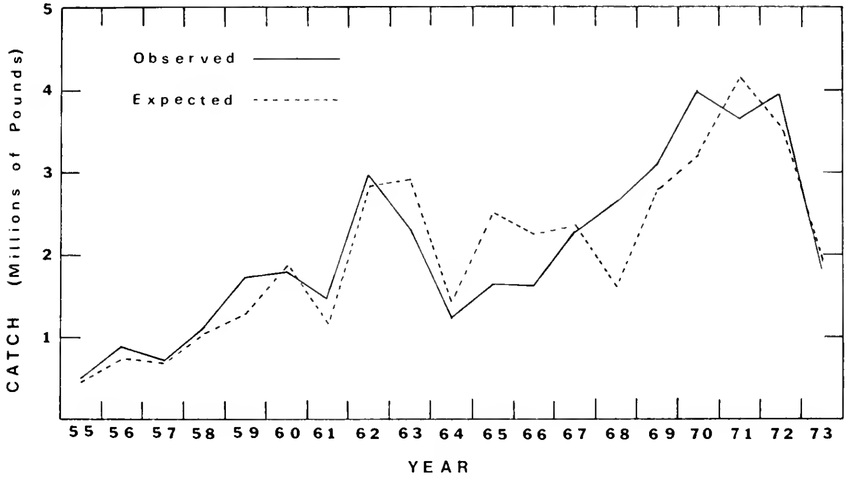

FIGURE 2. Annual combined California and Oregon landings of shrimp from Area A and annual landings as estimated by GENPROD.

A shrimp population dynamics in 1973. We believe this analysis has produced a new understanding of the Area A shrimp population, and an explanation of the failure of a management scheme based on the stock production model.

APPLICATION OF THE YIELD MODEL TO SHRIMP

In hopes of finding a reliable, relatively inexpensive way of managing the Area A fishery through an annual quota, Abramson and Tomlinson (1972) fit Pella and Tomlinson's (1970) modification of the Schaefer model to the catch and effort data for the Area A bed using the program GENPROD developed by Pella and Tomlinson (1970). Although the computer program used is capable of fitting a series of curves, the nature of the data precluded considering anything other than the simple parabola.

The program operates by making a patterned search through a wide range of possible parameters. The observed effort and a set of parameters are used to develop an expected catch history. This expected catch history is then compared to the actual catch history using a least squares technique. The program ends when a set of parameters is found that minimizes the sum of squares of the deviations.

The fit between observed and expected catch has always been reasonable (Figure 2). Even though some large deviations occurred, the model appeared to reflect the fishery rather well. Abramson and Tomlinson's (1972) fit through 1969 depicted a population that was capable of yielding an equilibrium catch of 2.5 million pounds from a stock of 4.8 million pounds (Figure 3). The stock size at the beginning of the 1970 season was predicted to be 7.1 million pounds.

The management strategy proposed by Abramson and Tomlinson was to fish at a rate above that required to take the maximum equilibrium yield until the population was brought down to optimum size. They deemed it advisable to bring the stock down gradually over a period of years to preclude developing undesirable instability in the population. The quota for 1970 was calculated as 3.4 million pounds.

It should be mentioned that the data set was far from ideal. Two assumptions inherent in the model are that catch per unit of effort accurately reflects population size, and that population size is the only factor influencing the productivity of the stock. However, shrimp do not school in the same way each year or even each week, and a dense school will show a higher catch per unit of effort than the same amount of shrimp in a larger, less dense school. In addition, the environment will influence productivity by affecting growth or recruitment. These factors caused a wide scatter in the data points and, with only 16 data points originally available, caused very unstable estimates of the model parameters. Finally, all observations were from stock sizes calculated by model to be above optimum density on the right side of the production curve. Trying to define the top of a parabola from this kind of data is risky business at best.

On the other hand, it was to be expected that estimates would improve as time went on. A new point would be added each year. These points would be from populations closer to the optimum size and provide a better definition of the whole relationship.

Adding data for 1970 and 1971 caused no insurmountable problems. The estimate of the maximum equilibrium yield fluctuated somewhat, ending up at 2.9 million pounds after the 1971 data was added. This seemed well within reason, although the data set still lacked stability. Simulations of the 1972 season showed relatively large changes in the parameter estimates could be expected for relatively small deviations of catch per unit of effort from the expected.

Adding data for 1972 caused problems, however. The year was characterized by a strong year class passing through the fishery as well as above average concentrations of shrimp. This combination produced a high catch per unit of effort and resulted in a much stronger estimate of stock

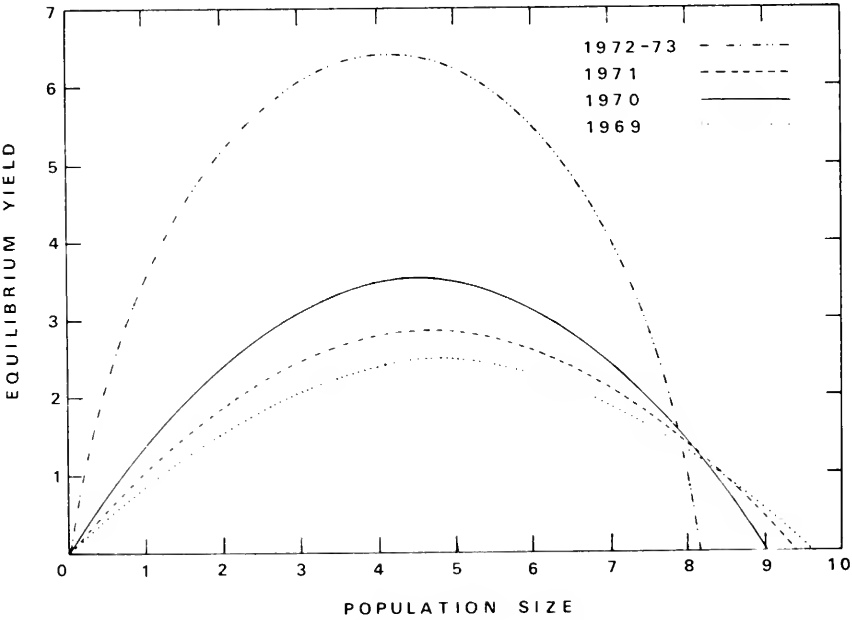

FIGURE 3. Equilibrium yield curves generated by GENPROD for the years 1969 through 1973. Yield and population size in millions of pounds.

size than would have been predicted by the model. Because the 1972 data represented a large amount of catch and effort, it had a large effect on the fitting procedure. As a consequence, the estimate of maximum equilibrium yield more than doubled to 6.5 million pounds (Figure 3). This representation of the stock was inconsistent with what had been learned about the resource from past cruises and observations of the fishery. The model thus provided little information for setting the 1973 quota. Consequently the quota was left at the 1972 level.

We hoped 1973 data when run through the model might bring the parameters back into line with the pre-1972 data. However, this did not happen. The 1973 fishery was poor, with no large concentrations of shrimp on the Area A bed; while off of central Oregon, good concentrations of shrimp attracted many of the northern California fishermen. As a consequence, catch and effort were both low, while catch per effort remained reasonable, producing a weak data point that had little influence on the whole series of data. The parameters thus did not return to pre-1972 levels.

GENERALIZED CATCH EQUATION

Abramson and Tomlinson (1972) had used the generalized Murphy catch equation to analyze aged catch data and had obtained fair agreement between the estimates obtained from the Murphy method and those produced by the Schaefer yield model. We have used the Murphy method to extend the parameter estimations of Abramson and Tomlinson (1972) for the shrimp population in Area A.

The generalized Murphy catch equation (Tomlinson 1970) uses age structured catch data and an average instantaneous natural mortality rate to compute population size in numbers, instantaneous fishing mortality rates, and exploitation rates for a single cohort. The age structured catch data (Table 1) were derived from the commercial shrimp landings using methods described by Abramson and Tomlinson (1972) and form a continuation of their Table 2.

In fitting this data to the generalized Murphy catch equation, we have also used the methods of Abramson and Tomlinson (1972) so that the fishing mortality rates (Table 2), the exploitation rates (Table 3), and the biomass and catchability coefficient, *q*, estimates (Table 4) are extensions of Tables 5, 6, anjd 7 in their publication. We have rerun part of the 1967 and 1968 data using the additional fishing seasons available to us on the 1966 and 1967 year classes to improve the estimates made by Abramson and Tomlinson (1972). For this reason, these tables begin with 1967 instead of 1969. For brevity we have not included the original tables which go back to 1955, and anyone interested in the early data or in a detailed discussion of the methods used to obtain the parameter estimations should consult Abramson and Tomlinson (1972). A number of the figures presented in this paper include data taken from Abramson and Tomlinson (1972) for years prior to 1967.

We have adjusted mortality rates so as to hold *q* fairly constant throughout the period as did Abramson and Tomlinson (1972). In maintaining an average *q* of about 8.5×10^{-5}, we are assuming that variations in total catch and catch per effort between different cohorts primarily reflect real changes in abundance and not changes in availability. Several independent sources of data tend to support this assumption.

TABLE 1. **Aged Catch and Catch-Per-Effort (C.P.E.) Statistics for Area A, 1969–1973 (Pounds and Numbers in Thousands).**

Season	Month	Age group	Relative frequency	Average weight	C.P.E. numbers	Pounds	Numbers
1969	May	I	.527	.0048	78.1	364.7	76,753
		II	.452	.0109	67.0	716.9	65,830
		III	.021	.0155	3.1	47.4	3,058
	June	I	.574	.0050	35.3	476.3	94,383
		II	.412	.0117	25.3	790.8	67,745
		III	.014	.0159	.9	36.5	2,302
	July	I	.665	.0052	51.2	277.2	53,721
		II	.321	.0121	24.7	315.8	25,932
		III	.014	.0168	1.1	19.0	1,131
	Aug.	I	.826	.0056	62.2	37.7	6,724
		II	.167	.0120	12.6	16.3	1,359
		III	.007	.0164	.5	.9	57
1970	May	I	.153	.0046	9.0	51.2	11,234
		II	.783	.0086	46.0	493.6	57,490
		III	.064	.0147	3.8	69.1	4,699
	June	I	.264	.0053	20.5	153.8	28,973
		II	.721	.0095	56.0	754.2	79,127
		III	.015	.0177	1.2	29.1	1,646
	July	I	.220	.0066	21.0	303.2	46,149
		II	.771	.0098	73.7	1577.1	161,733
		III	.008	.0159	.8	26.7	1,678
	Aug.	I	.238	.0077	20.9	97.5	12,614
		II	.753	.0099	66.1	394.5	39,909
		III	.009	.0168	.8	8.0	477
	Sept.	I	.238	.0086	13.0	6.3	728
		II	.753	.0101	41.1	23.3	2,304
		III	.009	.0170	.5	.5	28
1971	June	I	.334	.0038	14.1	71.5	18,757
		II	.635	.0107	26.9	385.0	35,622
		III	.031	.0135	1.3	23.5	1,741
	July	I	.334	.0044	16.7	162.2	36,492
		II	.656	.0114	32.8	816.8	71,576
		III	.010	.0202	.5	22.0	1,091
	Aug.	I	.711	.0049	47.1	540.3	109,755
		II	.284	.0136	18.8	596.7	43,840
		III	.005	.0179	.3	13.8	773
	Sept.	I	.834	.0062	52.7	421.3	68,328
		II	.164	.0142	10.3	191.6	13,436
		III	.002	.0150	.1	2.5	164
	Oct.	I	.876	.0068	71.1	299.9	44,296
		II	.124	.0137	10.1	86.1	6,270
		III	--	--	--	--	--
1972	Mar.	I	.010	.0026	1.1	1.5	584
		II	.880	.0067	94.1	343.8	51,358
		III	.110	.0126	11.8	80.6	6,420
	Apr.	I	.044	.0027	4.1	5.6	2,064
		II	.862	.0069	81.7	281.8	40,758
		III	.094	.0130	8.9	57.6	4,443
	May	I	.055	.0029	4.4	9.4	3,189
		II	.860	.0075	70.0	377.2	50,299
		III	.085	.0155	6.9	77.4	4,983
	June	I	.072	.0034	5.3	8.3	2,469
		II	.856	.0080	62.9	234.3	29,442
		III	.072	.0155	5.3	38.4	2,470
	July	I	.140	.0054	9.2	60.7	11,285
		II	.822	.0093	54.1	614.4	66,125
		III	.038	.0153	2.4	45.9	2,995
	Aug.	I	.282	.0053	18.4	112.3	21,072
		II	.697	.0097	45.4	506.9	52,101
		III	.021	.0173	1.4	26.8	1,551

Season	Month	Age group	Relative frequency	Average weight	C.P.E. numbers	Pounds	Numbers
	Sept.	I	.368	.0066	25.2	147.2	22,266
		II	.616	.0110	42.3	412.5	37,346
		III	.007	.0170	.5	7.3	430
	Oct.	I	.406	.0069	32.2	128.2	18,612
		II	.584	.0122	46.5	327.4	26,818
		III	.007	.0203	.5	6.4	315
1973	Apr.	I	.180	.0053	11.0	34.8	6,603
		II	.736	.0109	45.1	294.9	27,055
		III	.081	.0146	5.1	44.9	3,080
	May	I	.357	.0054	21.1	58.3	10,893
		II	.614	.0107	36.3	200.8	18,736
		III	.029	.0151	1.7	13.4	888
	June	I	.552	.0062	42.4	21.6	3,507
		II	.438	.0126	33.6	35.0	2,783
		III	.010	.0182	.8	1.2	66
	July	I	.484	.0069	30.1	289.9	41,872
		II	.509	.0132	31.7	580.6	44,047
		III	.007	.0185	.4	9.7	523
	Aug.	I	.459	.0078	13.5	56.6	7,282
		II	.533	.0144	15.7	121.3	8,437
		III	.008	.0236	.2	3.1	131
	Sept.	I	.459	.0078	7.1	4.3	553
		II	.533	.0144	8.3	9.2	640
		III	.008	.0236	.1	.2	8

Post-season shrimp cruises have been made every year from 1966 through 1972 except for 1970. One of the objectives of these cruises was to assess the incoming year class. In 1966 and again in 1968, large numbers of age 0 shrimp were found on the Area A bed; while in 1967, 1969, 1971 and 1972 lower numbers of age 0 shrimp were observed on the bed (Dahlstrom pers. commun.). This corresponds quite well with the biomass estimates for these year classes as 1-year-old shrimp (Table 4).

Another independent estimate of the incoming year class can be obtained using an index derived from the number of age 0 shrimp found in hake stomachs (Gotshall 1970). Although this method is fraught with possible bias and cannot give absolute values of the size of the incoming year class, it does appear to be a fair index to the relative strength of the incoming year class. In the period from 1966 through 1973, the largest year class as indicated from biomass estimates was the 1968 year class which coincides with the largest hake stomach index (Table 5). Likewise the hake stomach index for the two poor year classes of 1971 and 1972 averaged about one-tenth of the 1968 index.

Growth is another factor that apparently reflects year class abundance. In most years, the average weight of age I shrimp (Table 1) is inversely related to the number of shrimp in that year class. This relationship is discussed in more detail in another section.

SEXUAL DEVELOPMENT

Prior to examining certain aspects of the population dynamics of Area A shrimp, a brief review of their unusual sexual development may be useful.

Adult ocean shrimp mate in the fall when the males transfer their sperm to the females where it is held until the eggs are spawned and fertilized. The fertilized eggs are carried externally by the female for several months until the larval shrimp hatch in March or early April. The young shrimp are pelagic in the early stages but begin settling to the bottom by midsummer or fall when a few individuals show up in the commercial landings as the age 0 shrimp (Dahlstrom 1973).

The following spring and summer these shrimp, which are now into their second year (age I shrimp) begin developing into either males or females and most if not all will be sexually mature by the fall or early winter. These age I shrimp will spawn in the fall at about 18 months of age and the females will carry eggs until they hatch in the spring. The males begin to change into females sometime after the fall mating and by the following fall will function as mature females. In California it appears that most, if not all age I males, will become females by the following spawning season. However, in the northern portion of their range where growth rates are slower, shrimp appear to mature at a later age, and age II males can occur (Dahlstrom 1970). Once an ocean shrimp becomes a female, it will continue to function as a female.

TABLE 2. **Monthly Instantaneous Fishing Mortality Coefficients for Area A, 1967–1973.**

Year	Month	Age		
		I	II	III
1967	Mar.	.0014	.0041	.0261
	Apr.	.0069	.0206	.0676
	May	.0017	.0056	.0203
	June	.0462	.1900	.1939
	July	.1115	.3975	.3468
	Aug.	.0648	.1622	.2391
	Sept.	.0148	.0496	.0761
	Oct.	.0032	.0151	.0270
	Mean	.0313	.1056	.1246
1968	May	.0130	.2409	.7600
	June	.0270	.5049	.4384
	July	.0288	.5272	.2394
	Aug.	.0096	.4326	.7195
	Sept.	.0011	.1466	.1591
	Oct.	.0002	.0188	.0200
	Mean	.0133	.3118	.3894
1969	May	.0371	.3600	.4054
	June	.0536	.6950	.5510
	July	.0362	.5690	.5226
	Aug.	.0053	.0465	.0401
	Mean	.0330	.4176	.3798
1970	May	.0075	.1402	.6590
	June	.0221	.2660	.4607
	July	.0407	1.1891	1.1034
	Aug.	.0130	1.0118	1.0390
	Sept.	.0008	.1222	.1299
	Mean	.0168	.5159	.6784
1971	June	.0093	.1302	.3401
	July	.0206	.3767	.3374
	Aug.	.0728	.3798	.3862
	Sept.	.0545	.1741	.1201
	Oct.	.0417	.1054	--
	Mean	.0398	.2332	.2368
1972	Mar.	.0005	.0945	.2324
	Apr.	.0023	.0926	.2284
	May	.0038	.1451	.3917
	June	.0034	.1088	.3123
	July	.0179	.3435	.6914
	Aug.	.0386	.4521	.8696
	Sept.	.0478	.6181	.5702
	Oct.	.0475	1.1678	.9999
	Mean	.0198	.3778	.5370
1973	Apr.	.0087	.1561	.7423
	May	.0163	.1414	.4454
	June	.0060	.0258	.0484
	July	.0841	.6236	.5806
	Aug.	.0172	.2080	.2522
	Sept.	.0014	.0200	.0200
	Mean	.0223	.1958	.3482

ESTIMATING THE PERCENTAGE OF AGE I FEMALES

In ocean shrimp, the percentage of age I females in a year class can be estimated directly from the sex composition of age I shrimp at the end of the fishing season. However, male shrimp are smaller than female shrimp and undoubtedly have a higher escapement rate than do females; this may result in an overestimation of the percentage of female shrimp. In addition, the timing of the sexual change may vary from season to season. If the change is well under way by the end of fishing season, the estimates will be accurate, but if the change is later or the fishing season closes early, females may be underestimated.

