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Author:
Mais, Kenneth F

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The California Department of Fish and Game started routinely acoustically surveying the smaller schooling pelagic fish resources in the California Current System in 1966. This report covers the first 6.5 years of these surveys (1966–1973).

The purpose of these surveys was to determine the abundance, distribution, availability, and other pertinent biological information of the commercially important northern anchovy, jack mackerel, Pacific sardine, and Pacific mackerel. Latent resource species including Pacific saury, Pacific hake, squid, and pelagic red crab also were surveyed. The principal technique consisted of running acoustic transects with a horizontal ranging sonar and vertical echo sounder during daylight hours and fishing a midwater trawl at night.

Results show the northern anchovy grossly dominates all other species in terms of biomass and abundance with the southern California-northern Baja California region containing most of the total population. Although it was not possible to determine absolute population size, results indicate the estimates of 2 to 6 million tons made from egg and larvae surveys are reasonable. Behavior and availability studies indicate that although the anchovy population is large, its vulnerability to harvest by the present commercial fishery varies considerably from year to year as well as seasonally. Most of the common schooling behaviors are unfavorable for effective harvest by roundhaul net. Only a small portion of the population is harvestable during any particular time period.

Acoustic surveys were much less effective for estimating abundance of Pacific sardines, Pacific mackerel, and jack mackerel. The distribution of jack mackerel was patchy with nearly all significant concentrations located at a limited number of rocky banks and island coasts. Pacific sardine and Pacific mackerel population levels in California were apparently too low to assess. There were indications of larger populations of both species in Baja California.

of the latent resource species under survey, pelagic red crabs and market squid appear to be the most favorable for future exploitation. However, the crabs are located almost entirely within Mexican territorial waters and the vulnerability of squid for large scale harvest is uncertain.

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Pelagic Fish Surveys In The California Current

by
Kenneth F. Mais

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Frontispiece. California Department of Fish and Game Research Vessel ALASKA aboard which all pelagic fish survey field work was conducted. Photo by Jerry Spratt.

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ABSTRACT

The California Department of Fish and Game started routinely acoustically surveying the smaller schooling pelagic fish resources in the California Current System in 1966. This report covers the first 6.5 years of these surveys (1966–1973).

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Of the latent resource species under survey, pelagic red crabs and market squid appear to be the most favorable for future exploitation. However, the crabs are located almost entirely within Mexican territorial waters and the vulnerability of squid for large scale harvest is uncertain.

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KENNETH F. MAIS

1. INTRODUCTION

Over the years commercial fishery production from waters off California has decreased while demand has increased. This decrease is primarily due to declining populations of the mainstay species of the wetfish fishery, the Pacific sardine, Sardinops sagax caeruleus, and the Pacific mackerel, Scomber japonicus.

Some American fisheries have not been able to compete successfully with foreign competitiors. In recent years Russian and Japanese fishing fleets operating off our coast have been catching fish which could have been taken by our fishermen; however, most of these fish occur outside the traditional operational range of our coastal based fleet and were not being harvested by California fishermen. Quite a few living marine resources off the California coast are relatively underutilized or as yet unexploited. These include but are not to limited to the northern anchovy, Engraulis mordax; market squid, Loligo opalescens; Pacific hake, Merluccius productus; and Pacific saury Cololabis saira.

There has been a movement in the United States, especially in California, within the last 10 years to assist the commercial fishing industry in more fully utilizing our marine resources. As an initial step toward this end, an assessment was necessary of both currently exploited and latent resources. Sea surveys designed to assess the distribution, abundance, availability, and other vital parameters of fish populations of the California Current System were initiated to meet this objective.

The California Department of Fish and Game has routinely conducted sea surveys in the California Current System since 1949. From 1949 to 1965 these surveys were designed primarily to assess the annual recruitment of young sardines and Pacific mackerel. Survey coverage was normally limited to within 37 km (20 miles) of the coast where the young of these species normally occur. A night-light and blanket net were utilized to attract and capture fish. Although this type of survey was moderately effective on sardines and produced useful information on several other species, it was totally ineffective on others and surveyed only a small portion of the California Current System.

In the latter half of 1966 a new type survey was initiated that employed acoustic fish locating equipment and a large midwater trawl. This survey was expanded to include smaller fishes in the upper layers of the California Current System. All species vulnerable to survey methods were included although emphasis was placed on species of present or potential fishery value. The principal fish species studied were; northern anchovies; jack mackerel, Trachurus symmetricus; rockfishes, Sebastes spp.; Pacific hake; Pacific mackerel; Pacific sardine; and Pacific saury. Noncommercial species included lanternfishes, family Myctophidae, and deep sea smelts, family Bathylagidae. Important invertebrates were market squid, Loligo opalescens, and pelagic red crab, Pleuroncodes planipes.

This new expanded survey was created under a federal aid program (Commercial Fisheries Research and Development Act of 1964, Public Law No. 88-309). Techniques and results of the first 6.5 years (1966–1973) of work are described herein.

2. METHODS

The sea surveys initiated in 1966 primarily made use of an acoustic transect method supplemented by midwater trawling. Other methods occasionally utilized were night-light/blanket net surveys and night scouting with a searchlight and night-light. Fish behavior and school size assessment were studied using acoustic equipment, diver observations, commercial purse seiner charters, field trips on commercial fishing vessels, and fishermen interviews. Special experimental cruises were conducted to improve or develop gear and acoustic survey techniques. Several cruises were devoted to evaluation of different midwater trawl systems to improve trawl effectiveness. All field work, except the purse seiner charter and trips on commercial fishing vessels, was conducted on the California Department of Fish and Game research vessel ALASKA.

2.1. Acoustic-Midwater Trawl Surveys

2.1.1. Acoustic Phase

The California Current System was divided coastwise into four major survey regions based on natural boundaries of fauna and oceanographic features. These regions were designated northern California, central California, southern California - northern Baja California, and Baja California which included central and southern Baja California (Figure 1).

Cruises of 15 to 30 days duration were scheduled to cover each region, except northern California, during each season of the year. Because of time limitations seasonal coverage was accomplished over a period of years rather than the same year.

The central California and southern California - northern Baja California regions received intensive effort due to their relatively larger pelagic fish populations and importance to California commercial fisheries. Extreme weather conditions in northern California limited surveys to the summer season. Most effort was concentrated on northern anchovies because of their importance in the California Current ecosystem, the socioeconomic controversy concerning their utilization, and a paucity of biological information.

Surveys were accomplished by operating an echo sounder and sonar along transect lines spaced 18.5 to 55.6 km (10 to 30 miles) apart. No consistent pattern of transects was established due to operating restrictions. Fish school echograms were enumerated hourly between vessel position fixes or every 20 minutes of longitude. Species identification, school depths below the surface, and echogram sizes were recorded. Transects usually extended from near shore to the 1,829 m (1,000 fathom) depth contour or a minimum distance of 64.8 km (35 miles) seaward. Survey offshore limits ranged from 64.8 to 305.6 km (35 to 165 miles) with the southern California region receiving the greatest seaward coverage. All regular acoustic work was conducted during daylight hours. Vessel sounding speed was normally 9 knots but was reduced to 7 knots or slower during bad weather.

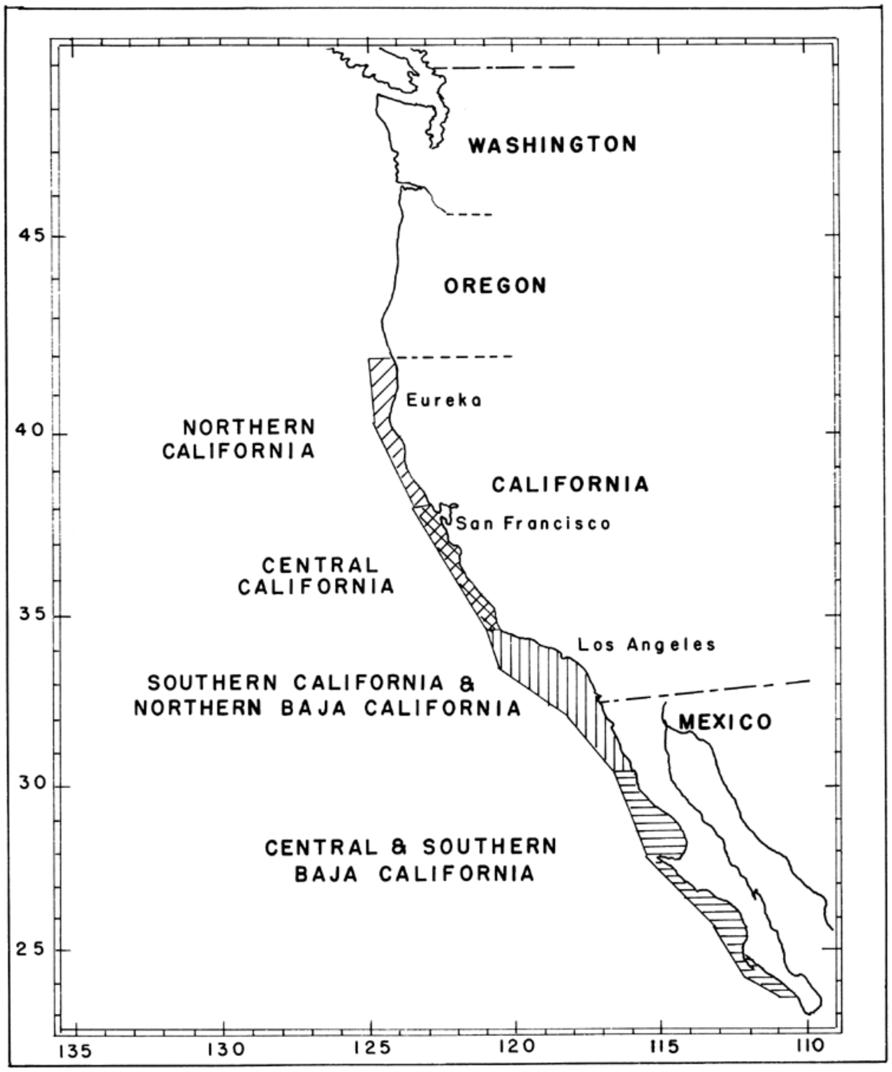

FIGURE 1. Major survey regions.

FIGURE 1. ***Major survey regions.***

2.1.2. Transect Patterns and Acoustic Data Treatment

Acoustic surveys proved effective only for anchovies; consequently, data treatment and transect patterns were designed principally for this species. Analysis of acoustic data was performed only on cruises designed to systematically survey anchovy populations.

Prior to 1968, transects were established in a somewhat loose variable pattern of parallel lines perpendicular to the coast line. Later survey transects were stratified into sub-areas of 20 minute grids of latitude and longitude. At least one transect per grid in an east-west or west-east direction was occupied. As more experience was gained on anchovy distribution, greater effort was concentrated in grids where anchovy schools were most numerous and less effort in those with few schools. In areas considered good anchovy habitat transects were spaced 18.5 km (10 miles) apart and up to 55.6 km (30 miles) apart in poor areas (Figure 2). By treating each grid as an individual survey area and then combining school estimates of all grids, an effort weighted estimate was made of total anchovy schools in a region under survey. By so doing the effect of patchy distributions or nonrandomness was minimized.

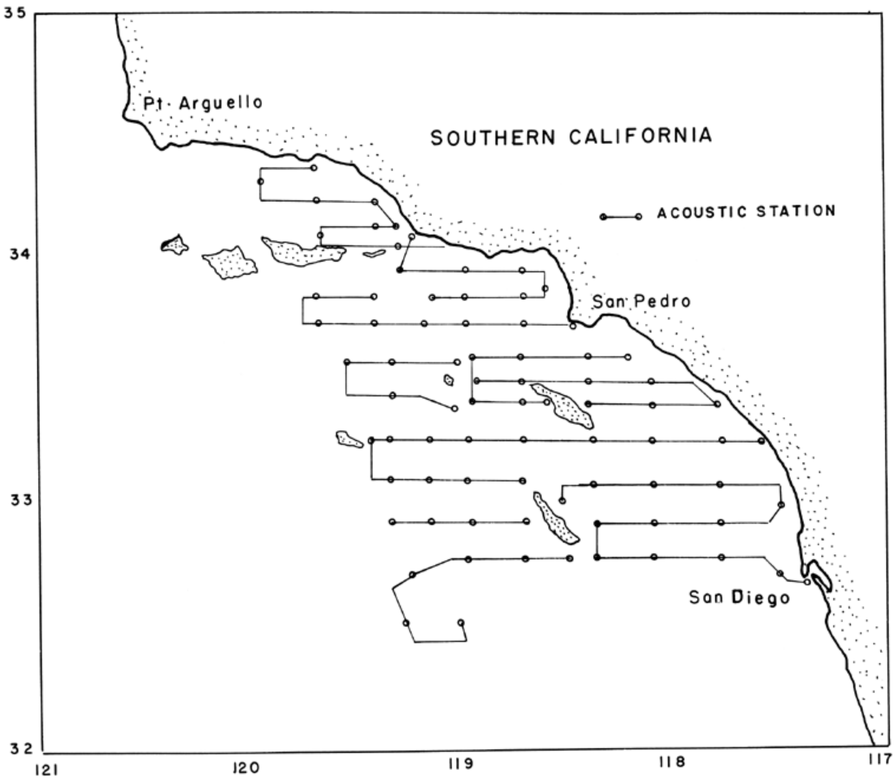

FIGURE 2. **Transect pattern of typical acoustic survey in southern California. Distance between circles (23 to 29 km; 14 to 18 miles) comprises a single acoustic station.**

FIGURE 2. ***Transect pattern of typical acoustic survey in southern California. Distance between circles (23 to 29 km; 14 to 18 miles) comprises a single acoustic station.***

Surveys of 1966 and 1967, when no effort was made to systematically cover 20 minute grids, were later converted to this system by interpolating transect stations that spanned two or more grids. Those grids bordering survey limits were adjusted in surface area in proportion to the length of a full grid transect length of 31.5 km (17 miles) or more (20 minutes of longitude at lat 33° N = approximately 17 miles).

Upon completion of a cruise, sonar and echo sounding recordings were edited for species identification and school counts. Sonar echograms were assigned an effective range which is the interval over the total range of the equipment that all sizes of anchovy schools were most effectively detected and recorded. Most effective ranges excluded extremely short and long ranges. At stations where no schools were detected, the previous station's range was recorded. Only schools within the effective range were counted in analyzing acoustic data.

The lengths and effective ranges of transects within each grid were multiplied and summed to obtain the surface area actually searched by sonar. School counts were divided by this figure to obtain a density factor expressed as schools per square mile searched. This factor was then applied to the total area of the grid for an estimate of the number of anchovy schools within it. The estimates for all grids surveyed during a cruise were summed to produce a total school estimate in the region surveyed.

Only an echo sounder was used for surveying prior to 1969. Conversion factors to estimate equivalent sonar detections relative to echo sounding results were derived by calculating mean ratios of sonar to echo sounder anchovy school detections for each survey region for years 1969 to 1971 when both types of sonic equipment were operated simultaneously. These conversion factors were weighted for each cruise by the number of miles sounded.

Mean ratios of the number of sonar detected schools to those detected by echo sounder during simultaneous operation of both equipments ranged from 1.97:1 in central California to 6.65:1 in southern California - northern Baja California. These ratios were multiplied by the number of schools detected by echo sounder during surveys prior to 1969 to approximate sonar results (Table 1).

Sonar search area (surface area insonified) was estimated by calculating the mean number of miles traversed necessary to search 1 mile^2 (3.43 km^2) from data collected after acquisition of the sonar. Miles traversed on surveys from 1966–1968 were divided by this factor to provide an estimate of sonar search area for these years. This factor ranged from 6.24 to 8.26 km (3.37 to 4.46 miles) for the different survey regions and translates to a mean effective range (Table 1) of 415 to 549 m (453.7 to 600 yds).

2.1.3. School Identification

Fish school targets detected by sonar and echo sounder were identified by a variety of methods which included visual observation, echogram characteristics, midwater trawling, and commercial catches.

Echogram characteristics was the prevalent method of identification. Characteristics of species previously identified by other means were used as criteria. These include depth below surface or in relation to bottom, school thickness, shape and density of echogram, aggregation of schools into school groups, location of school groups from shore, and orientation to bottom topography. The characteristics of individual species are based on confirmation of echogram identification by a wealth of midwater trawl catch data, extensive experience and knowledge by commercial fishermen, and direct visual observation of schools. The problem of confusing two or more species when schooled together was not as serious as expected. Commercial catch records and midwater trawl data indicate none of the major species under survey school in the same manner and localities simultaneously in appreciable quantities.

A small problem of this type occurs between small juvenile jack mackerel and adult anchovies in the deep water basins of southern California. Midwater trawl catch data and the extreme paucity of commercial catches of jack mackerel in these areas indicate quantities of this species are very minor compared to anchovy magnitude.

Sauries and anchovies also occur in the same areas, but sauries are rather easily observed from the surface and present a rather distinct echogram. Sauries are attracted readily to lights where they are easily identified.

Midwater trawling was the second most utilized method of identification. The majority of trawls were made after dark in the general vicinity of school groups detected during the day (midwater trawling was effective only at night). Concentrated efforts to identify schools by trawling were nearly always successful. Experience based on a large number of trawls indicates this is a fairly reliable method, but it does have obvious drawbacks.

Visual confirmation of school identity was utilized whenever possible. Observations were made from the vessel's bridge and underwater viewing ports. Diver observation also was used for this purpose. Some identifications were obtained by night-lighting acoustically detected school groups. Fish attracted to the light were then identified visually. This method was used most frequently during midwater trawl operations when the vessel was stopped during trawl retrieval.

Catch composition of commercial vessels sometimes was used for school identification when surveys coincided with commercial fishing operations. This method was particularly effective in identifying jack mackerel schools.

We feel confident our school identification is 90% correct. Schools that could not be positively identified comprised 15.2% of those detected by echo sounder and 4.5% of sonar detections; however, some individual surveys resulted in over 90% of acoustic targets classified as "unidentified".

2.1.4. Midwater Trawling

A large midwater trawl was fished at night in the vicinity of the acoustic transect line completed during daylight hours to sample and identify acoustically detected fish. Trawl tows were normally spaced 12.9 to 22.2 km (7 to 12 miles) apart or located in areas where acoustic search detected concentrations of schools. Normally tows were of 20 minutes duration with towing speeds of 2.5 to 3.1 knots (4.63 to 5.75 km/hr). Fishing depths were usually in the upper 30 m (100 feet) unless echo sounder information indicated otherwise. Trawl catch data collected included species enumeration by weight and number, fish size ranges, and length-age composition of the important commercial species.

2.2. Night-Light Blanket Net Surveys

Night-light blanket net surveys were originally initiated in 1949 by the California Department of Fish and Game to assess annual Pacific sardine recruitment and to determine the relative abundance and age structure of sardines beyond the fishery's range. During the period 1949–1965 a great amount of effort was expended on this type of survey. With the advent of acoustic surveys in 1966, night-light blanket net surveys were suspended until 1970 when they were resumed at a much lower level of effort. These surveys were conducted during the summer or fall of 1970 through 1972. They were designed to assess the incoming year class strengths of Pacific sardines and Pacific mackerel and measure the relative abundance of older fish. A moratorium on the commercial harvest of Pacific mackerel and a small catch quota for sardines necessitated these surveys in order to gather pertinent information concerning the populations of these species.

One hour night-light stations were occupied at various locations along the Baja California and southern California coast. Sardines and mackerel attracted to the light were captured by blanket net or hook and line. Length frequency and age data were collected to determine age structure of these resources. Relative abundance was based on percentages of successful stations.

2.3. Night Scouting With Searchlight

Exploratory surveys for Pacific sauries were made in the late fall of 1970 and 1971 by scouting at night with a searchlight. The light was swept over the sea surface at 5 to 10 minute intervals as the vessel steamed at 9 knots (16.68 km/hr). Schools of sauries were located by their jumping behavior when swept by the light beam. The vessel was turned and stopped with all deck lights and several 1500 watt night-lights switched on. Sauries attracted to the lights were sampled by dip net to obtain length frequency data, and school sizes were estimated visually. Relative abundance was determined by the number and sizes of schools located in various areas surveyed. These surveys were conducted only in southern and central California and ranged from 1.9 to 166.7 km (1 to 90 miles) offshore.

2.4. Data Collection and Processing

Prior to 1968 data were logged on a standard data form used on all cruises by California Department of Fish and Game research vessels. Data were transcribed upon completion of a cruise to coded sheets which were used in keypunching IBM punchcards. After 1968 all field data were entered directly on the coded sheets.

A computer program was used to screen and edit data for completeness and accuracy. At the end of each calendar year a data report was compiled by a computer and published. Data for each cruise made during a year are presented in these reports which are published in the California Cooperative Oceanic Fisheries Investigations Data Report Series under authority of the State of California Marine Research Committee.

3. EQUIPMENT

3.1. Acoustic

3.1.1. Echo Sounder

Echo sounding equipment used from 1966 through 1970 consisted of a 12 kHz echo sounder interfaced with a precision depth recorder. The transducer beam form was a 30° cone. The precision depth recorder presented echograms on 48 cm (19 inch) wide dry electrosensitive recording paper. Useable depth ranges were 183 and 732 m (100 and 400 fathoms). Most echo sounding operations were performed in the 732 m (400 fathom) range with a 3 millisecond pulse length. A constant receiver gain setting was maintained while running transects. This equipment was designed for bottom topography surveying and proved less than optimum for detecting fish.

During the latter half of 1971 a new echo sounding system was installed. It consisted of a 38 kHz sounder designed for scientific fisheries application and a more modern precision depth recorder. This system has much greater fish detecting capabilities plus advantageous features which include time varied gain, white line, and a wide selection of pulse lengths and ranges. Transducer beam measurements are 13° athwartships and 7° or 20° alongships. During transect work a range of 366 m (200 fathoms), a pulse length of 0.3 millisecond, and the narrow alongships beam width were used.

3.1.2. Sonar

A horizontally directed sonar was used from the latter half of 1968 through 1973. This equipment operates on a 29 kHz frequency and has a 1500 m (1640 yd) maximum range. The acoustic beam is 16° horizontally and 10° vertically. When used for surveying, the transducer was fixed 75° to 90° from the vessel's heading. The 1500 m (1640 yd) range and a 20 millisecond pulse length were normally used. Receiver gain was maintained at the highest level without obscuring fish school targets. Schools of fish in a horizontal plane on one side of the vessel were detected and enumerated.

3.2. Midwater Trawls

A small four panel midwater trawl with a mouth opening 7.62 m (25 feet) wide and 6.71 m (22 feet) deep was used during the first 2 years of surveys. Mesh sizes ranged from 8.89 cm (3.5 inches) stretched measure in the wings and mainbody to 1.27 cm (0.5 inch) in the codend (Figure 3). Four small hydrofoil shaped doors were attached to each wingtip to spread the trawl.

After mid-1968 a larger midwater trawl measuring 13.72 m (45 feet) wide and 11.58 m (38 feet) deep was used (Figure 3). This trawl was constructed of webbing ranging from 15.24 cm (6 inches) stretch measure to 3.81 cm (1.5 inches) with a 1.27 cm (0.5 inch) codend liner. Mouth opening was achieved by two 1.52 x 2.44 m (5 x 8 foot) curved steel "Suberkrub" type otter doors.

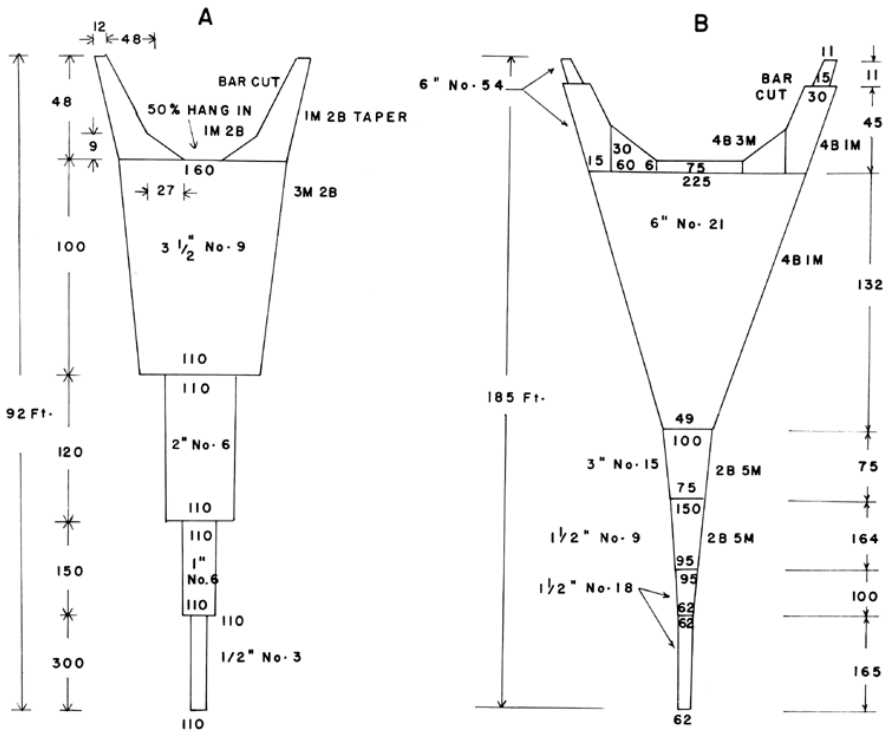

FIGURE 3. Midwater trawls used on surveys. Trawls consist of four identical panels sewn together along nylon rope riblines. Dimensions in meshes. Mesh sizes are stretch measure. Nylon filament webbing throughout.

