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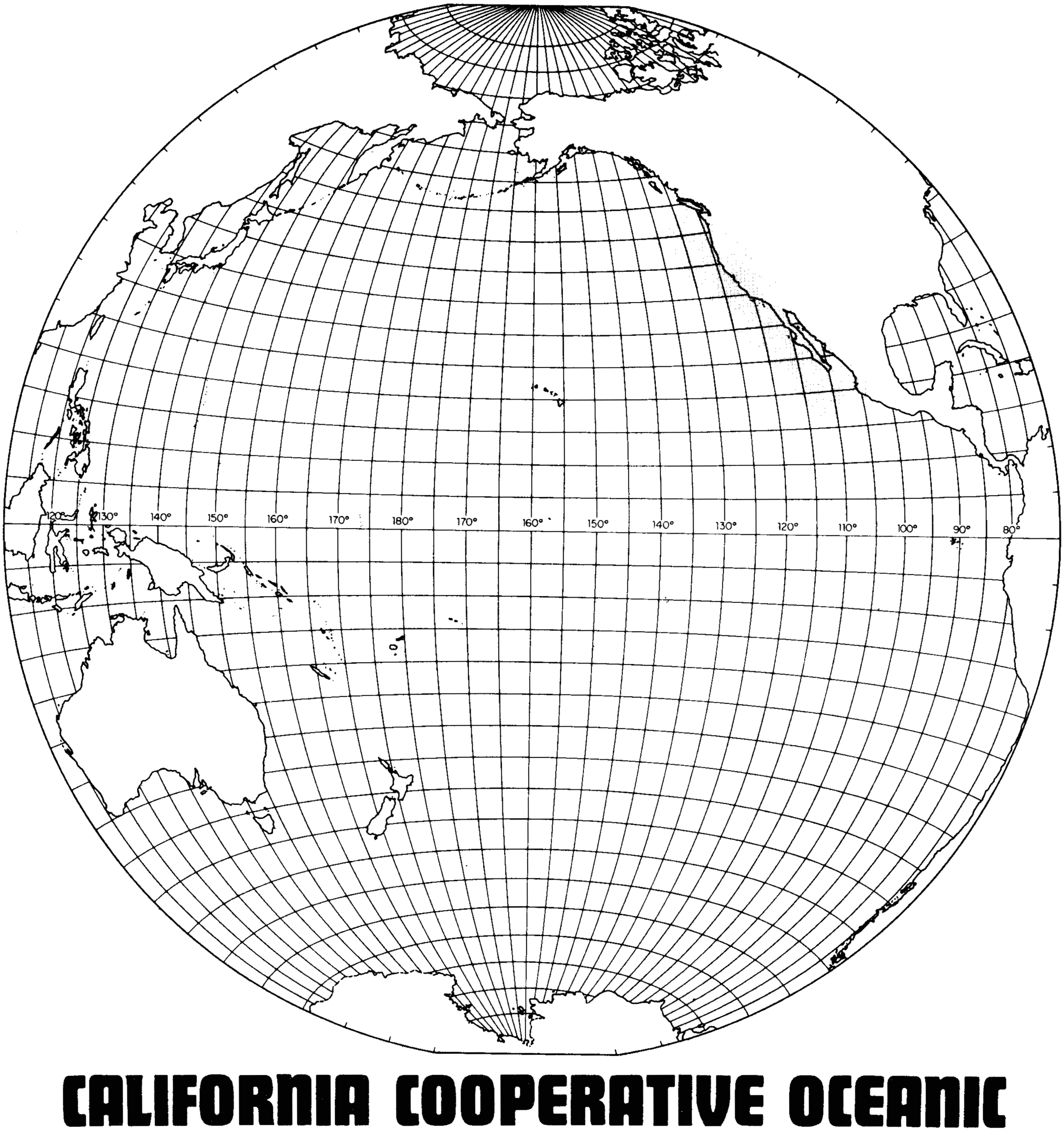
MARINE RESEARCH COMMITTEE



CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

REPORTS

VOLUME XIX

OCTOBER 1977

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STATE OF CALIFORNIA
DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

Reports

VOLUME XIX

1 July 1975 to 30 June 1976

Cooperating Agencies:

CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, NATIONAL MARINE FISHERIES SERVICE

October 1977

STATE OF CALIFORNIA—RESOURCES AGENCY EDMUND G. BROWN JR., Governor

DEPARTMENT OF FISH AND GAME
MARINE RESEARCH COMMITTEE

1 October 1977

The Honorable Edmund G. Brown Jr.
Governor of the State of California
Sacramento, California

Dear Governor Brown:

We have the honor to submit the nineteenth report of the California Cooperative Oceanic Fisheries Investigations.