The percentage of age I females also can be estimated from the sex composition of these same shrimp at age II early in the following fishing season. These shrimp are larger and almost fully recruited to the fishery; therefore, males will be caught at about the same ratio as females. However, if some individuals that previously functioned as males change to females before the beginning of the fishing season, the age I females will be overestimated.

TABLE 3. **Monthly Exploitation Rates for Area A, 1967–1973.**

Year	Month	Age		
		I	II	III
1967	Mar.	.0014	.0022	.0277
	Apr.	.0064	.0107	.0703
	May	.0017	.0029	.0219
	June	.0425	.0895	.1929
	July	.0996	.1554	.3323
	Aug.	.0591	.0569	.2622
	Sept.	.0138	.0166	.0983
	Oct.	.0029	.0050	.0370
1968	May	.0121	.2023	.1767
	June	.0251	.3755	.0676
	July	.0267	.3880	.0281
	Aug.	.0090	.3324	.0552
	Sept.	.0011	.1287	.0081
	Oct.	.0001	.0176	.0009
1969	May	.0342	.2858	.3152
	June	.0493	.4753	.4013
	July	.0333	.4111	.3857
	Aug.	.0049	.0429	.0370
1970	May	.0070	.1235	.4577
	June	.0205	.2205	.3494
	July	.0377	.6630	.6366
	Aug.	.0121	.6058	.6150
	Sept.	.0008	.1085	.1150
1971	June	.0086	.1151	.2727
	July	.0191	.2969	.2708
	Aug.	.0662	.2988	.3031
	Sept.	.0500	.1510	.1067
	Oct.	.0386	.0945	--
1972	Mar.	.0005	.0850	.1960
	Apr.	.0021	.0836	.1929
	May	.0037	.1276	.3066
	June	.0032	.0973	.2535
	July	.0166	.2748	.4737
	Aug.	.0356	.3442	.5522
	Sept.	.0441	.4371	.4118
	Oct.	.0436	.6567	.6016
1973	Apr.	.0081	.1364	.4973
	May	.0152	.1245	.3402
	June	.0056	.0240	.0445
	July	.0760	.4399	.4173
	Aug.	.0162	.1772	.2106
	Sept.	.0014	.0187	.0187

TABLE 4. **Ocean Shrimp Population Biomass in Thousands of Pounds by Age and Month for Area A**

Year	Month	Ages			Total	Est. q × 10⁶
		I	II	III		
1967	Mar.	7,251	1,311	334	8,896	59
	Apr.	6,710	1,235	315	8,260	66
	May	6,461	1,177	274	7,915	59
	June	6,417	993	205	7,615	83
	July	6,031	690	144	6,865	123
	Aug.	5,515	501	101	6,120	94
	Sept.	5,226	420	89	5,735	57
	Oct.	4,884	402	92	5,378	60
1968	May	6,002	2,433	131	8,566	107
	June	5,702	1,541	66	7,312	235
	July	5,418	877	41	6,339	169
	Aug.	4,785	479	21	5,288	110
	Sept.	3,582	283	10	3,875	151
	Oct.	3,515	224	9	3,748	163
1969	May	9,960	1,991	117	12,068	95
	June	8,796	1,140	66	10,002	49
	July	7,756	552	36	8,344	70
	Aug.	7,253	350	22	7,625	62
1970	May	6,921	3,525	105	10,551	46
	June	6,970	2,828	63	9,861	67
	July	7,462	1,333	24	8,819	98
	Aug.	7,514	390	8	7,912	105
	Sept.	7,391	190	4	7,585	71
1971	June	7,740	2,931	69	10,740	34
	July	7,832	2,166	65	10,063	46
	Aug.	7,388	1,570	36	8,994	55
	Sept.	7,777	1,095	20	8,892	53
	Oct.	7,209	813	17	8,039	77
1972	Mar.	2,717	3,645	348	6,710	116
	Apr.	2,499	3,032	253	5,784	120
	May	2,374	2,598	197	5,169	125
	June	2,459	2,163	123	4,745	127
	July	3,428	1,791	66	5,285	112
	Aug.	2,902	1,118	31	4,051	139
	Sept.	3,070	665	13	3,748	171
	Oct.	2,714	280	7	3,001	267
1973	Apr.	4,049	1,889	60	5,998	104
	May	3,614	1,417	30	5,061	104
	June	3,639	1,358	25	5,022	139
	July	3,437	932	17	4,386	145
	Aug.	3,273	584	12	3,869	87
	Sept.	2,875	461	9	3,345	53

TABLE 5. **Numbers of Age 0 Shrimp Found in Pacific Hake Stomachs by Year from July Through October**

Year	Number of stomachs examined	Empty*	Number of shrimp per stomach
1965	390	68	0.22
1966	880	115	1.29
1967	435	82	0.11
1968	324	26	1.32
1969	977	266	0.09
1970	376	63	0.82
1971	339	45	0.17
1972	407	59	0.05
1973	280	56	1.13

* Empty stomachs not included in calculations.

We have used both the sex ratio of age I shrimp and the sex ratio of the same year class as age II shrimp to estimate percentage of age I females in that year class. The sex composition of the landings for each month of the fishing season was plotted for a year class as age I and age II. A straight line interpolation was made across the closed season and the January value was the value used as the estimate of the percentage of age I females (Table 6). All year classes had a higher percentage of females at the beginning of their 3rd year than at the end of their 2nd year, except for the 1968 year class which went from about 63% females at age I to about 40% females at the beginning of the next fishing season. The 1968 year class exhibited less growth at age I than any other year class on record. This could have lead to the males being much less vulnerable to the fishery than usual, and caused a large overestimate of the age I females. Under the circumstances, it seems better to use the observed percentage at age II rather than the interpolated value for 1968.

TABLE 6. **Percentage of Age I Females by Year Class Obtained from a Straight Line Interpolation Across the Closed Season**

	Year class									
	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972
Percentage	47	58	37	65	55	48	55	42	42	65

It is likely that the straight line interpolation across the closed season overestimates age I females as do the other methods, but the values pool all the available information and tend to fluctuate less than values derived from only one season. Using this method, estimates of age I females for year classes since 1963 have varied from a low of 37% for the 1965 year class to a high of 65% for the 1966 and 1972 year classes and averaged about 50%. Comparable data for seasons prior to 1963 were not available.

The mechanism regulating sexual development is unknown. There are indications that sex change in *Pandalus borealis* is under hormonal control (Allen 1959). Similarly, Rasmussen (1953) was able to predict the percentage of immature, males, and females in *Pandalus borealis* based on size range of age groups at the beginning of the breeding season.

In *Pandalus jordani,* sex composition appeared to be related to the size of age I shrimp. Consequently, we calculated a least squares regression using the percentage of age I females (Table 6) as the dependent variable and the condition index (Table 7), which is derived from the average weight of age I shrimp in June and July, as the independent variable (Figure 4).

TABLE 7. **Condition Index (C_i) by Year (i) from 1955 Through 1973**

Year	C_i	Year	C_i	Year	C_i	Year	C_i
1955	.92	1960	.96	1965	.95	1970	1.09
1956	.93	1961	1.03	1966	1.05	1971	.75
1957	1.10	1962	.94	1967	1.08	1972	.78
1958	.99	1963	.85	1968	1.13	1973	1.22
1959	1.17	1964	1.28	1969	.93		

The slope of the regression line was positive (.266) showing that year classes with larger age I shrimp tend to have a higher percentage of age I females. However, the correlation coefficient was only .48, indicating that approximately 23% of the difference between year classes in the percentage of age I females can be related to the average size of shrimp in those year classes. Consequently, although the size of age I shrimp may be an indication of the percentage that will function as females in the fall, considerable variation is evident between year classes. Whether this variation reflects the effect of factors other than size of age I shrimp or may actually be an artifact reflecting differences between the sex composition of shrimp landings and that of the population is not known.

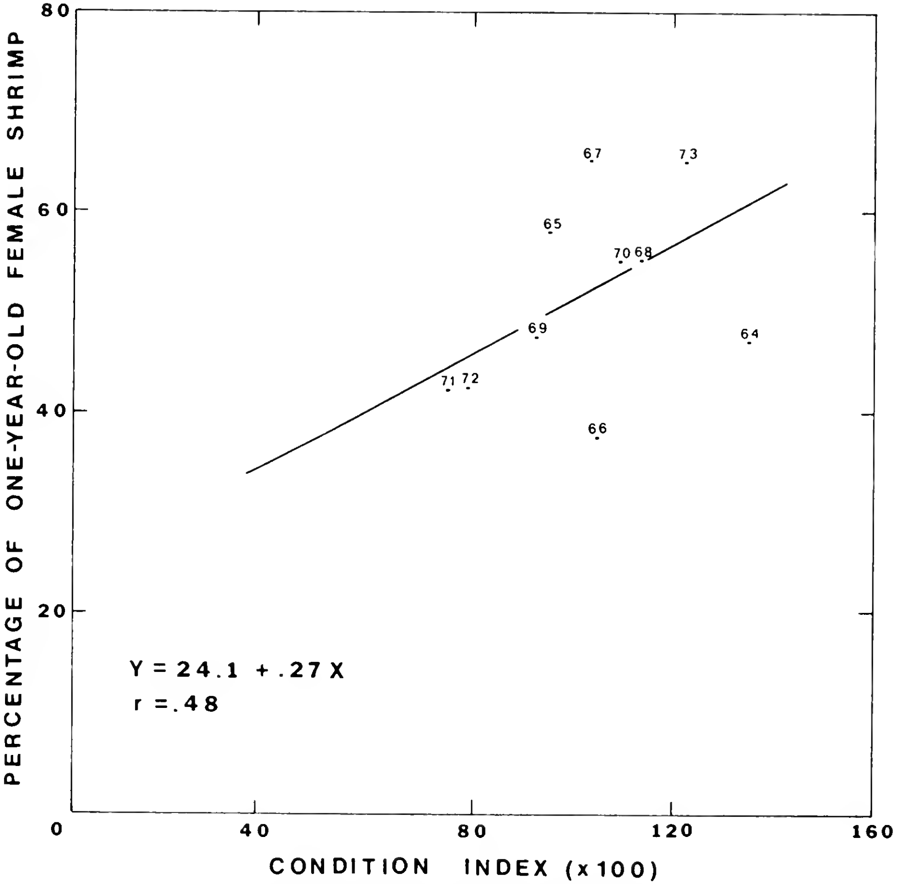

FIGURE 4. Least squares regression with the condition index as the independent variable and percentage of 1-year-old female shrimp as the dependent variable.

However, the advantage to the population in having the percent of age I females increase as the average size of individuals in the year class increases is readily apparent. Year classes with large numbers of shrimp generally grow more slowly than year classes with lower numbers of shrimp, probably reflecting the effect of intraspecific competition. Because weaker year classes grow more rapidly, a greater percentage will function as age I females. Consequently, fluctuations in spawning biomass will be of a lower amplitude than variations in recruitment. This may be of considerable significance in Area A when the high natural mortality and the intense fishery result in low numbers of age II and age III shrimp.

IMPLICATIONS OF AGE I FEMALES ON SPAWNING STOCK

Quantifying the spawning stock is important in the management of a fishery. When the sex ratio of a population is stable, the spawning stock size can be calculated from age structured biomass estimates and age at maturity data. Estimations of spawning stock size for ocean shrimp are more difficult because sex ratios can change with each year class.

Usually the ratio of males to females in age I shrimp has been near 50:50 but has ranged from a low 35:65 to a high 63:37 (Table 6). During this same period, the fall biomass of age I shrimp has averaged over 85% of the combined fall biomass of age I and older shrimp. At a low value of 37% females, the age I shrimp furnished 68% of the spawning female biomass; while in an average year, age I females have contributed over 74% to the spawning female biomass. In recent years, at these levels, age I females have been the major component of the spawning stocks of shrimp on the Area A bed and must be taken into account in any studies of spawning stock size.

SPAWNER-RECRUIT RELATIONSHIP

Female spawning biomass consists of age I females and all older shrimp. Abramson and Tomlinson (1972) used a mean value of 33% to predict the biomass of age I shrimp functioning as females. However they could not determine a realistic spawner-recruit relationship. Because the percentage of age I females varies considerably from season to season, it would seem that any spawner-recruit relationship may be masked by using a constant value. As a result, we examined the spawner-recruit relationship using the estimates of age I females by year class from 1963 through 1970 to compute the total female spawning biomass for the years 1964 through 1971.

The six year classes from 1965 to 1970 show a reasonable relationship with spawning biomass (Figure 5). The next 2 years were years of poor recruitment despite a large spawning biomass, and no relationship is discernible for the 8-year period. Consequently, the refinement of the data and the inclusion of 4 new years have still left us without a meaningful spawner-recruit relationship.

Despite the lack of a clear spawner-recruit relationship, there is a tendency for year class strength to alternate (Figure 6). In the early years of the fishery, the stronger year classes coincided with odd years. However, the 1963 year class was small, while the 1964 year class became the stronger. From 1964 through 1970, the even years have produced the strong year classes. However, with the poor year class in 1972, we appear to have had another reversal. This alternation of strong and weak year classes is not fully explainable at present but is apparently related to the heavy fishery on older shrimp coupled with the phenomenon of age I females. This alternation of year classes would seem to indicate that the number of older shrimp affects survival of the incoming year class.

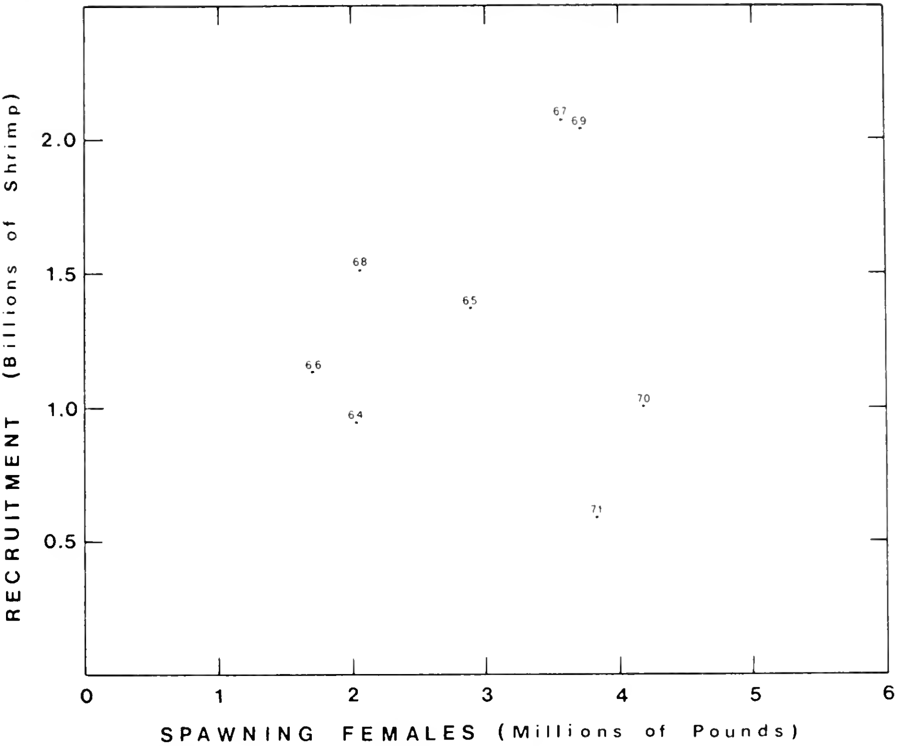

FIGURE 5. Number of recruits on May 1 of year *i* + 2 produced by spawning biomass of September, year *i*.

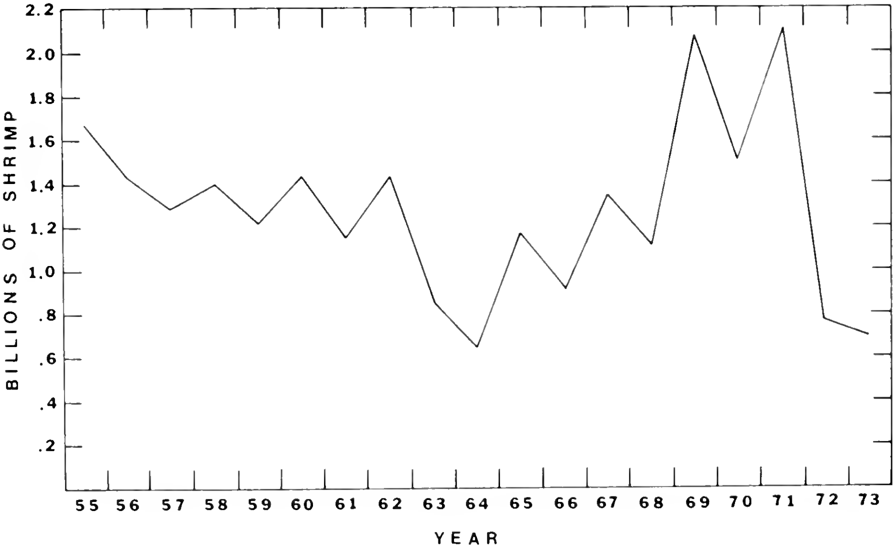

FIGURE 6. Estimated number of 1-year-old shrimp on Area A bed in May.

RECRUITMENT

The lack of a spawner-recruit relationship most likely arises from a high sensitivity of incoming year classes to environmental conditions. We have no idea what these factors are or what magnitude of variation is required to influence recruitment. However the effect of these factors on recruitment can be seen by comparing landings and biomass estimates from 1955 through 1972 (Tables 1 and 4). The effect of quotas can generally be ignored as a controlling factor in landings. Except for the early years of the fishery, quotas have tended to reflect shrimp abundance. In years when fishing was good, quotas were generally increased; while in years of poor fishing, quotas had little or no effect on landings.

The combined California-Oregon landings from the Area A bed increased almost steadily from under 4,000 pounds in 1952, the first year of the fishery, to near 3 million pounds in 1962. Biomass estimates from 1956 through 1962 remained relatively stable (Abramson and Tomlinson 1972). However, in the following 2 years, total biomass at the beginning of the fishing season fell to about two-thirds of the 1962 level as a result of 2 successive years of poor recruitment. Landings declined to a low of about 1.2 million pounds in 1964 reflecting decreased shrimp abundance. Following this low period, both landings and biomass increased almost annually with landings reaching a high of about 4 million pounds in 1970 while biomass reached a high the previous year. Recruitment from 1966 through 1970 was considerably above the series average despite the intensified fishery. Spawning biomass almost doubled from 1964 to 1971 (Figure 7). Despite the high spawning biomass present in the fall of 1970 and 1971, the 1971 and 1972 year classes were very weak and in 1973 landings dropped to 1.8 million pounds, almost 2 million pounds less than in 1972.