A. Small trawl, mouth opening 6.7 to 7.6 m (22 to 25 feet).
B. Large trawl, mouth opening 11.6 to 13.7 m (38 to 45 feet).

FIGURE. 3. ***Midwater trawls used on surveys. Trawls consist of four identical panels sewn together along nylon rope riblines. Dimensions in meshes. Mesh sizes are stretch measure. Nylon filament webbing throughout.***

A wireless depth telemetry system for positioning midwater trawls was used until 1969. Due to poor performance and lack of adequate repair facilities, it was replaced by a system developed by the National Marine Fisheries Service (Luz, 1967). This system utilizes an electronic pressure sensing transducer attached to the end of one of the trawl warps. Depth signals are transmitted to a digital readout on the vessel's bridge via the trawl warp which is made of special electromechanical cable.

3.3. Blanket Net

This net is identical to that used on California Department of Fish and Game Sea Surveys from 1950–1965 (Radovich and Gibbs, 1954). It consists of a rectangular piece of variable mesh size webbing, 15.24 x 18.29 m (50 x 60 feet) which is bunched in both dimensions to produce a bag shape. The blanket net is set between two outrigger poles and is drawn under fish attracted to a night-light. It hangs vertically in the water when set and is drawn up and outboard by haul-in lines running through pulleys on the ends of the poles. It is effective only on fish near the surface which are attracted to the light. It can only be operated in relatively calm seas.

4. RESULTS

4.1. Field Work Effort Summary

During the period of this study (June 1966–February 1973), 53 research vessel cruises totaling 1,025 days were conducted. Acoustic transect-midwater trawl surveys comprised 76% of these cruises and night-light blanket net surveys 8%. The remaining cruises were devoted to developing methods of determining anchovy school sizes from acoustic records, development of sampling gear, studying effects of a major oil spill, and utilizing porpoise for locating commercial concentrations of fish. Southern California and northern Baja California received the most effort with 56% of all cruises being conducted in this region, followed by 24% in central California, 16% in central and southern Baja California, and 4% in northern California.

4.2. Acoustic-Midwater Trawl Surveys

4.2.1. Problems and Limitations

Acoustic Surveys Direct resource assessment of schooling pelagic species by acoustic survey is a most difficult undertaking. In a simple ideal situation a series of acoustic transects is run throughout an area or region. The number of schools detected is counted by species over the area insonified and a density of schools per square mile calculated. Assuming schools are randomly distributed, this density factor is applied to the entire area for an estimate of total number of schools. If the mean school size in terms of biomass can be determined, the schooled population size can be estimated. A number of problems complicate this method in actual practice to produce large errors or completely invalidate the method. These include nonrandom distribution of schools; highly variable schooling behavior causing large variance in school counts; species identification; extreme difficulty in determining school shape, size, and biomass; and shortcomings in acoustical equipment.

None of the species under study are randomly distributed throughout the California Current System. Some species such as anchovies and lanternfishes are extremely numerous and widely dispersed but their distribution cannot be termed random. Other species such as jack mackerel, Pacific sardines, Pacific mackerel, and rockfishes are distributed in rather restricted and specific areas.

Schooling behavior affects detection by acoustic equipment and is another source of serious error. School numbers, shapes, and fish sizes vary tremendously. Aggregation into defined schools varies over a range of compact, well defined schools to widespread scattering layers. This problem exists with all species under study but is particularly troublesome with anchovies. Behavior of this species is extremely varied and virtually unpredictable. Schooling ranges from countless inseparable small schools to extremely large ones, or concentrations that are not detectable or definable whatsoever. The latter behavior causes serious underestimation of population size or may nullify comparisons of populations of different regions.

School biomass is difficult to determine precisely since no method has yet been devised to accurately measure school shapes and densities nor has an effective method been developed to capture an entire school for certainty.

School identification has been a problem only with species in low abundance such as Pacific sardines and Pacific mackerel or isolated individual schools not in the proximity of school groups. Schooling habits, echogram characteristics, visual observations, midwater trawling, and commercial catches are utilized to identify acoustically detected targets.

Acoustic equipment has inherent shortcomings for transect surveys of schooling species. In the upper layers of the water column an echo sounder searches a small area in the horizontal plane, perpendicular to the vessel's heading. Near surface schools tend to flare and split away from the vessel's path which biases school enumeration to the low side. The echo sounder search area is usually smaller than the horizontal dimensions of most pelagic fish schools. The disparity between school size and search area causes gross overestimation of school densities (numbers of schools per unit area of sea surface) unless school dimensions are accurately known. These dimensions are nearly impossible to determine with an echo sounder alone. Fish detecting capabilities vary between equipments of different makes and frequencies. The 12 kHz used in this study had poor resolution in discriminating closely spaced targets and failed to detect weak or small targets deeper than 137.16 m (75 fathoms). This equipment was the only acoustic device used during the first 2.5 years of this work. For this reason surveys during this period were of poorer quality than in later years. Echo sounding was of most value in studying vertical distribution of schools and measuring their thickness.

Sonar presents a number of problems that complicates acoustic surveys. Horizontal detection range is greatly affected by downward thermal refraction of the sound beam. Strong shallow thermoclines greatly reduce detection range in the upper layers. Internal waves further complicate this effect. Thermal stratification also may cause the sound beam to split upward and downward leaving gaps where schools cannot be detected. Since thermal stratification is constantly changing, sonar range as well as beam shape and strength vary continuously. In addition to the complications of thermal refraction there are mechanical limitations of sonic beam coverage. At short ranges the conical shaped beam is narrow and passes over schools lying close to the vessel. At long range the reverse may be true with the beam passing under targets near the surface. Schools detected at close range are insonified for a shorter period of time than more distant ones and thus appear smaller in size on the echogram. The smaller schools may not be detected at the same range as larger ones thus introducing bias toward fewer schools. Schools located on or near the bottom and at midwater over shallow bottom depths are difficult to detect due to confusion with bottom echoes. This problem is especially serious over rough bottom topography. Sea surface conditions greatly affect sonar. In rough seas, rolling and pitching displace the beam to such an extent that the equipment often is completely ineffective. For this reason surveys in areas of characteristically rough sea conditions are very difficult to conduct and results are subject to great error. Since most of the problems involved with sonar tend to reduce or limit school detection, the overall effect is an underestimation of the species under survey.

It is the author's opinion from 6.5 years of experience that the most useful information derived from acoustic surveys is (ranked in order of importance) : distribution in space and time, availability, relative abundance, behavior, and location of areas of commercial concentrations. Realistic estimations of absolute population sizes of most species under survey are not possible due to the large magnitude of error from unknown and assumptive factors. Anchovy is the only species in this study whose population size can be realistically estimated by this method. Even with this species, the confidence limits of such estimates are quite large at present.

Midwater Trawl Surveys Midwater trawling was conducted chiefly to identify and sample species surveyed acoustically; however, trawling also constituted a separate survey method. In the latter respect it was useful for surveying non-schooling species or those not effectively surveyed by acoustic equipment. Included in this group are sardines, Pacific mackerel, jack mackerel, lanternfishes, squid and hake. Identification of acoustically detected school groups was accomplished by trawling in the general area of detection during hours of darkness. Occasionally specific schools were trawled immediately after detection. Except in rare instances midwater trawling was effective only at night. The chief value of midwater trawling was identification of major acoustically detected concentrations as well as determining their age and size composition. Distributional information for some species not vulnerable to acoustic surveys also was gained.

Quantitative trawl catch data as related to abundance must be treated with caution and reserve due to an extremely high variance of vulnerability to capture within and between species. Most species under survey were quite successful in evading the trawl. of the hundreds of tows completed, not one commercial sized catch of any species was made although our 13.72 m (45 foot) mouth opening trawl is as large as many commercial midwater trawls. Water clarity and schooling behavior were very important factors affecting the size of trawl catches. Turbid shallow water characteristic of inshore areas, low bioluminescence, and extensive schools of "loose" compaction provided optimum conditions for midwater trawling. Large compact schools, clear deep water, and bright bioluminescence produced the poorer catches. Such factors can easily mask real differences in absolute or relative abundance, and cast doubt on quantitative interpretations of midwater trawl catches. Large differences in trawl avoidance also were found between species. Generally the larger and more active species were more elusive. Pacific mackerel and sauries were the most successful species in avoiding the trawl. Even lanternfishes, which are small and relatively inactive, demonstrated surprising avoidance behavior when monitored by an echo sounder attached to the trawl headrope.

Trawl effort was more concentrated in inshore protected areas or regions characterized by fair weather due to trawling operations being limited to good to moderate weather. For this reason effort was high in southern California inshore waters and low in northern and central California as well as offshore portions of southern California (Figure 4).

FIGURE 4. Midwater trawl effort 1966–1971 by 20 minute grids.

FIGURE 4. ***Midwater trawl effort 1966–1971 by 20 minute grids.***

Northern anchovies were most effectively surveyed by midwater trawl. Moderate success was attained on jack mackerel and pelagic red crab. Poor results were obtained for rockfishes, Pacific hake, Pacific mackerel, Pacific sardines, and market squid. Midwater trawl surveys for Pacific sauries were nearly valueless.

Favorable schooling behavior, wide distribution, and a relatively large stock biomass all contributed to anchovies being the most effectively surveyed species. Other species were much more difficult to survey due to extremely patchy distribution, unfavorable schooling behavior, and trawl avoidance behavior.

4.3. Spacial and Temporal Distribution of Effort

4.3.1. Northern California

This region received the least survey effort. Only two cruises were conducted with 2,222 km (1,200 miles) of acoustic transects sounded and 34 midwater trawl tows made. Poor weather conditions and a paucity of schooling pelagic fishes were responsible for this small amount of effort. Surveys were made only in August and September of 1967 and 1968.

4.3.2. Central California

This was the second most intensively surveyed region, receiving approximately one-third as much effort as southern California. Twelve cruises were conducted with 15,592 km (8,419 miles) of acoustic transects sounded and 206 midwater trawl tows completed. Most surveys were made during spring and fall months with very little or no effort in winter. Poor weather and persistent large concentrations of jellyfish combined to severely hamper and reduce survey operations in this region. Rough seas, which prevail much of the year, created unfavorable conditions for acoustic survey. For this reason data from two surveys were unusable for analysis. Jellyfish concentrations continually damaged midwater trawl gear by clogging the meshes.

4.3.3. Southern California-Northern Baja California

This was the most intensively and thoroughly surveyed region. Its great importance as habitat for major pelagic commercial species, good weather, and optimum acoustic conditions were prime factors in concentrating most effort in this region. During the 6.5 year period of this work, 27 cruises were conducted, 53,436 km (28,853 miles) of acoustic transects sounded, and 860 midwater trawl tows completed in this region. Surveys were made during all months except March and July. The fall and spring seasons were most heavily worked and summer the least. Due to a large area within the 1,828.8 m (1,000 fathom) depth contour and an abundance of fish, the seaward limit of surveys (139–204 km; 75–110 miles) in southern California was greater than other areas.

4.3.4. Central and Southern Baja California

This region was surveyed because some of its pelagic fish populations contribute to California fisheries. Effort consisted of seven survey cruises during which 10,566 km (5,705 miles) of acoustic transects were run and 275 midwater trawl tows completed. Surveys were usually less intense than those in California waters. offshore coverage was normally limited to 111 km (60 miles) by the narrowness of the coastal shelf and concentration of species in the cooler inshore waters. Most surveys were conducted during spring and fall. None were made in July, August, October, and December.

5. SPECIES

5.1. Anchovies

Both acoustic and midwater trawling operations provided overwhelming evidence that anchovies are the dominant species in terms of biomass in the California Current System. of the many thousands of targets detected by sonar and echo sounder, over 80% were identified as anchovy schools. Anchovies were taken in 70.8% of the 1,384 midwater trawl tows completed. They greatly surpassed all other species both in occurrence and quantity (Figure 5).

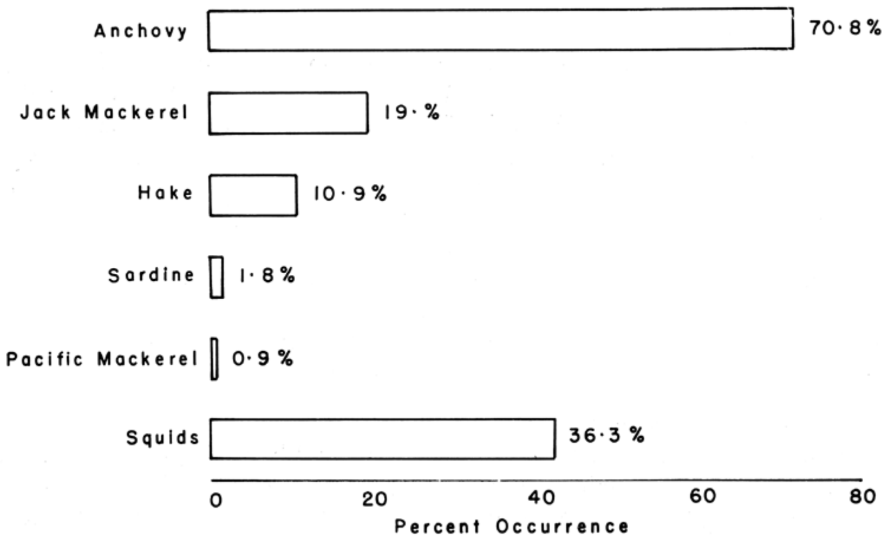

FIGURE 5. Occurrence of major commercial species in all midwater trawl tows 1966–1971.

FIGURE 5. ***Occurrence of major commercial species in all midwater trawl tows 1966–1971.***

Surveys found anchovies occurring from northern California southward to within 185.2 km (100 miles) of the tip of the Baja California Peninsula. Anchovies were detected from shore to a maximum seaward distance of 305.6 km (165 miles), but the bulk of the population was located within 92.6 km (50 miles) of shore. Schools occurred over bottom depths ranging from 9.3 to 3,658 m (5 to 2,000 fathoms).

Abundance varied greatly within the species range with a scarcity of fish at the extreme ends and a relatively large population at the center. The northern limits were ill defined with a very gradual increase of fish southward. The southern limit was rather abrupt and numbers of anchovies increased rapidly to the north. Surveys indicate a relatively small population in northern California waters, a small central California population, a very large one in the southern California - northern Baja California region, and a moderate sized population off central and southern Baja California. Mean estimates of anchovy schools in each region based on acoustic surveys from 1966 to 1973 indicate 4.2% of the total schools were located in northern and central California waters, 72.0% in southern California - northern Baja California, and 23.8% in central and southern Baja California. These percentages agree with distribution of spawning biomass based on egg and larvae surveys reported by Vrooman and Smith (1971).

5.1.1. Northern California

Anchovy stocks in this region are apparently too small and distributed too close to shore for effective acoustic survey. No anchovy schools were detected or observed in the 2,222.4 km (1,200 miles) of echo sounding transects. Reports received from fishermen and biologists (Daniel Gotshall, California Dept. Fish and Game, pers. commun.) indicate most schools of adults in this region are distributed within 0.9 km (0.5 mile) of shore which is inside the practical inshore limit of our surveys.

A total of 34 midwater trawl tows produced two anchovy catches of very small juveniles. Interestingly, these catches were located 74 km (40 miles) offshore whereas anchovy occurrence in trawl catches in other regions was relatively infrequent this distance from shore.

The relative size of the anchovy population in this region is probably larger than survey results indicate. Reports received from this region indicate apparent abundance varies greatly from few or no observed schools during most years to occasional years of conspicuous localized inshore concentrations. The summers of 1970 and 1971 were such years when concentrations were reported from the Eureka area.

The overall evaluation of this region as anchovy habitat must be rated submarginal. The population is much smaller than other regions investigated and is probably subject to large fluctuations when favorable oceanographic conditions occur. The nearshore distributional behavior renders schools highly observable and may create an illusion of a larger population than exists, especially in years of unusual abundance. The population is certainly too small for extensive commercial exploitation. An educated guess, based on the relative population sizes in other regions, is a total biomass of 10,000 tons which may increase several times this amount during favorable years.

5.1.2. Central California

Relative Abundance Compared to other survey regions, central California waters ranked second lowest in relative abundance of anchovies. Results of acoustic surveys indicate this region contains only 4.2% of the total anchovy resources off California and Baja California. None of the 12 surveys totaling 15,592 km (8,419 miles) of acoustic transects found large numbers of schools such as in regions to the south. Schools per mile (1.85 km) of echo sounding and per square mile searched by sonar were determined for all acoustic surveys made except those where weather or breakdowns in equipment prevented adequate spatial coverage. Estimates of the number of anchovy schools in the survey region, based on sonar data, were made for each survey. Echo sounding detection

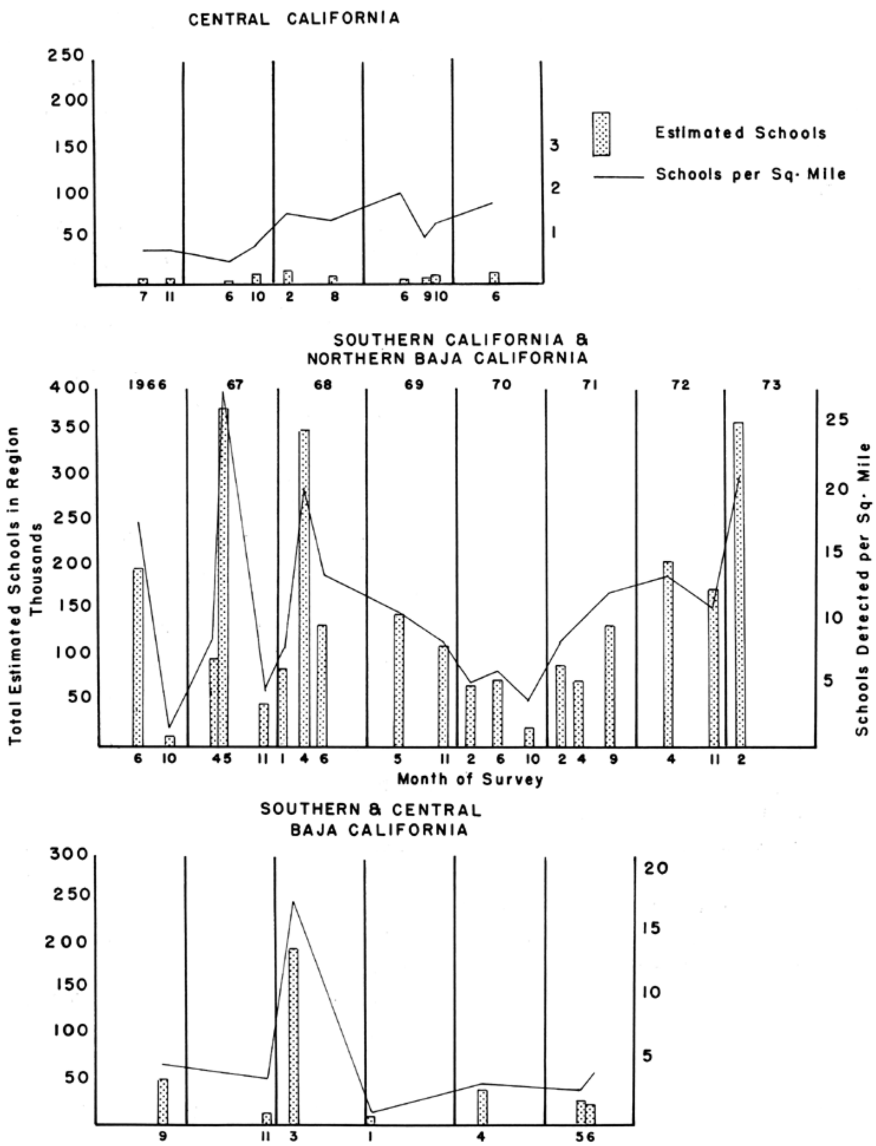

FIGURE 6. Anchovy acoustic survey results estimated from horizontal ranging sonar operation. Each bar represents an estimate of total anchovy schools inhabiting a particular region during a single survey. Solid line represents the number of schools detected per square mile of sea surface area.

FIGURE 6. ***Anchovy acoustic survey results estimated from horizontal ranging sonar operation. Each bar represents an estimate of total anchovy schools inhabiting a particular region during a single survey. Solid line represents the number of schools detected per square mile of sea surface area.***

rates in central California ranged from 0.06 to 0.25 school per mile sounded compared to rates ranging to over 1.0 school per mile in regions to the south. Sonar rates ranged from 0.49 to 2.02 schools per mile^2 searched compared to a maximum of 27.10 in southern California. The actual numbers of schools detected by sonar and echo sounder

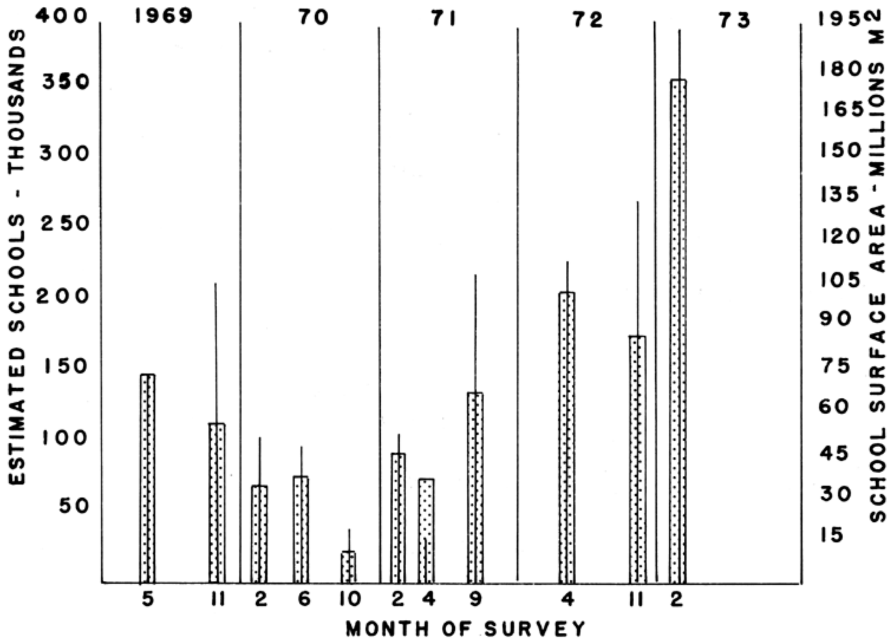

FIGURE 7. Anchovy acoustic survey results in southern California and northern Baja California adjusted for school size. Bars represent estimated schools (Figure 6) and solid lines represent total school surface area.

FIGURE 7. ***Anchovy acoustic survey results in southern California and northern Baja California adjusted for school size. Bars represent estimated schools (Figure 6) and solid lines represent total school surface area.***

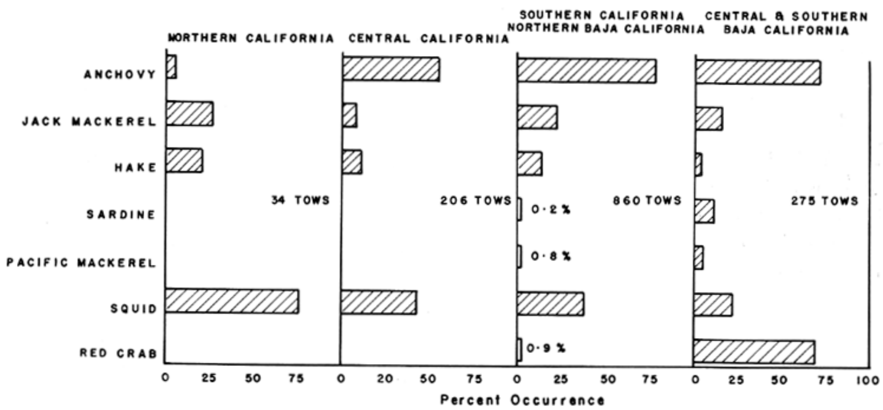

FIGURE 8. Occurrence of major commercial species in midwater trawl catches by survey region.