The report consists of three sections. The first contains a review of the administrative and research activities during the period 1 July 1975 to 30 June 1976, a description of the fisheries, and a list of publications arising from the programs.

The second section consists of papers presented at a Symposium, "The Anchovy Management Challenge," held December 9, 1975. Participants in the Symposium included knowledgeable scientists and resource managers from various parts of the world interested in the management of pelagic fish resources. In particular, Daniel Lluch of the Instituto Nacional de Pesca of Mexico and Robert Kaneen of the California Department of Fish and Game discussed, respectively, the exploitation and conservation of the Northern anchovy as seen from Baja California and California.

The third section consists of scientific contributions that represent research directly pertinent to the living marine resources of California. Some of these were original papers given at the Symposium on Fishery Biology, held in Ensenada, Baja California, Mexico, February 1975.

Respectfully submitted,

MARINE RESEARCH COMMITTEE
Charles R. Carry, Chairman

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Part I

REVIEW OF ACTIVITIES

1 July 1975 to 30 June 1976

REPORT OF THE CALCOFI COMMITTEE

During the year, the informal cooperative research activities between CalCOFI agencies and the Instituto Nacional de Pesca (INP) of Mexico have continued and have been enhanced. Additional "work groups" were established and cooperative work in the areas of egg and larva surveys, acoustic surveys, catch per-unit-of-effort, fishery monitoring, and data processing was either continued or initiated. Considerable attention was given to the anchovy resource fished in common by both United States and Mexican fishermen.

The subject of the CalCOFI Conference symposium, "The Anchovy Management Challenge," on December 9, 1975, is good evidence of the interest of both California and Mexico in the anchovy resource. With Mexico's growing capability to harvest and process anchovies, the fishery will continue to enlarge. Part of the symposium addressed the pelagic fisheries off South Africa and Peru. These fisheries on similar species may provide additional insight on the management of the northern anchovy and Pacific sardine resources off California and Mexico. In addition to marine scientists and managers, both commercial and recreational interests attended the symposium and participated in the question and answer sessions.

One of the products of the cooperative work between CalCOFI and INP biologists is presented in this publication. For the first time, a report detailing both the Mexican and California fisheries on the central anchovy stock has been produced. This should be the beginning of a series of publications that may be extended to other species in the future.

Izadore Barrett, Herbert Frey, John Radovich, and Joseph Reid.

CALIFORNIA ACADEMY OF SCIENCES

July 1, 1975–June 30, 1976

In previous reports we have dealt with the major food items found in the stomachs of a number of species of fish of present or potential interest to fishermen along the California coast. Rather commonly, fishes large enough to enter the commercial fishery feed on marine organisms large enough to be identified by macroscopic observation, although owing to maceration during digestion, individual organisms may have to be identified through microscopic study of fragments (legs, eyes, antennae, or other recognizable parts).

However, in identification of the fish and macroplankton ingested by the commercial fishes under study, no attention has been directed specifically to a search for very small plankton (nannoplankton) which might have been ingested along with larger food. Murray and Hjort suggest in their classic book *The Depths of the Ocean* (p. 356) that these hard-to-get small plankton species may, because of their numbers, play a more important role than all of the others combined. It was accordingly decided to make a detailed restudy under the microscope of the stomach contents of the fishes involved in this investigation.

Briefly it may be stated that no nannoplankton was found, and with two exceptions, no phytoplankton whatever. The exceptions were two Jack Mackerel caught south of Catalina Island in May 1969; each contained among other items found in the stomach, one diatom *(Chaetophora* sp.). One of them also contained part of a blade of eel-grass.

The re-examination of stomach contents is not, however, considered fruitless. Negative information has a value of its own; and further, some additional organisms were found in the stomach contents of three species of fish from which they have not previously been reported by us, as follows:

Jack Mackerel (735 stomachs re-examined). Protozoa (Foraminifera); Jellyfish larvae; Bryozoa "cyphonautes" larvae; Copepod eggs; Ostracod larvae; Sagitta and their teeth; Appendicularia (*Oikopleura*); Hemicordate larvae; Cephalocordate larvae.