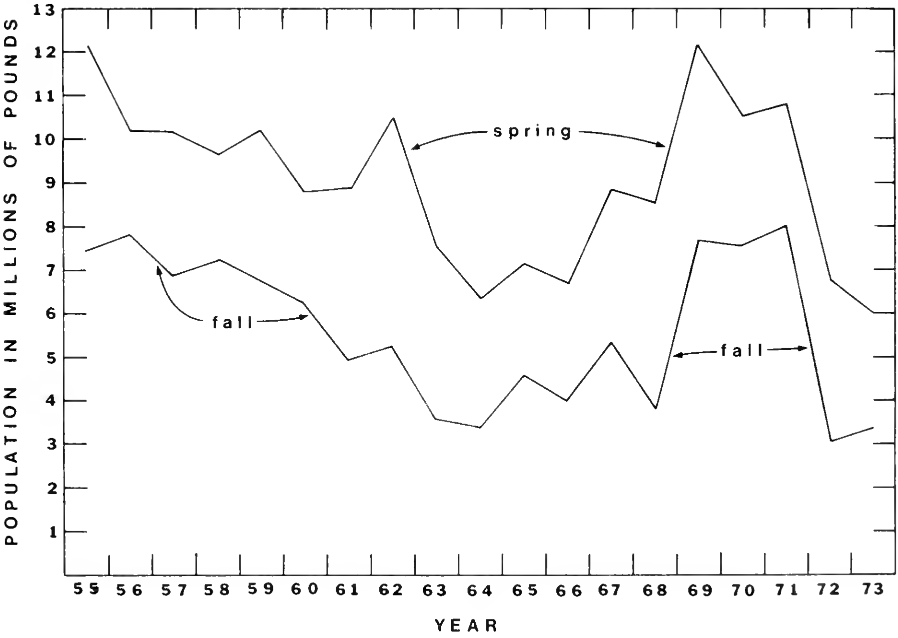

FIGURE 7. Annual maximum and minimum biomass as estimated from the Murphy method.

From an analysis of both landings and biomass, it is apparent that the Area A shrimp population has gone through two major periods when conditions were favorable for recruitment. The first period from 1955 through 1962 was one of fairly constant recruitment during an increasing fishery. The second period from 1965 through 1971 saw both the landings and shrimp biomass increased to near record levels. Along with the two favorable periods, there were two short periods from 1963 to 1964 and 1972 to 1973 when recruitment dropped significantly apparently as a result of poor environmental conditions.

CONDITION INDEX

We have quantified the growth of age I shrimp to obtain a growth index; because this index also reflects conditions affecting recruitment, we have called it the condition index.

The condition index (C_i) for each year (i) was derived by summing the June and July mean weights of age I shrimp for the years 1955 through 1972 and dividing by the number of years to obtain $\bar{\bar{w}}$, the mean of the combined June and July mean weights for the period, which was then used to divide the sum of the June and July mean weights for each year. That is

$$\bar{\bar{w}} = \frac{\sum_i \sum_j \bar{w}_{ij}}{18}$$

$$C_i = \frac{\sum_j \bar{w}_{ij}}{\bar{\bar{w}}}$$

where $\bar{w}_{ij}$ is the mean weight of age I shrimp in month j of year i, j = 6, 7 which refers to June and July, and i = 1955, . . . , 1972.

The June and July mean weights were used because samples of landings were obtained during these 2 months in all years of the series.

From this description, it can be seen that the long-term mean weight has a C_i value of 1. Years when shrimp size was less than the long-term mean have C_i values less than 1, while years when shrimp were larger than the long-term mean have C_i values greater than 1.

The effect of the numbers of age I shrimp on their size is probably reflected in the tendency of C_i to alternate from year to year with less abundant year classes attaining a larger size as age I shrimp (Table 7). However, from 1955 through 1973, there are 2 years when the size of age I shrimp deviated from this pattern (Figure 8). In 1963 and again in 1972, the size of age I shrimp was depressed even though both the 1962 and the 1971 year classes were small. These 2 years of abnormally slow growth also produced unexpectedly poor year classes, resulting in breaks in the normal cycle of strong and weak year classes. These atypical years do not appear to be related to the shrimp fishery but rather seem to indicate variations in environmental conditions affecting both shrimp growth and shrimp recruitment.

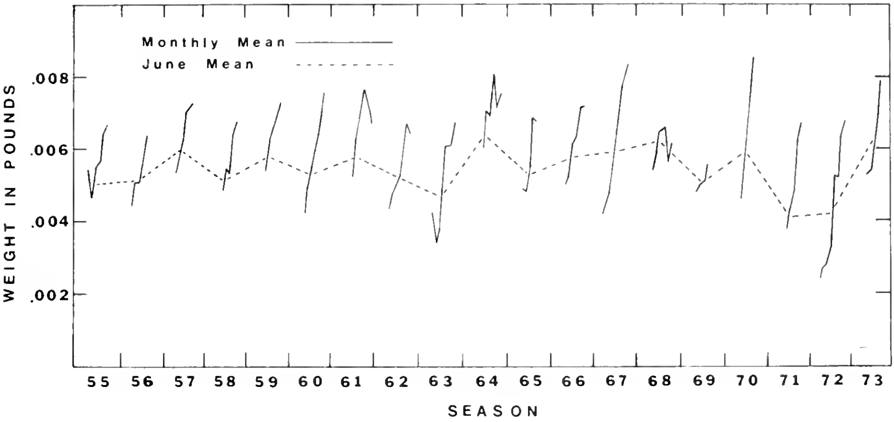

FIGURE 8. Growth of 1-year-old shrimp by month during the fishing seasons and the mean June weight by year.

MANAGEMENT IMPLICATIONS

It should be clear that if environmental conditions have a strong influence on shrimp productivity, any density dependent relationships will be quite difficult to discover. Because the General Production model treats environmental conditions as constant, any relationship defined by this model will be of limited value in managing shrimp because the environmental effects will not be included. Thus, in periods of favorable environmental conditions, more biomass will be available than will be computed by the model. The converse will be true under poor environmental conditions. In this situation a constant quota based on the model will not prevent overfishing but will limit the fishery when a surplus is available.

One consequence of not being able to define a relationship between production and population size is that we are left without a reliable method of establishing annual quotas. However, quotas were initially established for the shrimp areas to protect the resource from over harvesting and thus insure an adequate spawning stock. Later, when the Schaefer model was applied to the fishery and an equilibrium yield calculated, the quota was intended to insure annual yields approaching the theoretical maximum equilibrium yield. With the additional data now available, the use of the quota for the latter reason is unrealistic.

Because age I females have been the major component of the spawning stock, we can insure an adequate spawning stock by providing protection to the age I shrimp.

In recent years, a greater number of shrimp in every year class have been landed as two-year-olds than as one-year-olds (Table 1). Similarly, exploitation rates of age I shrimp average only about 10% of the exploitation rates of older shrimp (Table 3). By comparing the total weight landed by age group during the season (Table 1) with the total biomass present at the beginning of the season (Table 4), it can be seen that approximately 70 to 90% of age I shrimp were either unavailable to the fishery or escaped through the fishing gear. Studies to assess the effect of mesh size on escapement have shown that about 80% to 90% of the age I shrimp can escape through a 1.5-inch (3.8-cm) mesh beam trawl (Nancy Ferguson, pers. commun.). The present fishery uses otter trawls and although we have not made similar studies on the effect of mesh size on otter trawl catches, it is probably safe to assume that larger mesh sizes in otter trawls will allow increased escapement of smaller shrimp.

This low availability of age I shrimp has resulted in a take of less than 13% of the number present at the beginning of the season even in years of heavy fishing effort. The large number of age I females in every year class (Table 6) thus has provided a female spawning biomass adequate to keep the stocks in relatively good condition. If environmental conditions, the fishing gear, and the operations of the fishery remain about the same in the future, a continued adequate spawning stock will be assured. However, if the exploitation rate of age I shrimp should increase substantially, quotas, shortened seasons, a limited entry fishery, or other management alternatives could become necessary. At present, however, a quota appears unnecessary to maintain an adequate spawning stock.

CONCLUSIONS

Since the beginning of the shrimp fishery on the Area A bed, landings, effort, catch per unit of effort, age composition, and shrimp abundance have fluctuated over a wide range. These fluctuations are related to changes in recruitment resulting primarily from variations in environmental conditions and having little relationship to the commercial shrimp fishery.

During this period, quotas have been imposed on the fishery as a means of assuring continued productivity of the bed. However, with biomass fluctuating widely from season to season, the establishment of meaningful quotas has become difficult. In the past, GENPROD was used to estimate the mean annual sustainable yield, the population size, and the quota. It is now apparent that these estimates have little meaning because the assumptions of the model are not met or at best are met only poorly.

However, we do know that under the existing fishery, the exploitation rate on age I shrimp has been much lower than on older shrimp. In addition, on the average about 50% of the age I shrimp function as females. Consequently, if minimum mesh size is maintained at 1.5-inch and other regulations are continued as in the past, a reasonable spawning stock should be assured without the need of a quota. If the exploitation rate of age I shrimp increases appreciably, then additional restrictions on the fishery may be required, such as shortened seasons, limited entry, etc.

Finally, we can conclude that ocean shrimp are sensitive to the environment, and we should therefore not expect a trouble free fishery in the future. Thus, the fishery should be kept under surveillance so that changes in the fishery or in the behavior of shrimp that may affect management will be detected.

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FOOD OF THE COPPER ROCKFISH, *SEBASTES CAURINUS* RICHARDSON, ASSOCIATED WITH AN ARTIFICIAL REEF IN SOUTH HUMBOLDT BAY, CALIFORNIA [1]

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The stomachs of 241 copper rockfish captured around an artificial reef in South Humboldt Bay, California, were collected from March 1971 through March 1972. Food habits were compared with fish age (size), season, and time of day.

Copper rockfish can be best categorized as opportunistic carnivores. Crustaceans, followed by fish and molluscs, were the most important food groups in the copper rockfish diet in terms of volume, number, and frequency of occurrence, followed by fish and molluscs. Juvenile Dungeness crabs, *Cancer magister,* were the most important individual food item in terms of volume and frequency of occurrence.

Food habits varied considerably with changes in copper rockfish age (size). Generally, copper rockfish relied less on reef associated food organisms as their age (size) increased.

During the summer months, copper rockfish exhibited a low percentage of empty stomachs and a high average volume of stomach contents. This coincided with an increase in growth of copper rockfish during the summer on the Humboldt Bay artificial reef (DeWees 1970).

Copper rockfish fed at least as much at night as they did during daylight hours.

INTRODUCTION

Rockfishes (Scorpaenidae) are an important commercial and recreational species (Patten 1973) and although there are over 50 scorpaenids endemic to the Pacific Coast of North America, the food habits of only a few are known. Gotshall, Smith and Holbert (1965) and Rogers (1958) have made the only detailed food habits studies on the genus *Sebastes*. An investigation by Patten (1973) resulted in the only published data on food of the copper rockfish, *Sebastes caurinus*.

In March 1971, research was initiated to determine the food of the copper rockfish inhabiting the artificial reef in South Humboldt Bay, California, in relation to fish age (size), season, and time of day.

METHODS

For stomach analysis, copper rockfish were separated into four age class and length frequency categories (Table 1). Age evaluations were made by scale analysis and length frequency calculations (Blodgett 1972). Tagged fish of known ages and length frequencies from DeWees (1970) were also used in aging fish.

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TABLE 1. **Age Class and Length Frequency Categories of Copper Rockfish from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Age class	Length (TL) in millimeters	Number of stomachs
Age 0	110–155	38
Age I	138–196	87
Age II	172–231	73
Age III	220–300	43
		Total 241

The specimens used for stomach analysis were collected primarily by hook and line, although spearguns were occasionally used. Standard collection procedures (equipment, fish baits, and optimum tidal cycles) as stated by DeWees (1970) were employed in this study. Total length (TL) and a scale sample were taken for each fish and the sample coded for identification. Stomachs were extracted within 15 minutes after capture, opened, and the contents preserved in 70% ethyl alcohol.

Stomach contents were examined under a dissecting microscope (12×) and food items were separated into major taxonomic groups. Most of the food items were identified to species. Material that was mutilated, digested, or otherwise unidentifiable was designated to the lowest possible taxon or labeled miscellaneous. All questionable items were saved for later verification by personnel with expertise in the appropriate taxonomic area.

Gammarid amphipods presented a special problem because of their small size, difficult identification, and rapid deterioration. They were treated separately and quantified as a group instead of individually by volumetric displacement.

The sample size of copper rockfish was based on previous population estimates by DeWees (1970). A minimum of 10 stomachs per month and a total of 241 stomachs for the entire period were collected. This sample represented more than 60% of the copper rockfish population as estimated by DeWees (1970).

RESULTS

From March 1971 through March 1972, 451 fishes representing 10 species were collected from the reef area. Copper rockfish were taken with the highest frequency, comprising 53.5% (241) of the total catch (Table 2).

Copper rockfish ate organisms from at least six different phyla (Table 3). Crustaceans made up the largest portion of the diet.

Dungeness crab, *Cancer magister,* was the most important individual food item of copper rockfish in volume and frequency of occurrence (Table 4). Using the index of relative importance (Pinkas, Oliphant and Iverson 1971) to rank major food items, Dungeness crabs were followed by gammarid amphipods and spotted bay shrimp, *Crangon nigromaculata,* as important components in the copper rockfish diet (Table 4).

Fishes were the second most important food group. The northern anchovy, *Engraulis mordax,* comprised the largest portion of fish in the copper rockfish diet (Table 4). The shiner perch, *Cymatogaster aggregata,* was also an important food species for copper rockfish.

Eel grass (*Zostera* sp.) was present in 6.5% of the stomachs, but in small quantities (Table 3).

TABLE 2. **Monthly Catch Totals by Species on the Humboldt Bay Artificial Reef, March 1971 through March 1972.**

Species	Month													Total	Percentage of total catch
	M	A	M	J	J	A	S	O	N	D	J	F	M		
Sebastes caurinus	13	19	15	37	21	16	29	19	14	9	18	16	15	241	53.5
Sebastes melanops	1	--	9	2	--	11	10	16	6	11	4	6	5	81	17.9
Sebastes auriculatus	--	3	--	3	6	5	2	--	--	2	1	2	5	29	6.4
Sebastes mystinus	--	--	--	1	--	--	--	1	--	--	--	1	1	4	.8
Hexagrammos decagrammus	--	2	--	2	2	--	10	3	9	6	6	20	11	71	15.7
Enophrys bison	--	--	--	--	--	--	--	1	1	--	--	--	--	2	.4
Leptocottus armatus	1	--	1	--	--	1	--	--	--	2	--	--	--	5	1.1
Hemilepidotus spinosus	--	--	--	--	--	--	--	--	--	--	--	1	--	1	.2
Embiotoca lateralis	--	--	--	--	--	--	--	--	1	--	--	--	--	1	.2
Phanerodon furcatus	--	--	--	--	--	1	--	3	--	--	1	1	--	6	1.3
Rhacochilus vacca	--	--	--	--	--	2	--	--	--	--	--	--	--	2	.4
Ophiodon elongatus	--	--	1	1	--	1	--	1	--	--	--	--	--	4	.8
Platichthys stellatus	--	--	2	--	1	1	--	--	--	--	--	--	--	4	.8
Totals	15	24	28	46	30	38	51	41	31	30	30	47	37	451	

TABLE 3. **The Food of 241 Copper Rockfish (110–300 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Food items	Number of organisms		Volume of organisms		Frequency of occurrence	
	Number	Percentage of total	Milliliters	Percentage of total	Frequency	Percentage of total
ANNELIDA						
Armandia bioculata	1	0.1	tr*	--	1	0.5
Nereidae (epitoke)	1	0.1	tr	--	1	0.5
Hirudinea	1	0.1	tr	--	1	0.5
Unidentified	3	0.3	tr	--	3	1.5
Subtotal	6	0.6	tr	--	--	--
ARTHROPODA						
Crangon nigricauda	15	1.8	20.7	4.2	14	7.1
Crangon nigromaculata	65	8.0	76.0	15.7	55	27.9
Crangon franciscorum	1	0.1	1.0	0.2	1	0.5
Crangon sp.	24	2.9	7.2	1.4	22	11.1
Spirontocaris brevirostris	1	0.1	1.0	0.2	1	0.5
Spirontocaris sp.	9	1.1	2.5	0.5	5	2.5
Cancer magister	104	12.9	140.0	28.9	62	31.4
Cancer productus	8	0.9	10.9	2.2	6	3.0
Cancer antennarius	2	0.2	3.5	0.7	2	1.0
Cancer sp.	32	3.9	46.7	9.6	21	10.6
Cancer megalops larvae	12	1.4	1.1	0.2	7	3.5
Pinnixa faba	23	2.8	15.3	3.1	21	10.6
Pinnixa littoralis	13	1.6	tr	--	12	6.0
Loxorhynchus crispatus	1	0.1	1.0	0.2	1	0.5
Unidentified	3	0.3	tr	--	3	1.5
Caprella laeviuscula	42	5.2	0.7	0.1	14	7.1
Caprella californica	30	3.7	0.5	0.1	18	9.1
Caprella equilibra	14	1.7	tr	--	9	4.5
Caprella incisa	1	0.1	tr	--	1	0.5
Tritella pilimana	3	0.3	tr	--	3	1.5
Gammaridea	250	31.0	3.1	0.6	56	28.4
Cumacea	18	2.2	tr	--	6	3.0
Nebaliacea	1	0.1	tr	--	1	0.5
Mysidacea	6	0.7	tr	--	4	2.0
Idothea resecata	7	0.8	2.2	0.4	7	3.5
Livoneca vulgaris	1	0.1	0.5	0.1	1	0.5
Caligoida (parasitic)	1	0.1	tr	--	1	0.5
Subtotal	687	84.1	333.9	68.4	--	--
COELENTERATA						
Obelia sp.	1	0.1	0.1	<0.1	1	0.5
Unidentified	4	0.4	0.5	0.1	4	2.0
Subtotal	5	0.5	0.6	0.1	--	--

TABLE 3—Continued

The Food of 241 Copper Rockfish (110–300 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.