FIGURE 8. ***Occurrence of major commercial species in midwater trawl catches by survey region.***

ranged from 214 to 360 and 35 to 160 for respective equipments. The estimated number of schools for each survey based on sonar data ranged from 3,443 to 14,488 with a mean of 9,142 (Figure 6). This mean constitutes 4.2% of the sum of the means of all survey regions.

Midwater trawling was ineffective for measuring anchovy abundance except to establish their presence or absence. Anchovies were taken in

112 (54.5%) of the 206 midwater trawl tows completed. This compares with successful percentages of 77.8% and 70.9% in southern California and Baja California waters respectively (Figure 8). There were no obvious differences in catch sizes compared to other regions although smaller catches were taken slightly more often in central California.

Although acoustic surveys consistently indicated a relatively low anchovy population in central California, commercial catch records and aircraft fish spotter reports during presurvey years indicate large fluctuations may occur. A record commercial catch of 22,783 tons during 1952 was followed by decreases to 8,384 tons in 1953 and 253 tons in 1954. The decreases were caused by a scarcity of fish since economic demand was good (Miller and Wolf, 1958). Commercial fish spotters operating from aircraft over this region sighted large numbers of anchovy schools during the early and mid-1960's but have seen few or none since (Squire, 1972).

It appears central California waters are marginal anchovy habitat, but historical data indicate they occasionally may support a much larger population during perids of favorable conditions than indicated by our surveys.

Distribution Anchovies were distributed in a narrow coastal strip along the entire central California coast. Most schools were located within 27.8 km (15 miles) of shore with the greatest concentrations less than 18.5 km (10 miles) offshore. However, several major school groups were located 37 to 55.6 km (20 to 30 miles) seaward during surveys in 1966 and 1968. Occasional minor midwater trawl catches of one to 10 fish were made at greater distances offshore.

Areas where anchovies were more abundant include: Morro Bay to Point Arguello, Pfeiffer Point, Monterey Bay, and Pidgeon Point to San Pedro Point. Anchovies were consistently and overwhelmingly most abundant in the southernmost area, Morro Bay - Point Arguello, during the period of this study. The other areas were much less consistent with few or no fish in some years. The Pfeiffer Point area contained concentrations in 3 of the 4 years studied. Schools were numerous in Monterey Bay during 1968 when 0.25 school per mile of echo sounding were detected. School sizes were much larger there than in other areas. Relatively large numbers of schools were detected in the Pidgeon Point - San Pedro Point area during 1968 and 1969 when detection rates ranged from 0.36 to 0.86 school per mile sounded which were among the highest rates observed in central California waters. Few or no fish were found in this area during other years. The northern part of this area produced the largest portion of the record central California commercial catch landed in 1952 (Messersmith, 1969).

No obvious seasonal variation in the number of schools detected by echo sounding was observed such as in survey regions to the south. Very little fluctuation occurred between central California surveys in different seasons of the same year; however, there was considerable variation between years. Surveys during 1966 and 1967 found very few schools. Echo sounding detection rates in these years ranged from 0.06 to 0.11 school per mile sounded. Much larger numbers were detected during 1968 and 1969 with overall rates ranging from 0.14 to 0.25.

Availability and Behavior Over 90% of all anchovy schools detected acoustically or observed visually were too small to be fished commercially. The great majority consisted of small surface schools ranging from 200 pounds to 10 tons in biomass. Anchovies in these schools remained in a schooling attitude during daylight hours at depths ranging from 9.2 to 73.2 m (5 to 40 fathoms), rose to the surface and dispersed into a coarse scattering layer at dusk where they remained until midnight or later. After midnight surface schooling became progressively greater until dawn when the daytime behavior prevailed.

The only commercial size schools were detected and observed during the fall months of 1966 and 1967. At that time extremely large schools were found during daylight hours at depths of 164.6 to 182.9 m (90 to 100 fathoms) in Monterey Canyon and over the nearshore submarine escarpments near Pfeiffer Point. These schools rose to the surface shortly before sundown and remained intact until dark when they divided into smaller schools and moved into shallower water. Several of these schools were among the largest detected during this study. One such school was 300 m (328 yd) wide, 28 m (92 feet) thick, and very densely concentrated. It very likely contained 1,000 or more tons. Smaller commercial schools ranging from an estimated 15 to 40 tons were located in the Morro Bay - Point Arguello area. No commercial size school was found more than 18.5 km (10 miles) offshore.

Size Composition and Age at Length Anchovy length frequency data were derived from 57 trawl caught samples totaling 1,503 fish. Central California anchovies were the largest caught during this study. The mean standard length was 122.7 mm (4.8 inches) SL compared to 120.0 mm (4.7 inches) SL for the next largest fish which were taken in southern California. Although there is only a small difference in means, the percentage of larger fish was much greater in central California. Fish larger than 130 mm (5.1 inches) SL comprised 48.3% of the total catch in these waters compared to 27.5% of the fish taken in southern California waters (Figure 9). The number of smaller fish (<100 mm, 3.9 inches, SL) in central California samples effectively lowered the mean size, but these small fish very likely were oversampled by the trawl. Poor weather conditions in central California resulted in a large number of trawls being made close to shore where conditions were less severe. Small juvenile fish generally favor inshore areas; thus, trawls in this region probably oversampled them.

Age at length data were derived from 37 of the length frequency samples. A total of 268 fish was aged. The results clearly indicate anchovies in the central California region exhibit the most rapid growth rate of all regions studied. At an age of 1 year their mean size is nearly equal to that of a 2 year old southern California fish (121.6 mm, 4.78 inches SL vs 120.9 mm, 4.76 inches SL), and by age 4 they equal a 6 year old southern California fish (Figure 10).

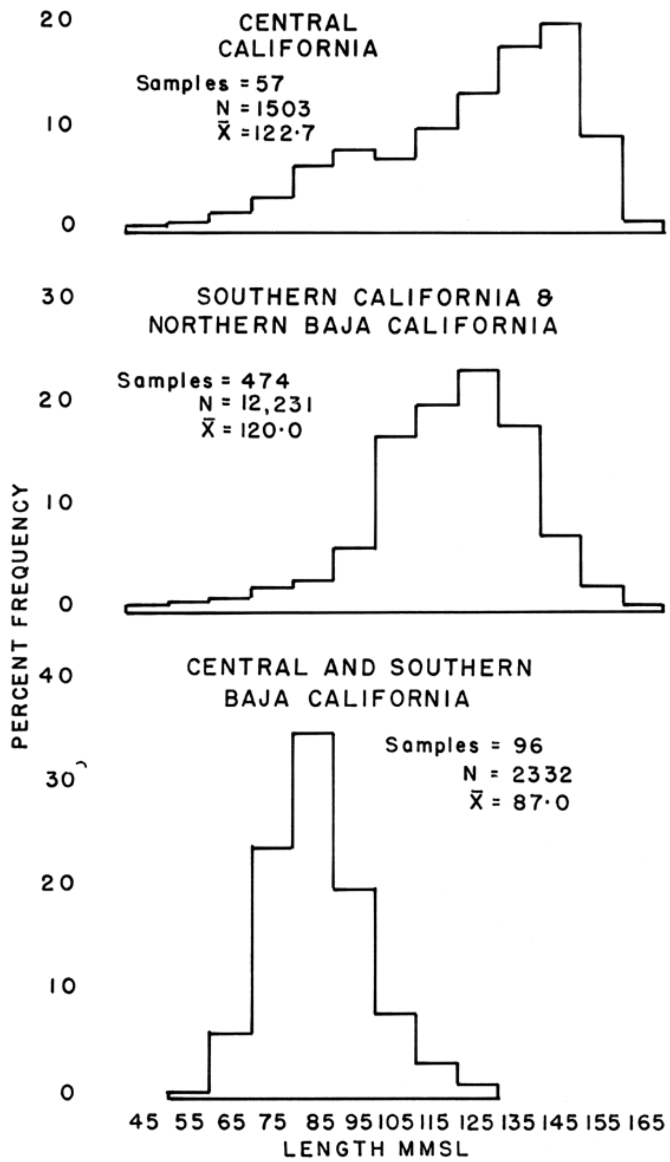

FIGURE 9. Anchovy trawl catch length frequencies.

FIGURE 9. ***Anchovy trawl catch length frequencies.***

The actual age and size composition of the anchovy population was impossible to determine with any degree of accuracy due to difficulty in randomly sampling all age groups.

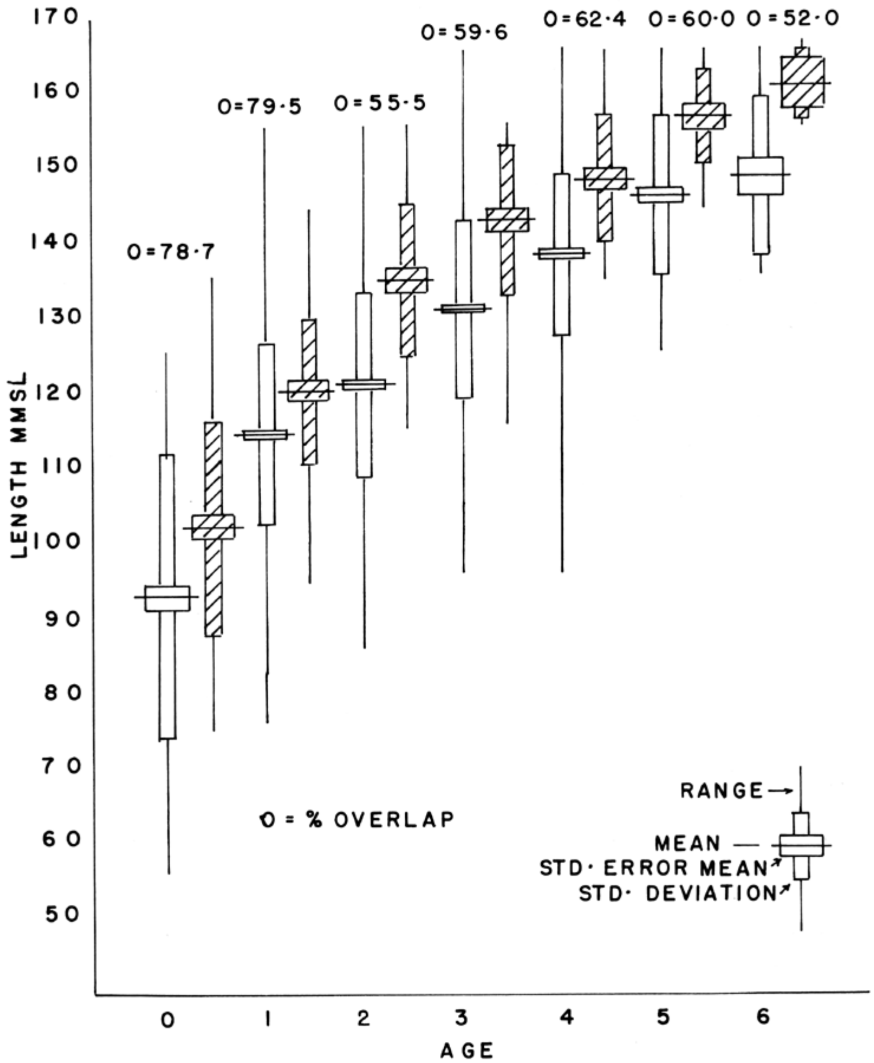

FIGURE 10. Anchovy trawl catch age-length data from southern California (open bars) and central California (hatched bars). Overlap values of length frequencies of same age groups indicated by "0".

FIGURE 10. ***Anchovy trawl catch age-length data from southern California (open bars) and central California (hatched bars). Overlap values of length frequencies of same age groups indicated by "0".***

5.1.3. Southern California-Northern Baja California

Relative Abundance Data from the many and extensive surveys made in this region indicate the bulk of the California Current System anchovy resource resides in this region. Anchovies were grossly and consistently more numerous here than any other survey region. This dominance was evident in both the acoustic and midwater trawl phases of the surveys.

Nearly 53,708 km (29,000 miles) of acoustic transects produced by far the largest school counts, detection rates, and estimates of total schools. Echo sounding detections per mile sounded ranged from 0.04 to 1.93 with a mean of 0.51 school per mile. By comparison, means of other regions were 0.25 and 0.13. Actual school counts ranged from 42 to 2,608. Sonar school counts ranged from 696 to 11,476 (Table 1). Mean detection rates per mile^2 of sea surface searched ranged from 2.05 to 21.24 schools.

Higher school counts and detection rates were estimated for presonar surveys (1966–1968). These estimated sonar results were based on conversion factors obtained from simultaneous operation of both instruments after 1968. Sonar detection rates of 27.10 schools per mile^2 were obtained. The highest actual sonar school detection rate in other regions was 3.76 schools per mile^2 and an estimated 17.52 from echo sounding conversion.

The measure which indicated greatest difference in relative abundance was the total population of schools estimate. This estimate, which is the most representative of relative abundance, was derived by applying sonar detection rates to the entire surface area under survey. Estimates for surveys in presonar years ranged from 12,029 to 378,571 schools and 21,920 to 343,070 during years when sonar was used (Figure 6). The mean, including all years, was 150,996 schools per survey compared to means of 53,130 for central and southern Baja California and 9,142 for central California. The southern California - northern Baja California proportion of the sum of these means is 72%.

It is highly unlikely that the large differences in school number estimates represent changes in anchovy abundance, but rather are the result of the degrees of school formation and variance of school biomass. A much better measure of relative abundance could be obtained if school biomass was determinable. Without this capability, use of school surface area was considered as an alternative which might provide a better measure of abundance. Mean school surface areas for each survey were calculated from sonar records in which all schools were considered round in shape. These means were then multiplied by school number estimates for an estimate of total survace area of all schools per survey in the southern California - northern Baja Region. Results of these estimates reduced abundance variance between some surveys and increased it between others when compared to school number estimates. The net effect was somewhat greater variance (Figure 7). Apparently the degree of school formation behavior is the dominant factor causing large survey result fluctuations, or else school surface area by itself is not a good indication of school biomass.

The very large school estimates for 1967 and 1968 (378,571 and 354,904), when echo sounding only was conducted, were originally suspect of large error until very recently when results of an excellent sonar survey in February 1973 produced an estimate of 343,070 schools. Actual schools detected on this survey totalled 11,476 by sonar and 2,608 by echo sounder. The actual change in anchovy population size during the period of this study is very difficult to ascertain. The relatively high estimates of 1966–1968 are followed by a decrease which reached a minimum in 1970 and then increased to previous high levels in 1973 (Figure 6). The population level may have fluctuated in like manner, but certainly not to the degree indicated. A record high commercial catch of 96,242 tons was attained during 1970 which was the year of lowest acoustic results. Conversely, mediocre and very poor commercial catches were made during 1967 and 1968 when acoustic results were the highest. This inverse relationship may be a function of school biomass and availability. Results of aerial fish spotter observations indicated a paucity of commercial schools in 1968 (Squire, 1972) when acoustic surveys produced a very high school number estimate.

As stated previously midwater trawling was a poor method of measuring abundance; however, anchovy occurrence in trawl catches gave some indication of their abundance. A high occurrence frequency of 77.8% was achieved for the 860 midwater trawls made in this region compared to 70.9% in the next higher which was central and southern Baja California. This difference is greater than the data indicate when location of trawls is considered. A larger number of trawls was made in the more offshore areas of southern California (Figure 5). Since anchovy catch occurrence definitely decreased in a seaward direction, a bias toward a lower percentage of successful trawls was present in surveys of this region.

Distribution Anchovy distribution in southern California - northern Baja California was the most widespread and variable of all regions surveyed. The great bulk of the population was consistently located in the Southern California Bight, an area of 41,237 to 51,546 km^2 (12,000 to 15,000 $miles^2$) of semiprotected waters bounded by Point Conception, California, in the north and Point Descanso, Mexico, in the south (Figure 11). The western or seaward boundary is a nearly continuous series of banks and islands extending in a northwest-southeast direction from San Miguel Island to the Sixty Mile Bank. This area is approximately 398 km (215 miles) long and extends seaward 46.3 to 166.7 km (25 to 90 miles). It is characterized by deep water basins (366 to 1,829 m; 200 to 1,000 fathoms) interspersed with a series of islands and banks. Nearshore bottom topography is steep with submarine canyons and escarpments lying 0.46 to 9.26 km (0.25 to 5 miles) from shore. Shallow "flats" comprise a relatively small area except in the

TABLE 1
Acoustic Survey Statistics
Central California

Mo.	Yr.	Miles sounded	Anchovy schools: Echo sounder	Anchovy schools: Sonar	Unidentified schools: Echo sounder	Unidentified schools: Sonar	Area insonified by sonar (mi^2)	Surface area surveyed (mi^2)	Estimated anchovy schools	Mean anchovy school diameter (m)
July	1966	1,127	99	(195)	66		(252.9)	10,126	(7,797)	
Nov.	1966	771	70	(138)	10		(173.0)	9,658	(7,726)	
Jun.	1967	628	35	(69)	35		(140.9)	7,041	(3,443)	
Oct.	1967	699	75	(148)	34		(156.9)	11,378	(10,732)	
Feb.	1968	636	119	(234)	50		(142.8)	8,842	(14,488)	
Aug.	1968	633	160	221	7	9	159.9	6,447	9,874	25.8
Jun.	1969	522	84	214	107	126	105.8	3,243	4,146	30.5
Sep.	1969	687	83	(164)	76		154.1	6,199	(6,597)	
Oct.	1969	827	119	245	140	119	182.4	2,836	8,936	
Jun.	1972	820	33	360	346	111	196.8	8,412	12,696	
								x = 7,418	x = 9,142**	

Mean sonar to echo sounder school ratio = 1.97:1†
Mean miles run necessary to insonify 1 mi^2 = 4.46†

TABLE 1
Acoustic Survey Statistics
Central California

Southern California—Northern Baja California

Jun.	1966	1,787	719	(4,778)	20		(471.5)	19,723	(199,853)	
Oct.	1966	1,025	42	(279)	71		(270.4)	11,667	(12,029)	
Apr.	1967	1,058	359	(2,386)	16		(279.2)	11,578	(98,938)	
May	1967	1,131	1,217	(8,087)	7		(298.4)	13,968	(378,571)	
Nov.	1967	836	98	(651)	32		(220.6)	16,474	(48,614)	
Jan.	1968	987	297	(1,974)	6		(260.4)	11,514	(87,276)	
Apr.	1968	1,409	1,130	(7,509)	40		(371.8)	17,573	(354,904)	
Jun.	1968	800	426	(2,831)	15		(211.1)	10,115	(135,642)	
*Sep.	1968	1,423	331		28			Not a routine survey		
*Nov.	1698	1,255	258		4			Not a routine survey		
May	1969	1,623	731	3,719	33	167	354.6	13,213	145,745	25.9
*Aug.	1969	978	449	873	26	10	282.7	15,953	40,248	33.6
Nov.	1969	1,200	413	1,899	21	66	243.3	15,837	110,316	34.5
Feb.	1970	1,156	219	1,567	46	153	305.0	11,942	69,768	29.5
Jun.	1970	1,203	468	2,150	50	91	339.8	13,998	75,488	27.7
Oct.	1970	704	113	696	57	124	229.8	8,854	21,920	31.9
*Nov.	1970	181	99	1,270	0	0	86.1	313	5,189	38.3
Feb.	1971	1,095	273	3,442	25	39	415.1	13,513	92,089	26.3
Apr.	1971	956	186	2,008	8	16	201.3	7,944	74,934	15.2
Sep.	1971	929	479	3,861	1	2	321.5	11,252	135,675	31.4
Apr.	1972	1,397	784	4,916	34	98	372.7	17,042	207,892	25.5
Nov.	1972	1,295	888	6,714	45	182	546.3	15,609	153,844	32.1
Feb.	1973	1,347	2,608	11,476	138	7	551.3	17,329	343,070	26.0
								x = 13,115	x = 150,996**	

Mean sonar to echo sounder school ratio = 6.65:1†
Mean miles run necessary to insonify 1 mi² = 3.79†

Southern and Central Baja California

Sep.	1966	568	123	(787)			(168.9)	11,014	(51,314)	
Nov.	1967	407	58	(371)	37		(120.9)	4,798	(14,720)	
Mar.	1968	815	663	(4,243)	113		(242.2)	11,253	(197,130)	
Jan.	1969	1,037	160	173	204	118	276.9	13,879	9,907	37.1
Apr.	1970	1,116	166	879	36	57	328.1	15,505	39,180	24.2
May	1971	916	46	651	25	234	282.8	16,424	27,885	22.9
Jun.	1971	578	143	831	31	37	205.3	6,241	23,437	27.2
								x = 11,301	x = 53,130**	

Mean sonar to echo sounder school ratio = 6.40:1†
Mean miles run necessary to insonify 1 mi² = 3.37†

Numbers in parenthesis are estimations from conversion of echo sounding data.

* Not routine surveys, data not used in analysis
** Weighted by surface area surveyed
† Weighted by miles run

TABLE 1—Cont'd.

northern part. The dominating oceanographic feature is a large permanent back eddy of the California Current which occupies much of the area.

Anchovies in this area were widely distributed from shore to 157.4 km (85 miles) seaward. The greatest concentrations were generally located within 37 km (20 miles) of shore over deep water (228.6 to 731.5 m; 150 to 400 fathoms) basins. Some of the best concentrations were found over the escarpments and submarine canyons which lie within 9.26 km (5 miles) of shore. Such areas included Santa Monica Basin, Santa Monica Canyon, Redondo Canyon, San Pedro Basin, and the nearshore escarpments off Palos Verdes Peninsula and Newport Beach. School densities per mile^2 of surface area were not particularly great in these areas (5 to 10 schools), but school sizes and concentrations were much larger than elsewhere.

The more distant deep water basins lying 37 to 111 km (20 to 60 miles) offshore collectively contained the largest portion of the anchovy population in this region with small but very numerous schools distributed over large areas. School densities as determined by sonar frequently ranged from 15 to 30 schools per mile^2. The better of these areas were in the southern half of the southern California Bight and included San Nicolas Basin, Santa Catalina Basin, Gulf of Santa Catalina, and San Clemente Basin (Figure 11).

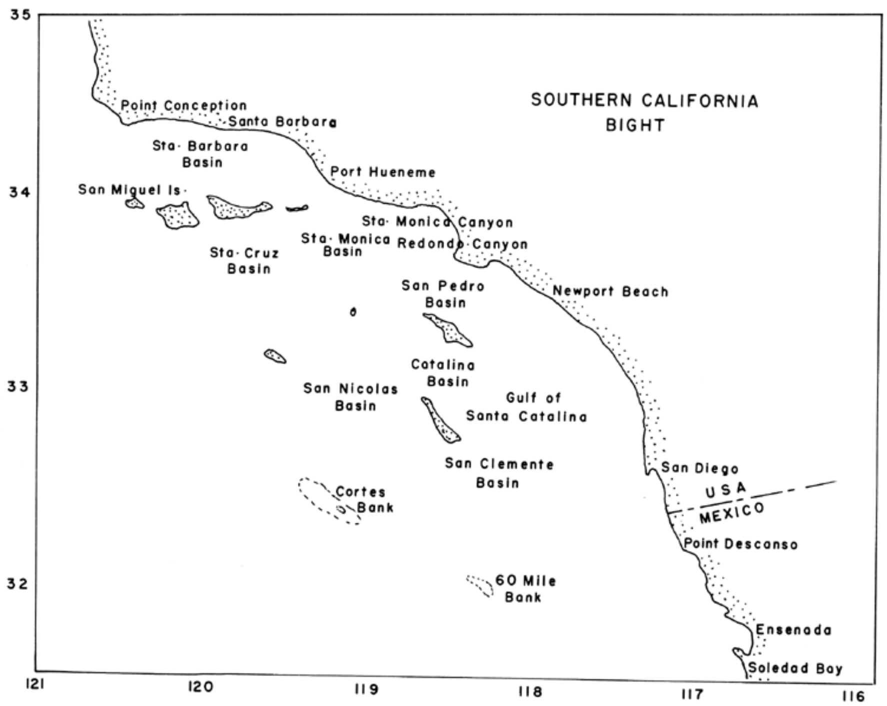

FIGURE 11. Detail chart of Southern California Bight.

FIGURE 11. ***Detail chart of Southern California Bight.***

Relatively small amounts of fish were found in the shallow (less than 91.5 m; 50 fathoms) banks and inshore waters. School groups or concentrations rarely exceed or equaled those of deeper water. However, these areas may be more important than results indicate since acoustic equipment, particularly sonar, is less efficient in detecting schools in shallow water. In addition a common scattered schooling behavior in shallow water often made school enumeration difficult or impossible. The better inshore concentrations were located between Port Hueneme and Santa Barbara where the largest "flats" area in southern California occur. Shallows elsewhere usually contained some fish but in no obviously large quantities.