Pacific Mackerel (161 stomachs re-examined). Protozoa (Foraminifera, Radiolaria, Tintinnida); Ctenophores; Bryozoa "cyphonautes" larvae; Ostracod larvae; Crustacean (?) eggs; Crustacean "zoea" larvae; Gastropod larval parts; Chaetognath eggs; *Sagitta* and their teeth; Hemichordate larvae; Appendicularia (*Fritalleria*); Cephalochordate larvae.

Pacific Saury (91 stomachs re-examined). Protozoa (*Radiolaria, Foraminifera, Tintinnida*); Bryozoa "cyphononautes" larvae; Ctenophores; Copepod eggs; *Sagitta* parts and teeth; Hemichordate larvae; Appendicularia (*Oikopleura* and *Fritallaria*).

No new forms were found in the stomach contents of the Pacific hake or the market squid.

In those species in which re-examination yielded additional data, the number of kinds of organisms found has been increased as follows: Jack mackerel, 60 plus 9, or 69; Pacific mackerel, 60 plus 14, or 74; Pacific saury, 19 plus 10, or 29. In each case the ones found in the first examination may be regarded as dominant, since the ones discovered only on re-examination were scarcer and harder to find. It may further be concluded that the diet of all three species is essentially zooplankton, since in the specimens studied and restudied, phytoplankton is close to zero. It is clear also that the organisms reported in the first study are the dominant food in each case, since greater effort and higher magnification was required to find the forms added by restudy.

Robert C. Miller
Anatole S. Loukashkin

CALIFORNIA DEPARTMENT OF FISH AND GAME

July 1, 1975 to June 30, 1976

Sea Survey

Acoustic surveys conducted during the fall and spring indicated the central stock of anchovies to be at its lowest level since Sea Survey biomass estimates were initiated. The fall surveys produced an estimate of 740,000 tons off southern California and an additional 131,000 tons off northern Baja California. During the spring, 767,000 tons were detected off southern California and only 25,000 tons were located off northern Baja California. The fall estimate represents a 50% decline in stock size from the previous season while the spring estimate represents a 66% decrease from the previous year. Age composition data gathered during the year indicated the decline may have been the result of poor larval survival during 1974 and 1975.

Additional evidence of successful jack mackerel spawning during 1974 was gathered during fall and winter cruises. Jack mackerel were taken in 50% of the sets off southern California during the night-light cruise, the highest rate of occurrence in 25 years of this type survey. Additionally, they were captured in large numbers during trawling operations, further indicating the unusual strength of the 1974 year class.

Pacific mackerel were taken during most of the season but not in quantities large enough to indicate a strong year class. Originally it was hoped the 1974 year class would be as strong as the jack mackerel was but it appears that it will not be up to previous expectations.

During the year a joint venture between the Instituto Nacional de Pesca of Mexico, National Marine Fisheries Service, and California Department of Fish and Game was initiated to standardize acoustical survey methods. The final format for reporting data should closely follow the one developed in Sea Survey. Completion of the project should result in a more complete and effective assessment of the anchovy stocks residing in the California Current System.

Market Squid Study

The department, in cooperation with Sea Grant, continued to work on electrophoretic studies to determine genetic variations in market squid. Four cruises were scheduled to collect specimens for protein analysis. Preliminary work on the enzyme phosphoglucomutase (PGM) showed that there are five allozymes present and nine phenotypes represented. Comparing the phenotype distribution against Hardy-Weinberg equilibrium expectations, using the chi-square test, suggested that PGM is homogeneous throughout the range tested with the possible exception of La Jolla squid. This electrophoresis work and that of another laboratory will supplement the morphometric and morphological work conducted by Sea Grant in an endeavor to distinguish among stocks for proper management of the resource.

Pacific Mackerel

The department continued to monitor the Pacific mackerel population in response to legislation passed in 1972. Current regulations allow for incidental catches of less than 18% Pacific mackerel in mixed loads. Additionally, the legislature called for a limited fishery when the spawning biomass exceeds 10,000 tons.

During the summer and fall, 7,153 Pacific mackerel were tagged to determine population size. Subsequently, 97 tags were recovered from the partyboat fishery. Analysis of the data indicated mackerel did not mix with fish from adjacent areas. In light of this, no estimate was made since tags would have to be returned from throughout the range for the estimate to be valid. A localized estimate of 2,000 tons of spawning biomass was arrived at for Santa Monica Bay.

