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THE ANCHOVY RESOURCES OF THE CALIFORNIA CURRENT REGION OFF CALIFORNIA AND BAJA CALIFORNIA

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INTRODUCTION

The northern anchovy (*Engraulis mordax*) is probably the most abundant species in the California Current System and has exhibited a dramatic increase during the past 15 years. Because of its great abundance and the small amount harvested it is a relatively unexploited resource.

Our purpose is to review the data relating to anchovy biology and to the growth in magnitude of the population during recent years.

The basic evidence demonstrating the tremendous population increase is derived largely from egg and larva survey data obtained by the U.S. Bureau of Commercial Fisheries from 1951 through 1966 (Ahlstrom, 1966a, and pers. commun.). These data show that the spawning population grew rapidly from 1951 through 1954, remained relatively stable through 1957, increased gradually through 1961 and then exploded to its present high plateau (4–5 million short tons) in 1962. Based on relative numbers of larvae, the spawning population is now about 21 times as large as it was in 1951 and about 2½ times as large as it was in 1958.

BIOLOGY

General

Anchovies are pelagic schooling fishes generally found in coastal waters with surface temperatures between 14.5° and 20.0° C (58.1° and 68.0°F). They are short-lived, rarely exceeding 4 years of age and 7 inches (17.78 cm) in length, although individuals 7 years old and 9 inches (22.86 cm) long have been recorded. Anchovies are apparently indiscriminate filter feeders, accepting zooplankton or phytoplankton. They also have been observed preying on small fish. The species of fish, birds and mammals which prey upon anchovies probably include most of the predatory species in our waters (Baxter, 1967).

Distribution

Anchovies occur from the Queen Charlotte Islands, British Columbia to Cape San Lucas, Baja California. California Cooperative Oceanic Fisheries Investigations (CalCOFI) surveys show they are most abundant from San Francisco to Magdalena Bay. North of San Francisco, occasional surveys by the Department of Fish and Game have not found anchovies in abundance. Pruter (1966) reported that anchovies occur in dense schools along the Oregon and Washington coasts. Eggs and larvae have been found from Cape Mendocino, California to Cap San Lucas and as far as 300 miles offshore; however, most occur within 100 miles of shore. Egg and larva surveys have not been conducted with any regularity north of San Francisco and the distribution off Oregon and Washington is not known.

Movements

During March 1966, the Department began a tag and recapture study on the anchovy to determine migratory habits, mortality rates, and population estimates. The study has progressed only far enough to comment on large-scale movements.

Anchovies are tagged with a type 430 stainless steel alloy internal tag (Vrooman et al., 1966; Wood and Collins, ms). The tags are recovered by permanet magnets placed in the final stages of the reduction process. This method of recovery precludes assigning tags to individual vessels and specific recapture localities. Consequently recoveries can be assigned only to major fishing areas such as Monterey Bay, southern California, and northern Baja California. This method is excellent for determining movements between major fishing areas, but is of little value for determining local movements. An additional system of magnets, which should allow study of local movements off southern California, has been installed but as yet has not been tested under production conditions.

During the period March 14, 1966–January 31, 1968, 224,168 anchovies were tagged and 531 recovered. Recoveries demonstrate that anchovies move from San Francisco Bay (Sausalito) to Monterey Bay, from Monterey Bay to southern California (south of Pt. Conception), from southern California to northern Baja California (Ensenada), and from southern California to Monterey Bay (Figure 1). Fish also moved between southern California offshore areas and Los Angeles Harbor.