The remainder of the southern California - northern Baja California survey region extends 232 km (125 miles) southeastward along the Baja California coast of Mexico to San Quintin Bay. Anchovies were considerably less numerous than in the Southern California Bight and distributed much closer to the coast; however, this area's overall ranking as anchovy habitat must be considered as good. Acoustic surveys found school densities ranging from 0 to 12.7 schools per mile^2. A coastal distribution similar to that of the central California region was prevalent with most schools located within 27.8 km (15 miles) of shore. Nearshore submarine escarpments and canyons along areas of upwelling were especially favored by anchovies. Such areas included San Quintin Bay, San Martin Island, Cape Colnett, Soledad Bay, and Descanso Bay. The San Quintin Bay area appears to be the center of abundance for all anchovies in th entire Baja California Peninsula.

Anchovy distribution within the Southern California Bight varied considerably both seasonally and annually. During the fall months a large portion of the population was located inshore and in the more northern part of the bight. Concentrations were normally found from Santa Barbara southward along the coast to Newport Beach especially favoring nearshore submarine canyons and escarpments. Schools were generally larger in size but fewer in number than in any other season. Anchovies also were found throughout the remainder of the bight during fall but were not aggregated in large concentrations.

Commencing in late winter, an offshore and southeastward movement occurred coinciding with the onset of major spawning activity. At this time the population was widely spread over large areas offshore and south of San Pedro. During some years this offshore distribution extended beyond the Sixty Mile Bank into northern Baja California. Schools became extremely numerous and small reaching peak numbers usually in April or May. A return northward also occurred at this time with part of the population forming large daytime surface schools during some years. Time of formation of these schools varied from the middle of March to late June.

Information on summer distribution is sparse since only one survey was made in this season. This survey in August 1969 found fish widely scattered in tiny schools both inshore and offshore in the northern half of southern California. Aerial observations in the summers of 1970 and 1971 found dense extensive schools within 5.6 km (3 miles) of shore in the shallow flats between Ventura and Santa Barbara. A commercial boat, fishing anchovies during July and August 1970, found scattered small schools throughout the southern California area until the last week of August when distribution changed to that typical of fall.

Seasonal distribution in northern Baja California was less varied and different than in southern California. During a large portion of the year anchovies were found in concentrations in deep water close to shore similar to the southern California fall distribution. In contrast to southern California, however, very few schools were detected during spring months, and few or any fish were found more than 27.8 km (15 miles) offshore except near the offshore border area between the two localities. The only summer survey in this area found the largest concentrations of anchovies ever detected in Mexican waters.

Distributional differences also were apparent between years. In 1966 most fish were located in the north between Santa Catalina Island and Santa Cruz Island. The center of abundance shifted south of San Pedro during the following year. During 1968 the bulk of the population was located more offshore than any of the years studied.

School Behavior and Availability The schooling behavior of anchovies in this region affects the commercial catch more than any other natural factor. The time, location, and occurrence of certain schooling behaviors determine the success or failure of the present commercial fishery in southern California. The record catch of 95,179 tons in 1970 and the 1968 catch of only 11,261 tons were due primarily to schooling behavior as it affects availability. Studies based on sonar, echo sounding, and visual sightings from surface craft, aircraft, and underwater observations all indicate anchovies are available for commercial harvest for relatively short time periods. The dominant and prevailing schooling behaviors render anchovies invulnerable to capture using present commercial fishing techniques. Only a very small portion of the population is vulnerable at any particular time even in periods of relatively high availability. There are also periods lasting up to several months when virtually the entire population cannot be fished effectively.

By far the most prevalent and common schooling behavior observed was the formation of small very low density near surface schools during daylight hours. These schools normally ranged from 5 to 30 m (16.4 to 98.4 feet) in horizontal extent and were 4 to 15 m (13.1 to 49.2 feet) thick. They were found from the surface to 54.9 m (30 fathoms) but were most commonly located 9.1 to 18.3 m (5 to 10 fathoms) from the surface (Figure 12). Due to their low densities these schools could not normally be seen from air or surface craft. Observations from the surface coordinated with observers in an airplane verified low schooling density. The surface disturbance caused by a school could be seen at a distance from both aircraft and vessel; however, when the airplane was directly over the school, nothing could be seen since the angle negated observation of the disturbance and the school was not dense enough to cause a color contrast against the sea background. Aboard the surface vessel the same school could be seen at all times, but at close range only scattered flashes of individual fish were occasionally visible.

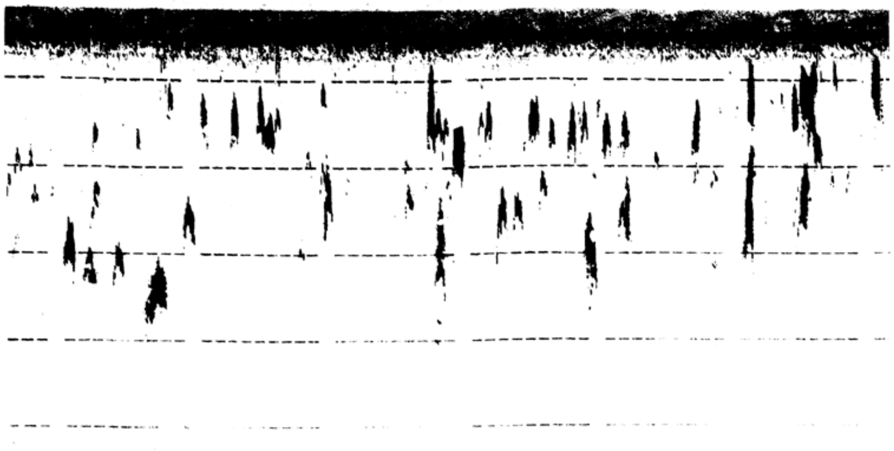

FIGURE 12. Profusion of small near surface anchovy schools over deep water during daylight hours, northern Baja California, March 1973. Depth scale is 18.3 m (10 fathoms) between dashed lines. Horizontal scale is approximately 7.2 km (4.5 miles).

FIGURE 12. ***Profusion of small near surface anchovy schools over deep water during daylight hours, northern Baja California, March 1973. Depth scale is 18.3 m (10 fathoms) between dashed lines. Horizontal scale is approximately 7.2 km (4.5 miles).***

Sparse schooling densities also were indicated by other surface sightings, underwater observation with scuba gear, and low intensity echograms from sonar and echo sounder operations. After dark observed anchovy schools invariably dispersed into a thin surface scattering layer and remained so until the following dawn.

Small low density schools near the surface were always found over bottom depths of more than 183 m (100 fathoms) and were widely distributed over thousands of square miles of sea surface area. Although they were found over deep water everywhere, they were the only type schools distributed in the more offshore areas. Schools of this type comprised an estimated 90% of all detected by sea surveys. They were the dominant type during all seasons but were most numerous and prevalent during late winter and spring. At this time schools are very small (probably 0.5 to 6.0 tons) and wary. All the actively spawning anchovies we collected were from this type of school.

When anchovies are in these small, low density, near surface schools, their commercial availability is virtually zero due to small school size, difficulty of observation, and wary behavior.

A schooling behavior favorable for commercial harvest occurs from fall through winter. Large schools measuring 25 to 150 m (82 to 492 feet) horizontally, 12 to 40 m thick (39 to 131 feet), and 0 to 55 m (0 to 30 fathoms) from the surface occurred during daylight hours over the deep water basins and channels adjacent to the coast (Figure 13). School densities were relatively light but were more dense than

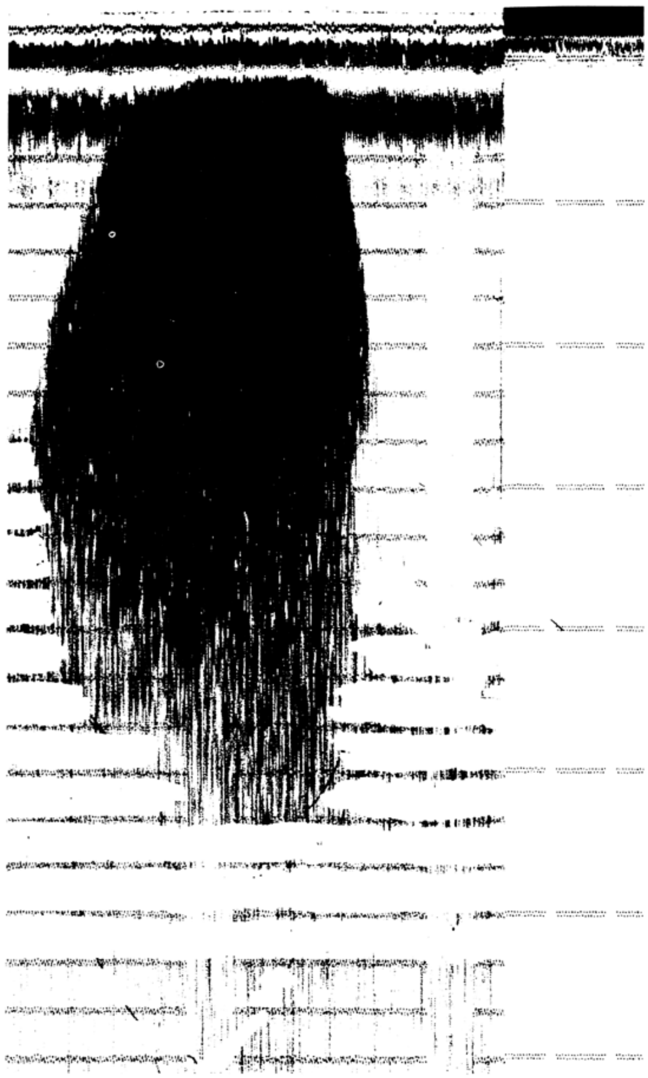

FIGURE 13. Echogram of extensive daytime anchovy school typical of fall months. Dispersed schooling density was evidenced by visual observation from underwater viewing ports. This school was approximately 80 m (262.5 feet) in diameter. Depth scale is 3.1 m (10 feet) between dashed lines.

FIGURE 13. ***Echogram of extensive daytime anchovy school typical of fall months. Dispersed schooling density was evidenced by visual observation from underwater viewing ports. This school was approximately 80 m (262.5 feet) in diameter. Depth scale is 3.1 m (10 feet) between dashed lines.***

the previously mentioned school type. At sundown these schools dispersed into a coarse scattering layer and remained in this attitude until near midnight when distinct schools began to form progressively, frequently starting with long narrow bands or strings which usually condensed into large irregularly shaped schools. Schools were usually largest (20 to 300 tons) and densest slightly before dawn. Time of school formation varied considerably from 6 hours to 20 minutes before dawn. Later in the year schools did not form until after daylight. Failure to form schools during hours of darkness became progressively more common until by January or February it was the dominant behavior.

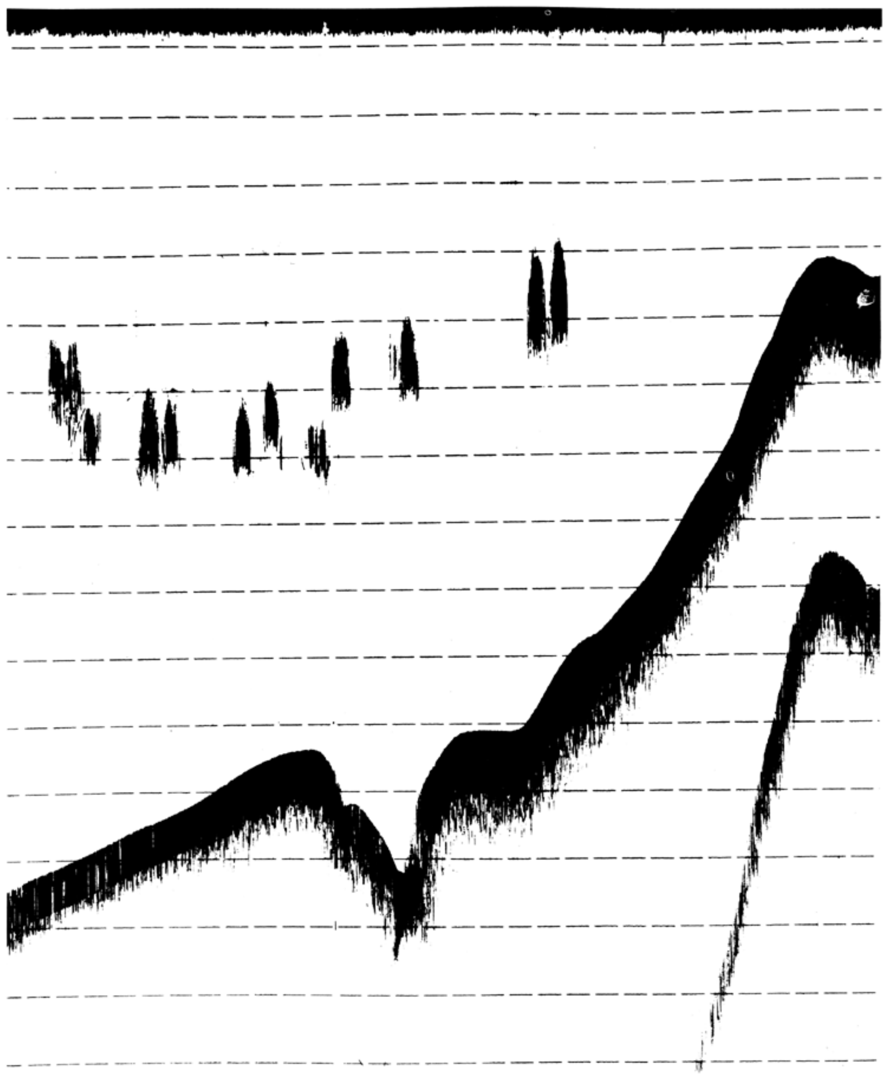

FIGURE 14. Echogram of daytime deep dwelling (146 to 219 m, 80 to 120 fathoms) anchovy schools, Santa Monica Canyon, October 26, 1969.

FIGURE 14. ***Echogram of daytime deep dwelling (146 to 219 m, 80 to 120 fathoms) anchovy schools, Santa Monica Canyon, October 26, 1969.***

Both day and night schools were unwary and were relatively easy to approach by surface vessel. Daytime schools were generally not dense enough for visual detection from aircraft and surface vessel. Sonar was the only effective method of detection.

Most of the commercial catch of southern California is made during the night phase of this behavior period. The day phase is generally fished in the winter when night schooling ceases. Although the overall occurrence of both phases of behavior is not common of the total anchovy population, it is the most favorable behavior for commercial exploitation.

Another similar schooling behavior was the formation of extremely large dense schools during daylight hours at depths ranging from 119 to 220 m (65 to 120 fathoms) below the surface (Figure 14). These schools were nearly always found along steep bottom gradients of submarine canyons and escarpments lying within 9.3 km (5 miles) of shore. Schools often exceeded an estimated 100 tons in biomass, and were frequently concentrated in relatively small areas producing localized superabundance. At dusk these schools rose rapidly to the surface and within 30 minutes dispersed into a heavy scattering layer (Figure

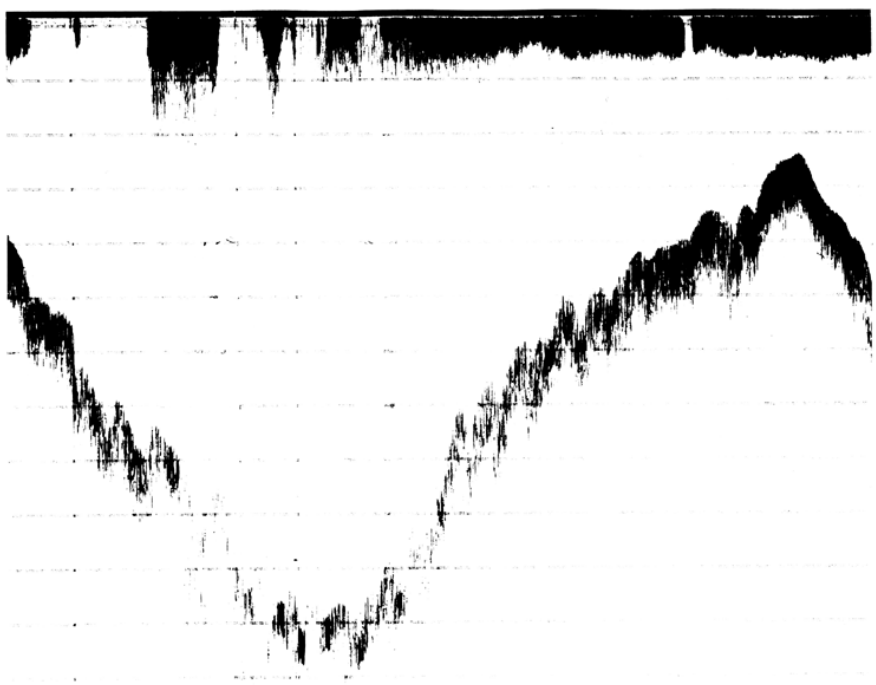

FIGURE 15. **Predawn behavior of anchovies in Santa Monica Canyon, October 27, 1969. Fish are schooled as dense surface layer (right), later forming compact defined schools (left). Dense compaction of schools on left is indicated by long light tail traces from bottoms of schools. Vertical scale is 36.6 m (20 fathoms) between dashed lines. Time span is 38 minutes.**

FIGURE 15. ***Predawn behavior of anchovies in Santa Monica Canyon, October 27, 1969. Fish are schooled as dense surface layer (right), later forming compact defined schools (left). Dense compaction of schools on left is indicated by long light fail fraces from bottoms of schools. Vertical scale is 36.6 m (20 fathoms) between dashed lines. Time span is 38 minutes.***

15). After midnight, schools again began to progressively form (Figure 15). Schools were generally largest and densest slightly before dawn. With the first light of dawn they rapidly submerged to daytime schooling depths. This type of schooling behavior is one of the most favorable for commercial exploitation. Predawn schools are large and easy to catch by purse seine, and sets exceeding 200 tons have occasionally been made on them. The chief disadvantage is the relatively short time (0.5 to 6 hrs.) they are on the surface and concentrated into fishable size concentrations. This type of behavior occurred only in relatively small localized areas and did not persist for more than a few weeks. While this behavior was observed mostly in the early fall months, it has been recorded in August along the northern Baja California coast and occasionally in spring with juvenile fish in southern California. It is not a common behavior but when it occurs it may be conducive to high fishing success.

Bathythermograph casts made to daytime schooling depths demonstrated temperature differences of 9.5 to 10.8 C (17.1 to 19.4 F) between the surface and schooling depth. The rapidity of vertical migration and the large differential in temperatures encountered indicate a eurythermal tolerance for anchovies.

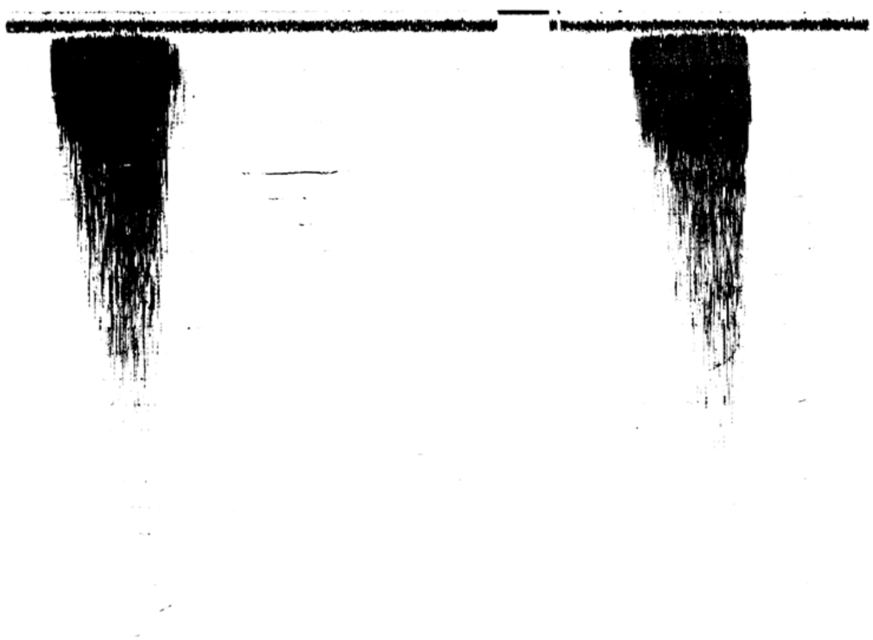

FIGURE 16. Echograms of a very large dense anchovy school on surface during daylight hours in spring, San Pedro Basin, May 1, 1969. This school was approximately 85 m (279 feet) in diameter. From aircraft and surface vessel it appeared as a conspicuous "black spot".

FIGURE 16. ***Echograms of a very large dense anchovy school on surface during daylight hours in spring, San Pedro Basin, May 1, 1969. This school was approximately 85 m (279 feet) in diameter. From aircraft and surface vessel it appeared as a conspicuous "black spot".***

Another schooling behavior was the formation in spring or early summer of dense schools at or near the surface during daylight hours. Schools of this type were generally not large in surface area or thickness but were extremely compact making them highly visible from aircraft and surface vessels. School thickness (Figure 16) usually ranged from 12 to 40 m (39 to 131 feet) with horizontal dimensions 10 to 100 m (33 to 328 feet). School sizes ranged from 10 to 1,000 tons as estimated by commercial fish spotters from aircraft. Schools of this type nearly always occurred during the spring or early summer months between March and late June and persisted from several weeks to 2 months. These dense surface schools were located over the deep water basins and channels adjacent to shore. Very few were observed more than 37 km (20 miles) offshore. Fish in these schools were generally of intermediate size and in a postspawning stage of sexual condition.

This type of behavior is the most favorable for commercial fishing since schools are large, easily located, and can be fished 8 to 14 hours per day. The chief disadvantage is their action inside the purse seine puts damaging strain and weight on the gear. For this reason the size of individual hauls must be limited to prevent gear damage. The success of the spring anchovy fishery depends heavily on this behavior which sometimes occurs after the present legal season closes or fails to appear completely.

A behavior often observed during daylight hours in the area of shallow flats between Ventura and Santa Barbara consisted of a loose extensive scattering layer in waters ranging from 18 to 91 m (10 to 50 fathoms) in depth (Figure 17). These scattering layers, often covering over 342 km^2 (100 miles^2) of surface area, were impossible to enumerate as schools or to measure quantitatively. After dark the fish remained scattered but were all on or near the surface. This behavior was observed during all seasons of the year. It was totally unfavorable for commercial harvest using present techniques.

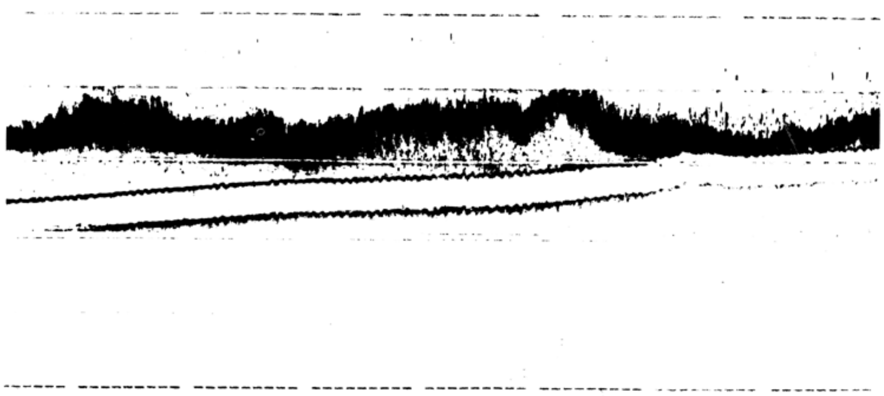

FIGURE 17. Echogram of anchovy layer near and on bottom in shallow water off Santa Barbara, daylight hours, November 1972. Depth scale is 18.3 m (10 fathoms) between dashed lines. Horizontal dimension is approximately 6.4 km (4 miles).

FIGURE 17. ***Echogram of anchovy layer near and on bottom in shallow water off Santa Barbara, daylight hours, November 1972. Depth scale is 18.3 m (10 fathoms) between dashed lines. Horizontal dimension is approximately 6.4 km (4 miles).***

Another similar behavior occurred over deep water. Daytime surface scattering layers with few or no discernible schools were infrequently monitored by both sonar and echo sounder. often only the echo sounder was effective in detecting fish exhibiting this type of behavior since target strengths of these aggregations were too weak for detection by sonar. The only summer survey in southern California waters found a considerable portion of fish in the more offshore areas behaving in this manner. Prospects for fishing them were nonexistent using present methods.

The last and least common behavior observed in southern California was the formation of dense schools in shallow inshore areas. These schools generally lay on or near the bottom in 18 to 91 m (10 to 50 fathoms) of water and were located out to 11.1 km (6 miles) from shore. Occasionally school groups appeared at the surface during daylight hours. At night all fish scattered until after midnight when reformation of fishable schools occurred. This type of behavior occurred infrequently and was observed mainly in the Ventura-Santa Barbara area in summer and fall.