Food items	Number of organisms		Volume of organisms		Frequency of occurrence	
	Number	Percentage of total	Milliliters	Percentage of total	Frequency	Percentage of total
MOLLUSCA						
Saxidomus nuttalli	3	0.3	22.0	4.5	3	1.5
Unidentified	22	2.7	0.5	0.1	2	1.0
Tresus capax	2	0.2	1.8	0.3	2	1.0
Barleeia sp.	1	0.1	tr	--	1	0.5
Phyllaplysia taylori	4	0.4	2.0	0.4	3	1.5
Subtotal	32	3.7	26.3	5.3	--	--
VERTEBRATA						
Ammodytes hexapterus	2	0.2	1.5	0.3	2	1.0
Citharichthys spp.	2	0.2	6.0	1.2	2	1.0
Cymatogaster aggregata	8	0.9	26.5	5.4	6	3.0
Engraulis mordax	14	1.7	54.0	11.1	10	5.0
Gasterosteus aculeatus	1	0.1	2.5	0.5	1	0.5
Allosmerus elongatus	2	0.2	2.5	0.5	2	1.0
Pholis ornata	4	0.4	5.0	1.0	2	1.0
Unidentified	15	1.8	15.8	3.2	15	7.6
Subtotal	48	5.5	113.8	23.2	--	--
SPERMATOPHYTA						
Zostera sp.	13	1.6	0.5	0.1	13	6.5
MISCELLANEOUS	14	1.7	8.3	1.7	13	6.5
TOTALS	805	--	483.4	--	--	--

* trace

TABLE 4. **Ranking of Major Food Items for 241 Copper Rockfish (110–300 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Food item	Percentage			Index of relative importance* (N + V) F = IRI
	Number N	Volume V	Frequency F	
Cancer magister	12.9	28.9	31.4	1313
Gammarids	31.0	0.6	28.4	897
Crangon nigromaculata	8.0	15.7	27.9	661
Cancer sp.	3.9	9.6	10.6	143
Engraulis mordax	1.7	11.1	5.0	64
Pinnixa faba	2.8	3.1	10.6	63
Crangon sp.	2.9	1.4	11.5	49
Crangon nigricauda	1.8	4.2	7.1	43
Unidentified teleosts	1.8	3.2	7.6	38
Caprella laeviuscula	5.2	0.1	7.1	38

* Pinkas, Oliphant and Iversen 1971.

Food by Fish Age and Size

In the young of the year (age 0) copper rockfish, gammarid amphipods were the dominant individual food item, according to the index of relative importance, followed by spotted bay shrimp, *Crangon* sp., and the pea crab, *Pinnixa faba* (Table 5).

TABLE 5. **Ranking of Major Food Items for 38 age 0 Copper Rockfish (110–155 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Food item	Percentage			Index of relative importance* (N + V) F = IRI
	Number N	Volume V	Frequency F	
Gammarids	55.2	3.8	32.1	1894
Crangon nigromaculata	5.2	40.9	28.5	1314
Pinnixa faba	2.5	25.5	14.2	398
Crangon sp.	3.9	11.8	14.2	223
Caprella laeviuscula	5.9	1.9	7.1	55
Cancer sp.	4.6	7.8	3.5	43
Pinnixa littoralis	1.9	tr†	10.7	20
Unidentified arthropods	1.9	tr	10.7	20
Idothea resecata	0.6	3.8	3.5	15
Spirontocaris spp.	1.3	tr	7.1	9
Miscellaneous	1.3	tr	7.1	9

* Pinkas, Oliphant and Iversen (1971).
† tr = trace

Young of the year copper rockfish showed a distinctive preference for small size food organisms such as gammarids, spotted bay shrimp, pea crabs, and caprellids (Table 5). *Spirontocaris* sp., the smallest sized species of shrimp found in the copper rockfish diet, was more important to young of the year than to any other age group. Larger sized food organisms such as fishes, molluscs, and larger crabs were either absent in the young of the year or present in very small quantities (Table 5).

In age I, II, and III copper rockfish, Dungeness crab replaced gammarids as the most important food item. Spotted bay shrimp and gammarid amphipods became the second and third most important food to age I copper rockfish. This trend was reversed for age II and III categories (Tables 6, 7, and 8).

TABLE 6. **Ranking of Major Food Items for 87 Age I Copper Rockfish (138–196 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Food item	Percentage Number N	Percentage Volume V	Percentage Frequency F	Index of relative importance (N + V) F = IRI
Cancer magister	15.2	41.6	37.5	2130
Crangon nigromaculata	8.0	26.4	30.5	1019
Gammarids	27.4	tr†	26.3	721
Crangon nigricauda	3.0	8.1	9.7	108
Caprella californica	4.5	tr	9.7	44
Cancer sp.	3.0	1.0	8.3	33
Zostera sp.	2.6	0.4	9.7	29
Caprella laeviuscula	3.8	tr	6.9	26
Crangon spp.	1.9	1.7	6.9	25
Cancer productus	1.5	4.5	4.1	25

tr = trace

TABLE 7. **Ranking of Major Food Items for 73 Age II Copper Rockfish (172–231 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Food item	Percentage Number N	Percentage Volume V	Percentage Frequency F	Index of relative importance (N + V) F = IRI
Cancer magister	13.1	23.5	34.9	1277
Gammarids	27.1	1.0	30.1	846
Crangon nigromaculata	9.8	14.8	28.5	701
Engraulis mordax	2.9	15.2	9.5	172
Cancer sp.	4.3	5.4	15.8	153
Pinnixa faba	3.6	3.1	12.6	84
Cymatogaster aggregata	1.8	10.8	6.3	79
Caprella laeviuscula	6.5	0.2	7.9	53
Unidentified teleosts	2.5	2.3	11.1	53
Caprella californica	4.7	tr†	9.5	45

tr = trace

TABLE 8. **Ranking of Major Food Items for 43 Age III Copper Rockfish (220–300 mm TL) from the Artificial Reef in South Humboldt Bay, March 1971 through March 1972.**

Food item	Percentage Number N	Percentage Volume V	Percentage Frequency F	Index of relative importance (N + V) F = IRI
Cancer magister	22.0	28.5	35.2	1778
Gammarids	16.9	0.3	26.4	454
Crangon nigromaculata	7.6	7.0	20.5	299
Cancer sp.	4.2	20.9	11.7	294
Engraulis mordax	5.0	15.0	11.7	234
Unidentified teleosts	5.0	5.2	17.6	180
Crangon sp.	5.9	0.3	17.6	109
Pinnixa faba	3.3	2.5	11.7	68
Caprella californica	3.3	0.3	11.7	42
Cymatogaster aggregata	2.5	3.3	5.8	34

The diet of age I copper rockfish closely paralleled that of age group 0, with small size organisms such as caprellids still being relatively significant in their diet (Tables 5 and 6). Although fish did show up in the diet of this age group, they occurred less than 2% of the time.

Age II and III copper rockfish also had very similar diets. Fishes, both northern anchovy and shiner perch, played an increasingly important role in the diet of these older fish. Gammarid amphipods still ranked second in overall importance (Tables 7 and 8) to older age groups, testifying to the significance of these small but abundant invertebrates in the copper rockfish diet.

Copper rockfish fed more on non-reef associated food organisms such as Dungeness crabs, fishes, and molluscs, and seemed to rely less on the artificial reef for food as their age and size increased (Tables 5, 6, 7, and 8).

Seasonal Feeding

The lowest percentage of empty stomachs occurred during the summer months, while the highest percentage of empty stomachs was found in winter and early spring (Figure 1).

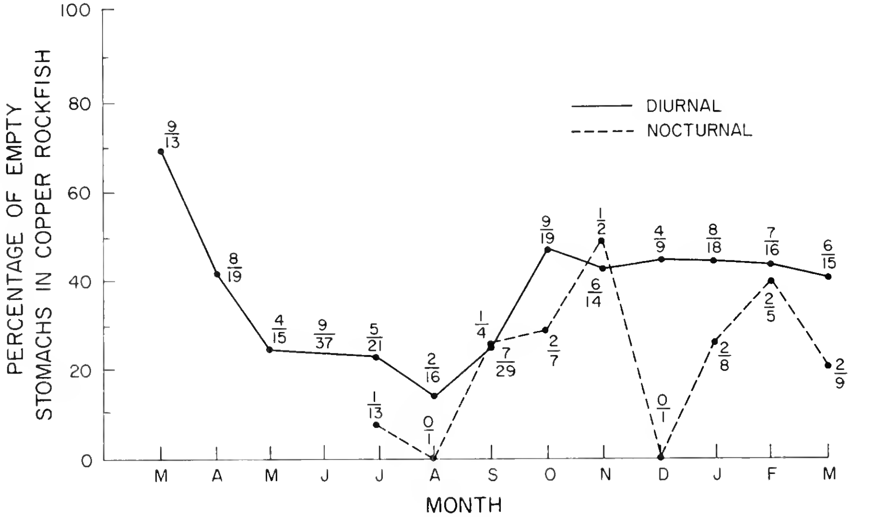

FIGURE 1. Percentage of empty stomachs in copper rockfish from artificial reef in South Humboldt Bay, March 1971 through March 1972. Fractions represent number of copper rockfish stomach samples that were empty (>0.5 ml) over total copper rockfish sample for that month.

The largest mean volumes of stomach contents occurred during mid-summer and the smallest in mid-winter (Figure 2).

General observations indicated a few important trends in the seasonal availability of copper rockfish food. The Dungeness crab was found to be more abundant in the copper rockfish diet during summer and fall, while occurring less frequently in winter and early spring. This was not true for grass shrimp and gammarid amphipods, which were found in stomach contents of every monthly sample.

Noctural Feeding

The percentage of empty stomachs of copper rockfish caught at night was similar to those caught during the day, and the percentage of copper rockfish in the total catch was higher in nocturnal samples (Figures 1 and 3).

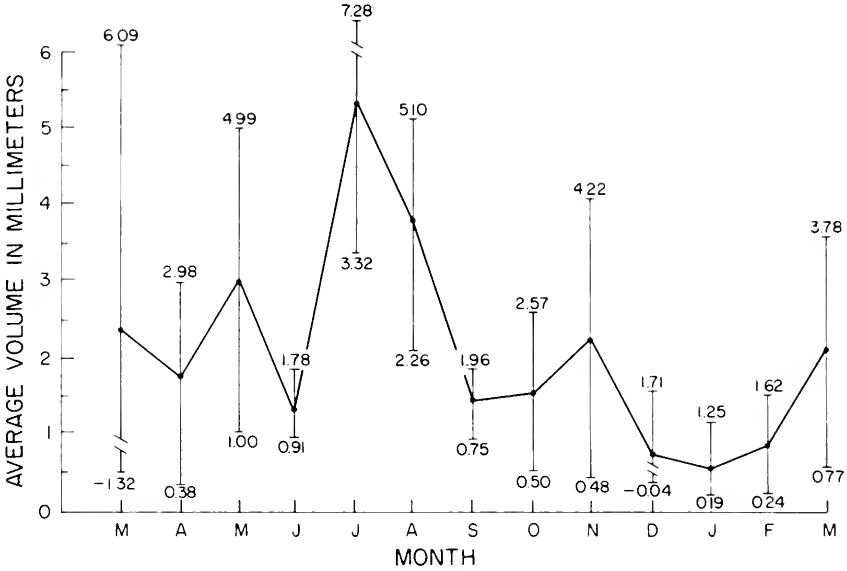

FIGURE 2. Monthly average volume of stomach contents (with 95% confidence limits) of copper rockfish from artificial reef in South Humboldt Bay, March 1971 through March 1972.

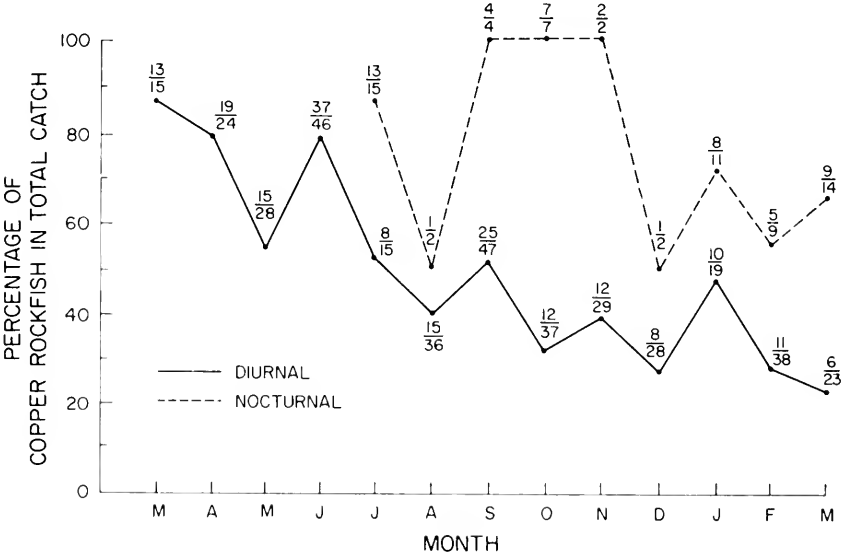

FIGURE 3. Percentage of copper rockfish (110–300 mm TL) in total catch from artificial reef in South Humboldt Bay, March 1971 through March 1972. Fractions represent number of copper rockfish in total catch during a particular month.

DISCUSSION

The food habits of copper rockfish can be best categorized as those of an opportunistic carnivore (i.e., feeding on whatever animal is available). This type of food habit is substantiated by the data of Patten (1973), who examined the stomachs of 271 copper rockfish from Puget Sound, Washington.

In our study, crustaceans were the most important food group in the diet of copper rockfish. Patten (1973) found a very similar situation with the copper rockfish in Puget Sound, and Rogers (1958), Phillips (1964), and Gotshall, Smith and Holbert (1965) found that crustaceans were very important in the diet of other scorpaenids.

Eel grass was observed, on one occasion, trailing from the anus of a copper rockfish and appeared to be undigested in the stomach contents. The plant material was probably ingested incidentally along with some of the other food items. The affinity that many of the copper rockfish food organisms have for eel grass (Light, et. al 1964) could help explain the incidental occurrence of plant material in the diet of copper rockfish and other carnivorous fishes. Gotshall, Smith, and Holbert (1965) found undigested plant material in the stomach contents of blue rockfish, *S. mystinus,* and Patten (1973) found a small amount of plant material in the stomachs of copper rockfish.

The predominance of juvenile Dungeness crabs in the diet of the copper rockfish emphasizes the importance of this individual food item and the relative availability of crab in the study area.

Underwater observations showed that large influxes of Dungeness crabs inhabited the study area during spring, summer, and fall. Dungeness crabs use Humboldt Bay as a nursery during certain times of the year. The extent of this utilization would seem quite significant because the largest commercial concentrations of Dungeness crabs in California occur off Eureka and Crescent City (Frey 1971).

Although the general status of Dungeness crab populations on the west coast is known, no population estimates have ever been published. Because Dungeness crabs are the most important food item to copper rockfish inhabiting the artificial reef, important managerial implications exist.

Gotshall (1969) showed that a selective predator like Pacific hake, *Merluccius productus,* could be used as a biological sampler to estimate the annual mortality rates and population size of the commercially important shrimp, *Pandalus jordani.* Because of their preference for the Dungeness crab as food, copper rockfish show a similar potential as biological samplers in estimating the annual mortality and relative abundance of juvenile Dungeness crabs in Humboldt Bay. Gotshall, Smith and Holbert (1965) suggest that another scorpaenid, *Sebastes mystinus,* shows promise as a biological sampler because of its opportunistic feeding habits.

Because of their small size, gammarid amphipods would not seem to give copper rockfish a significant amount of nutritional value, yet they were the second most important individual food item (Table 4). Other authors have also suggested that gammarid amphipods are an important food source for scorpaenids: Rogers (1953), Phillips (1964), and Gotshall, Smith, and Holbert (1965).

The change of food habits with size and age of fish is well known (Nikolsky 1963). Generally, larger fish eat larger sized and a greater variety of food organisms, while smaller fish consume less diverse and smaller sized food items. The food habits of copper rockfish seemed to follow these trends quite closely. Young of the year exhibited a restricted diet (monophagic), feeding almost exclusively on small crustaceans, while larger fish progresssively ate a greater variety of larger food organisms (stenophagic diet). Thus, fish became a progressively more important food item in the diet of older copper rockfish. Patten (1973) found this trend to hold true for the copper rockfish he examined in Puget Sound, and Gotshall, Smith, and Holbert (1965) found similar results with blue rockfish.

Copper rockfish relied less on artificial reef associated food items (substrate specific organisms like gammarid amphipods) as their age and size increased. This seems logical in light of the size, strength, and speed that would allow older fish to pursue food outside the perimeter of the reef.

DeWees (1970) found offshore upwelling and the resulting increase in food production to be an important factor regulating the growth of copper rockfish on the artificial reef in South Humboldt Bay. When the upwelling was high during spring and early summer, DeWees found the growth rate of copper rockfish increased sharply. Conversely, when the upwelling factor was low during winter, the growth curve leveled off. Miller, Odemar, and Gotshall (1967) also found that rapid growth of blue rockfish in Monterey Bay occurred during and after periods of upwelling, while Gotshall, Smith, and Holbert (1965) determined that the lowest percentage of empty stomachs in blue rockfish occurs after periods of heavy upwelling. The low percentage of empty stomachs observed in this study during the summer months (Figure 2) compares favorably with the increase in growth curves observed by DeWees during this period. This may be due to upwelling, as well as seasonal changes in light, water turbidity, and temperature, all of which regulate primary and secondary production (Odum 1971).

The average volume of stomach contents was also highest during summer (Figure 3), along with an increase in growth rate and lowest percentage of empty stomachs. Conversely, slower growth rates (DeWees 1970), higher percentage of empty stomachs (Figure 2), lower average volumes of stomach contents (Figure 3) corresponded with reduced primary and secondary production in the winter.

The findings on nocturnal feeding indicated that copper rockfish fed at least as much at night as they did during the daylight hours. However, this conclusion must be tempered with the fact that nocturnal collection of fishes was restricted to hook and line sampling. Night sampling was conducted only once per month from July 1971 through March 1972 and may not be entirely representative of the nocturnal feeding habits of copper rockfish. This is especially relevant when examining the extremely low night catches experienced during some months (Figure 3). This data is supported by Patten (1973) who found that the copper rockfish in Puget Sound fed most actively at dawn or during the night

SUMMARY

The study indicates that: (1) food habits of copper rockfish can be best categorized as those of an opportunistic carnivore; (2) crustaceans were the most important food group followed by fish and molluscs; (3) juvenile Dungeness crabs were the most important food item and thus show potential as a biological sampler for this species of crab; (4) gammarid amphipods, despite their small size, were the second most important food item; (5) eel grass and other plant material was consumed incidentally along with the other food items; (6) the change in food habits with size and age

of fish follows the well known pattern of other species; copper rockfish relied less on reef associated food items as the age and size increased; (7) the low percentage of empty stomachs and high average volume of stomach contents for copper rockfish occurred during summer months. This compares favorably with the increase in growth of copper rockfish on the Humboldt Bay reef (DeWees 1970), and is due, at least in part, to upwelling; and (8) copper rockfish fed at least as much at night as they did during daylight hours.