Tagging Pacific mackerel failed to provide a valid population estimate so a second technique independent of marking fish was used. The method called for an estimate of the ratio of Pacific mackerel to jack mackerel in cannery landings. Since the size of jack mackerel population is known, it was then possible to estimate the size of the Pacific mackerel by extrapolation. Using this method, an estimated 5,000 to 11,000 tons of spawning biomass was present. Since the mean was 8,000 tons, no fishery was recommended in 1976.

Stephen J. Crooke

MARINE LIFE RESEARCH GROUP SCRIPPS INSTITUTION OF OCEANOGRAPHY

July 1, 1975, to June 30, 1976

The Marine Life Research Group continued to carry out a wide range of research, related to the California Current and other regions as well. The second half of 1975 saw the completion of the triennial CalCOFI cruises, which are used to monitor the pulse of the physical oceanography and pelagic fish status in the California Current. In addition to measurements normally collected in the pelagic region, many stations much nearer shore were occupied to collect data tying the nearshore and pelagic regions together, and to improve understanding of the sport fishes' relationship to the pelagic fish.

A new ship the NEW HORIZON, primarily for the Marine Life Research program, has been approved by the University and the State of California. It will replace the ALEXANDER AGASSIZ, which was acquired in 1961 from the military reserve fleet and converted by MLR for use primarily in the CalCOFI program. The new research ship should be constructed in time for the CalCOFI cruises that begin in December 1977. Its research capability will be much greater than that of the AGASSIZ, and it will therefore increase the types of research that can be carried out by Marine Life Research.

Continued cooperation with the Instituto Nacional de Pesca in Mexico and student participation from the Escuela Superior de Ciencias Marinas at Ensenada, Baja California, have been an important part of the MLR cruises and of CalCOFI research in the California Current.

The following are brief reviews of the research by various members of MLR.

Last year's study of the seasonal range of sea elevation off northern Baja California has been extended to include the west coast of North America, the Aleutian Islands, and Kamchatka. Reid and Mantyla observed that coastal sea elevations measured at tide gages in the northern North Pacific show a seasonal high in winter (November–February). This high is well out of phase with the midocean response of the sea surface elevation to the heating and cooling cycle, which produces greatest elevations in July–October. It has been found that sea surface elevation near the coast varies seasonally in phase with measurements at tide gages and that high elevations in winter are a consequence of the circulation of the subarctic cyclonic gyre of the North Pacific Ocean—that is, the California Countercurrent, the Alaska Current, and the Kamchatka Current. The flow of the coastal limb of this gyre (along the eastern, northern, and western boundary of the ocean) is intensified in winter, and in geostrophic balance the sea surface slopes upward toward the coast, accounting for the winter rise. Along these coasts the sea surface stands about 14 to 30 cm higher in winter than in summer, while in midocean the sea surface stands about 6 to 8 cm higher in summer than in winter. Reid and Mantyla propose that sea elevation along the eastern boundary does not slope uniformly downward from the equator toward higher latitudes but has several maxima and minima. These appear to be the consequence of sea surface slopes associated with the quasi-geostrophically balanced system of cyclonic and anticyclonic gyres in high and middle latitudes and zonal flows near the equator.

There has been a continued study of eddies in the California Current by Schwartzlose. This last year a cruise on the AGASSIZ to examine an eddy was successful. An eddy was found at exactly the same location where one was found in 1957. While the eddy reported earlier was cyclonic, the recent cruise found a strong anticyclonic eddy. Measurement of temperature and salinity within the first 100 m did not show the effect of the eddy, but it was shown clearly by movement of parachute drogues near the surface. At 200–400 m temperature and salinity measurements gave evidence of the eddy, and there were some indications of it to a depth of more than 500 m. The eddy persisted at the same position for at least 3 weeks. This is an area where the California Current swings shoreward and divides, part going into the Southern California Bight and part going southward along the Baja California coast. This area also is a region of warmer, more tropical water pushing northward beneath the surface into the California Current.