Seasonal availability in southern California was usually greatest in early fall, reached a peak in October, and gradually declined until January or February when it abruptly diminished to a low level. After February when anchovies move southward and offshore for spawning, poor availability persisted for variable periods pending formation of the highly available daytime spring surface schools. In some years these schools appeared in the middle of March or early April and persisted through May. In other years they occurred in late May and June. Very recent observations (1972) found these schools occurring from the middle of June through the last week of July. There were 2 years, 1968 and 1971, when none appeared. Scanty data in the summer months indicate very poor availability except in northern Baja California where very good commercial schools were located in August 1969.

Overall availability varied considerably between years. In the fall of 1967 and spring of 1968, when anchovies were distributed more offshore than in other years, availability was very low. A poor commercial catch in southern California of only 1,503 tons during this period was attributed chiefly to this factor. During the spring of 1971 the large daytime schools which usually form at this time failed to appear resulting in complete failure of the spring fishery. Unusually high availability in the fall months of 1969, 1970, and 1971 resulted in record catches of 40,096 and 59,480 tons during this season in the first 2 years. A lower catch of 20,000 tons in the fall of 1971 was due to economic and shore plant pollution factors and not low availability of fish.

Areas of high availability were nearly always located within 37 km (20 miles) of shore from Dana Point to Santa Barbara. Occasional occurrences at Santa Catalina Island, San Nicolas Island, and San Clemente Island were the only more offshore observations of favorable availability. The areas offshore south of Newport Beach collectively

TABLE 2

Echo Sounder Trace Characteristics of Most Commonly Detected Species (Daytime only)

Depth to Bottom fm	Depth from Surface fm	School Thickness m	Horizontal Diameter m	Trace Density	Season Occurring	Habitat Type	Comments
				Anchovies			
10–50	10–30	4–20	100–1,000+	Light	Su. F.	Shallow flats	Forms extensive scattering layers.
10–50	10–30	10–35	10–100+	Various	Su. F. W.	Shallow flats	Various school densities, some commercial size.
60–350	60–125	15–50	30–100+	Heavy	Su. F.	Steep bottom slope	Mostly over escarpments and canyons.
80–700	0–20	4–18	100–1,000+	Light	Sp. Su.	Open sea	Forms extensive scattering layers.
" "	0–30	4–15	5–30	Light	All	Open sea	Most prevalent during spring, most common.
" "	" "	12–40	25–100+	Moderate	F. W.	Open sea	Fairly common, but difficult to exploit.
" "	" "	" "	15–100+	Dense	Sp. Su.	Open sea	Occurs irregularly, optimum for exploitation.
				Jack mackerel			
0–50	5–40	18–40	10–100+	Moderate	F. W. Su.	Rocky banks and island coasts	Concentrates in quantity at relatively few locations.
80–700	0–10	4–10	5–20	Light	Su. F.	Open sea	Small juveniles only, found under floating kelp.
				Pacific hake			
25–100	15–100	3–6	--	Light	Su.	Coastal flat bottom	Forms discontinuous layers, echograms resemble groups of detached sawteeth.
300–450	125–160	" "	--	Light	Sp.	Open sea	
				Market squid			
10–250	6–50	30–40	70–200	Light	Sp. F.	Shallow flats, deep sea basins	Echograms cloudlike.
				Red crab			
6–40	0–35	8–20	--	Light	W. Sp.	Shallow bays	Also found over deep water but usually not dense enough to be recorded, echograms cloudlike.

TABLE 2

Echo Sounder Trace Characteristics of Most Commonly Detected Species (Daytime only)

contained the largest amounts of fish, but availability was consistently low. Surveys conducted concurrently with commercial fishing operations often indicated relatively small quantities of fish may be highly available while nearby much more extensive concentrations are unfished due to poor availability.

School Measurements Horizontal and vertical measurements were made by echo sounder and sonar. School shapes are known to vary tremendously and cannot be readily determined by acoustic measurement. Information gained by monitoring and acoustically measuring schools that were subsequently captured by a purse seine vessel or assessed biomass by an expert aerial spotter, strongly indicated that physical measurement of anchovy schools is an unreliable indicator of biomass without a good measure of density. Sonar records of schools of known biomass did not reflect the great differences which existed between schools. A sonargram of a 500 ton school did not appear significally different from one of similar surface area containing only 25 tons. The dense surface schools that sometimes occur in spring contain much larger quantities of fish than other schools of far larger surface area. However, the vast majority of schools observed on surveys were of relatively low density. Furthermore within a given area and time period, schooling densities varied only slightly. Observations of these schools from the surface, underwater viewing ports, and by diving produced subjective density estimates ranging from 25 to 100 fish per m^3 (1.31 yd^3). These schools appeared as a loose aggregation of individual fish with no well defined school outline, shape, or color. Normally they could be observed only when the vessel was directly over them or very close by. Observation from aircraft was generally not possible. Dense schools appeared as a solid mass of fish producing a well defined shape and a dark color contrast against the sea background. These schools could sometimes be seen at distances of .9 km (0.5 mile) from the vessel and were very observable from aircraft. Density of these schools was exceedingly difficult to assess by visual observation, but appeared to be 5 to 10 times greater than the sparse schools.

School diameter measurements of sonargrams perpendicular to the vessel's course were made on 22,834 anchovy schools detected during 1966 to 1971.

It was impossible to make precision measurements due to the poor resolution produced by small recording paper size (130 mm; 5.12 inches) and the long range used (1,500 m; 4,921 feet). The echogram of a 35 m (115 feet) diameter school measured only 4 mm (0.16 inch) on the recording paper. A bias of measurements favoring the nearest 10 or 20 m (32.8 or 65.6 feet) resulted.

Diameters ranged from 5 to 385 m (16 to 1,263 feet), but 82.8% were less than 36 m (118 feet), and 14.2% were in the 36 to 85 m (118 to 279 feet) range. Only 3.0% were greater than 85 m (279 feet). The mean diameter of all schools (Table 3) was 29.39 m (96.4 feet). Surprisingly, diameters between the different survey regions varied only slightly with means of 27.2, 29.7, and 24.8 m (89.2, 97.4, and 81.4 feet) in central California, southern California - northern Baja California, and central and southern Baja California respectively. Greater differences were found between seasons of the year with the largest diameters occurring in fall and the smallest in spring. Means for fall, winter, spring, and summer were 34.47, 27.19, 23.63, and 29.30 m (113.1, 89.2, 77.5, and 96.1 feet) respectively. Nearly 90% of spring schools were smaller than 40 m (131 feet) with the largest percentage of schools in the 5 to 15 m (16.4 to 49.2 feet) size class (Table 3). Fall schools were most numerous in the 31 to 40 m (101.7 to 131.2 feet) size class and with 76.89% (Table 3) smaller than 40 m (131.2 feet). School diameters for individual surveys did not vary appreciably from the overall frequency distribution.

TABLE 3

Anchovy School Diameter Frequency Distribution

Size Class m	Spring		Summer		Fall		Winter		Total	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%	Freq.	%
1– 10	1,601	26.49	654	16.80	1,379	15.76	1,022	24.65	4,656	20.39
11– 20	1,481	24.50	1,255	32.24	1,597	18.25	917	22.11	5,250	22.99
21– 30	1,017	16.81	500	12.84	1,477	16.88	711	17.14	3,705	16.23
31– 40	1,333	22.04	779	20.02	2,275	26.00	910	21.94	5,297	23.18
41– 50	214	3.53	197	5.06	466	5.33	152	3.67	1,029	4.51
51– 60	131	2.17	147	3.78	392	4.48	123	2.97	793	3.47
61– 70	63	1.04	70	1.80	207	2.37	48	1.16	388	1.70
71– 80	53	0.88	46	1.18	169	1.93	50	1.21	318	1.39
81– 90	86	1.42	120	3.08	412	4.71	96	2.31	714	3.15
91–100	9	0.15	19	0.49	59	0.67	23	0.55	110	0.48
101–110	13	0.22	20	0.51	57	0.65	16	0.39	106	0.46
111–120	7	0.12	12	0.31	41	0.47	12	0.29	72	0.32
121–130	9	0.15	7	0.18	31	0.35	12	0.29	59	0.26
131–140	18	0.30	31	0.80	82	0.94	27	0.65	158	0.69
141–150			4	0.10	18	0.21	10	0.24	32	0.14
151–160	4	0.07	3	0.08	9	0.10	2	0.05	18	0.08
161–170	2	0.03	4	0.10	20	0.23	2	0.05	28	0.12
171–180	1	0.02	5	0.13	6	0.07			12	0.05
181–190			2	0.05	21	0.24	5	0.12	28	0.12
191–200	1	0.02	9	0.23	11	0.13	2	0.05	23	0.10
201–210	2	0.03	2	0.05	12	0.14	1	0.02	17	0.07
211–220			2	0.05					2	0.01
221–230			1	0.03	1	0.01	3	0.07	5	0.02
231–240			1	0.03	1	0.01			2	0.01
241–250					2	0.02			2	0.01
251–260					1	0.01			1	0.01
261–270										
271–280					1	0.01			1	0.01
281–290					1	0.01	1	0.02	2	0.01
291–300										
301–310										
311–320					1	0.01			1	0.01
321–330										
331–340			1	0.03			2	0.05	3	0.02
341–350										
351–360										
361–370										
371–380										
381–390			1	0.03	1	0.01			2	0.01
391–400										
Total	6,045		3,892		8,750		4,147		22,834	
Mean	23.63		29.30		34.47		27.19		29.39	
Std. Dev.	19.81		28.15		30.24		26.28		27.08	

TABLE 3

Anchovy School Diameter Frequency Distribution

Accurate school thickness measurements were much more difficult to obtain due to vessel avoidance behavior and uncertainty in passing directly over schools with the echo sounder. Studies using sonar to position the vessel directly over schools and diver observations indicate thickness within the same school may vary by as much as a factor of 2. Data from voluminous echogram records indicate anchovy school thickness ranges from 4 to 65 m (13 to 213 feet) with a mean of about 12 m (39.4 feet). The true mean is probably higher due to vessel avoidance behavior.

School Biomass Without a good measure of anchovy school density, shape, and thickness, estimates of biomass are apt to be erroneous. Nevertheless, knowledge of the commercial fishery operation is of value in setting an upper limit on mean school biomass. Commercial fishermen generally attempt to capture schools of 20 tons and larger. Extensive acoustic survey experience both within and outside the fishery very strongly indicates only a very small proportion of anchovy schools are larger than 20 tons, and the average school must be considerably smaller than this size. School size estimates by aerial fish spotters during 1962–1969 indicated a mean of 36.5 tons (Squire, 1972). This is probably a good estimate of mean commercial size. Our extensive acoustic and visual experience strongly indicates more than 90% of all anchovy schools are not visible from the air and are much smaller in biomass than the ones that are.

A highly successful survey in southern California waters during the fall of 1972 was analyzed in detail to estimate population biomass. Every school detected in each 20 minute grid was measured for diameter and its surface area calculated. Sonar effective ranges, transect lengths, and the sum of school areas were utilized to estimate the total area within the grid occupied by anchovy schools. A volume was calculated by applying the mean school thickness of schools in the grid detected by echo sounder. Grid volumes were summed to estimate the total volume of anchovy schools in the southern California region.

Estimates of the number of fish occupying this volume were made using 50 and 75 fish per m^3 (1.31 yd^3) as the most likely school densities. Total biomass was then estimated using a mean fish length (converted to weight) derived from midwater trawl catches made during the survey. Biomass estimates for the two densities were 1,522,000 and 2,283,000 tons. An average school biomass of 8.65 tons resulted using the lower density factor and 13.00 tons with the higher density. Assuming schools were round cylinders, of mean thickness, and the total estimate of 175,882 schools was fairly accurate, the density figure of 50 fish per m^3 is probably more reflective of actual density when compared to the occurrence of minimum commercial sizes. The mean diameter and thickness of the 7,884 schools measured was 32.12 m (105.38 feet) and 10.88 m (35.7 feet) respectively. The mean school biomass using 50 fish per m^3 and the average weight per fish from trawls was an estimated 7.11 tons, and an estimated 10.66 tons for 75 fish per m^3. Our best estimate of mean anchovy school biomass for this 1972 fall survey was between 7 and 9 tons.

Size Composition and Age at Length Length frequency data were obtained from 474 samples taken in southern California and northern Baja California by midwater trawl from 1966 to 1971. A total of 12,231 fish measured produced a mean of 120 mm (4.72 inches) SL. A histogram of length frequencies from these data was unexpectedly normal shaped and symmetrical about the mean for a short lived fish like the anchovy which is subject to a high natural mortality rate (Figure 9). Small fish comprised only a slightly larger proportion of the distribution than the largest fish. One would expect a pronounced left skewed distribution for a species that has an annual mortality rate of approximately 66% (MacCall, 1973). The shape of the curve for our distribution strongly indicates undersampling of small or young fish. Length frequencies of the commercial catch in southern California for the same time period as our surveys demonstrated a lower portion of small fish (14.6% vs 28.9%) and a slightly lower percentage of larger fish (23.5% vs 27.6%). A minimum legal size limit of 5 inch TL (approximately 105 mm SL) was responsible for the difference in small fish.

Midwater trawl length frequency data were compiled into 20 minute grids of latitude and longitude. Analysis of these data demonstrated a definite onshore-offshore size distribution with larger fish more prevalent offshore and smaller fish favoring inshore areas. Anchovies in grids contiguous with the coast (approximately 0 to 18.5 km, 0 to 10 miles, offshore) averaged 112 mm (4.41 inches) SL. Grids bordering these coastal grids (18.5 to 37.0 km, 10 to 20 miles, offshore) contained anchovies averaging 119 mm (4.69 inches) SL, and fish in those 33.8 to 161 km (20 to 100 miles) offshore averaged 130 mm (5.12 inches) SL (Figure 18). The commercial fishery normally operates within 37 km (20 miles) of the coast and therefore does not exploit the larger older fish inhabiting offshore areas.

Ages were determined for 2,641 fish comprising 304 samples taken during 1966 through 1971. Anchovy age composition for this period was 5.1% age zero; 24.9%, 1 year old; 33.6%, 2 years old; 21.9%, 3 years old; 10.9%, 4 years old; 3.0%, 5 years old; and 0.6%, 6 years old. The low proportion of zero and 1 year old fish is evidence of undersampling of these age groups. Age composition of the southern California commercial catch during the same time period contained higher percentages of these two age groups (15.5 vs 5.1% and 30.6% vs 24.9% respectively) and lower percentages of 3, 4, 5, and 6 year old fish (14.0 vs 21.9%, 3.2 vs 10.9%, 0.4 vs 3.0% and 0.1 vs 0.6% respectively). The difference in young fish cannot be logically explained; however, the difference in older fish is attributed to their more offshore distribution which is beyond the present range of the commercial fishery. Since our surveys encompass a much larger area than the commercial

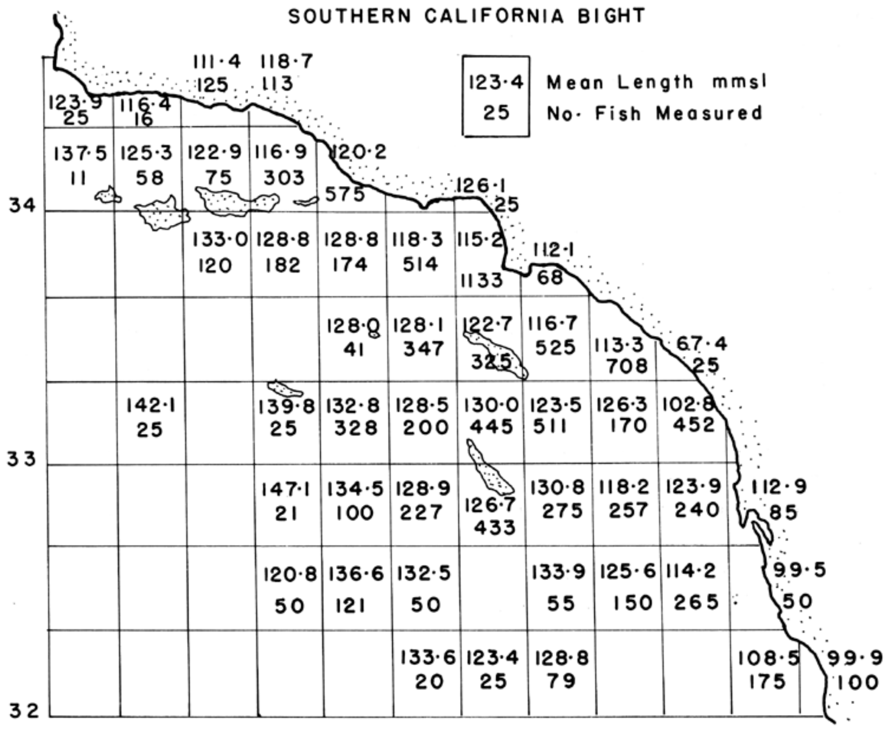

FIGURE 18. Mean standard lengths of anchovy trawl catches by 20 minute grids.

FIGURE 18. ***Mean standard lengths of anchovy trawl catches by 20 minute grids.***

fishery, age data thus obtained should be more representative of the true age composition of the anchovy population except for the younger age groups.

Age at length data indicate southern California - northern Baja California anchovies are second only to central California fish in growth rate and size at a given age. A 1 year old fish averaged 115 mm (4.53 inches) SL, and a mean of 149 mm (5.87 inches) SL was attained by age 6 (Figure 10). As noted in other anchovy age-length studies (Collins and Spratt, 1969) considerable overlap of ages at a given length was present. Age-length data of the southern California commercial catch were compared with that of sea surveys. Both agreed closely except age zero sea survey fish were 13 mm (0.51 inch) smaller. This difference is undoubtedly due to the commercial minimum size limit which restricts capture of fish smaller than 105 mm (5 inches TL) SL. Sea survey sampled fish 5 and 6 years old which were slightly larger than commercially caught fish due to the more offshore distribution of large old fish which were sampled more heavily.

Spawning Evidence of anchovy spawning was observed during all months of the year during which cruises were conducted; however, the peak months were February through May. A minimum of spawning activity was observed during September and October. Sexual maturity data were collected from the 3,290 female fish taken by midwater trawl from 1966 to 1971. These data were classified into seven subjective stages of sexual condition which were: Stage 1, resting or immature; Stage 2, eggs small, unyolked; Stage 3, eggs small, yolked; Stage 4, eggs large, yolked; Stage 5, some eggs clear; Stage 6, ripe, eggs clear, loose, ovaries greatly distended; Stage 7, spent, ovaries sac-like, empty.

Stage 1 was the most prevalent comprising 32.4% of all observed fish, and Stage 7 was the least common with 2.7%. Stages 2 to 6, which are indicative of spawning activity, comprised 22.2%, 20.4%, 14.2%, 4.1%, and 4.0% respectively of all observed fish. The low percentages of the most advanced stages are probably due to the very short duration of these stages, perhaps several hours, immediately prior to spawning.

A study of the relationship of surface temperature to sexual development indicates a pronounced peak of spawning activity occurs in a range 13.5 to 14.0 C (56.3 to 57.2 F). The four most developed stages (3 to 6) were combined and their percent occurrence plotted by 0.5 degree intervals (Figure 19). The same was done for the ripe stage only and the resting stage. The combined group and the ripe stage peaked very sharply at 13.5 to 14.0 C with minor peaks at 15.5 to

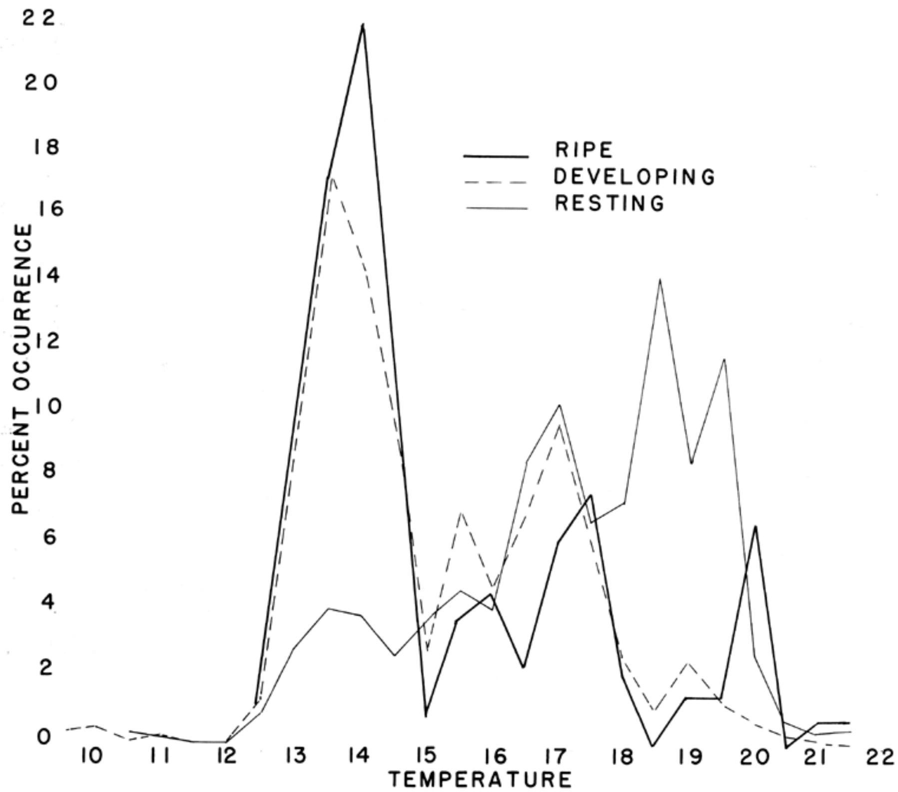

FIGURE 19. **Sexual maturity stages of anchovy trawl catch plotted against sea surface temperature.**

FIGURE 19. ***Sexual maturity stages of anchovy trawl catch plotted against sea surface temperature.***

16.0 C (59.9 to 60.8 F) and 17.0 to 17.5 C (62.6 to 63.5 F). The ripe stage also exhibited a minor peak at 20.0 C (68.0 F). The resting stage predominated in waters warmer than 16.0 C (60.8 F). Low percentages below 12.0 C (53.6 F) and above 20.5 C (68.9 F) are due to the infrequent occurrence of these temperatures in southern California.

Fish that were actively spawning at time of capture were invariably found in the small wary surface schools which predominate during the late winter and spring months. Many samples of these fish had highly unequal sex ratios with no particular sex consistently dominating. Ratios for any one sex ranged from 1:9 to 11.5:1 with 32.8% of the samples comprised of more than 70% of one sex. However, the overall average ratio of the 63 spawning samples was very close to 1:1.

5.1.4. Central and Souther Baja California

Relative Abundance Anchovy abundance in this region rated between the very low abundance of central and northern California waters and relatively high abundance in southern California - northern Baja California. Approximately 24.1% of the estimated mean number of anchovy schools in the three major areas under study were located in this region.

Due to schooling behavior, assessment of abundance by acoustic surveys was more difficult and subject to greater error than in other regions. Anchovies in central and southern Baja California very often do not form defined schools which can be distinguished and enumerated by sonar or echo sounder. Many of those that were well defined were located over shallow water where sonar is less effective. There was a scarcity of schools larger than 50 m (164 feet) in diameter, and a fish size composition that was only about one-third the mean weight of California anchovies. The total effect of these factors probably result in an underestimation of anchovy abundance in this region.

The seven acoustic surveys conducted in central and southern Baja California waters produced highly varied results. A survey in March 1968, when schooling behavior was optimum for acoustic survey, produced the highest estimate of school numbers which was four times larger than that of the second highest survey and 20 times greater than the lowest. In addition, school sizes were considerably larger than found on most other surveys in this region.

Echo sounder detection rates per survey ranged from 0.05 to 0.81 schools per mile sounded. The grand mean computed from the total distance sounded and schools detected on all seven surveys was 0.25 schools per mile. This compares with means of 0.13 and 0.51 for the Central California and southern California - northern Baja California regions respectively. The largest number of schools detected by echo sounder on any survey was 663, the second largest was 166, and the least 46.

Sonar results were less variable with a school density range of 0.71 to 3.76 schools per mile^2 for individual surveys when sonar was in use (1969–73). Estimates for presonar surveys (1966–1968), computed from an echo sounding conversion factor, ranged from 3.07 to 17.52 schools per square mile. The largest number of schools detected on any survey was 879 and the lowest 173. By comparison ranges in central California and southern California - northern Baja California were 214 to 360 and 696 to 11,476 respectively (Table 1).

Estimates were made of the total schools in the region per survey based on school densities per square mile as determined by sonar. These estimates ranged from 9,907 to 197,130 anchovy schools (Figure 6) distributed over a mean survey area of 38,761 km^2 (11,301 miles^2). A mean estimate for the seven surveys was computed by weighting each individual survey estimate by the number of square miles encompassed by that survey. The mean thus computed was 53,130 schools which compares to similar means of 9,142 and 150,996 schools for the central California and southern California - northern Baja California regions respectively.