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FOOD HABITS OF THE LEOPARD SHARK, *TRIAKIS SEMIFASCIATA,* IN ELKHORN SLOUGH, MONTEREY BAY, CALIFORNIA [1]

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Four hundred thirty-six leopard sharks, *Triakis semifasciata,* were collected in Elkhorn Slough, Monterey Bay, California from October, 1971, through November, 1972. Three hundred sixty-seven (84.2%) of the shark's stomachs contained identifiable food items which were analyzed as to frequency of occurrence, percentage of total volume, and numerical importance. The Index of Relative Importance (IRI), which combines the numerical, volumetric, and frequency of occurrence measurements of each prey item into one value, was used to rank the importance of each food item. Leopard sharks from Elkhorn Slough fed largely on crabs, clams, fish, fish eggs, and the echiuroid worm, *Urechis caupo.* Considerable variation occurred in the diets of different sized sharks. The yellow shore crab, *Hemigrapsus oregonensis,* was the most important food item for sharks under 90 cm (3 ft) total length but as they approached 90 cm, *Urechis caupo* and fish eggs became increasingly important. *Urechis caupo* was the most important species in the diet of sharks over 90 cm but various species of crabs, clams, and fish eggs were also important items. The diet of sharks 120 to 130 cm (3.9 to 4.3 ft) was almost evenly divided between crabs, clams, fish, fish eggs, and *Urechis caupo.* Fishes were the most important food items in sharks 130 to 140 cm (4.3 to 4.6 ft). There was no significant difference between the diet of male and female leopard sharks of similar size. Leopard sharks were able to utilize a variety of food sources in Elkhorn Slough without being dependent on any one source.

INTRODUCTION

Virtually no research has been conducted on the ecology or life history, including food habits, of any California shark except the spiny dogfish, *Squalus acanthias,* and the soupfin, *Galeorhinus zyopterus.* These species once were heavily fished due to high level of vitamins in their livers (Bonham et al. 1949; Foerster 1942; Herald and Ripley 1951; Ripley 1946; Templeman 1944; Westrheim 1950). Leopard sharks, *Triakis semifasciata,* are of minimal economic importance and possibly for this reason have been studied little. Some information is available on leopard shark food in San Francisco Bay and Tomales Bay (Russo 1975). However, the only published information on leopard sharks from Elkhorn Slough is in catch analyses of the annual shark derbies held in Elkhorn Slough usually during the months of May and June (Herald and Dempster 1952; Herald 1953; Herald et al. 1960). This information consists mostly of a tabulation of numbers caught, sex ratios, and total poundage. Information on leopard shark food is presented in the form of casual observations.

The leopard shark, the most abundant shark in Elkhorn Slough, ranges from Mazatlan, Mexico, to Oregon (Miller and Lea 1972), and is common inshore around jetties, piers, and bays in central and southern California (Miller et al. 1965). Although leopard sharks have sharply pointed teeth, they are generally considered harmless to man due to their timidity (Limbaugh 1963). However, there is one recorded attack on a scuba diver

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(Dewitt 1955). Leopard sharks are one of the most easily identified sharks because of their distinctive color pattern (Schott 1964).

Increasing concern about the future uses of Elkhorn Slough and environs has created a need for knowledge of the life history and ecology of fishes occurring there (Browning 1972). A knowledge of food habits is vital in assessing the ecological requirements of a species. This paper presents the results of an investigation on the food habits of leopard sharks and the effects of sex, size, and season on overall diet patterns.

STUDY AREA

This study was carried out in Elkhorn Slough, located on the east side of Monterey Bay midway between Monterey and Santa Cruz (Figure 1). Elkhorn Slough consists of about 2,500 acres of submerged areas, tidal flats, and salt marsh. The slough proper is characterized by extensive mudflats that are periodically exposed during low tide and inundated during high tide. The slough has a maximum depth of approximately 4 to 5 m (13.1 to 16.4 ft). Pickle weed, *Salicornia* sp., is the dominant plant at the high tide level.

Originally, Elkhorn Slough was part of the Salinas River drainage system and was largely fresh water during part of the year. In 1908 the Salinas River, during a period of heavy runoff, broke through the sand dunes and began flowing into the ocean at its present location, approximately 8 km (5 miles) south of the slough. To prevent future flooding of agricultural land, the old Salinas River channel was dammed up forcing the river to remain in its new channel (Browning 1972). In 1946, the present entrance channel to the Moss Landing Harbor was constructed resulting in a much greater tidal flux in the slough. The gradually sloping banks of the slough were subject to considerable erosion in some places with subsequent expansion of some of the mudflats.

Factors continuing to influence the slough and the type and abundance of organisms living there are tides, water terperature, and precipitation. The Salinas River continues to affect the slough during periods of heavy rainfall, usually in winter, when the rate of flow increases markedly in the river. The tide gates are opened in the old Salinas River channel causing fresh water to enter the slough in large quantities. In addition, several tributaries from the surrounding hills drain into Elkhorn Slough. This influx of fresh water dilutes the slough water and affects the composition of the fishes found in the slough.

MATERIALS AND METHODS

Leopard sharks were captured over a 14-month period from October 1971, through November 1972, with 90-m (295-ft) nylon gill nets, divided equally among three mesh sizes: 10.2-, 15.2-, and 22.9-cm (4-, 6-, and 9-inch) stretch mesh. In order to avoid capturing large numbers of bony fishes, no mesh size smaller than 10.2-cm (4-inch) stretch was used, resulting in selection against small sharks. In addition to gill netting, leopard sharks were obtained from two Elkhorn Slough shark derbies during June 1972, in which specimens were captured during daylight hours by hand-held hook and line.

Gill nets were set perpendicular to water flow in the slough (Figure 1). Nets were set 1 or 2 hr before sunset and picked up the following morning. An attempt was made to set nets every week but weather conditions, equipment failures, and other unavoidable circumstances did not always allow this. During the month of July a green algae, *Enteromorpha* sp., grew profusely in the slough, completely clogging the nets each time they were set.

All leopard sharks were measured to the nearest mm total length (TL), weighed, sexed, and labeled. Stomachs were removed, labeled, wrapped in cheese cloth, and placed in 10% formalin solution. Stomach contents were sorted into major taxonomic groups and members of each group placed into a separate container for further study. Identification of stomach contents was carried to the lowest possible taxonomic level when condition of the material permitted. The number of each species of food organism was recorded and the volume determined by water displacement to the nearest ml.

The identification of each food group posed a different problem. Whole or slightly digested fish presented little difficulty. Partially or near totally digested fish were often identified by otoliths (sagittae), using a reference collection from species common to the area. Occasionally, fish were identified by use of skeletal elements in conjunction with a reference collection of cleared and stained fish common to Elkhorn Slough (Clothier 1950). Fish eggs were recorded as the number of egg masses consumed rather than individual eggs because large numbers of eggs were always clumped together. Identification was based on a reference collection taken from common Elkhorn Slough fishes known to be spawning in the slough at the time of capture.

Specific identification of intact crustaceans normally presented no problem. In cases where digestion had reached an advanced state, the number of crustaceans recorded was the maximum number of individuals observed based on the number of carapaces, paired chelipeds, or thoraxes, whichever were more abundant. Specific identification of clams was not usually possible except in a few cases when part of the shell remained intact. The gaper clam, *Tresus nuttallii,* is easily identified by an intact siphon with plates, but such intact siphons rarely occurred. Thus, clams were identified only as clams, with the number established by counting either siphons or bodies, whichever represented the greatest number of individuals. The echiuroid worm, *Urechis caupo,* was easily identified by its posterior setae. Specific identification of polychaete worms was not possible since it normally requires appendages to be attached and intact.

Bait consisting almost entirely of market squid, *Loligo opalescens,* was found in several stomachs of sharks captured during the 1972 shark derbies. This material was easily identifiable as bait and not part of leopard shark's regular food in Elkhorn Slough. Therefore, bait was excluded as a food item in all tabulations.

The Index of Relative Importance (IRI), which combines numerical, volumetric, and frequency of occurrence measurements of each prey item into one value, was used to rank the importance of each food item in the diet. The IRI of each food item was established as a linear combination of its numerical importance, volumetric importance, and frequency of occurrence (Pinkas et al. 1971). The numerical importance of a particular item was the percentage ratio of its abundance to the total abundance of all items in the contents. The volumetric importance of a food item was the percentage ratio of its volume to the total volume of all items in the contents. The percent frequency of occurrence of a food item was the percentage of fish containing at least one individual. The combination of percentages, (number + volume) × (frequency), equals the Index of Relative Importance. The value of the IRI ranges from zero, when all

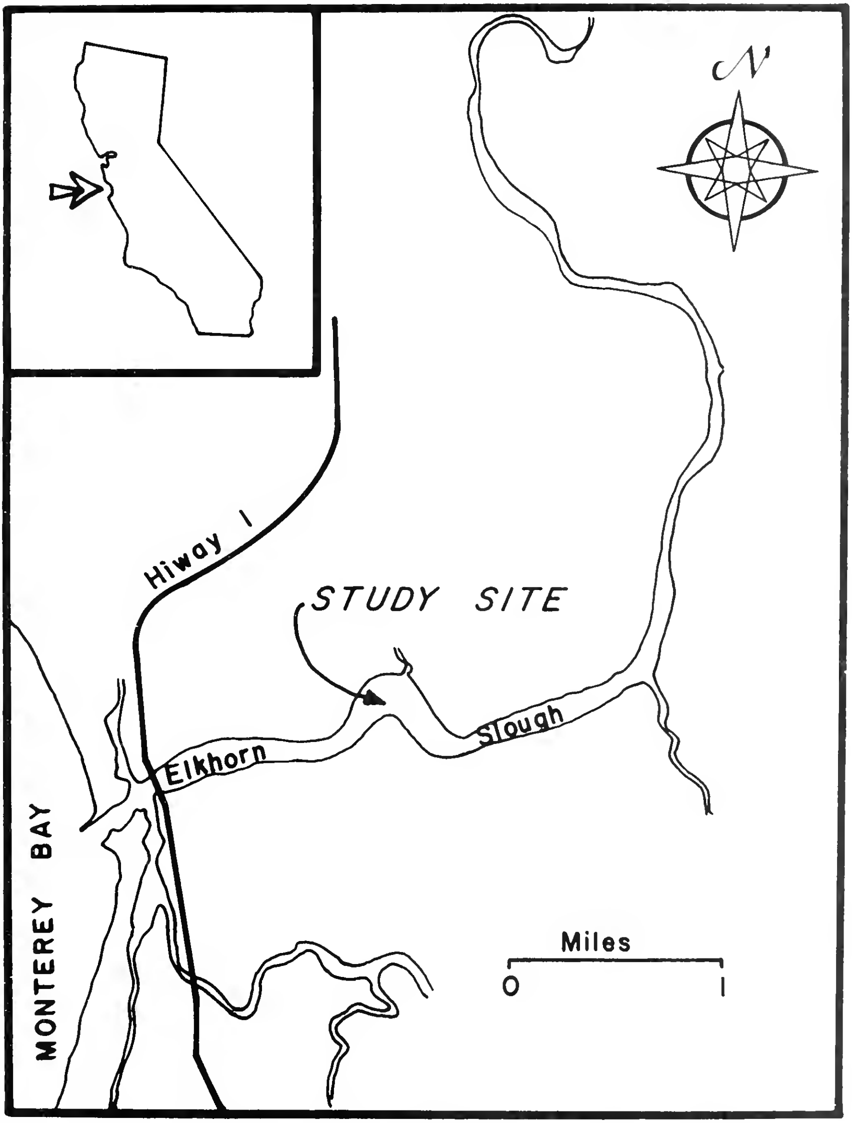

FIGURE 1. Map of study area showing location of sampling station.

three values are zero, to 20,000, when all three indices are 100%.

To facilitate seasonal comparisons of food habits, the year was divided as follows: summer (May, June, July); fall (Aug., Sept., Oct.); winter (Nov., Dec., Jan.); spring (Feb., Mar., Apr.).

The data presented in Figure 2 and Tables 1, 2, 3, and 4 relate only to the number of stomachs that contained food.

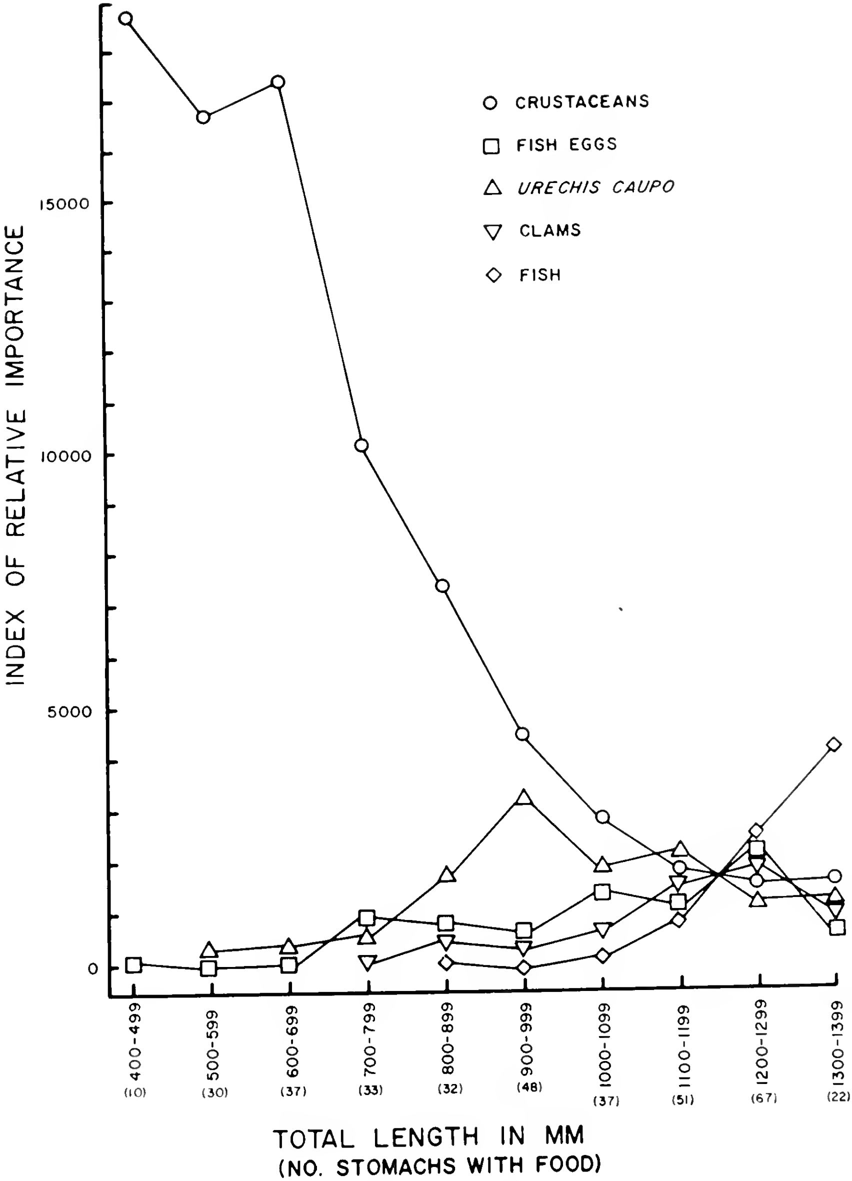

FIGURE 2. Variation in the relative importance of five major food groups in the diets of different length classes of leopard sharks, *Triakis semifasciata,* captured in Elkhorn Slough. The number of stomachs containing food in each length class is indicated in parentheses.

TABLE 1. **Percent Volume (%V), Percent Number (%N), Percent Frequency of Occurrence (%F.O.), and Index of Relative Importance (IRI) of Food Items in the Diet of Leopard Sharks, 400 to 999 mm Total Length, Captured in Elkhorn Slough, Monterey Bay, California**

FOOD ITEM	TOTAL LENGTH (mm)											
	400–599 (40)*				600–799 (70)*				800–999 (80)*			
	%V	%N	%F.O.	IRI	%V	%N	%F.O.	IRI	%V	%N	%F.O.	IRI
Plant Material	--	--	--	--	1.0	.5	1.4	2	5.0	2.0	6.3	44
Polychaeta	.7	.7	2.5	4	1.5	6.0	12.9	97	.8	6.9	16.3	126
Echiuroidea												
Urechis caupo	7.7	2.7	7.5	78	13.4	10.0	12.9	302	25.9	31.4	45.0	2579
Crustacea												
Decapoda (total)	87.8	95.3	97.5	17852	67.6	78.2	91.4	13326	40.4	44.1	68.8	5814
Carides												
Crangon sp.	.3	.7	2.5	3	.2	.5	1.4	1	.1	.4	1.3	1
Brachyura												
Cancer antennarius	2.1	.7	2.5	7	4.3	2.0	5.7	36	--	--	--	--
Cancer gracilis	6.3	4.2	10.0	105	11.3	7.5	8.6	162	6.6	8.2	11.3	167
Cancer magister	--	--	--	--	--	--	--	--	5.8	1.2	3.8	27
Cancer productus	2.5	.7	2.5	8	10.8	3.5	5.7	82	6.9	2.9	6.3	62
Hemigrapsus oregonensis	68.5	87.6	85.0	13269	30.2	62.2	77.1	7124	5.4	26.9	33.8	1092
Pachygrapsus crassipes	2.1	.7	2.5	7	2.3	1.5	4.3	16	--	--	--	--
Unidentified crab parts	3.2	--	5.0	16	7.2	--	14.3	103	4.9	--	22.5	110
Anomura												
Blepharipoda occidentalis	--	--	--	--	.2	.5	1.4	1	10.0	3.3	7.5	100
Callianassa californiensis	2.8	.7	2.5	9	1.1	.5	1.4	2	.1	.4	1.3	1
Emerita analoga	--	--	--	--	--	--	--	--	.5	.4	1.3	1
Upogebia pugettensis	--	--	--	--	--	--	--	--	.1	.4	1.3	1
Mollusca												
Bivalvia												
Clams	3.5	.7	2.5	11	1.3	1.0	2.9	7	7.7	5.7	16.3	218
Cephalopoda												
Octopus sp.	--	--	--	--	--	--	--	--	.3	.8	2.5	3
Fish eggs	.4	.7	2.5	3	15.2	4.5	12.9	254	16.0	6.9	21.3	488
Pisces (total)	--	--	--	--	--	--	--	--	4.0	2.0	5.0	30
Bothidae	--	--	--	--	--	--	--	--	.1	.4	1.3	1
Batrachoididae	--	--	--	--	--	--	--	--	3.8	.8	2.5	12
Unidentified fish	--	--	--	--	--	--	--	--	.1	.8	2.5	2

* Number of shark stomachs containing food.