Fishing effort and consequently tag recoveries have been sporadic and therefore conclusions concerning migratory patterns are preliminary at best. It is obvious that fish from as far away as San Diego and San Francisco contribute to the Monterey Bay fishery and that fish from Monterey Bay reach southern California. Some exchange of anchovies between major fishing areas occurs; however, the extent of the exchange cannot be determined as yet. There has not been enough tagging in Monterey Bay where fishing has been most consistent, or sustained fishing

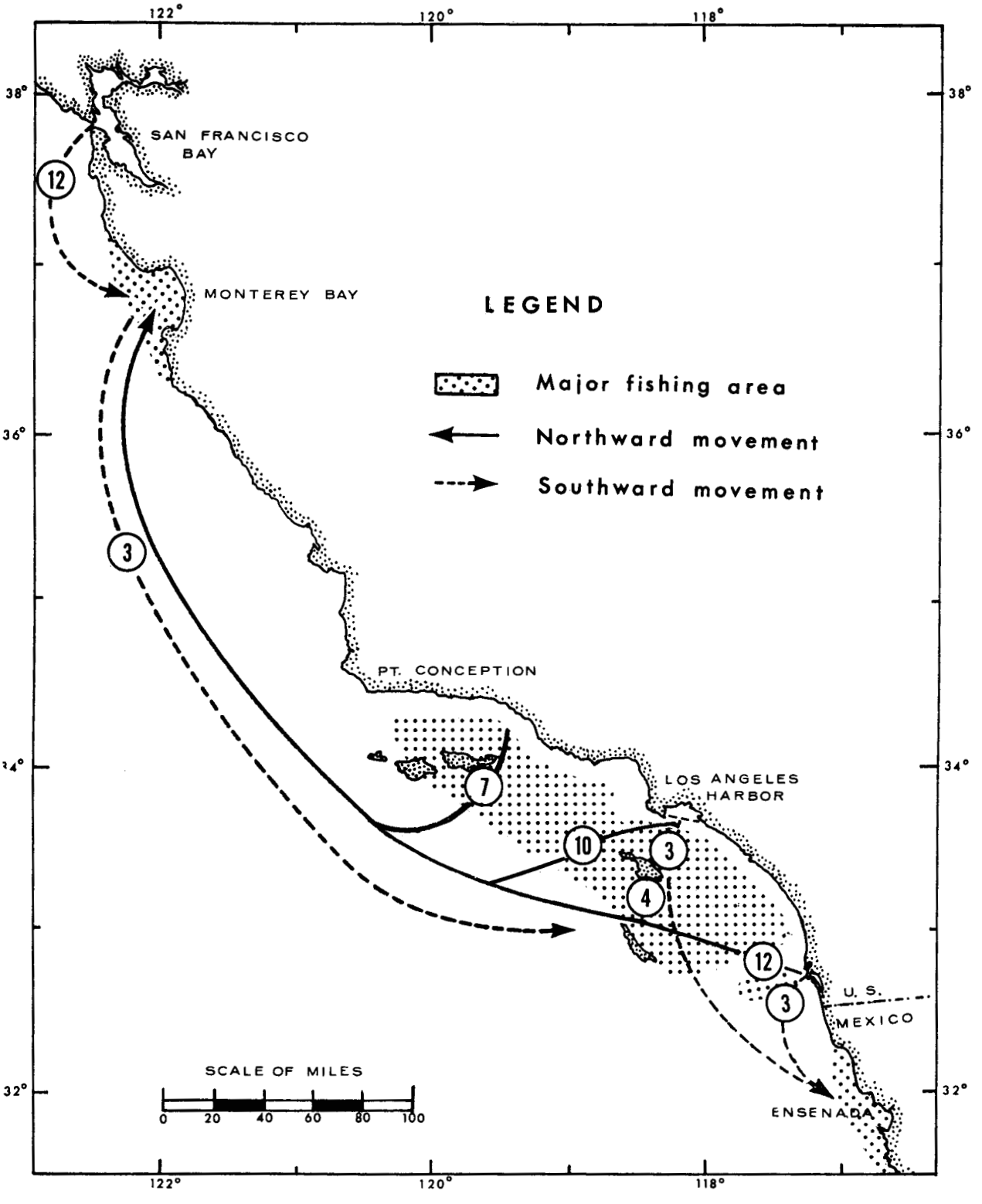

FIGURE 1. Gross movements of anchovies tagged and recaptured March 14, 1966–January 31, 1968. Tags are recovered from magnets in reduction plants and therefore can only be assigned to major fishing areas.

in southern California where most of the tagging has occurred.