Distribution The bulk of the anchovy population in central and southern Baja California was distributed along a narrow coastal band in shallow "flats" and bays. Over 85% of all schools were detected within 55.6 km (30 miles) of shore over bottom depths of less than 183 m (100 fathoms). The greatest concentrations were consistently located in areas of upwelling. These areas included Punta Baja to Punta Canoas, Cedros and San Benitos Islands, Punta Eugenia to Ballenas Bay, and Cabo San Lazaro to Punta Tosco (Figure 20). The southern limit of the northern anchovy's range was established approximately 185.2 km (100 miles) north of the tip of the Baja California Peninsula.

The best and largest concentrations were found in the northernmost sector from Punta Baja to within 37 km (20 miles) of Cedros Island, an area of major upwelling. Acoustic transects in this area produced detection rates averaging 3.60 schools per mile^2 for sonar and 0.62 school per mile sounded for echo sounding. Maximum rates ranged to 33.90 and 2.24 for respective equipments. Most of the record number of schools detected by a survey in March 1968 were located in this area. Incidental acoustic search during a cruise in September 1972 in this area discovered an exceptionally large concentration (Shainberg and Pedrin 1974). School sizes were larger and located more offshore than any other area of central and southern Baja California.

Anchovy concentrations from Cedros Island southward were generally smaller in both school numbers and school sizes. Sonar and echo sounder detection rates averaged 3.12 and 0.24 schools per mile sounded with maximums of 17.70 and 3.78 respectively. Most of the fish within this area were located within 27.8 km (15 miles) of the coast in waters shallower than 110 m (60 fathoms). Areas of local abundance were Ballenas Bay, San Hippolito Bay, Asuncion Bay, San Cristobal Bay,

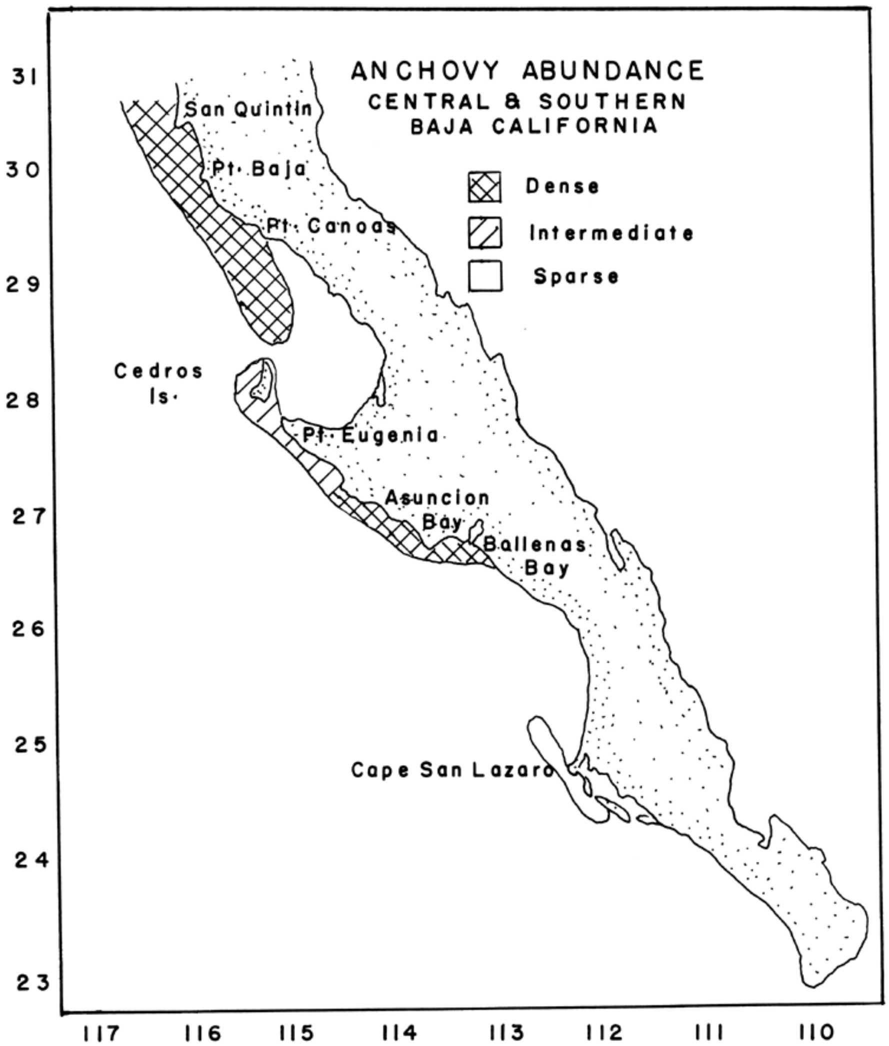

FIGURE 20. Principal areas of anchovy abundance in central and southern Baja California.

FIGURE 20. ***Principal areas of anchovy abundance in central and southern Baja California.***

and the immediate vicinity of Cedros and San Benitos Islands. Several surveys also detected small nearshore concentrations outside Santa Maria and Magdalena Bays in the far south.

Exceptions to inshore distribution were a record offshore occurrence located 306 km (165 miles) west of Magdalena Bay in May 1971 and a 55.6 to 92.6 km (30 to 50 miles) offshore distribution west of San Juanico Bay in September 1966. Schools in the former area were comprised of 95% Panama lightfish, Vinciguerria lucetia, and 5% postlarval anchovies. Fish in the latter area were located in waters over 183 m (100 fathoms) deep and were presumably avoiding the extremely warm inshore waters in that area.

Seasonal distribution was considerably less variable than in other survey regions. The only notable difference within the central and southern Baja California region was a more offshore distribution in the spring months which was most pronounced on the March 1968 survey.

School Behavior and Availability Schooling behavior in this region was considerably different than in any other survey region. Defined compact schools were very uncommon especially in southern Baja California. The prevalent schooling behavior during daylight hours was a very loose aggregation of fish resembling a layer rather than a school. These aggregations were commonly found on or near the bottom in waters shallower than 110 m (60 fathoms). often these schools were located on the surface in shallow bays and "flats" where they formed a scattering layer covering up to 342.5 km^2 (100 $miles^2$) of surface area. Enumeration of these concentrations by sonar and echo sounder was very difficult as no separate or defined schools could be distinguished on the echograms. At night anchovies were even more dispersed on the surface with no defined schools visible. Nearly all anchovies detected or observed in the fall and summer behaved in this manner.

There was some evidence of moderately defined surface schools during early spring in the northernmost sector where anchovy behavior was somewhat similar to that of the southern California - northern Baja California region. The survey in March 1968 found large numbers of daytime surface schools 27.8 to 55.6 km (15 to 30 miles) offshore in the Punta Canoas area in the far northern sections of this survey region. Some of these schools were of commercial size and could have been fished by round haul net. Surveys in May and June 1971 found some large compact schools both on the bottom and surface during daylight hours. Some of these schools also were located on the surface between midnight and dawn. School sizes ranged from an estimated 25 to 300 tons, and were the only other schools that could have been fished commercially that were detected by our surveys.

Based on the results of surveys made thus far, the general availability of anchovies must be rated very poor compared to other regions surveyed.

The prevailing nonschooling behavior is completely unfavorable for purse seine fishing, and favorable behavior patterns occur infrequently. For these reasons the prospects are dim for development of a major commercial fishery in central and southern Baja California. An unrelated equally important detriment is the small size of fish. The mean size of anchovies in this region was 87 mm (3.43 inches) SL which is well below optimum for present California processing methods in canning and reduction.

Subpopulations Anchovy length frequency-age data consistently have indicated a gross difference between fish from Baja California and regions to the north. The geographical demarcation, which is rather sharp, is located between lats 29 and 30° N off central Baja California. The data indicate fish south of this line are much smaller for their age, shorter lived, and attain less maximum length than anchovies in northern Baja California and California waters.

All length frequency and age data from south of lat 28° 30' and southern California (lats 32° 20' to 34° 30' N) were compared. Each of these regions was represented by a large number of samples taken over a 5.5 year period. Length frequency data were taken from 474 samples (12,231 fish) caught in southern California and from 96 samples (2,332 fish) taken in Baja California. The length frequency comparison by itself demonstrated an obvious size composition difference. The mean standard length for the combined southern California fish was 120 mm (4.7 inches) and 87 mm (3.4 inches) for the Baja California fish. The ranges for these regions were 35 to 176 mm (1.4 to 6.9 inches) and 55 to 125 mm (2.2 to 4.9 inches) SL respectively (Figure 9). of all Baja California fish measured, less than 10% exceeded the California commercial minimum size limit of 5 inches TL (106 mm SL) while 79% of southern California surpassed or equaled this limit.

A T test of grand means between the two regions indicated a significant difference (P = <0.5%). The concept of overlap developed by Royce (1957) was used to estimate the amount the two length frequency distributions overlapped each other. The calculated overlap was 33.8% (i.e.) the percentage of one distribution that was included in the other. This low degree of overlap is a strong indication of separate subpopulations. By contrast length frequency distributions of southern and central California fish overlapped 94.2%.

The weight difference between these two groups is more pronounced than that of length. Length-weight formulas developed for southern California anchovies by Messersmith (1969) were used to convert standard length to weight. Baja California fish mean weight per fish was estimated at 6.8 g (0.24 oz) and southern California fish at 18.2 g (0.64 oz). Thus it would require approximately 2.7 times as many Baja California fish to equal the same biomass of southern California fish.

A total of 72 samples (602 fish) from Baja California fish and 304 samples (2,641 fish) from southern California was combined in an age-length comparison of the two regions. Baja California anchovies were grossly smaller than those of the same age from southern California. Differences were greater in the older age groups especially 3, 4, and 5 year old fish. Age 0 fish differed the least with central and southern Baja California fish averaging 78.0 mm (3.07 inches) SL and southern California - northern Baja California fish 93.4 mm (3.68 inches) SL. Five year old fish from respective regions averaged 94.0 and 146.6 mm (3.70 to 5.77 inches) SL (Figure 21). Baja California fish apparently attain near maximum length by age 3 while southern California fish exhibit considerable growth past this age. The Baja California group contained fewer fish in the older age groups. Only 6.1% were more than 3 years old compared to 14.5% of the southern California fish.

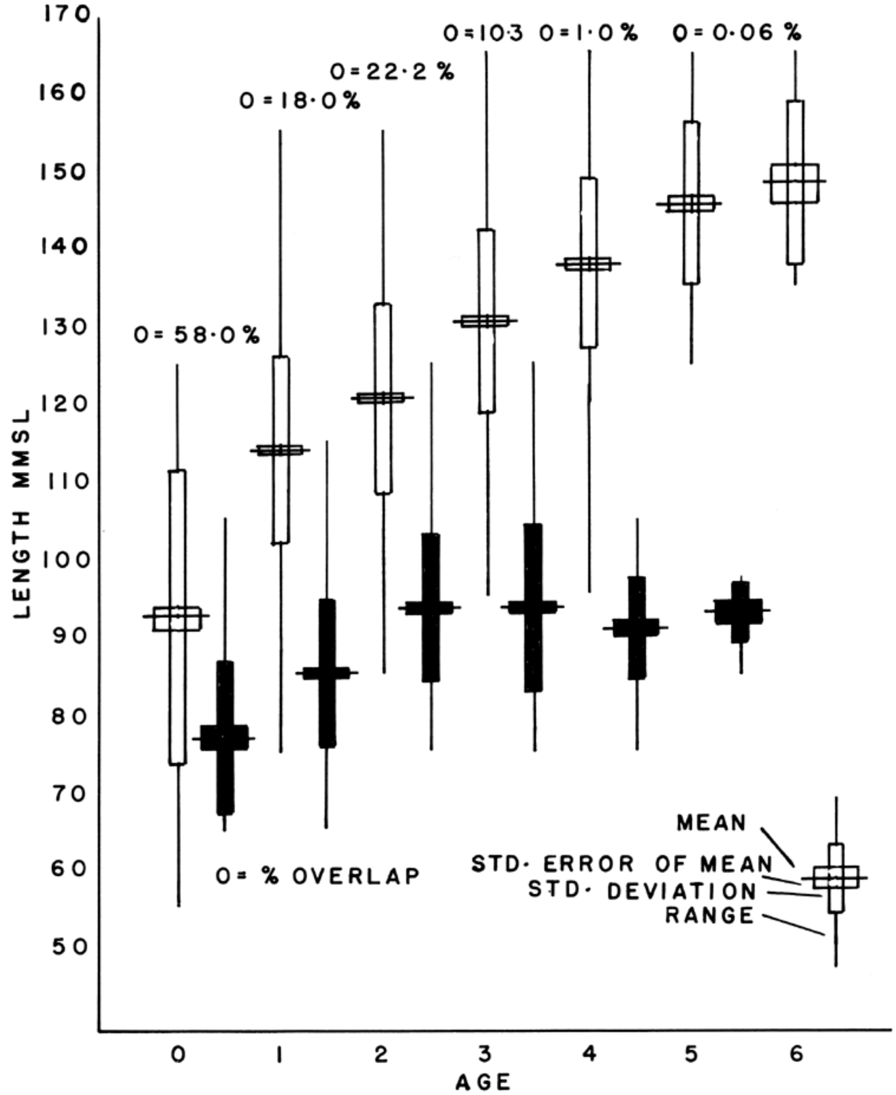

FIGURE 21. Anchovy trawl catch size and length data from southern California (open bars) and central and southern Baja California (solid bars). Overlap of length frequency distributions of the same age groups indicated by "0".

FIGURE 21. ***Anchovy trawl catch size and length data from southern California (open bars) and central and southern Baja California (solid bars). Overlap of length frequency distributions of the same age groups indicated by "0".***

Gonad maturity observations made during peak spawning season (January–June) indicated southern California anchovies spawn over a longer period of time and peak much later than Baja California fish. Data from four surveys in each region showed southern California-northern Baja California female ovary development peaked in April but was spread over the entire January through June period. Central and southern Baja California fish peaked in January and rapidly diminished to near zero by June. All southern California female fish in a ripe running condition were greater than 100 mm (3.9 inches) SL and all corresponding Baja California fish were smaller.

The obvious differences between Baja California and California anchovies and the wealth of supporting data are conclusive evidence of distinct subpopulations. Blood genetic and morphometric studies by Vrooman and Paloma (National Marine Fisheries Service, pers. commun.) and otolith weight-age comparisons by Spratt (1972) also strongly indicate separate subpopulations inhabiting these regions. The exact degree of intermingling of these two populations in California waters is unknown, but the low overlap percentages of length frequency and age-length distributions indicate very little, if any, mixing occurs. The contribution of the central and southern Baja California population to the present California fishery would be insignificant even if 100% mixing occurred since the commercial minimum size limit would exclude over 90% of the fish in these stocks. For these reasons it appears highly unlikely this population is harvested by the California fishery. The quantity of anchovies belonging to the California population that ranges into northern Baja California appears to vary seasonally and annually. Recent surveys indicate perhaps as much as 65% may migrate into this region for short periods of time during late winter and early spring.

5.2. Jack Mackerel

5.2.1. Survey Effectiveness

Acoustic-midwater trawl surveys have proved ineffective for any realistic assessment of jack mackerel resources. The chief obstacles have been extreme difficulty in locating and identifying schools in the open sea during acoustic transect surveys, and obtaining representative samples of the population by midwater trawl.

Our acoustic survey experience, commercial catch locality information, and interviews with fishermen all indicate jack mackerel school distribution is extremely patchy. Acoustic surveys could locate and identify schools only over localized rocky banks or in shallow waters immediately adjacent to islands and the mainland coast. The San Pedro wetfish commercial fleet with greater scouting and detecting capabilities which include aircraft fish spotters has only very rarely located and captured jack mackerel in the open sea. Apparently schools are too deep or are schooled too loosely to detect or identify. Jack mackerel may not form detectable sized schools in the open sea or their schools may persist for only short time periods in open waters. The extremely patchy distribution of schools greatly reduces the effectiveness of our acoustic transect surveys which systematically cover a large general area. Commercial catch-effort information would be far more reliable in assessing the resource than acoustic-midwater trawl surveys.

The adequacy of sampling the jack mackerel resource by midwater trawl is unknown, but is very likely subject to considerable error. Trawl avoidance was directly observed on several occasions when large schools were trawled upon during daylight hours. In these instances jack mackerel were completely successful in escaping capture. Low numbers of fish captured per tow may be indicative of successful avoidance. Half of the catches made in southern California with our large midwater trawl contained only one to five fish and 80% took less than 32 fish. Poorer catches were made with the smaller trawl (Figure 22).

Size composition of trawl caught fish differed greatly from commercial purse seine catches. In southern California the trawl took mostly small juveniles and postlarval fish (35–160 mm, 1.4 to 6.3 inches, FL) while the commercial fishery captured larger juveniles 130–290 mm (5.1 to 11.4 inches) FL (Figure 23). This difference may be due to more effective trawl avoidance by the larger fish, or may represent a separation of sizes by area since the commercial fishery operates strictly over banks and in nearshore areas while most of our trawls are made in open offshore waters.

5.2.2. Relative Abundance

Acoustic results were too few and scattered to make any rational assessment of relative abundance. Despite the limitations and inadequacies of midwater trawl surveys, some information was gained on relative abundance between survey regions.

Jack mackerel were second only to anchovies in frequency of occurrence in midwater trawl catches. of 1,375 trawl tows completed, they occurred in 19.1% compared to 70.8% occurrence of anchovies (Figure 5). The frequency and size of trawl catches gave some indication of relative abundance between regions. The data indicate the southern California - northern Baja California region ranks first in jack mackerel abundance, the central and southern Baja California region is a poor second, and central California a very poor third (Figure 8). Data from northern California waters were too scanty for rational assessment.

The highest catch rates and largest catches were made in southern California-northern Baja California waters where jack mackerel were taken in 22% of 860 tows (Figure 8). Catches were also much larger relative to other regions with 20% containing 32 to 700 fish (Figure 22). The central and southern Baja California region ranked second with 16.4% occurrence in 275 tows. Catches were considerably smaller with the majority consisting of only one fish and a maximum of 80. The central California region had the poorest catches both in frequency and size. Only 8.2% of the 206 tows contained jack mackerel, and the largest catch was 15 fish. The highest actual occurrence was in northern California waters where 26.5% of the tows were successful, however, only 34 tows were completed and catches consisted of one to six postlarval fish.

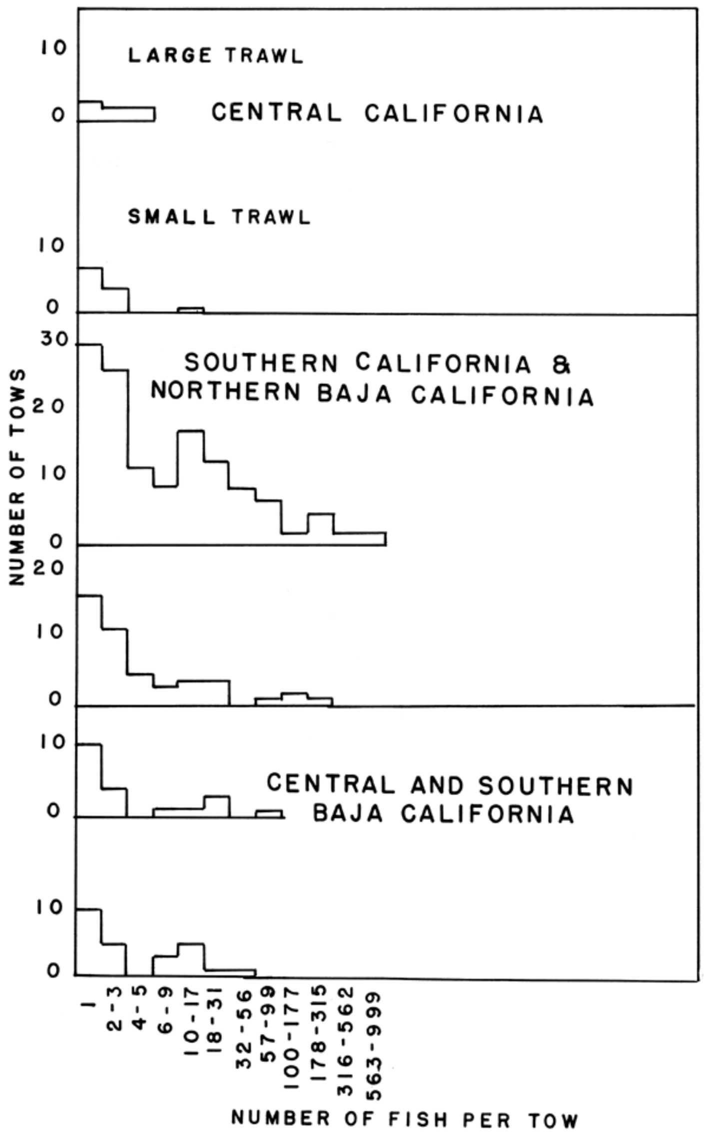

FIGURE 22. Jack mackerel catches by survey region and trawl size.

FIGURE 22. ***Jack mackerel catches by survey region and trawl size.***

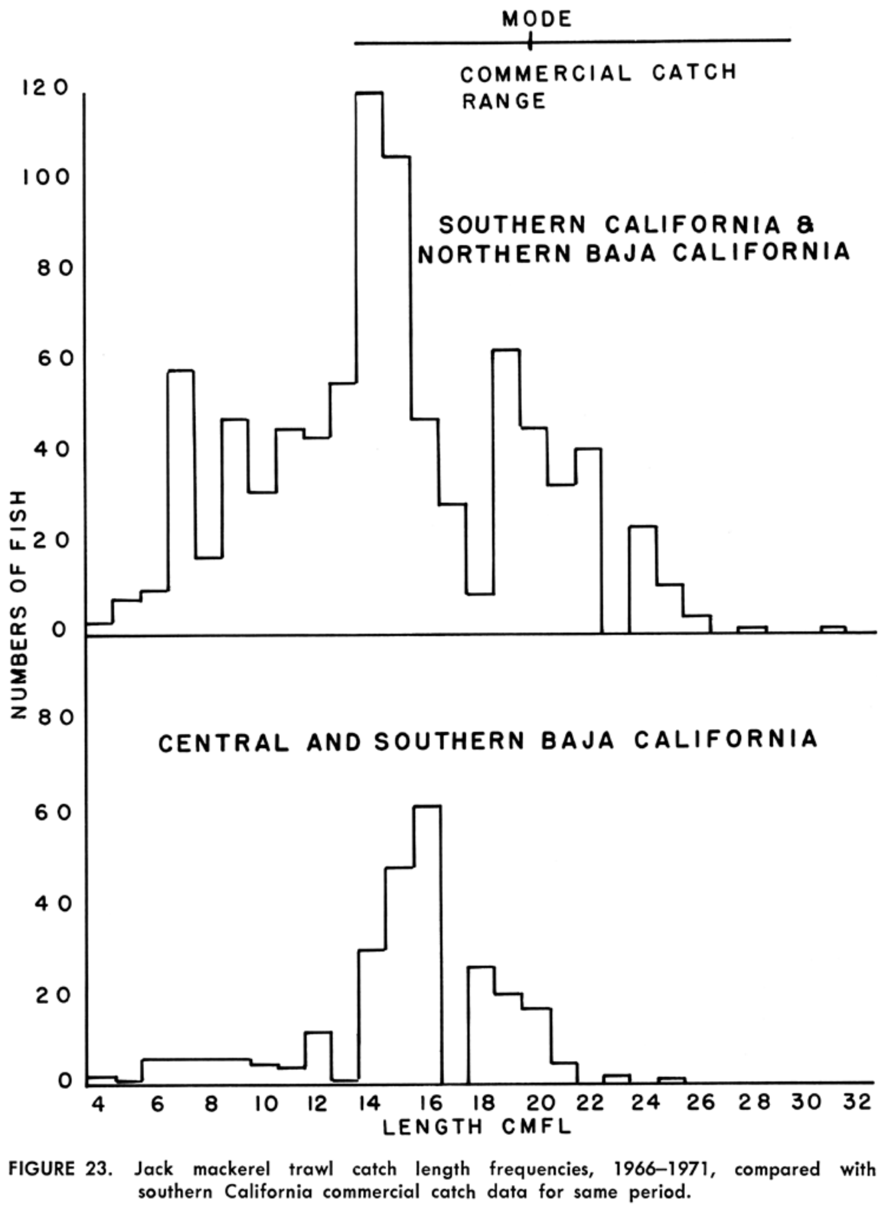

FIGURE 23. ***Jack mackerel trawl catch length frequencies, 1966–1971, compared with southern California commercial catch data for same period.***

5.2.3. Distribution

Except for small juveniles, jack mackerel distribution by size was extremely patchy. Schools of commercial size fish were found only in very specific localities and types of habitat. Due to this type of distribution, systematic broad general surveys were ineffective.