TABLE 2. **Percent volume (%V), Percent Number (%N), Percent Frequency of Occurrence (%F.O.), and Index of Relative Importance (IRI) of Food Items in the Diet of Leopard Sharks, 1000 to 1399 mm Total Length, Captured in Elkhorn Slough, Monterey Bay, California**

	TOTAL LENGTH (mm)							
	1000–1199 (88)*				1200–1399 (89)*			
FOOD ITEM	%V	%N	%F.O.	IRI	%V	%N	%F.O.	IRI
Plant Material	.4	.7	2.3	3	.7	.7	2.3	3
Polychaeta	.3	1.4	4.6	8	.1	.3	1.1	<1
Echiuroidea								
Urechis caupo	18.2	33.9	38.6	2011	11.3	26.6	38.2	1448
Crustacea								
Decapoda (total)	24.5	20.7	48.9	2210	18.5	16.2	44.9	1558
Carides								
Crangon sp.	.1	.7	1.1	1	.1	.3	1.1	<1
Brachyura								
Cancer antennarius	2.5	2.5	5.7	29	3.3	2.9	4.5	28
Cancer gracilis	2.2	7.1	9.1	85	2.5	3.3	4.5	27
Cancer magister	7.7	4.3	4.6	55	.6	.3	1.1	1
Cancer productus	5.2	3.2	7.9	66	9.1	7.1	14.6	237
Hemigrapsus oregonensis	.2	1.8	5.7	11	.4	2.3	4.5	12
Unidentified crab parts	4.9	--	19.3	95	2.5	--	20.2	51
Anomura								
Blepharipoda occidentalis	1.7	1.1	2.3	6	--	--	--	--
Mollusca								
Bivalvia								
Clams	19.7	13.9	35.2	1183	20.4	16.2	43.8	1603
Cephalopoda								
Octopus sp.	2.6	5.7	5.7	47	--	--	--	--
Fish eggs	22.5	10.7	31.1	1132	26.8	11.4	39.3	1501
Pisces (total)	12.1	13.1	23.9	602	22.7	28.7	44.9	2308
Rhinobatidae	.6	.4	1.1	1	1.5	.7	2.3	5
Clupeidae	2.5	2.9	4.6	25	1.7	1.3	4.5	14
Engraulidae	--	--	--	--	.4	5.5	1.1	7
Sciaenidae	--	--	--	--	.1	.3	1.1	<1
Embiotocidae	.9	1.1	2.3	5	2.8	2.3	6.8	35
Gobiidae	.4	.4	1.1	1	1.1	.7	2.3	4
Scorpaenidae	--	--	--	--	.5	.3	1.1	1
Cottidae	.1	.4	1.1	1	1.5	4.0	9.0	50
Atherinidae	.2	.7	1.1	1	1.8	3.9	7.9	45
Bothidae	.1	.4	1.1	1	--	--	--	--
Cynoglossidae	--	--	--	--	.1	.3	1.1	<1
Batrachoididae	4.5	1.4	4.6	27	8.0	2.6	7.9	84
Unidentified fish	2.8	5.4	11.4	94	3.2	6.8	19.1	191

* Number of shark stomachs containing food.

RESULTS

Identifiable food was found in 367 (84.2%) of the 436 leopard shark stomachs examined. Regurgitation of stomach contents was observed several times while sharks were struggling in the net and undoubtedly accounted for a number of the 69 empty stomachs.

Leopard sharks fed mostly on crustaceans, clams, fish, fish eggs, and the echiuroid worm, *Urechis caupo.* Considerable variation in food habits occurred between different sized sharks (Tables 1 and 2). Small sharks fed almost entirely on crabs; but, as they increased in size, *Urechis caupo,* clams, fish, and fish eggs made up a larger portion of their diet (Figure 2). As a group, crabs remained the most important food source until sharks reached 110 cm (3.6 ft). *Urechis caupo* was the most important single food species for all sharks over 90 cm (3.0 ft). Its importance as a food item reached a peak in sharks 90 to 100 cm (3.0 to 3.3 ft). The diet of sharks 120 to 130 cm (3.9 to 4.3 ft) was almost evenly distributed between crabs, clams, fish, fish eggs, and *Urechis caupo.* Fish made up the greatest portion of food eaten by sharks 130 to 140 cm (4.3 to 4.6 ft).

Polychaete worms and octopuses occurred in a number of leopard shark stomachs. Although the volume and number eaten were small, the fre-

TABLE 3. **Seasonal Variation in the Index of Relative Importance (IRI) of Food Items in the Diet of Leopard Sharks, 400 to 999 mm Total Length, Captured in Elkhorn Slough, Monterey Bay, California**

FOOD ITEM	TOTAL LENGTH (mm)											
	400–599				600–799				800–999			
	Summer (23)*	Fall (12)*	Winter (5)*	Spring (0)*	Summer (23)*	Fall (41)*	Winter (4)*	Spring (2)*	Summer (28)*	Fall (39)*	Winter (2)*	Spring (11)*
Plant Material	--	--	--	--	16	--	--	--	205	4	--	--
Polychaeta	--	36	--	--	286	37	--	553	314	40	--	164
Echiuroidea												
Urechis caupo	--	87	2452	--	201	277	--	4632	1431	4493	13349	992
Crustacea												
Decapoda (total)	19008	18526	9380	--	10349	17085	15000	1816	4606	6933	116	5990
Carides												
Crangon sp.	--	--	213	--	9	--	--	--	--	--	--	42
Brachyura												
Cancer antennarius	--	65	--	--	--	50	--	1816	--	--	--	--
Cancer gracilis	--	302	1629	--	787	5	245	--	96	147	--	728
Cancer magister	--	--	--	--	--	--	--	--	110	--	--	--
Cancer productus	--	72	--	--	107	28	1685	--	82	12	--	372
Hemigrapsus oregonensis	17538	14283	1570	--	2776	13558	5353	--	661	2250	--	45
Pachygrapsus crassipes	--	65	--	--	--	22	643	--	--	--	--	--
Unidentified crab parts	--	--	1059	--	334	25	72	--	21	120	116	592
Anomura												
Blepharipoda occidentalis	--	--	--	--	9	--	--	--	115	85	--	115
Callianassa californiensis	29	--	--	--	--	--	571	--	4	--	--	--
Emerita analoga	--	--	--	--	--	--	--	--	--	6	--	--
Upogebia pugettensis	--	--	--	--	--	--	--	--	5	--	--	--
Mollusca												
Bivalvia												
Clams	35	--	--	--	--	25	--	--	121	315	--	365
Cephalopoda												
Octopus sp.	--	--	--	--	--	--	--	--	--	14	--	--
Fish Eggs	8	--	--	--	1106	--	--	6000	1352	--	3210	1888
Pisces (total)	--	--	--	--	--	--	--	--	133	2	--	--
Bothidae	--	--	--	--	--	--	--	--	4	--	--	--
Batrachoididae	--	--	--	--	--	--	--	--	72	--	--	--
Unidentified fish	--	--	--	--	--	--	--	--	4	2	--	--

* Number of shark stomachs containing food.

quency of occurrence was noteworthy. Polychaetes were commonly found in stomachs of sharks 60 to 120 cm (2.0 to 3.9 ft) whereas octopuses occurred most often in sharks 90 to 120 cm (3.0 to 3.9 ft).

The species of crabs utilized as food varied with the size of shark. *Hemigrapsus oregonensis,* a small-sized crab usually less than 25 mm (1 inch) in diameter, was the most important food item for sharks under 90 cm (3.0 ft). However, as sharks increased in size, larger species of crabs became more important. *Cancer gracilis,* a medium-sized crab, was the most important crab in the diet of sharks 90 to 120 cm (3.0 to 3.9 ft). *Cancer productus* replaced *Cancer gracilis,* and was the most important species of crab in the diet of sharks 120 to 140 cm (3.9 to 4.6 ft). *Cancer productus, Cancer antennarius,* and *Cancer magister,* are large crabs and most adult individuals were in the soft shelled stage when eaten. Most *Cancer productus* eaten were juveniles.

Clams formed an important part of the diet of sharks over 80 cm (2.6 ft). Clam siphons made up the bulk of clam material eaten but several large complete specimens were found in stomach contents, all without shells. Several species of clams were probably eaten, but due to the absence of all, but very small shell fragments, specific identification of most

TABLE 4. **Seasonal Variation in the Index of Relative Importance (IRI) of Food Items in the Diet of Leopard Sharks, 1000 to 1399 mm Total Length, Captured in Elkhorn Slough, Monterey Bay, California**

	TOTAL LENGTH (mm)							
	1000–1199				1200–1399			
FOOD ITEM	Summer (21)*	Fall (20)*	Winter (20)*	Spring (27)*	Summer (9)*	Fall (16)*	Winter (33)*	Spring (31)*
Plant Material	--	--	10	6	--	--	--	22
Polychaeta	46	13	6	--	--	--	--	3
Echiuroidea								
Urechis caupo	1138	370	3494	3079	163	576	925	2624
Crustacea								
Decapoda (total)	1551	3022	907	3346	79	2733	1760	1212
Carides								
Crangon sp.	19	--	--	--	--	--	--	3
Brachyura								
Cancer antennarius	--	123	169	--	--	--	209	--
Cancer gracilis	42	190	31	96	36	136	8	7
Cancer magister	274	--	--	86	--	38	--	--
Cancer productus	15	--	--	500	--	126	208	459
Hemigrapsus oregonensis	--	338	--	--	--	247	4	--
Unidentified crab parts	60	432	112	31	3	17	81	59
Anomura								
Blepharipoda occidentalis	124	--	--	--	--	--	--	--
Mollusca								
Bivalvia								
Clams	37	5016	1518	916	186	5277	954	1580
Cephalopoda								
Octopus sp.	10	91	231	--	--	--	--	--
Fish eggs	981	14	1865	2130	170	--	2849	2284
Pisces (total)	2312	78	442	159	7693	2207	1970	1138
Rhinobatidae	22	--	--	--	--	42	10	--
Clupeidae	109	--	--	17	245	--	--	19
Engraulidae	--	--	--	--	--	--	48	--
Sciaenidae	--	--	--	--	--	15	--	--
Embiotocidae	91	--	--	--	580	15	8	7
Gobiidae	--	--	--	9	72	--	5	--
Scorpaenidae	--	--	--	--	--	33	--	--
Cottidae	--	--	7	--	133	236	29	6
Atherinidae	--	--	--	--	38	--	59	69
Bothidae	--	--	7	--	--	--	--	--
Cynoglossidae	--	--	--	--	--	--	4	--
Batrachoididae	122	--	--	11	922	--	--	189
Unidentified fish	530	78	135	4	482	367	227	32

* Number of shark stomachs containing food.

clam parts was not possible. However, several gaper clams, *Tresus nuttallii,* were identified by their siphon plates, and most clam parts appeared to be from this species. Another clam identified from parts was the Washington clam, *Saxidomus nuttallii,* and rarely, the rough piddock clam, *Zirfaea pilsbryi,* was found.

Fish eggs became increasingly important as a food item as leopard sharks increased in size. Almost all fish eggs found in stomach contents appeared to be either jacksmelt, *Atherinopsis californiensis,* or topsmelt, *Atherinops affinis.* Some overlap occurred between the spawning periods of these species and differentiation of the eggs was not always possible. On a few occasions, Pacific herring, *Clupea harengus pallasi,* eggs were found in stomach contents but were insignificant as food items.

Several leopard shark stomachs contained plant material consisting mostly of algae, *Gracilaria* sp., and some eel grass, *Zostera* sp. All plant material observed was associated with fish eggs. Usually the eggs were firmly attached to the plant material by long filaments. Apparently the spawning fish attached their eggs to the plants and leopard sharks swallowed pieces of plant material incidentally along with the eggs.

Several species of fish were eaten by leopard sharks. The northern midshipman, *Porichthys notatus,* was the most important species of fish eaten, due largely to the considerable volume of each individual consumed. Of particular interest was the presence of three yellowfin gobies, *Acanthogobius flavimanus,* among the fish eaten by leopard sharks. The first record of this introduced species in Elkhorn Slough is July 17, 1970 (Kukowski 1972). These additional specimens indicate that this goby is becoming well established in the slough. Three small specimens of shovelnose guitarfish, *Rhinobatos productus,* represented the only elasmobranchs found in leopard shark stomachs. Other species of fish identified in stomach contents were *Citharichthys stigmaeus, Clupea harengus pallasi, Cymatogaster aggregata, Embiotoca jacksoni, Engraulis mordax, Genyonemus lineatus, Leptocottus armatus,* and *Symphurus atricauda.* No one species of fish was eaten in large numbers. Leopard sharks thus appeared to be opportunistic feeders on fish, feeding on species most abundant or easiest to catch.

There was no significant difference in diet of male and female leopard sharks of similar size. However, it should be noted that females attain a larger size than males and therefore made up a greater proportion of the largest size class.

Although a sufficient number of stomachs could not be collected throughout the entire year to make good monthly comparisons of diets for each size class, some seasonal trends were observed (Tables 3 and 4). Small sharks, less than 80 cm (2.6 ft) fed mostly on crabs throughout the time they were captured while larger sharks showed some seasonal variation in their diets. Much of the variation was due to almost total absence of fish eggs in their diet during fall. Jacksmelt and topsmelt are reported to spawn from October to April and May through July respectively (Clark 1929; Schultz 1933). Because of the unavailability of fish eggs as a food source, leopard sharks probably fed more heavily on clams and crabs during the fall than at other times. During winter and spring, the yellow shore crab, *Hemigrapsus oregonensis,* decreased to insignificance as a food item simultaneously with an increase in importance of several species of *Cancer* crabs, fish eggs, and *Urechis caupo.* Large sharks ate fish mostly during the summer, at which time clams decreased to their lowest value of the year.

DISCUSSION

Leopard sharks of many sizes, except those below 40 cm (1.3 ft), frequenting Elkhorn Slough were captured during this study. Most leopard sharks examined appeared to have fed in Elkhorn Slough and not Monterey Bay. Food items such as *Urechis caupo* and *Hemigrapsus oregonensis* are usually associated with mudflats and rarely occur in strictly sandy substrates such as are generally found in the bay (MacGinitie 1935). Most other major food items are found in Elkhorn Slough in abundance although, many are also common in the bay. However, *Blepharipoda occidentalis* and *Cancer magister* are usually not found in the slough proper, although they are common in the bay. The presence of these species in the diet of leopard sharks probably indicates that a few sharks fed in the bay shortly before being captured in the slough.

Although crabs and fish are presumably taken through a simple pursuit and capture, leopard sharks seem to be capable of utilizing a variety of methods for capturing other types of organisms. Leopard sharks must be very adept at feeding on *Urechis caupo,* as it was the most important prey species in the diet of sharks over 90 cm (3.0 ft). This echiuroid worm lives in a U-shaped burrow about 1-ft deep in mud and reportedly never leaves its burrow (MacGinitie and MacGinitie 1968). It seems unlikely that the morphology of leopard sharks would allow them to dig *Urechis* out of mud. However, *Urechis* may protrude, on occasion, a few mm from its burrow during maintenance of the burrow or elimination of waste products and then be captured by leopard sharks. Another and more probable possibility is that leopard sharks pull *Urechis* from their burrows by suction. Some species of sharks are capable of creating enough suction, by rapid expansion of their pharyngeal cavity, to obtain food from tubes and may obtain much of their food in this manner (Tanaka 1973). The fact that most intact *Urechis* found in stomachs were completely undamaged seems to indicate that teeth probably were not used to pull the worms from their burrows.

Leopard sharks probably feed on clams by swimming over the bottom and seizing the extended siphons. Most clam material in stomach contents consisted only of siphons. Leopard sharks apparently unable to pull the entire clam out of mud, pull until the siphon breaks at some point along its length. In several cases, entire gaper clam bodies were found without shells in stomach contents. Apparently these clams were pulled free of the mud or possibly had already been eroded out of the substrate by tidal currents. It is not known how the shells were removed. The small and pointed teeth of leopard sharks appear to be efficient at holding onto prey but unsuited for cutting or crushing clam shells.

Food habit data indicate that leopard sharks are primarily opportunistic bottom feeders, fish being the only food item not always taken from the bottom. Sharks in the smallest size groups were most restricted in their diet, feeding primarily on one species of crab, *Hemigrapsus oregonensis,* but they utilized a much wider variety of food items as they increased in size. Seasonal variation in food item selection may have been a result of increasing abundance of one item or the decrease in abundance of another, or both. Changes in the population density of leopard sharks along with intra- and interspecific competition for food also may have been contributing factors to food item selection. Generally, leopard sharks were quite versatile in their feeding habits throughout the year, being able to utilize several major food sources without being dependent on any one. This flexibility of feeding habits along with the differences in the food habits of leopard sharks in the various size groups undoubtedly permits an efficient utilization of Elkhorn Slough's food resources and probably allows a greater density of leopard sharks to live in the slough.

Russo (1975) suggested that leopard sharks in San Francisco and Tomales Bay did not feed intertidally and *Hemigrapsus oregonensis,* a crab usually associated with an intertidal habitat, was absent from examined stomach contents; although it was common in the diet of brown smoothhounds, *Mustelus henlei,* taken from the same general area. In Elkhorn Slough, leopard sharks do feed intertidally and *Hemigrapsus oregonensis* is an important food item. It is apparent that the food habits of leopard sharks in any one area may not be representative of the food habits elsewhere within the species' range. Large leopard sharks are opportunistic feeders and probably can utilize a number of food sources in a variety of habitats. However, shall leopard sharks appear to have a more restricted diet and may require a special environment, such as Elkhorn Slough, where a particular food item is abundant. Further research is needed to determine if leopard sharks have specific nursery grounds and if so, how important these areas are to the survival of the species.

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NOTES

ADDITION OF *CITHARICHTHYS FRAGILIS* GILBERT TO THE CALIFORNIA FAUNA

On May 15, 1974, one specimen of the sanddab, *Citharichthys fragilis* Gilbert 1890, was taken near Dana Point, California at 88 m (290 ft) during a quarterly trawl survey conducted by the Southern California Coastal Water Research Project (SCCWRP). This species (Figure 1) is common in the Gulf of California (Jordan and Evermann 1896–1900; Norman 1934), but the most northerly record was for Punta Cabras, on the west coast of Baja California Norte (Scripps Institution of Oceanography collection, SIO 60-471). Since May 1974, nine more specimens have been taken at two locations near Dana Point at 88 m (290 ft), and seven specimens have been taken at three locations near Palos Verdes Peninsula at 137 to 143 m (452 to 472 ft) (Table 1). In examining the collection at the University of California, Los Angeles, I found three additional specimens (UCLA W 59-215) taken on May 28, 1959 off Manhattan Beach, California at 54 m (178 ft).