Subpopulations

McHugh (1951) concluded that the anchovy population is divided into three subpopulations which do not intermingle completely: (i) British Columbia to northern California (Monterey Bay), (ii) off southern California and northern Baja California, and (iii) off central and southern Baja California. His conclusions were based on an analysis of meristic data (dorsal, anal, and pectoral fin rays, vertebrae and gill rakers).

Miller (1956), working with age and size compositions of commercial and live-bait catches from central and southern California, aerial surveys, and sea surveys, suggested the possible exitence of "local" stocks and the complete separation of central and southern California populations.

The tagging studies have shown considerable movement between southern and central California as well as some movement from southern California to northern Baja California. However, returns to date are too fragmentary either to refute or substantiate the findings of McHugh. To obtain sufficient tag returns to do so will require a sustained fishery and one much larger than now exists.

Reproduction

Some anchovies reach sexual maturity at the end of their first year of life when 3.5 to 3.9 inches (90 to 100 mm) SL; about 50 percent are mature at 5.1 inches (130 mm) SL when between 2 and 3 years old; all are mature when 5.9 inches (150 mm) SL or 4 years old (Clark and Phillips, 1952). MacGregor (1968) reports that female anchovies, 3.8 to 5.4 inches (97-138 mm) SL, contained 4,025 to 21,297 eggs in an advanced stage of development. This equals 574 per gram of fish or 520 million eggs per short ton of female biomass. He was unable to determine the number of times a female spawns in a season.

Although spawning has been noted in every month of the year it usually peaks during late winter and spring. The eggs are pelagic, typically ovoid, clear and translucent and require 2 to 4 days to hatch depending on the temperature of the water (Bolin, 1936).

Ahlstrom (1959) reports that approximately 95 percent of the larvae are taken in water between 14.0° and 17.4° C (57.2° and 67.3° F) while most eggs are taken between 13.0° and 17.5° C (55.4° and 63.5° F). Fish-of-the-year apparently tolerate somewhat higher water temperatures than do adults.

MAGNITUDE OF THE RESOURCE

Because of the lack of fishery data, population estimates are based on egg and larva surveys conducted by the U.S. Bureau of Commercial Fisheries with some independent confirmation by the California Department of Fish and Game which is conducting echo-sounder surveys of adult populations.

Egg and Larva Survey

The egg and larva survey consists of sampling a systematic pattern of stations designed initially to cover the entire spawning range of the Pacific sardine (*Sardinops caeruleus*). The pattern extends from the Oregon-California border to Cape San Lucas, Baja California, but coverage has been most intensive between San Francisco and Magdalena Bay. The stations run from about 2 miles (3.2 km) to as much as 300 miles (482.7 km) offshore. These surveys were conducted at monthly intervals from 1951 to 1960 and at quarterly intervals from 1961 through 1965. Monthly surveys were resumed for calendar 1966.

Estimates of the size of the anchovy spawning population are based on these egg and larva surveys following the method developed by Ahlstrom (1966b). He tied the measure of anchovy abundance to that of sardine for which good estimates of population size were available. Ahlstrom used 1958 as a reference year because that was the last year of a substantial enough sardine fishery to provide a good population estimate. Sardines were highly available that year and the California-Baja California catch reached 126,000 short tons. This represented a fishing mortality of about 50 percent so the adult sardine population would have been on the order of 250,000 tons. These estimates agree well with those of Murph (1966). To be ultra-conservative, Ahlstrom placed the figure at 200 to 250,000 tons. During 1958 the ratio of sardine to anchovy larvae in the egg and larva surveys was 1 to 18 (11,000 vs. 206,000 larvae).

Ahlstrom equates one sardine larva to two anchovy larvae, on the basis of studies by John S. MacGregor that showed that adult anchovies spawn two times as many eggs per unit of weight as sardines. He assumed that the mortality rates of the two species between their egg and larval stages were the same, therefore the adult anchovy population was 9 times, not 18 times, as large as the sardine population. On this basis the estimated weight of the 1958 anchovy population off California and Baja California was 1.8 to 2.25 million tons.