Habitats favored by jack mackerel consisted of shallow rocky banks and the rocky perimeters of islands. Rocky coastal areas associated with kelp beds sometimes contained mackerel schools, especially in waters off Mexico. Schools on banks were often concentrated around the shallowest rocky areas in waters 9 to 55 m (5 to 30 fathoms) in depth (Figure 24). Island associated schools were usually found from 45 m (50 yards) to 0.9 km (0.5 mile) of shore and were often in or near kelp beds.

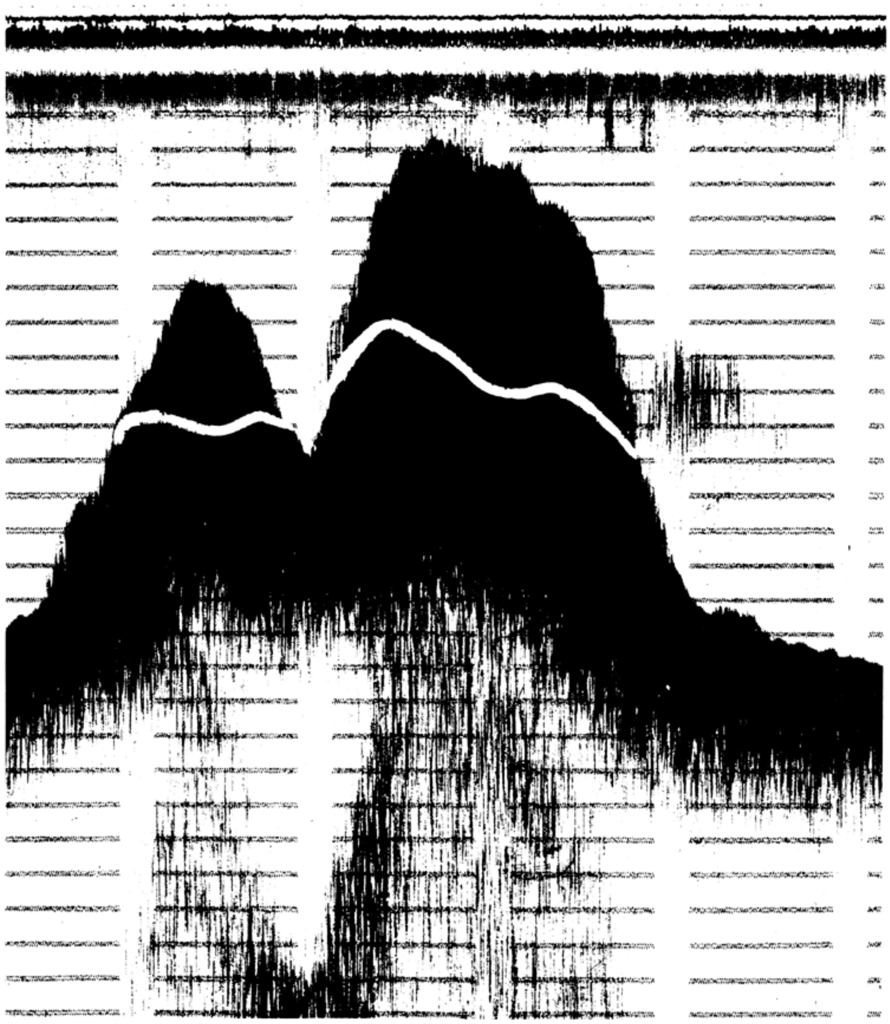

FIGURE 24. Echogram of jack mackerel school in close proximity to rocky pinnacle. Fish separated from bottom by white line, Farnsworth Bank, December 1969.

FIGURE 24. ***Echogram of jack mackerel school in close proximity to rocky pinnacle. Fish separated from bottom by white line, Farnsworth Bank, December 1969.***

In southern California waters all schools were located from Santa Monica Bay southward with more schools being detected at Santa Catalina and San Clemente Islands and Cortes Bank. Almost all jack mackerel detected or observed in Baja California waters were located within 0.9 km (0.5 mile) of rocky coastal areas. Several schools were observed within several hundred meters of Guadalupe Island which is located 259 km (140 miles) offshore and is surrounded by very deep oceanic waters. Fewer than 10 schools were detected or observed in waters off Baja California. No schools that could be positively identified as jack mackerel were detected or observed in central and northern California waters. The few trawl catches in these regions indicate a distribution mostly within 3.7 km (2 miles) of shore.

Midwater trawl catches and visual observations indicated small juveniles ranging to 150 mm (5.9 inches) FL were widely distributed 9.3 to 111.1 km (5 to 60 miles) from the mainland. This type of distribution was most prevalent in southern California waters where very small schools were observed near the surface over deep water basins. These schools were very often found under drifting kelp and debris. Schools were very small, rarely exceeding 136.4 kg (300 lbs.) in biomass. Some schools of this type were observed in kelp beds at Santa Catalina and San Clemente Islands.

Large adult jack mackerel were rarely taken and observed. Several fish 425 to 500 mm (16.7 to 19.7 inches) FL were taken by trolling in central California waters and a single fish of 445 mm (17.5 inches) FL was taken on a night-light station in northern Baja California. Late spring exploratory cruises for albacore, Thunnus alalunga, by the California Department of Fish and Game have found small schools of these adults widely distributed 222 to 926 km (120 to 500 miles) offshore between central Baja California and central California. Our two attempts to survey these fish in offshore areas in August 1970 and May 1972 were unsuccessful. No fish were located on the first survey and poor weather curtailed operations on the second.

5.2.4. Schooling Behavior and Availability

Jack mackerel schools were found at greater depths from the surface than most other pelagic schooling species of commercial importance. Schools on or near the surface were a rarity. Echo sounding found schools 9 to 73 m (5 to 40 fathoms) from the surface (Table 2). It was not possible to determine maximum schooling depth due to the difficulty in observing or capturing this species.

Echo sounder recordings of jack mackerel schools indicated rather loose aggregations of much greater horizontal than vertical dimensions, and school density or compaction appeared less dense than anchovies or sardines. Observations of bioluminescent schools at night indicated low density with ragged or ill defined perimeters.

Jack mackerel schools were much less active and vigorous in swimming than many other pelagic species. Observations by scuba diving and from the vessel's underwater viewing ports and bridge indicate a relatively low school activity level reflected by slow sluggish swimming action. The combination of deep schooling behavior, low school density, and low activity level make observation and location of jack mackerel schools much more difficult than the other major commercial species under study. These three factors greatly reduce the intensity and quantity of school bioluminescence necessary for visual detection. Jack mackerel schools appear at night as very faint indistinct bioluminescent areas on the dark surface of the sea. When searching for jack mackerel, commercial fishermen intermittently flash a white light over the sea surface which momentarily startles the fish resulting in a brighter and more visible bioluminescent glow.

Schools located over rocky banks and shallow rocky coastal areas often remained near the bottom or under kelp canopies during day-light hours and ventured into deeper surrounding areas at night. All commercial fishing for jack mackerel occurs in this type of habitat; thus, availability relies solely on occurrence of schools in such areas. The nearness to shore and association of kelp and shallow rocky bottoms often pose a physical hazard to fishing and prevents safe operation of a large research vessel.

The occurrence of small schools of young juvenile fish beneath floating kelp and debris in the open sea is a common schooling behavior which is most prevalent in the late summer and fall months. Due to the small fish and school sizes, commercial availability is zero.

5.3. Pacific Sardines

5.3.1. Survey Effectiveness

Due to a scarcity of sardines over most of their range, insufficient experience was gained in detecting and identifying schools to make effective and reliable acoustic surveys.

Night-lighting with a blanket net and midwater trawling were of doubtful value in making quantitative assessments of the population, but did provide some measure of relative abundance. Considerable data were collected using these methods in the 16 years preceding present surveys.

Night-light blanket net survey data and commercial catches in southern California correlated very closely from 1950 to 1958. Night-light success expressed as the percentage of stations on which commercial size sardines were present agreed quite closely on a relative scale with the success of the commercial fishery expressed as total landings. Based on these results, it was felt this type of survey was a reliable indicator for measuring the relative abundance of sardines and could be applied to other regions where no fishery or catch statistics exist.

With the initiation of present surveys emphasizing acoustic ranging and midwater trawling, night-light effort was sharply reduced. In recent years restricted catch quotas or monitoriums on sardines and Pacific mackerel necessitated resumption of night-light surveys as one means of monitoring the populations of these species.

Midwater trawling produced more variable results than night-lighting when both were conducted on the same cruise (Figure 25); however, comparisons of the two methods between major survey regions were in relative agreement. Although midwater trawl surveys are probably less effective than night-lighting, they may be utilized for general relative abundance comparisons between regions.

5.3.2. Relative Abundance

California waters From 1966–1973 both night-lighting and midwater trawling in central and southern California waters was very nearly 100% unsuccessful. No sardines were taken or observed on the 167 night-light stations occupied, and only a single fish was captured in a total of 1,066 midwater trawl tows. Data from previous years surveys (1950–1965), which are not included in this report, produced much more positive results. Night-light stations in southern California waters on which sardines were present ranged from 42.5% in 1950 to 0.0% in 1962 with interim years fluctuating from 4.0% to 21.0%. From 1963 to 1965 station success was considerably lower ranging from 0.0% to 2.8%. Midwater trawling has been conducted since 1962. Trawl station success from 1962 to 1965 ranged from 2.2% to 8.9%.

Pre-1966 night-light surveys in central California were considerably less successful with station success ranging from 0.0% to 13.5%. All midwater trawling in this region was totally unsuccessful.

It is quite evident the sardine population in California waters during the period of this study has declined to such a low level that our surveys have been unable to detect their presence. The pre-1966 and present data indicate night-light and midwater trawl surveys are capable of detecting major changes in relative abundance and will be useful in monitoring the sardine population.

Baja California waters Both night-lighting and midwater trawling were much more successful in Baja California. Sardines occurred at 14.3% of 105 night-light stations and in 9.1% of 265 midwater trawl tows completed from 1966 to 1971. Success rates varied greatly between the two methods, often resulting in contradictory results (Figure 25). In 1971 night-lighting success was the greatest in 11 years but midwater trawling was totally unsuccessful. results of the same method fluctuated rather drastically from one year to the next. Extensive night-light data from 1950 to 1962 indicate a rather stable population was maintained at a relatively high level from 1950 to 1959 with station success ranging from 25.5% to 33.6%. A decline to a much lower level began in 1960 and persisted through 1967. Station success during the period ranged from 9.0% to 18.0%. No effort in 1968 and 1969 and extremely variable results in 1970, 1971, and 1972 (3.0% to 25.0%) have created uncertainties in assessing relative abundance during the past five years (Figure 25).

Midwater trawling in Baja California waters from 1966 to 1972 indicated a decline in sardine abundance. Low or sharply reduced catch rates occurred in four of the six years following 1966. Only 1969 and 1972 deviated from this downward trend. As mentioned previously, the 1971 survey produced negative results in contrast to the night-light survey for this year which produced an 11-year high station success percentage (Figure 25).

Previous midwater trawl operations initiated in 1962 indicated a higher population from 1962 to 1966 than during the last five years with station success ranging from 16.0% to 36.0% vs 0.0% to 16.7% (Figure 25).

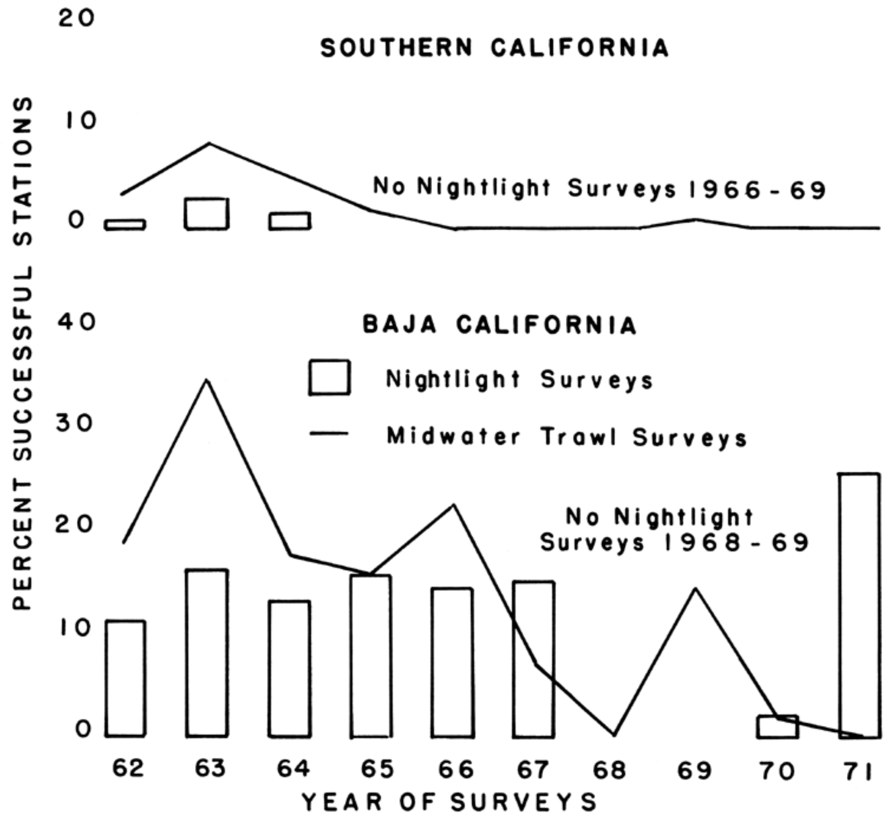

FIGURE 25. Comparison of results of Pacific sardine night-light and midwater trawl survey methods.

FIGURE 25. ***Comparison of results of Pacific sardine night-light and midwater trawl survey methods.***

Despite the gaps and inconsistencies in both night-light and midwater trawl data, there is a general implication that the Pacific sardine population off Baja California, excluding the stock in the Gulf of California, is now smaller than during the period of 1950–1961.

5.3.3. Distribution

The single midwater trawl catch made in California waters was located near San Diego. Most of the reported California commercial catch in recent years has been from this area.

All sardine catches in Baja California waters were made within 10 miles of the coast. The eastern shore of Sebastian Vizcaino Bay near Lagoon Head and Scammon Lagoon in central Baja California has consistently produced the largest and most numerous night-light and midwater trawl catches. Much of the Mexican commercial catch on the west coast of Baja California is taken in this area. The 1971 night-light survey, which was the most successful in recent years, found sardines distributed more northward than usual with catches occurring northward to Ensenada where fish have not been taken by surveys for many years. Distribution during the 1972 survey was limited to Sebastian Vizcaino Bay and Rompiente Point.

5.4. Pacific Mackerel

5.4.1. Survey Effectiveness

Acoustic surveys of this species were totally ineffective for the same reasons as for sardines, namely an extremely low population level and subsequent lack of experience in identifying echograms of mackerel schools. It is doubtful that these surveys would be of value even if a large population were present due to a patchy distribution similar to that of jack mackerel.

Midwater trawl catch rate success has been very low with successful stations ranging from 0.4% to 1.4% per year. Catches per trawl were also extremely low ranging from one to two fish. Trawls made in years previous to this report, when the Pacific mackerel population was much larger, were more successful ranging from 3.1% to 14.1% for the years 1962–1965. A high degree of trawl avoidance is indicated by the extremely small catches. Thus the paucity of positive results may introduce large errors in using this gear for surveying Pacific mackerel. At best only gross changes in population size may be detectable. General distribution also may be determined.

During the time period of this report, night-light blanket net surveys were conducted only during 1970 and 1972. Although this method of survey appears to be much more effective than acoustic transects and midwater trawling in determining relative abundance, it has been occasionally in considerable error. Identical surveys conducted between 1950 through 1965 reflected population changes fairly well for most years when the percent of successful stations was compared with population estimates derived from commercial catch data. However, night-light surveys during the years 1961 and 1962 deviated greatly from these estimates which indicated the largest population in the past 21 years. Conversely the 1970 and 1971 surveys indicated a substantially larger population than the very low estimate from the commercial catch.

5.4.2. Distribution and Relative Abundance

Pacific mackerel were found in the inshore waters of the coast and islands from southern Baja California to and including the southern California region. No evidence was obtained of their occurrence in central and northern California.

Midwater trawling was unproductive with a total of only 13 catches in 1,384 tows. The largest catch was two fish. There was indication of greater abundance in Baja California waters where Pacific mackerel occurred in 1.8% of tows vs 0.7% occurrence in tows in southern California. The highest catch occurrence in Baja California was during 1967 when two of 36 tows (5.5%) were successful. The best year in southern California was 1971 with 1.9% success. No catches were made during 3 of the 6 years surveyed in southern California (1966, 1967, and 1969) and during 2 years in Baja California (1968 and 1971). Trawl data from years previous to the period of this report also indicate greater abundance in Mexican waters. Trawl station success rates during 1962–1965 in Mexico ranged from 5.2% to 29.3% vs 1.0% to 5.0% in southern California.

Night-light blanket net surveys were conducted on a routine basis during 1970–1972. Pacific mackerel were present on only 11 of the 324 stations occupied. Greater abundance in Mexican waters was indicated by station success rates of 9.7%, 9.4%, and 2.0% vs 1.3%, 2.3%, and 4.4% in California waters during the 3 years surveyed. A wealth of data from 16 years (1950–1965) of intensive surveys of this type supports this evidence. Station success rates were greater in Mexican waters for 13 of these 16 years.

Changes in the Pacific mackerel population size based on the 1970–1972 surveys and previous periods (1950–1965) agree that a reduction has occurred in the later years, but the magnitude of this change is far less than that indicated by the commercial catch and population estimates which show a much more drastic decline.

Total station success for southern California and Baja California waters during the entire 1950–1965 period was 12.2% of 4,937 stations vs 3.4% of 324 stations in 1970–1972. The decline of the Pacific mackerel population over these periods is apparently very much greater than indicated by night-light surveys.

5.5. Latent Resource Species

Pacific Hake

Egg and larvae surveys by the National Marine Fisheries Service and cooperating agencies of the California Cooperative Fisheries Investigations strongly indicate hake is one of the more abundant species in the California Current System. Our acoustic and midwater trawl operations were unable to definitely verify these findings; however, our surveys were primarily designed for pelagic schooling species of the upper layers of the water column and were not very effective on species of demersal character such as hake. None of our surveys were able to locate or catch commercial concentrations of hake. Although hake may indeed be quite abundant, our surveys indicate poor prospects for large scale exploitation by California fishermen.

The extensive acoustic survey effort made over the past 6.5 years found only one large concentration which was located in San Pedro channel in southern California during March 1971. This concentration consisted of a thin coarse elongate scattering layer that was approximately 9.3 km (5 miles) in length. These fish were located 229 to 256 m (125 to 140 fathoms) from the surface over bottom depths of 869 to 887 m (475 to 485 fathoms). A midwater trawl tow positioned by depth telemetry captured several subadults 158 to 187 mm (6.2 to 7.4 inches) SL. Several similar but much smaller concentrations have been detected in southern California waters. Several cruises designed to survey reportedly prime hake habitat in the shallow waters off central and northern California failed to detect significant quantities. No concentrations of adults such as reported from the shallow waters off Oregon and Washington have ever been detected by our acoustic surveys. Adult hake in California waters apparently do not concentrate, or school too close to the bottom for acoustic detection.

The schooling behavior of hake made enumeration of schools impractical. Hake occur in a coarse scattering layer rather than single separate schools, and echo sounding was our only effective acoustical gear for detecting them. Echograms resemble detached saw tooth segments which constitute a thin layer. In northern and central California waters these layers of hake usually were located 3.7 to 14.7 m (2 to 8 fathoms) from the bottom in water depths of 46 to 183 m (25 to 100 fathoms). In southern California they occurred 229 to 293 m (125 to 160 fathoms) from the surface over deep water basins (Table 2).

More positive results were obtained by midwater trawling. The frequency of hake occurrence in trawl catches gives some indication of their reported great abundance. This species ranked third in frequency of occurrence with 10.9% of all tows containing hake (Figure 5). The best results were obtained in northern California waters where 20.6% of the tows were successful. The southern California-northern Baja California region was second with 13.1% followed by central California with 11.2%. Central and southern Baja California catches were the most infrequent with 3.3% occurrence. Not one catch of commercial quantity was taken. The largest catch was less than 300 lbs. and the greatest numbers in any tow was 4,000 very small juveniles. Over 90% of all catches consisted of less than 300 fish with many one fish catches. Greater catches probably could have been made if the trawl was fished at greater depths or on the bottom. Catches consisted mainly of fish smaller than 300 mm (11.8 inches) SL. Southern California-northern Baja California catches, from which most length frequency data were obtained, consisted of mainly fish smaller than 200 mm (7.9 inches) SL and only a very small percentage of larger sizes. Length frequencies taken from central and northern California catches indicated a greater proportion of larger fish with a maximum of 700 mm (27.6 inches) SL; nevertheless, sizes smaller than 300 mm (11.8 inches) SL predominated. All central and southern Baja California fish were smaller than 300 mm SL (Figure 26).

5.6. Pacific Saury

Sauries were superficially surveyed incidental to other species. Only three cruises were specifically designed to survey this resource and then only within 185.2 km (100 miles) of the coast. Night-lighting and night scouting with a large searchlight were the most effective methods of locating schools. Sonar search and visual observation were effective at

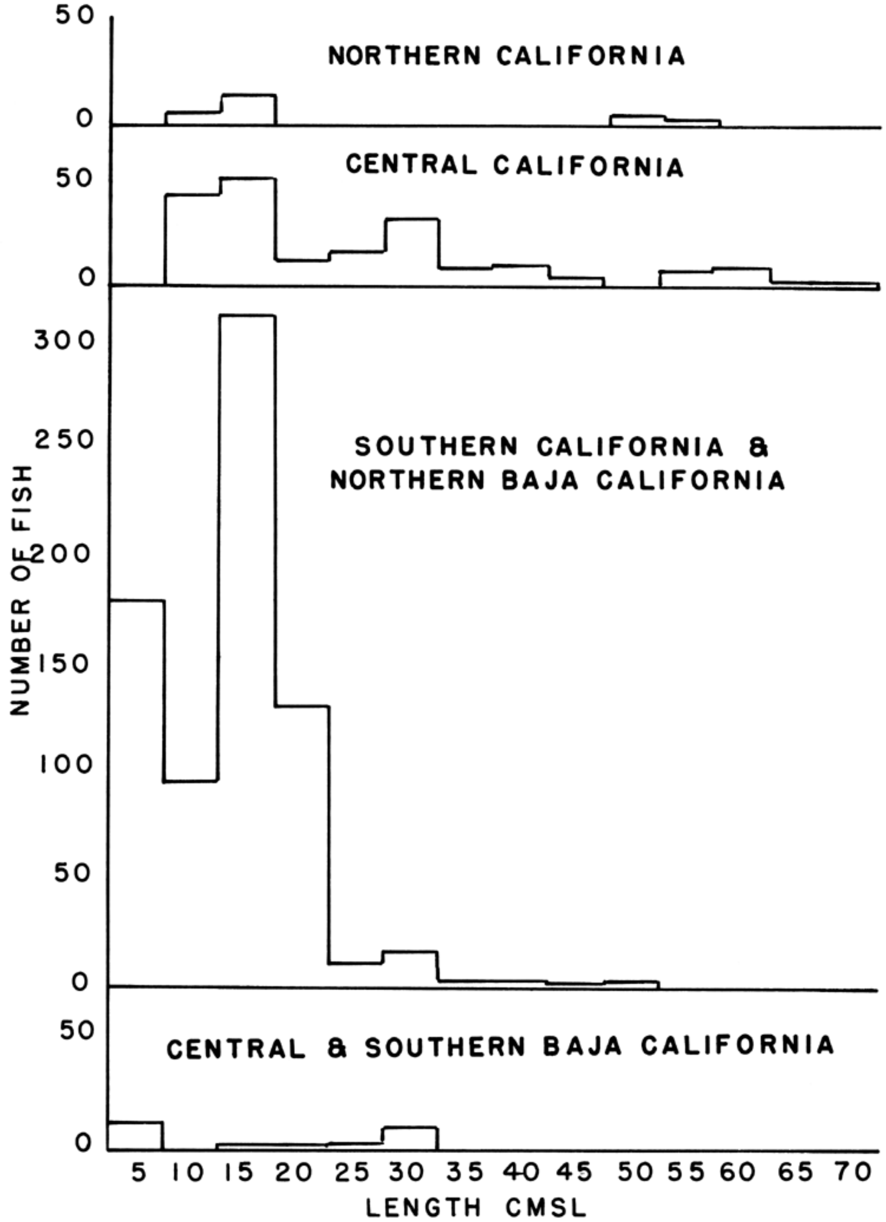

FIGURE 26. Length frequencies of Pacific hake trawl catches.