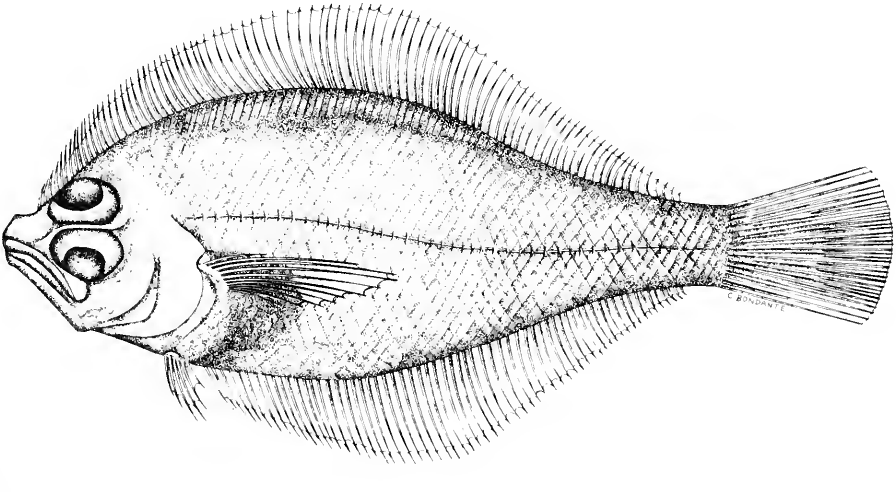

FIGURE 1. Gulf sanddab, *Citharichthys fragilis*. Illustration by Christine Bondante.

TABLE 1. **Location and Meristic Data on Specimens of *Citharichthys fragilis* Taken in California.**

Date and location	Latitude	Longitude	Depth (m)	Standard length (mm)	Rakers, lower limb, 1st arch	Scales lateral line	Fin rays	
							Dorsal	Anal
May 28, 1959, west of Manhattan Beach	33°51.50′	118°29.30′	51	75	17	46	56 +*	51 +*
				87	18	49	76	63
				93	17	49	78	67
May 15, 1974, north of Dana Point	33°29.00′	117°46.75′	88	100	20	48	81	64
July 5, 1974, north of Dana Point	33°27.50′	117°45.50′	88	101	18	48	86	67
				102	17	50	83	65
				104	16	47	84	66
August 23, 1974, north of Dana Point	33°29.00′	117°46.75′	88	110	19	50	88	68
				110	16	47	84	67
				116	17	51	84	66
				129	20	47	82	66
				120	18	46	69**	65
				122	17	48	84	66
November 18, 1974, south of San Pedro	33°36.00′	118°16.50′	137	108	18	47	81	61
				108	18	47	84	68
November 18, 1974, Palos Verdes Peninsula	33°13.80′	118°19.50′	140	110	18	48	87	68
				129	21	46	86	67
November 25, 1974, west of Redondo Beach	33°49.00′	118°26.00′	143	116	18	46	82	66
				127	19	49	38 +*	17 +*
				133	18	49	88	69

* Several rays broken off (net damage).

** This falls within the range of *Citharichthys gordae* Beebe and Tee-Van 1938 from the Gorda Banks, Baja California del Sur. Its anal rays (65), however, fall within the range of *Citharichthys fragilis*, and it has been included here as the latter species.

TABLE 2. **Comparisons of the Species of *Citharichthys* Found in California** *

Species	Geographic range	Max. size (mm)	Depth range (m)	Rakers, lower limb, 1st arch	Scales, lateral line	Fin rays		Pectoral fin
						Dorsal	Anal	
Gulf sanddab, *Citharichthys fragilis*	Manhattan Bch., Calif., to Gulf of Calif.	140	19–317	16–21	46–51	76–88	63–70	Extends beyond shadow of gastric cavity; shorter than head
Pacific sanddab, *Citharichthys sordidus*	Bering Sea to Cape San Lucas, Baja Calif.	403	9–549**	12–16	61–70	86–102	67–81	Extends beyond shadow of gastric cavity; shorter than head
Speckled sanddab, *Citharichthys stigmaeus*	Montague I., Alaska to Magdalena Bay, Baja Calif.	169	3–366†	8–10	52–58	75–97	58–77	Equal to or shorter than gastric cavity shadow
Longfin sanddab, *Citharichthys xanthostigma*	Monterey Bay, Calif., to Costa Rica	250	2–135	10–12	47–57	79–89	61–69	Longer than head

* Based on my observations and Jordan and Evermann (1896–1900); Miller and Lea (1972); Norman (1934); Dilworth Chamberlain (Univ. of South. Calif., pers. comm.); Alan Mearns (SCCWRP, pers. comm.).

** Seldom found deeper than 150 m in southern California.

† Seldom found deeper than 90 m in southern California.

Three other species of sanddab occur in California: the speckled sanddab, *Citharichthys stigmaeus,* the Pacific sanddab, *C. sordidus,* and the longfin sanddab, *C. xanthostigma. C. fragilis* differs from all of these in that it has more rakers on the lower limb of the first gill arch, and a rather sharp snout and mouth profile, with a distinct, angular projection on the snout (Table 2).

A simplified way of distinguishing sanddabs in the field has been suggested by Alan Mearns of SCCWRP who recognized certain relationships between the length of the pectoral fin and the gastric-cavity shadow. *Citharichthys fragilis* resembles *C. sordidus* in the extension of the pectoral fin beyond the shadow of the gastric cavity, and this fin in both is consistently somewhat shorter than the head, extending about half-way to the caudal base. In *C. stigmaeus,* the pectoral fin is shorter than or only as long as the shadow. In *C. xanthostigma,* it is longer than the head, extending two-thirds the distance to the caudal base. *C. fragilis* contrasts sharply with *C. sordidus* (and also *C. stigmaeus*), but not sharply with *C. xanthostigma* in the larger size of the scales; the counts of scales in the lateral line are 46-51 in *C. fragilis* and 61-70 in *C. sordidus.* There are usually more rakers on the lower limb of the first gill arch in *C. fragilis* than in *C. sordidus* and definitely more than in the two other species in California (Table 2).

The data suggest that *C. fragilis* may be found in low abundance in the general depth range in which the Pacific sanddab is dominant. It is possible that the 1959 specimens represent a successful recruitment into the area in the warm years of 1957–59 (Radovich 1961). The age of two 110-mm (4.3-inch) fish taken August 23, 1974 is about 18 months (estimated from otoliths by John Fitch, California Department of Fish and Game, Long Beach); this suggests that these specimens were recruited into the area early in 1973. The successful recruitment at that time of other more southerly species (Southern California Coastal Water Research Project, unpublished data) may indicate an intrusion of southern water into the area. Because most investigators have assumed that only three species of *Citharichthys* exist off California, *C. fragilis* may have been present in past collections but misidentified, particularly as Pacific or longfin sanddabs, which most closely resemble it.

At the suggestion of Carl Hubbs of Scripps Institution of Oceanography, I propose the common name "Gulf sanddab" in reference to the geographical area (Gulf of California) where it is most common.

The specimens collected by the Coastal Water Research Project have been deposited in the Project's reference collection of southern California benthic fish and invertebrates.

ACKNOWLEDGEMENTS

I would like to thank Carl Hubbs of Scripps Institution of Oceanography for his comments and suggestions made after reviewing this paper.

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Calif Fish and Game 62 (4): 304–305. 1976.

FIRST RECORDS OF THE NOTACANTH FISH, *NOTACANTHUS CHEMNITZI* BLOCH, FROM THE NORTHEASTERN PACIFIC

Fishes of the family Notacanthidae have been captured infrequently in Pacific waters. One species, *Polyacanthonotus challengeri*, was captured only recently off the continental slope of Oregon (Stein and Butler 1971). A second species was recorded off the Columbia River as *Notacanthus* sp. (Alton 1972). In a review of the family, McDowell (1973) indicated that the distribution of *N. chemnitzi* "may be world wide, although probably the species is missing from the equatorial region". He did not note specimens from the eastern North Pacific although he did note records from off Japan.

One specimen 382 mm (15 inches) in standard length (British Columbia Provincial Museum Cat. No. BCPM 71-194) captured off Oregon at Lat 45°54′N and Long 125°05′W in 1554 m (850 fm) on May 15, 1963, and three other specimens of 451, 486 and 501 mm (17.8, 19.1 and 19.7 inches) standard length (BCPM 71-219) (Figure 1) from Lat 45°50′N and Long 125°06′W in 1536 m (840 fm) on June 16, 1966 are morphologically similar to the description provided by McDowell and may even be the specimens re-

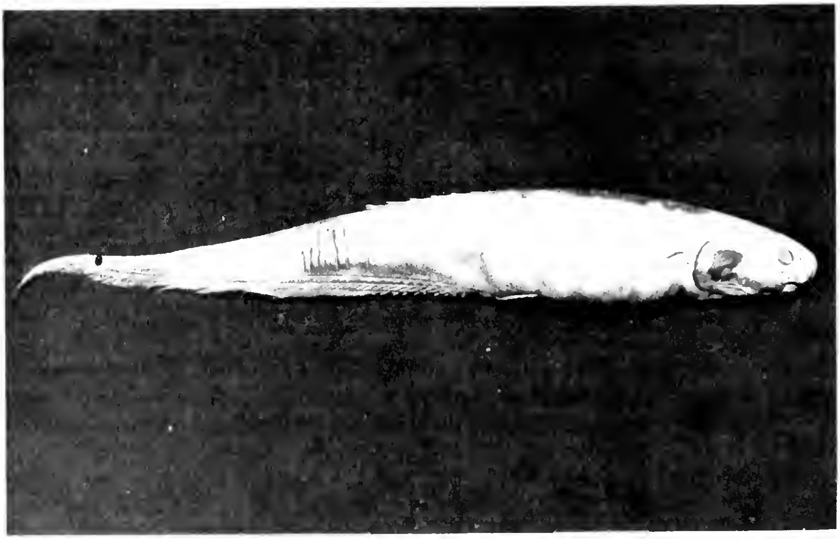

FIGURE 1. Photo of *Notocanthus chemnitzi* (BCPM 71-219). Black object on tail is a pin used to straighten tail for photographing. Photograph by Brent Cooke.

ferred to by Alton from a similar depth (1517 to 1554 m). In any case, these specimens support McDowell's supposition of *N. chemnitzi* inhabiting temperate regions such as the northeastern Pacific Ocean and provide first records of the species off western North America. Except for a 1797 m (988 fm) depth record these specimens are from greater depths than other specimens are known (McDowell 1973).

The diagnostic characters which help identify the specimens as *N. chemnitzi* are: dorsal fin spines, VIII to X; branchiostegal rays nine (on two specimens); gill filament length/length of longest raker, 1.4 to 1.6; distance from rear of spectacle (integument without pigment over eye) to posteriormost edge of opercle/distance from tip of snout to rear of spectacle, 1.6 to 1.7; recurved tips of premaxillary teeth compressed, broader than their shafts, and forming a continuous sawlike cutting edge; total of spinous and soft anal fin rays, 131 to 143; palatine and dentary teeth in two or more complete rows. One of the three specimens from collection BCPM 71-219 was donated to the fish collection curated by the School of Oceanography, Oregon State University, Corvallis, Oregon.

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Calif. Fish and Game 62 (4): 306–307. 1976.

SIMPLE CONTAINER FOR THE COLLECTION AND STORAGE OF OTOLITHS

The use of small glass vials for retaining fish otoliths appears to be a well-established practice among fishery biologists working at sea or dockside along the west coast of the United States. For most studies, however, the extensive time required in handling thousands of otolith vials and, particularly, the tedious task of labeling each vial suggest that more simple and efficient procedures would be desirable.

The otolith containers described in this report have proven highly beneficial for the collection of either random or stratified samples (Pinhorn and Fleming 1965) retained in groups by fish length or retained individually by specimen number.

The otolith containers (Figure 1) are constructed of plexiglas (10⅜ inches square by 2⅜ inches high), and are divided into 100 compartments (1-inch square by 2⅜ inches high). The overlapping lid is designed to seal the container and minimize evaporation of preservatives during storage. Four small rubber pads are attached to the bottom to prevent the container from moving as otoliths are being collected aboard ship. The dividers forming the 100 see-through compartments are gapped from the floor of the container, allowing preservatives to flow between compartments.

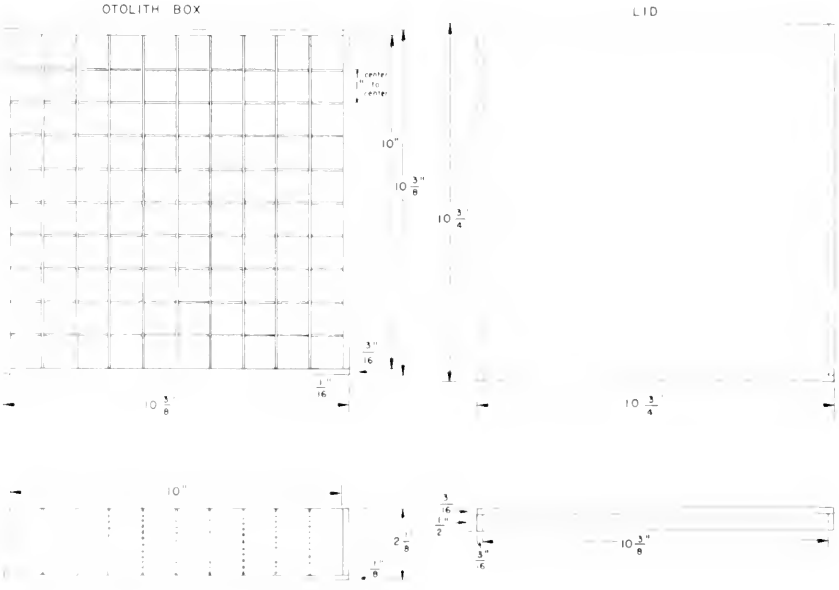

FIGURE 1. Construction details of otolith container showing top and side view of box on left and lid on right.

Thus, a fixed volume of fluid may be poured into the container to provide each compartment with preservative. This eliminates filling compartments individually as must be done with otolith vials.

Each otolith compartment is numbered, 1–100, with indelible ink. These numbers correspond to either an arbitrary group such as otoliths from fish of a specific body length, or to individually-numbered specimens. This numbering procedure provides versatility and allows the boxes to be used when collecting random or stratified samples of otoliths and retaining them either by fish length category or individually by number. Labeling individual otoliths or compartments of otoliths is unnecessary and only the container must be labeled.

The described containers have proven more practical than vials aboard ship when collecting random or stratified samples of otoliths which are stored individually or by fish length category. There is no advantage to this container when collecting otoliths used strictly for age frequencies because they are not individually identified or stored by fish-length categories.

Noteworthy advantages of the containers, when collecting random or stratified samples, are their convenience on deck during the collecting process and later for storage. However, the main advantage is the elimination of individual labels as in the case with vials. In addition to greater efficiency, this simplification and the design of the see-through compartments has considerably improved the accuracy of the otolith collection process.

Otolith readers have also indicated a preference for the containers over vials because of handling convenience, easy access to the otoliths, and simplified cleaning.

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FIRST RECORD OF THE DECORATED WARBONNET, *CHIROLOPHIS DECORATUS* (JORDAN AND SNYDER 1902), IN CALIFORNIA WATERS.

On June 8, 1962, an unusual fish was caught from the North Jetty of Humboldt Bay, Humboldt Co., California. The fish was taken on hook and line by Audrey Smith of McKinleyville, California and was first identified by S. G. Wright as a decorated prickleback, *Chirolophis polyactocephalus* (Pallas 1811), (Clemens and Wilby 1961) and preserved in the Humboldt State University Fish Collection (No. 28300-8). The name currently accepted by the AFS/ASIH for this fish is decorated warbonnet, *Chirolophis decoratus* (Jordan and Snyder 1902).

With the appearance of "Guide to the Coastal Marine Fishes of California" (Miller and Lea 1972) it became evident to me that this species had never been reported from California waters, and that the 1962 specimen represented the southernmost occurrence of the species. The published range of *C. decoratus* heretofore has been from Washington to the Aleutian Islands, the Bering Sea, and into the Sea of Okhotsk (Shmidt 1950; Andriyashev 1954; Quast and Hall 1972; Hart 1973.)

Mrs. Smith's fish, an ovigerous female, was 258 mm (10.2 inches) SL. The dorsal and anal fin spine and ray counts, LXI and I, 46, respectively, were well within the ranges presented by other authors (Makushok 1958; Clemens and Wilby 1961; Hart 1973.) The ovaries contained eggs in various stages of development, the largest and posteriormost measuring 0.38 mm in diameter.

Chirolophis decoratus is distinguished from other California members of the family Stichaeidae by the numerous cirri and branched club-like appendages on the head, extending rearward to the fourth to eighth dorsal spine; I, 4 pelvic fin count; a single spine in the anal fin; the short snout; large fan-like pectoral fins; and partial confluence of the dorsal fin membrane with the caudal fin. A similar though smaller member of the genus, the mosshead warbonnet, *Chirolophis nugator,* ranges along the California coast south to San Miguel Island. In *C. nugator*, the cirri and head appendages are developed to a much lesser extent than in *C. decoratus.*

According to Makushok (1958) members of the genus eat small invertebrates including molluscs, polychaetes, hydroids, and anemonies. *C. decoratus* has been captured at depths ranging from just subtidally to 91 m (50 fm). It is usually found among seaweed growths on stony bottoms.

The Humboldt Bay specimen is currently in the Fish Collection (No. 28300-8), Humboldt State University, Arcata, California.

ACKNOWLEDGEMENTS

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ADDITIONS TO THE LIST OF FISH SPECIES KNOWN FROM ALAMITOS BAY, CALIFORNIA, BASED ON STUDIES IN COLORADO LAGOON

Colorado Lagoon is a Y-shaped body of water situated at the northernmost end of Alamitos Bay, Long Beach, California. Originally a mudflat and estuarine environment, the lagoon has been altered greatly by dredging operations. It is connected to the marine stadium portion of Alamitos Bay via tide gates and an underground waterway. Freshwater influx is now restricted to six storm drains located throughout the lagoon. The surface area is approximately 4.8 ha (11.9 acres) at MHHW and 1.7 ha (4.2 acres) at MLLW with an average volume of about 2.0×10^{10} l (5.3×10^9 gal). Also, 704 m (2310 ft) of the perimeter is a City of Long Beach recreational area which receives heavy usage during the summer months (about 2,000 people per day).