Based on published data through 1964 and unpublished data for 1965 and 1966 (Ahlstrom, 1966a and pers. commun.), the anchovy population continued to increase in abundance and in 1962 reached a plateau roughly 2½ to 4 times greater than it was in 1958 where it remains (Figure 2). Ahlstom's (1966b) estimate of the present population size, 4.5 to 5.625 million tons for California and Baja California, was based on the minimal observed increase of 2½X. Although the portion of the anchovy population occurring off California during spawning is somewhat variable from year to year, it exceeded 50 percent in 1964, was close to 50 percent in 1965, and was again over 50 percent during 1966. Therefore, based on a 50-50 split the adult population now available off California is 2.25 to 2.81 million tons. During the period 1951–59 about one-third of the larvae were taken in the California area.

Radovich (1965) postulated that Ahlstrom's estimates should be reduced somewhat to take into ac-

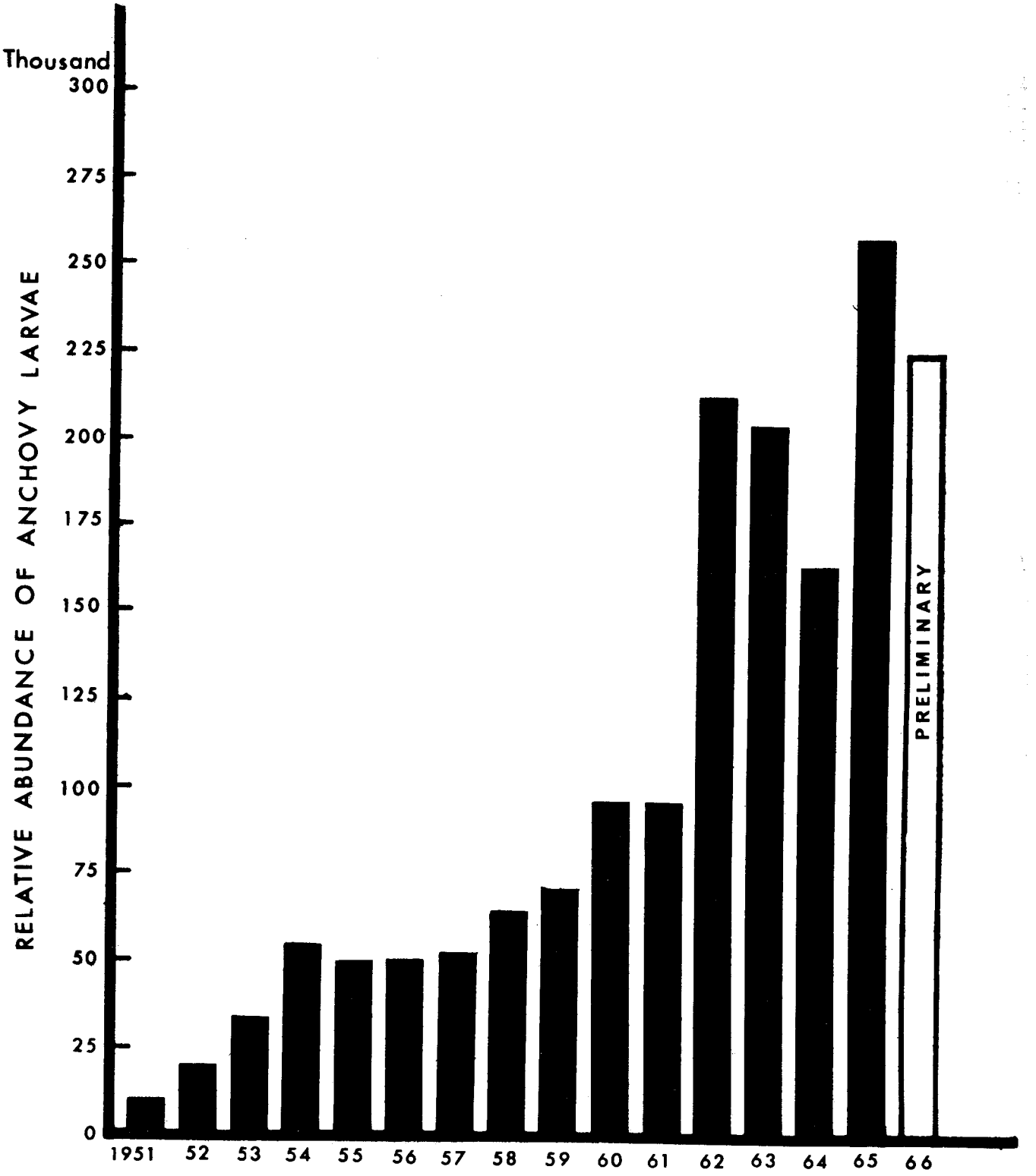

FIGURE 2. Relative abundance of anchovy larvae in the CalCOFI survey area during 1951–1966 (Data from Ahlstrom 1966a).

count different mortality rates for sardines and anchovies. He calculated that the annual survival rate for anchovies from 1951 through 1959 was 1.4 times that of sardines and divided Ahlstrom's population estimates by that factor. He deliberately attributed the entire differential to deaths between the egg stage and the larva stage to obtain the most conservative position possible. This gives a total population estimate of 3.2 to 4.0 million tons. However, since fishing pressure was heavier on sardines than anchovies during the 1950's, the entire difference cannot be attributed to differential mortality between egg and larva. Therefore Baxter (1966), Roedel (1967), and Ahlstrom et al. (1967) placed the total population size between the two estimates, or 4 to 5 million tons. This means there were between 2 and $2\frac{1}{2}$ million tons of anchovies off California during the period 1962–1966.

Sea Survey

With funds obtained through the Federal Aid for Commercial Fisheries Research and Development Act, the Department has greatly expanded its oceanic surveys of adult and juvenile fishery resources. The scope of the cruises was changed in June, 1966 from a survey of the inshore area during the fall months to a year-around survey of all pelagic and bathypelagic fishery resources. The survey covers the area from Oregon to Magdalena Bay, Baja California.