FIGURE 26. ***Length frequencies of Pacific hake trawl catches.***

times. Midwater trawling produced very poor results due to an extreme trawl avoidance behavior. Only seven catches, 80% of which consisted of one fish, were made in the 1,375 trawl tows completed.

Most of the 324 night-light and searchlight stations occupied during the period of this report were located in southern California and Baja California waters. Sauries were present on 164 or 47.8% of these stations. The vast majority of schools attracted to the light consisted of 10 to 200 small juveniles in the 50 to 130 mm (1.7 to 5.1 inches) FL range. Larger fish and greater schools rarely were attracted. Sonar search was successful at times in locating saury schools, particularly at night. Schools thus detected appeared as weak but well defined targets located on or near the surface. Homing by sonar on these schools and then flashing a search light over them as the vessel approached was quite effective for positive identification. Schools were usually too near the surface and too narrow in vertical aspect for detection by echo sounder. However, on one occasion during a daytime midwater trawl tow the echo sounder detected a large fish school 37 to 55 m (20 to 30 fathoms) from the surface. The trawl captured 18 large sauries and nothing else.

Commercial size concentrations were found on only two occasions in the 6.5 year period covered by this report. The largest of these was an estimated 10 to 20 ton school which was detected by scouting with a searchlight. This school, consisting of adult fish 200 to 270 mm (7.9 to 10.6 inches) FL, was located in shallow water within 3.7 km (2 miles) of Santa Cruz in central California. The other was a group of 10 schools estimated to average 5 tons which was found over the deep waters of Santa Cruz Basin in southern California waters. These fish averaged 150 mm (5.9 inches) FL. Both concentrations were observed during November 1970 on a cruise designed for saury survey. A more recent survey of this type in August 1972 found commercial concentrations in northern California near Point Arena and Point Reyes. Sonar detected 30 schools ranging up to 50 m (164 feet) in diameter in the former area and 6 schools were detected similarly in the latter. Fish in the Point Reyes area were large, ranging to 305 mm (12.0 inches) FL. One of these schools attracted to a night-light, was estimated at 5 to 10 tons. Other surveys specifically for sauries conducted in southern California and Baja California during spring and summer, were not successful in locating large concentrations.

These results indicate the northern and central California regions are most favorable for occurrence of large fish in commercial concentrations. Southern California and Baja California appear to be nursery grounds containing mostly juveniles dispersed over wide areas. The summer and fall are the best seasons for occurrence of large concentrations in northern and central California. The high percentage of successful night-light stations (47.8%) is indicative of a large population, but the paucity of concentrations of large fish is indicative of low or erratic availability. Although our saury surveys are admittedly sketchy and superficial, they are in general agreement with information from other sources. California Department of Fish and Game sardine surveys during the early 1950's found varying concentrations of sauries occurring during the same seasons and in the same areas as did the surveys considered by this report, but in much greater quantities (Eberhardt, 1954). Sardine surveys since the late 1950's have found concentrations scarce. Historical records reported by Eberhardt indicate that in times past this species was rare or unknown in many areas where they since have been reported abundant. Interviews with commercial fishermen reveal a highly irregular and erratic occurrence of large concentrations. This information coupled with results of our surveys suggest that although the saury resource probably is quite large, its availability is too erratic and irregular for development of a major fishery. Attempts by Japanese high seas fishing vessels to harvest sauries off northern California during the summer and fall of 1971 and 1972 apparently proved unprofitable.

5.7. Squid

Sea surveys strongly indicated squids are the largest latent fishery resource in California waters and may be on par with northern anchovies in terms of total biomass. Excluding economic factors and market demand, large scale utilization of this major resource is clouded due to behavior and distribution which apparently limit vulnerability to mass harvest methods. The resource is comprised chiefly of one species, the market squid, Loligo opalescens, which comprised nearly 90% of all sea survey catches. At least 23 other species were taken in small numbers during the course of this study.

Based on the high frequency of catches by midwater trawl and occurrence on night-light stations, the total squid population must be at least 1 million tons and probably much larger. Despite low vulnerability to midwater trawling, catches were second only to northern anchovies in frequency occurrence with 36.3% of 1,375 tows containing squid. Night-light station success was also relatively high with squid occurring on 28.7% of the 324 stations occupied.

Midwater trawling gave some indication of distribution and regional abundance. The northern California region had the highest frequency of trawl catches with 76.5% of tows containing squid; however, the number of trawls (34) made in this region was insufficient to reach any valid conclusions concerning regional abundance. Central California had the second highest frequency with 43.2% of 206 tows being successful, followed by southern California with 37.5% of 860 tows, and Baja California with 22.5% of 275 tows (Figure 8). These results indicate squid abundance increased northward reaching a maximum in central or northern California. Catches were very widespread with respect to locality. No particular habitat or areas excelled in squid catches. Trawls made in both shallow inshore waters and over deeper more offshore waters were equally successful. Night-light stations were concentrated inshore along the southern California and Baja California coasts and were somewhat biased for use as indicators of regional squid abundance and distribution.

Although frequency of trawl catches was high, the amounts caught were quite low. The majority of catches consisted of 1 to 20 squid with a maximum of 650. Only eight of the 499 squid catches contained more than 100 of these mollusks. This paucity of large catches is attributed to squid's low vulnerability to midwater trawl gear. The ineffectiveness of trawling was demonstrated on several occasions when large extensive schools were trawled upon with a maximum catch of only 25 squid.

Except for spawning squid, schools attracted by night-light stations were invariably small, consisting of less than 1,000 individuals. These schools remained deeper than 9 m (5 fathoms) beneath the light and occasionally swarmed momentarily to the surface. Schools would appear and reappear at 10 to 30 minute intervals. Some would appear only once under the light and then permanently disappear. All nonspawning squid attracted to the light were very active and easily frightened away. Capture by blanket net was difficult. Spawning squid attracted to the night-light concentrated in a very dense layer or "mat" on or near the surface where they remained docile and relatively inactive. Concentrations thus attracted occasionally exceeded an estimated 100 tons. Capture was easily effected by blanket net or dip net. These concentrations were observed infrequently and in only several small areas. Santa Catalina Island and the northern Channel Islands were the only areas our surveys found these concentrations in southern California waters. The only area in central California was near the City of Monterey in Monterey Bay. Spawning concentrations are the source of nearly all commercial catches. The few known localities where spawning concentrations occur and the invulnerability of nonspawning squid to present fishing methods may restrict harvest to only a very small portion of the total resource.

The few acoustically detected targets that could be identified as squid appeared as large extensive cloudlike schools which were 30 to 40 m (98 to 131 feet) thick and 70 to 200 m (230 to 656 feet) in horizontal dimension (Figure 27). These schools appeared to be of low density as evidenced by relatively weak target strength compared to other species. Echo sounding was more effective than sonar for school location. A midwater trawl tow through a school nearly 0.40 km (0.2 mile) long took 0.9 kg (2 pounds) of juvenile market squid 20 to 23 mm (0.79 to 0.90 inch) in mantle length.

5.8. Panama Lightfish

This small silvery gonostomatid fish is one of the more shallower dwelling of the mesopelagic species. California Cooperative Fisheries Investigations egg and larvae surveys indicate Panama lightfish, Vinciguerria lucetia, may be the most abundant fish in the subtropical eastern Pacific Ocean. Our sea surveys detected huge schools and concentrations of them off southern Baja California.

FIGURE 27. Echogram of market squid near rocky outcropping. School is 36.6 m (20 fathoms) thick and several hundred meters wide. Identification was made by midwater trawling, 43 Fathom Bank, March 1971.

FIGURE 27. ***Echogram of market squid near rocky outcropping. School is 36.6 m (20 fathoms) thick and several hundred meters wide. Identification was made by midwater trawling, 43 Fathom Bank, March 1971.***

Acoustic midwater trawl surveys during January 1969 and May 1971 in southern Baja Californ a found large concentrations of Panama lightfish 92.6 km (50 miles) west-northwest of Cape San Lucas and near Alijos Rocks. In the former area a single extensive concentration was distributed nearly continuously over an estimated 109.6 km^2 (32 $mile^2$) area. This concentration, which was detected by echo sounder during daylight hours, consisted of a nearly continuous loosely compacted layer measuring 38 to 78 m (125 to 256 feet) in thickness and was located 55 to 73 m (30 to 40 fathoms) from the surface (Figure 28) over bottom depths of 183 to 549 m (100 to 300 fathoms). A 20 minute daytime midwater trawl tow in this layer produced 22.7 kg (50 pounds) of Panama lightfish ranging from 30 to 65 mm (1.2 to 2.6 inches) SL. The concentration in the vicinity of Alijos Rocks consisted of school groups distributed from 9.3 to 74.0 km (5 to 40 miles) east of this locality. These moderately compact schools were 58 to 78 m thick (190 to 256 feet), 10 to 18 m (33 to 59 feet) in diameter, and were located 64 to 91 m (35 to 50 fathoms) from the surface during daylight hours. At night they rose to the surface and dispersed. Sonar search in this area detected 81 schools and echo sounder 14 over a 92.6 km (50 mile) transect. An aimed midwater trawl tow during daylight hours captured 100 Panama lightfish 35 to 64 mm (1.4 to 2.5 inches) SL and 15 juvenile northern anchovies of similar size. A night tow in the same area took 2,500 lightfish and 20 anchovies of the same general size range as the daytime tow.

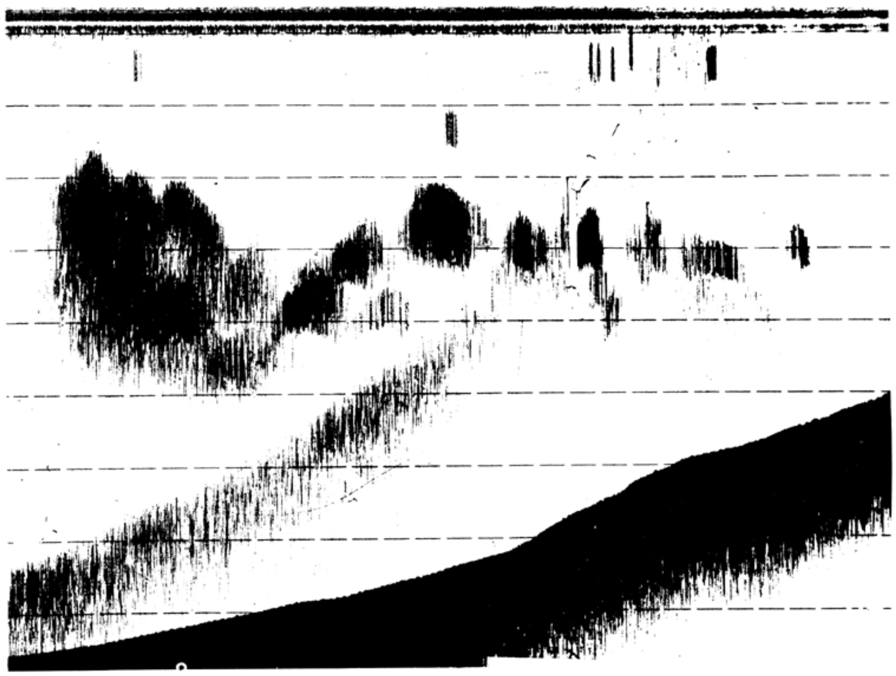

FIGURE 28. Echogram of Panama lightfish, *Vinciguerria lucetia,* off southern Baja California. Depth scale is 36.6 m (20 fathoms) between dashed lines. Light sloped echo is multiple bottom echo, not fish.

FIGURE 28. ***Echogram of Panama lightfish, Vinciguerria lucetia, off southern Baja California. Depth scale is 36.6 m (20 fathoms) between dashed lines. Light sloped echo is multiple bottom echo, not fish.***

These results of our very limited effort in southern Baja California waters indicate that this species may be an exploitable latent resource. The tendency of Panama lightfish to form large schools and their apparent great abundance are favorable factors for mass capture methods. However, the relatively deep depths schools occur would be unfavorable for capture by roundhaul seines, and the effectiveness of midwater trawling is uncertain. Our trawl's large 15.2 cm (6 inch) stretch measure netting in the forward mainbody section certainly would allow escapement if lightfish escape through the trawl. Smaller mesh size may be effective but has not proved so with species such as anchovies which avoid the trawl mouth.

5.9. Pelagic Red Crab

This species represents the largest readily harvestable latent resource found by our surveys. This resource is, for all practical purposes, limited to Mexican waters. Surveys found red crabs along the entire western coast of the Baja California Peninsula but only in major quantities in the central and southern parts. The greatest quantities and concentrations were located in coastal waters less than 183 m (100 fathoms) in depth, but some crabs were observed and captured 306 km (165 miles) offshore over bottom depths exceeding 1,829 m (1,000 fathoms).

Visual observations, frequency of midwater trawl catches, and echo sounding provided good evidence that red crabs were a dominant macro-constituent of the marine fauna in Baja California waters. Although the results of our surveys could not be used to objectively quantify the resource, they do indicate a very large population which may very likely amount to several million tons.

During winter and early spring when sea surface temperatures were cool off Baja California, red crabs were observed in enormous quantities on or near the surface. Crabs were distributed over hundreds of square miles of sea surface at this time. It was not uncommon to travel 27.8 km (15 miles) through a continuous surface layer of crabs which colored the sea red as far as the eye could see on either side of the vessel. During periods of rough weather crabs were often aligned in elongate windrows parallel to wind direction. These rows often extended for miles. Surface sightings were much less common during periods of warm temperatures and consisted of concentrations welling up from shallow banks and pinnacles. Crabs were usually observed nearer the surface at night than during daylight hours.

The abundance of pelagic red crabs was evidenced by the large and numerous midwater trawl catches. Slightly over 68% of all trawl tows made in waters off Baja California took crabs. Surveys during cool seasons when crabs are near the surface, made catches in 90 to 95% of the tows. Catches per 20 minute tow ranged from several pounds to 4 tons. Catches exceeding 1,000 pounds were common. Much greater catches could have been possible if a smaller mesh size had been used as netting in the forward part of our trawl. The 15.2 cm (6 inch) stretch measure undoubtedly allowed considerable escapement. Furthermore, large concentrations were purposely avoided to prevent large crab catches from obscuring and mutilating fishes also captured.

Echo sounding was effective in detecting the larger and more dense concentrations of crabs. Concentrations detected by this method were composed of midwater layers located over bottom depths of 11 to 73 m (6 to 40 fathoms). These layers were usually 9 to 18 m (29.5 to 59 feet) thick and extended horizontally to a maximum of 0.9 km (0.5 mile). Crab echograms could be distinguished from those of fish schools by their extensive horizontal dimensions, weak target strength, and poorly defined perimeters (Table 2). Midwater trawling on concentrations detected by echo sounder produced some of the largest catches.

The best areas for locating large quantities of red crabs were shallow flat bottomed coastal bays. Specific locations where large concentrations were found include: South Bay at Cedros Island, San Cristobal Bay, Asuncion Bay, San Hippolito Bay, Ballenas Bay, and Magdalena Bay. The center of abundance appears to be between Cedros Island and Magdalena Bay, a distance of 515 km (278 miles).

The pelagic red crab resource could very easily be harvested on a large scale should a commercial use for them develop. Midwater trawling with a small mesh net should be effective during winter and early spring when crabs are located near the surface. Better results possibly may be attained with a bottom trawl when the species becomes benthic during the warm seasons. The greatest portion of the population resides within Mexican territorial waters.

6. CONCLUSIONS

6.1. Evaluation of Methods and Data

6.1.1. Acoustic-Midwater Trawl Surveys

It is the author's opinion that acoustic-midwater trawl surveys are the most effective means for directly assessing the status of northern anchovies. This is the most ideal species in the California Current System for surveying by this method. The population is large and widely distributed over deep waters, formation of relatively well defined schools is a species characteristic, and occurrence of major quantities of other species in anchovy habitat is minimal. Sonar conditions are generally good in major anchovy population centers and acoustic target identification is facilitated by effective midwater trawling and visual observation.

Acoustic-midwater trawl surveys have provided good information on anchovy distribution and relative abundance. Availability, seasonal movements, schooling behavior, and vulnerability to harvest methods also have been readily determined. However, the prime objective of accurately estimating the anchovy population biomass has not yet been realized due to difficulty in determining individual school biomass from acoustic records. Solution of this problem will be a major breakthrough and may permit reliable estimation of population biomass.

Our acoustic surveys undoubtedly underestimate abundance of fish school targets due to several factors. Small weak targets are not detected at long ranges and scattered fish are detected in such a manner that they cannot be realistically enumerated or quantified. Some types of scattered fish cannot be detected at all. The offshore distributional limits of all species were not entirely covered by acoustic transects. The portions of poplations in these outlying areas were not included in abundance estimates. Regions characterized by generally poor weather conditions such as central and northern California were not as extensively or intensively surveyed as other regions. The acoustic equipment functioned much less effectively under bad weather conditions. One or all of these factors may result in underestimates of more than 50% in target abundance for some surveys. However, it is the author's opinion that under good survey conditions underestimation error is less than 20%.

Acoustic surveys with sonar were relatively ineffective on species dwelling on or near the bottom or in shallow rocky areas. Confusion of fish school targets with bottom echoes plus difficulty in species identification and more patchy distribution of fishes in this type of habitat were the chief problems encountered.

Acoustic data collected prior to acquisition of horizonal scanning sonar in 1969 is of inferior quality. Prior to 1969 only an echo sounder was used. The narrow path searched by an echo sounder and the tendency of near surface schools to flare from the vessel's path diminished the effectiveness of surveys. In addition, the echo sounding equipment then in use had poorer fish detecting capabilities than that obtained later.

6.1.2. Night-light Blanket Net Surveys

This method of survey has been used by the California Department of Fish and Game for over 15 years to determine year class success and estimate relative abundance of older Pacific sardines. The latter measure correlated extremely well with the commercial fishery success in southern California thereby proving validity of the method for determining relative abundance of sardines.

Survey effectiveness on most other species has not been clearly demonstrable. Some useful information may be gained on distribution and relative abundance of Pacific mackerel and jack mackerel as evidenced by consistently different station success rates between major survey regions.

The method is definitely inadequate for surveying northern anchovies due to highly variable phototactic behaviors which range from highly positive to completely negative.

Surveying Pacific sauries by this method has proved impractical due to the extremely large area over which this species is distributed. Weather conditions and vessel operational limitations are also major obstacles.

6.2. Summation and Evaluation of Results

6.2.1. Northern Anchovies

Surveys have confirmed or substantiated the findings of more indirect studies that indicate northern anchovies are the dominant and largest fishery resource in the California Current System. Although anchovy biomass cannot as yet be estimated precisely by our surveys, the overwhelming predominance of this species on surveys by sheer numbers of schools detected, high occurrence rates in trawl catches, and extensive visual sightings are indicative of a population size realistic with the 2 to 6 million ton estimates made by other investigators from egg and larvae surveys.

Acoustic surveys have demonstrated the southern California-northern Baja California region contains the bulk of the anchovy resource with the best concentrations occurring within 37 km (20 miles) of the coast between San Diego and Santa Barbara. The northern and central California regions are of minor importance as anchovy habitat with less than 10% of the resource occurring in these waters. Central and southern Baja California contains less than 25% of the anchovy resource with a large proportion of fish comprised of a separate subpopulation.

Availability and school behavior studies indicate, that while the anchovy population is quite large, only a very small portion is harvested due to low vulnerability during much of the year. The success of the present commercial fishery is chiefly a function of vulnerability and availability rather than population size. Schooling behaviors affecting vulnerability were extremely variable both within and between years. The causes of school behavior and their variations are as yet unknown.

6.2.2. Jack Mackerel

All methods of survey produced poor information concerning jack mackerel abundance. Midwater trawling indicates a widespread distribution with some implication that commercial and juvenile sizes are more abundant in southern California waters than elsewhere. Trawling also indicates small subcommercial size fish are more prevalent in the open deep-sea basins than commercial sizes which are taken more often over banks and shallow nearshore areas. The population of large old adults known to inhabit far offshore oceanic waters were virtually undetected by all survey methods.

Acoustic surveys indicated jack mackerel do not school densely in the open sea but form only small scattered schools or do not school at all. Fish accumulate on a few shallow rocky banks and limited rocky shorelines of islands and coasts where they form schools large enough for commercial exploitation. Catch data from the southern California jack mackerel fishery indicate these concentrations are subject to rather heavy fishing pressure which very likely results in a high fishing mortality.

6.2.3. Pacific Mackerel and Pacific Sardines

Night-light blanket net surveys for these species are in agreement with other studies and data which indicate very low population levels. Sardines were too scarce in southern California waters to be detected by these surveys. Central and southern Baja California were the only survey regions where this species commonly was found. Pacific mackerel were less effectively surveyed but the data indicate a reduced population when compared with background data from surveys conducted during the 15 years previous to this study.

6.2.4. Pacific Hake and Pacific Saury

Surveys of these species were mostly ineffective and inconclusive. The existence of a large abundant hake population as indicated by egg and larvae surveys could not be substantiated by acoustic or midwater trawl survey methods. The only significant quantity of hake detected by an acoustic survey was a 9.3 km (5 mile) long scattering layer of subadult fish in southern California waters. Midwater trawling operations strongly indicated that a large proportion of the juvenile population resides in southern California and northern Baja California waters with adults more prevalent in central and northern California. No midwater trawl catches of commercial quantities ever were attained.

Surveys found sauries widely distributed but occurrence of commercial concentrations was infrequent and erratic. Minor quantities of small juveniles were very frequently encountered in all regions surveyed. Adult fish were found much less often but constituted all observed commercial concentrations. The best commercial schools were located in northern and central California waters during fall months.

Although this resource is undoubtedly fairly large, its commercial value is uncertain due to erratic occurrence of fishable concentrations.

6.2.5. Pelagic Red Crab, Market Squid, and Panama Lightfish

There is no doubt that these species represent large latent resources, each very likely exceeding at least 1 million tons in biomass.

Pelagic red crabs are the most available and could be most easily harvested. Most of this resource is located within 22.2 km (12 miles) of shore. No significant quantities were found in California waters.

Market squid are very abundant and widely distributed in the California Current System. However, except during spawning season squid occur in small highly evasive schools. This behavior and the limited number of known spawning grounds may limit development of a major fishery.

Extensive concentrations of Panama lightfish found off southern Baja California were schooled densely enough to possibly be harvested commercially. Most fish were located in offshore waters. There is a strong possibility that similar concentrations occur to the south beyond the southern limits of our surveys. A large midwater trawl appears to be the most likely gear for successful exploitation.

7. RECOMMENDATIONS

7.1. Anchovies

Sea surveys strongly demonstrate that the southern California-northern Baja California region included between Point Conception, California, and San Quintin Bay, Mexico, is the largest and most important anchovy area in the California Current System and should be treated as a single biological unit in any resource management plan. Central California is a far less important area with less than 10% the quantity of fish in the southern California - northern Baja California region. Assignment of catch quotas in these two areas should be determined on this basis. North of San Francisco anchovies occur irregularly and are generally too scarce for development of a major commercial fishery.

Anchovies from central Baja California southward are certainly a separate stock or subpopulation that contributes nothing to the fishery off California. This stock should not be considered directly in management plans for the southern California - northern Baja California stock in relation to harvest by the California fishery.

Availability or vulnerability studies indicate anchovy schooling behaviors favorable for capture by purse seine are relatively uncommon and occur unpredictably in both time and space. In years when high availability occurs only during closed fishing season or in closed areas such as happened in 1971, a significant reduction of the commercial catch can be expected. None of our surveys or studies have produced any valid biological reasons for area or seasonal closures. Acoustic surveys have provided some measure of the relative abundance of anchovies. It is recommended that surveys of this type continue to be utilized to detect major changes or movements of anchovy populations. Data collected thus far should provide a good background for comparison with those of future surveys to detect gross changes both within and between regions.

7.2. Jack Mackerel

Sea surveys found commercial concentrations only in a few limited areas in southern California waters. The possibility of significantly increasing the present annual commercial catch by discovery of new areas or increasing effort appears very remote. Apparently only a small portion of the 2.1 to 4.8 million ton jack mackerel population estimated by California Cooperative Fisheries Investigations for the northeast Pacific is available to the fishery. This fishery, which applies heavy fishing pressure on the few areas where commercial concentrations occur, very likely removes a very high percentage of the available population.

Cortes Bank, San Clemente Island, and Santa Catalina Island now produce over 90% of the jack mackerel catch. Loss of any of these areas by closure or detrimental environmental changes could have serious adverse effects on the fishery. Cortes Bank is by far the most important area, the loss of which would be catastrophic to the fishery.

7.3. Pacific Mackerel and Pacific Sardines

The great preponderence of negative data from California waters when compared with similar more positive survey data of the 1950's and early 60's are in complete agreement with other studies that show the populations of these species have declined to a very low level and should be completely protected from further fishing mortality.

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