Sampling was accomplished by use of a 29-m (96-ft) bag beach seine, a 30-m (99-ft) monofilament gill net, hook and line, and shore and diving observations during all 12 months of 1973. Supplementary collections and observations were made earlier in the summer of 1971 while studying the population of northern quahog, *Mercenaria mercenaria*, in the lagoon (Crane et al. 1975). The importance of California's semi-enclosed bays as recreational areas makes it necessary that as much as possible be learned about their biota. Previously, the only published list of fishes from Alamitos Bay was by Reish (1968). This publication focused on invertebrates and was admittedly deficient in the number of fish species he listed (24). Findings in my 1973 study and 1971 observations and collections increased the list to 44 species including 24 families (Table 1). Reish listed 11 species not encountered in the lagoon. However, this study revealed 20 species not mentioned by Reish. The six most abundant species in the 1973 study made up 99.86% of the total catch. Of these, the northern anchovy, *Engraulis mordax*, which alone made up 90% of the year's catch, showed marked seasonality and was captured in the summer months only. The statistical analysis of the data from the 1973 lagoon study is presented in Allen and Horn (1975).

TABLE 1. **Composite Fish Species List for Alamitos Bay, Long Beach, California.**

Family Species—Common name	Colorado Lagoon 1971	Colorado Lagoon 1973	Alamitos Bay Reish (1968)	Relative abun. and status.
Rhinobatidae				
Rhinobatos productus (Ayres) —shovelnose guitarfish			X	
Myliobatidae				
Myliobatis californica Gill —bat ray		X		R*, S†
Dasyatidae				
Urolophus halleri Cooper —round stingray	X	X	X	R, S
Albulidae				
Albula vulpes (Linnaeus) —bonefish	X			R
Clupeidae				
Dorosoma petenense (Gunther) —threadfin shad		X		R, S
Engraulidae				
Engraulis mordax Girard —northern anchovy		X		C, S
Anchoa compressa (Girard) —deepbody anchovy	X	X		UC, S
Anchoa delicatissima (Girard) —slough anchovy	X	X		C, Res
Batrachoididae				
Porichthys myriaster Hubbs & Schultz —specklefin midshipman			X	
Gobiesocidae				
Gobiesox rhessodon Smith —California clingfish			X	
Cyprinodontidae				
Fundulus parvipinnis Girard —California killifish	X	X		C, Res
Atherinidae				
Atherinops affinis (Ayres) —topsmelt	X	X	X	C, Res
Leuresthes tenuis (Ayres) —California grunion		X		C, Res

Family Species—Common name	Colorado Lagoon 1971	Colorado Lagoon 1973	Alamitos Bay Reish (1968)	Relative abun. and status.
Syngnathidae				
Syngnathus leptorhynchus Girard —bay pipefish		X		
Cottidae				
Leptocottus armatus Girard —staghorn sculpin	X	X	X	C, Res
Clinocottus analis (Girard) —wolly sculpin			X	
Scorpaenichthys marmoratus (Ayres) —cabezon			X	
Serranidae				
Paralabrax clathratus (Girard) —kelp bass	X			R
Paralabrax maculatofasciatus (Steindachner) —spotted sand bass	X	X		R
Paralabrax nebulifer (Girard) —barred sand bass	X	X	X	R
Pristopomatidae				
Anisotremus davidsonii (Steindachner) —sargo	X		X	R
Xenistius californiensis (Steindachner) —salema	X			R
Sciaenidae				
Genyonemus lineatus Gibbons —white croaker	X	X	X	R, S
Menticirrhus undulatus (Girard) —California corbina		X		R, S
Roncador stearnsii (Steindachner) —spotfin croaker		X		R, S
Seriphus politus Ayres —queenfish		X		R, S
Girellidae				
Girella nigricans (Ayres) —opaleye		X	X	R
Embiotocidae				
Cymatogaster aggregata Gibbons —shiner surfperch	X	X	X	C, Res
Damalichthys vacca Girard —pile surfperch	X	X	X	UC, Res

Embiotoca jacksoni Agassiz —black surfperch	X	X	X	UC, Res
Hyperprosopon agrenteum Gibbons —walleye surfperch			X	
Micrometrus minimus Gibbons —dwarf surfperch	X			R
Phanerodon furcatus Girard —white surfperch		X	X	R, S
Mugilidae				
Mugil cephalus Linnaeus —striped mullet	X	X		R
Clinidae				
Gibbonsia elegans (Cooper) —spotted kelpfish			X	
Heterostichus rostratus Girard —giant kelpfish			X	
Stichaeidae				
Xiphister mucosus (Girard) —rock prickleback			X	
Gobiidae				
Clevelandia ios (Jordan & Gilbert) —arrow goby	X	X	X	C, Res
Gillichthys mirabilis Cooper —longjaw mudsucker			X	
Ilypnus gilberti (Eigenmann & Eigenmann) —checkspot goby		X		R
Quietula y-cauda (Jenkins & Evermann) —shadow goby		X		C, Res
Scombridae				
Sarda chiliensis (Cuvier) —Pacific bonito		X		R, S
Bothidae				
Paralichthys californicus (Ayres) —California halibut			X	
Pleuronectidae				
Hypsopsetta guttulata (Girard) —diamond turbot	X	X		R, Res
Total 44 species				

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* Relative abundance code: C = common (> 100 collected); UC = uncommon (10–100 collected); R = rare (< 10 collected).

† Occurrence code: S = seasonal; Res = resident.

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I would like to thank the many people who assisted in the field work. Regrettably, they are too numerous to mention by name. I also thank Jules M. Crane, Jr., Camm C. Swift and Michael H. Horn for their encouragement and help and Patricia Allen for her valuable assistance.

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BOOK REVIEWS

The Fly-Tyer's Almanac

by Robert H. Boyle and Dave Whitlock; Crown Publishers, Inc. New York. 1975. xii + 242 p. Profusely illustrated. $12.95.

Crown Publishers, Inc., continues to lead the field in top quality fishing books. *The Fly-Tyer's Almanac* is another fine example. To quote from the blurb on the cover, the *Almanac* is "a practical, fully illustrated guide to the latest advances and developments in fly tying, including more than 20 proven patterns for fresh- and saltwater, described by their creators—new materials, tools, and techniques . . ."

Unless a fly tyer is associated with a really fine fly typing shop or with a truly innovative tyer, his chances of developing the techniques and skills necessary to tie a really first quality fly are really pretty slim. Top quality shops and/or innovative tyers who are willing to share or teach on a one-to-one basis are always few and far between.

The *Almanac* is offered as a forum to present new ideas, techniques, and materials. A second volume designed to update this current volume is already planned. There are new, innovative imitations for taking trout, steelhead, black bass, striped bass, and other saltwater species. Caddis, dragon- and damselflies, midges, leeches, frogs, shrimp, and various fresh- and saltwater minnows are beautifully and artfully imitated. Materials range from the usual fur and feathers to polypropylene, liquid latex, and other synthetics. There are comprehensive chapters on life history aspects of dragonflies and caddis flies. The appendixes include a glossary of entomology, a list of basic scientific books and periodicals, names and addresses of the world's top dealers in fly tying materials, and profiles on this volume's contributors, to hit just the major sections.

The entire book is profusely illustrated with excellent, step-by-step photographs, and several color plates. This is really a top quality book and the first "how to" book that has sent me running to my fly shop to purchase the necessary materials so I could try some of the patterns. The price is a reasonable $12.95.—*K. A. Hashagen, Jr.*

Fisherman's Fall

by Roderick L. Haig-Brown; Crown Publishers, Inc., 1975; viii + 279 p. illustrated. $7.50.

Like the other three books in Haig-Brown's cycle of the seasons, *Fisherman's Fall* is a combination of excellent writing, personal observations, and fishing experiences. It was originally published in 1964 as the last book of the four-book series.

Fall in the northwestern United States and in British Columbia is the time of movement. Haig-Brown talks about the Pacific salmon, their life cycles, and their return to fresh water. His discussions cover all aspects of fishing and fisheries science. He touches on artificial spawning channels and their potential value. There is, as always, a strong plea for habitat protection and warnings of the danger of excessive logging and of dam construction.

One entire section of the book is devoted to estuaries—the description of an estuary, patterns and problems, and solutions and surmises. Steelhead, obviously the author's favorite fall species, are covered comprehensively. Low water, fast water, dry fly, personal observations, and actual experiences, when described by Haig-Brown, make fascinating and informative reading.

The final two sections, "Aquarium Notes" and "Conclusions", contain a comprehensive discussion of the author's observations of young fish and their forage in aquaria and *in situ* during snorkeling drifts down the rivers he fishes. He chronicles the arrival of the salmon and steelhead in the rivers in the fall, and his underwater observations of behavior, interactions, and holding locations of these fish in the rivers provide valuable information for the fisherman. Excellent writing, combined with accurate facts and interesting experiences, make this Haig-Brown book well worth the asking price of $7.50.—*K. A. Hashagen, Jr.*

Fisherman's Winter

by Roderick L. Haig-Brown. Crown Publishers, Inc., New York. 1975. 288 p. illustrated. $7.50.

Originally published in 1954, *Fisherman's Winter* is once again available, and like all other Haig-Brown books, this one is well worth the time it takes to read it. Unlike the other three books in the series (*Fisherman's Spring, Summer,* and *Fall*), this book is not about the Pacific Northwest and salmon and steelhead. *Fisherman's Winter* is about salmonid fishing in South America—Chile and Argentina—and is not about winter fishing but about a "second summer". Today most of the fishing magazines carry ads for fishing tours to South America, but Haig-Brown was there before this type of trip became relatively commonplace. The Tolten, Liucura, and Trancura rivers, Lago Maihue and the Calcurrupe, big water and big fish; the armchair fisherman can really sit back and enjoy this one.—*K. A. Hashagen, Jr.*

Fly Fishing Strategy

by Doug Swisher and Carl Richards; Crown Publishers, Inc., N. Y. 1975; 184 p., illustrated. $10.00.

The fly leaf of *Fly Fishing Strategy* indicates the book "presents a new system of practical fly fishing techniques—casts, approaches, patterns, and equipment—that every fly fishing enthusiast can use". After reading the book, I found I was having a little bit of trouble with that introductory sentence, particularly the words "new" and "every". The casts they attempt to teach are not new—the roll, the reach, and the curve casts—and the analogies they use to teach their system aren't new. Using the text and its accompanying illustrations, I was unable to "teach" myself how to cast, although I spent several hours casting with various rods out on the lawn. If you know enough about casting to understand the book's explanations, you probably don't need the book!

The chapters on hatches and fly tying are good, thought provoking, and clearly are what the authors should be writing about. The concepts of the stillborn dun and the no-wing spinner are interesting; but, with our unsophisticated California fish, I'm not sure how necessary. The chapters on the midwest salmon and steelhead fisheries, lake fishing, and saltwater fly fishing are weak, based on relatively few trips and a lot of talk and theory. The section on new tying materials and techniques has one major shortcoming in that it fails to tell the reader where the new products can be obtained.

The book is very handsomely illustrated, with line drawings in the margins by Dave Whitlock, and the few color photographs are superb. All-in-all, it is a fine book, well worth the price; it just doesn't have the "meat" that *Selective Trout* did.—*K. A. Hashagen, Jr.*

Fly Fishing for Trout

By Richard W. Talleur; Winchester Press, N.Y., 1974; 260 p., illustrated with both black and white and color photos. $10.00.

The complete title of this book is *Fly-Fishing for Trout—A Guide for Adult Beginners.* The book is complete. I really think someone who had never fly fished and knew no one who did, could pick up the book and quickly learn to go out and catch trout. The book begins very basically, describing how to put a rod together and string a line on it. Equipment is discussed thoroughly, including construction, care, cost, and quality. Casting—both basic and slightly more advanced—is covered. Leaders, fly tying, stream entomology, how to read water, and conservation are all covered thoroughly and completely. The photos, by Matt Vinciguerra, and the drawings, by Roberta Sullivan, are clear and detailed. If the book has any drawbacks at all, it would be that the author often gets a little too chatty and flowery for my taste. By reading Mr. Talleur's book and talking with competent fly fishermen, any adult can quickly master the delightful hobby of fly fishing.—*K. A. Hashagen, Jr.*

Fisherman's Summer

By Roderick L. Haig-Brown; Crown Publishers, Inc., New York, 1975; 253 p., illustrated. $7.50.

A Haig-Brown book doesn't need a long, detailed review to convince potential buyers that *this* is the book they should buy. Any fisherman who has read one Haig-Brown fishing book will quickly buy any new offering by the author.

Fisherman's Summer is another Crown Publishers, Inc. reprint. It is another of the four book series on the fishing seasons. It was first published in 1959 and quickly became a collector's item (as are original editions of the other three seasons). *Fisherman's Summer* talks about grayling, early British Columbia explorers, the Campbell River on Vancouver Island, summer steelhead, and salt water fishing. It is another delightful book by an excellent author and fisherman.—*K. A. Hashagen, Jr.*

Culture of Bivalve Molluscs

By P. R. Walne: Fishing News (Books Ltd.) 23 Rosemount Avenue, West Byfleet, Surrey, England. 172 p., illustrated. 1975 £5.85

This book evolved from a series of lectures given by the author in 1968 under the auspices of the Buckland Foundation. It is largely a review of the investigations made at the Fisheries Experiment Station, Conway, on the culture of oysters and other bivalve molluscs.

The opening chapter describes the structure, physiology and reproduction of bivalves which are particularly relevant to hatchery culture. Other topics in succeeding chapters deal with methods and conditions of rearing larvae of the European flat oyster in outdoor tanks during the summer months and the hatchery rearing of oyster larvae including the handling of the larvae, a description of the seawater supply, provision of adequate amounts of algae for food, and care of the breeding stock. The effect of various factors on growth and survival of oyster spat is discussed and also methods which have been found satisfactory for spat culture at Conway are described.

Although the principal work at Conway has been concentrated in the European flat oyster, experience of rearing six other species, five of which are not native to the British isles, are detailed. These species include the Chilean oyster, *Ostrea chilenses;* the New Zealand oyster, *Ostrea lutaria;*

the Pacific oyster, *Crassostrea gigas;* the Palourde or butterfish, *Venerupis decussata;* the Chilean mussel, *Chromytilies choros;* and Quahay, *Mercenaire Venus mercenaria.*

A total of 38 figures and 24 plates well illustrate the experiments and activities carried on at Conway.

This book, based on Dr Walne's outstanding success in his work at Conway for almost 25 years, should be of great benefit to aquaculturists who are engaged in or are contemplating entering the new and promising industry of shellfish cultivation.—*Walter A. Dahlstrom*

Northern Fishes

By Samuel Eddy and James C. Underhill; Univ. of Minn. Press, Minneapolis, 1974. 414 p. $17.50

This is the third edition of *Northern Fishes* (Fishes of Minnesota would be a more appropriate title). This edition was written to reflect significant changes in the distribution of Minnesota fishes, to add to the list of species, and to add up-to-date information on current knowledge of fishes and their environment. The last edition was published in 1947. The authors updated and improved chapters on fishing techniques, lake dynamics, population dynamics, and classification and origin of fishes. The chapter on management of waters was changed slightly from the second edition by adding a paragraph on pollution, and the chapter on improvement of lakes and streams was changed slightly by adding a discussion of two-storied lakes and improving lakes by introducing new species. The second edtion chapter on structure of fishes was improved considerably and it is now titled "Anatomy and Physiology of Fish". A new chapter on the diet of fish was added, and a chapter on fish parasites was expanded to include infections of fish. A new chapter was added which describes how the aquatic environment contrasts from the terrestrial environment. The remainder of the book is devoted to descriptions of families and species of fish. Species accounts include current information on characteristics, range, habits, spawning, value, and status. Although most of the information pertains to Minnesota, much of it has broader application. Descriptions of ranges, for example, embrace other areas of the continental United States.

The first and second editions had several photos of fishes, a few in color; this edition has good line drawings of almost all species.

Initially, *Northern Fishes* was published as a source of basic information for sportsmen and others who were concerned with the welfare of fish. The latest edition would be a worthwhile possession for any angler; it would be quite useful to students, and I believe it is a must for professional biologists and teachers.—*Larry K. Puckett*

Pollution Ecology of Freshwater Invertebrates

C. W. Hart, Jr. and Samuel L. H. Fuller, eds.; Academic Press, Inc., N.Y., 1974; 389 p., $24.50.

Any student of biology knows how tedious a literature search for information can be. Add to that a gross lack of data and a successful search becomes near impossible. Such is the case in the study of pollution and its effects on freshwater invertebrates. With the amount of interest focused today by government and private business on pollution and ecology, this scarcity of knowledge is incredible but sadly true.

Pollution Ecology of Freshwater Invertebrates was written with this problem in mind. It is multi-purpose in design: it presents discussions on both the normal and pollution ecology of freshwater invertebrates, gives the latest systematic interpretations, and compiles extensive reference lists as starting points for data searches. Each chapter covers a major taxonomic group and is written by an accepted authority in that field. Much of the text is tables and graphs.

There is much to recommend the book. Each of the authors has written a concise yet clear synopsis of the current knowledge of ecology in his field of interest. A semi-outline organization and a table of contents in each chapter make relocating any specific topic easy. The reference lists alone could save hours of individual labor and are, for that very reason, invaluable.

Some items deserve special mention. I greatly appreciated John Cairn, Jr.'s tips on how to collect and preserve protozoans during field studies. Also, Samuel Fuller's tables citing references for some freshwater mussels and their glochidial host fish could save a novice researcher much time and energy.

After reading this book, I think it would be a valuable addition to any reference library, whether public or private.—*E. V. Gleason*

Best Ways to Catch More Fish (in fresh and salt water)

By Vlad Evanoff; Doubleday and Co., Inc., Garden City, N.Y., 1975; 228 p., illustrated. $7.95

This is another in a series of "how to" by this author. At this stage of the game it seems a little superfluous that another general interest fishing book should be published. Indeed, even the author points out this shortcoming in his foreword. Recognizing this, the author has tried to ". . . impart to anglers some new and helpful information they can't find in other fishing books." In spite of this, the book *is* another general book; one of a genre that exists in sufficient numbers.

The material itself is mostly accurate. Reproduction of photographs is excellent. The format and text is easy to follow and a detailed index is included.

For a beginning fisherman, perhaps, this would be a beneficial book. It would be useful as a gift for a young fisherperson just starting out.—*Ed Littrell*

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