An echo sounder is operated continuously during the day over predetermined transect lines that extend perpendicularly from shore for at least 35 miles (56.3 km) or until the 1,000-fathom (1.829 m) depth contour is reached. These lines are spaced 15 to 30 miles (24.1 to 48.3 km) apart and average about 50 miles (80.5 km) in length. Hourly fixes are obtained and the number of schools appearing on the echo sounder are recorded for each hour of running time. Identification of species is accomplished visually, by echo trace characteristics and by midwater trawl. The trawl is also fished at regular 10-mile (16.1 km) intervals during the night as the vessel returns inshore over the outbound transect lines. A record is kept of all surface school sightings and other indications of fish during both day and night.

These surveys indicate that, in general, the fish spread over a large area in spring to spawn and concentrate in coastal areas during summer and fall. The most opportune time to estimate population size appears to be spring. With the large number of schools and extensive distribution, echo-sounder surveys are much more effective. School size and species identification are also more easily determined. Fall and summer distributions, with fewer and large schools, decrease the probability of detection by echo sounder and make species identification and school size determination more difficult.

A rough estimate of the schools present in southern California in June 1967 was based on a survey of this area. A school density factor per square mile searched (164.77) was applied to the total area (11,500 square miles) encompassed by the survey, producing an estimate of 1,895,000 schools. Although we do not have accurate means of determining school size, scientists and experienced fishermen on the survey judged that the schools were approximately one ton each (Kenneth F. Mais, pers. commun.). This preliminary study thus bears out the estimates based on egg and larva surveys.

AVAILABILITY

Anchovies have been the dominant species in all areas covered by echo-sounder cruises. These surveys have revealed important aspects of seasonal distribution and behavior. During spring the anchovy population was composed of thousands of very small schools distributed over large areas extending at least 50 to 80 miles offshore. These schools were located near the surface in clear, deep water and normally contained less than 2 tons of fish. All were adults in advanced spawning stages. Large compact schools, suitable for purse-seine fishing, were scarce and found only in a few localized areas. Juvenile fish were generally found close to shore in water shallower than 50 fathoms (91.5 m). During summer and fall all sizes of anchovies were found much closer to shore, at greater depths, and in larger but fewer schools. Decreases in school numbers from spring to fall in the southern California area exceeded 800 percent.

The sea surveys have also revealed school types and behavior patterns. During the day small numbers of horizontal-layer school types, 80 to 100 fathoms (146 to 183 m) below the surface, and more numerous "plumes", located 20 to 50 fathoms (36.6 to 91.5 m) deep, were the predominant schools in northern Baja California and central California (Figure 3). Plumes at shallower depths as well as the other types were observed off southern California. At nightfall all types came to the surface where almost all dispersed into surface scatter or loose detached school segments. Only a very few remained compact enough to be visible as a bioluminescent spot or register as an echo trace. As dawn approaches the fish aggregate into schools and go down.

The night behavior of anchovies appears closely associated with the upper extremity of the scattering layer that approaches the surface after dark. The after-dark rise and surface disperal suggests a feeding behavior as evidenced by the large numbers of recently ingested food organisms observed in stomachs of night-caught fish. A very high percentage of these food organisms were euphausiids, an important constituent of the upper scattering layer.

PROPOSAL FOR STOCK UTILIZATION

The role of the CalCOFI Committee has, since its organization in 1957, been one of acting as a scientific coordinating body, overseeing the cooperative research programs under the aegis of the Marine Research Committee, and reporting on its findings of interest.

It was in the latter context that CalCOFI, on 6 March 1964, submitted a paper entitled "Requirements for Understanding the Impact of a New Fish-

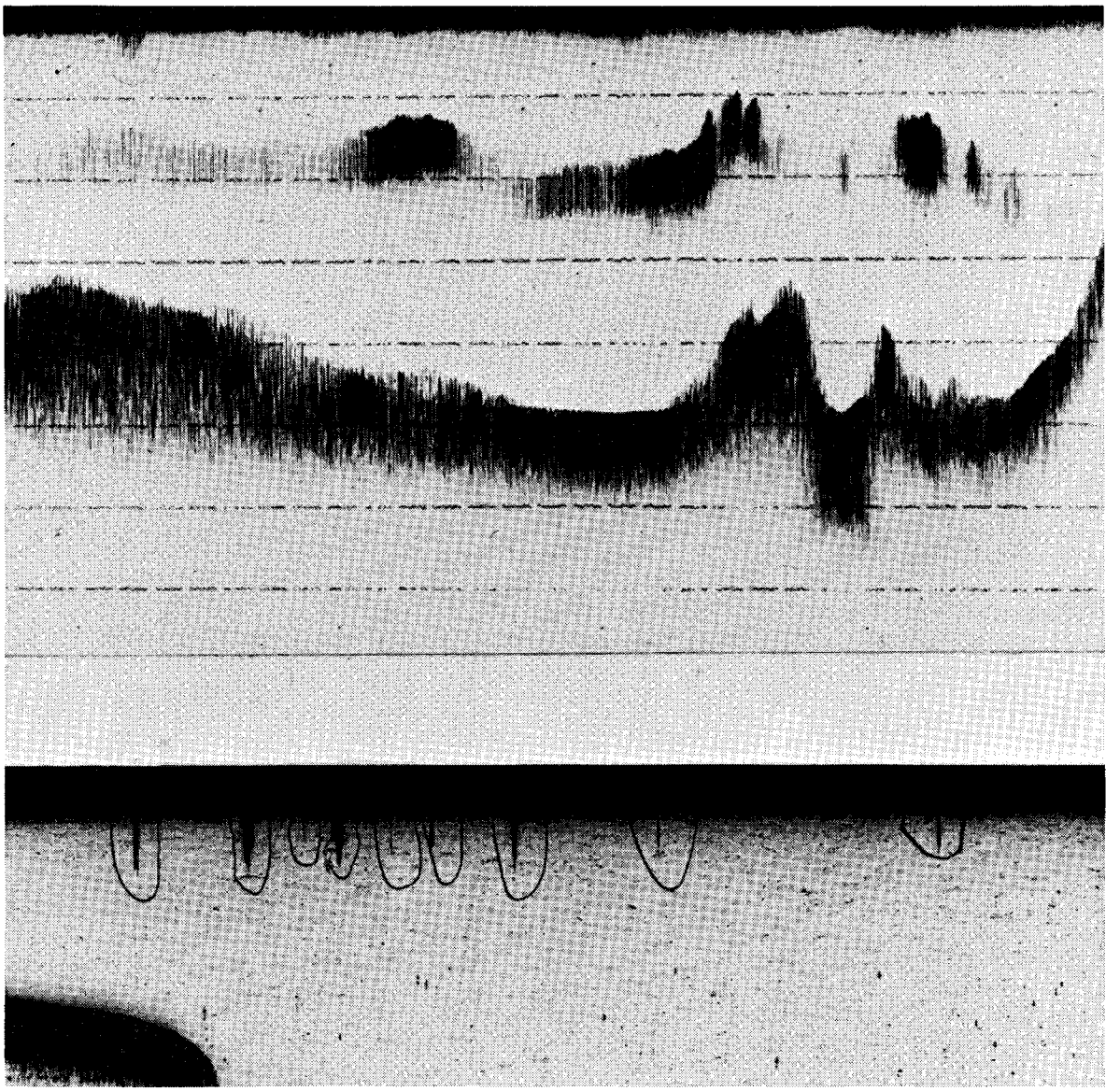

FIGURE 3. Echograms showing horizontal layer (upper photo) and plume type (lower photo) anchovy schools. The dark margin at the top of each echogram represents the surface. The circular marks around each plume in the lower photo are pencil marks made by cruise biologists when enumerating anchovy schools. The horizontal layer is located 20–40 fathoms (36.6–73.2m) below the surface. Plume type schools represent about 98% of the schools recorded and on this echogram are about 10 fathoms (18.3m) below the surface. *Photographs by Jack W. Schott.*

ery in the California Current System" (Murphy et al., 1964). In this paper, based on 1951–1959 data, the authors called attention to the rise of the anchovy population which closely followed the fall of the sardine. They suggested that "there is a real chance that simultaneously reducing the pressure on sardines and imposing pressure on anchovies will reverse the present equilibrium and assist in bringing back the more valuable sardine. This constitutes an exciting opportunity for marine science to assist society in meeting its complex needs" and proposed establishing a new fishery on the sardine-anchovy system devised as a careful scientific experiment.

This long-range CalCOFI proposal consisted of three phases, each lasting a minimum of 3 years. Phase 1 called for a harvest of 200,000 short tons of anchovies and 10,000 tons of sardines, 35 percent of both of these limits to be taken north of lat. 31° N. This line, near Cape Colnett, Baja California, was chosen because it is a natural oceanographic and faunal boundary. The 200,000 ton limit represented 10 percent of the minimum estimate of the total anchovy population. This is a conservative value as harvest rates of $\frac{1}{4}$ to $\frac{1}{3}$ are thought quite reasonable for fish of this sort. The annual harvest rate of the Peruvian anchovy (*E. ringens*) is about 43 percent (derived from data in Schaefer, 1967). However, CalCOFI felt that a 10 percent harvest would be sufficient to produce a measurable perturbation in the anchovy-sardine system. The amounts of anchovies

and sardines to be taken during Phase 2 were to be based on the results of studies of the fishery and fish populations conducted during Phase 1. Phase 3 had the ultimate objective of restoring the pre-decline balance between sardines and anchovies and maximizing the harvests consistent with all uses, i.e., food, recreation, etc.

This proposal was updated in February 1967 on the basis of additional data for eggs and larvae and called for raising the anchovy quota to 400,000 tons, 200,000 tons to be taken north of lat. 31° N., or 10 percent of the minimum standing crop during 1962–1966 (Ahlstrom et al. 1967). It also called for a moratorium on the sardine fishery. A law placing a moratorium on the take of sardines for 2 years became effective June 7, 1967.

The anchovy fishery remains very small for a variety of reasons, including those of a political, economic and sociological nature. Until these are resolved to the extent that a substantial fishery can exist, the CalCOFI proposal remains only that while its hypothesis gathers dust, untested.

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