Patzert has continued his work with the El Niño cruise data. Analysis of data confirms the preliminary evaluation that the El Niño disturbance was not confined to the surface layer, but extended as deep as 300 m. An atlas with various physical, chemical, biological, and meteorological data presentations is now in preparation. Some results of the El Niño Expedition were published in *Science.*

Evaluation of near-bottom current meter data obtained during the expedition has revealed exciting results. While hydrographic observations were indicating El Niño activity off the South American coast, the current meters (located near the equator, 300 km west of the Galápagos Islands) recorded a 25 day period oscillation of about 1000 km wave length and 4 cm/sec amplitude propagation westward at approximately 50 cm/sec. These characteristics agree with theoretical models of a first-mode baroclinic Rossby wave trapped at the equator. A paper describing these results has been accepted by *Science.*

During 1976, plans have been developed to initiate a long term monitoring network in the central Pacific Ocean. This network will be a shuttle between Honolulu and Tahiti utilizing ships, aircraft, moored current meters, drifting buoys, and island stations to monitor the low-frequency (months to years) fluctuations of the equatorial Pacific oceanic circulation in order to understand its dynamics. One of the ideas motivating this effort is the possibility that tropical oceans appear to be areas where ocean-to-atmosphere coupling may play an important role in short term variability of atmospheric climate, particularly in the Pacific Basin.

Hemingway has continued his studies into the functional morphology of feeding in marine predatory gastropods. He also organized and carried out a project of collecting plants and animals of the intertidal zone along the west coast of Baja California, Mexico, an area where our knowledge has been limited. Students and faculty from the Marine Science School in Ensenada, Baja California, particpated in this project.

The systematics and distribution of the deep-sea fish family Searsidae, and the young stages of two of these species, have recently been studied by Matsui. The larvae are large, measuring 9–16 mm in length during the yolk-sac stage. In the two commonest species from the eastern Pacific, the length decreases from 15–16 mm to about 11–13 mm while the yolk-sac is absorbed. The smaller sizes at the yolk-sac absorption stage are generally not too advanced and are emaciated. The larvae are collected over the same depth range as older stages, which is approximately 300–900 m.

In the family Searsidae we recognize 16 genera and 22 species; 3 genera and 4 species are new. These are relatively rare fishes that have been collected most frequently in areas of high productivity. It appears that oxygen content is a significant factor in the distribution of species; this is reflected in the degree of development of gill filaments.

Examination of phytoplankton from the central North Pacific Ocean has continued. Venrick, Beers, and Heinbokel completed a study on the effects of enclosing natural assemblages of microplankton in 250 ml bottles, a procedure universally employed for the determination of "simulated *in situ*" physiological rates such as primary productivity. Very striking changes in the composition of the assemblages occur within periods as short as 6 hours. Within 24 hours most of the taxa decrease in abundance and some microzooplankton components vanish completely. A most important finding of this study is that direct extrapolation of physiological measurements made on contained populations to populations in the field may not be valid.

A series of chlorophyll and productivity measurements were taken on *Indopac I* along an east-west transect across the Pacific. In addition to giving broader scope to intensive measurements made at 28°N, 155° W during the past several years, the data will be used to examine the hypothesis that mesoscale and megascale eddies enhance nutrient transfer into the euphotic zone, thereby stimulating primary production and increasing standing stock of phytoplankton.

Brinton and Knight have continued their studies of aspects of development and population ecology of euphausiid crustaceans ("krill"). These include behavioral means by which such planktonic animals conserve their stocks in a drifting milieu, maintain permanent ranges, breeding grounds, and access to adequate food resources. Regions of study are the diverse, overlapping habitats of the California Current and the Eastern Equatorial Pacific, contiguous to the south. Here, fertile and impoverished zones and O_2-rich and O_2-deficient waters abut, but all harbor characteristic populations. Evidently, species which undergo daily vertical migrations of several hundred meters, daily occupy currents of different speeds and directions, whereas nonmigrating species are vertically positioned at intermediate or greater depths, so as to maintain regional stability. Different life stages appear to live at different depth levels. Such ontogenetic changes in habitat—vertical and regional—are being investigated with respect to development and survivorship for the more accessible euphausiid species.

The study of larval development of the three species of the genus *Euphausia* which comprise the "*E. gibboides* group" is almost complete; illustrations and description of the growth stages of *E. fallax* are being prepared, those of *E. sanzoi* and *E. gibboides* are, respectively, in press and published. These species were studied as a group to investigate the relative importance and usefulness of an array of larval characters while providing a key to their identification in the plankton. The available descriptions of *Euphausia* larvae are for the most part based on overall size and general body plan, features which may separate very different species in one area but which may not be sufficient in waters in which similar congeners or members of a species group are found together. A detailed examination of the morphology of larval appendages and a comparison of body proportions as well as size and form have shown that certain features do vary consistently between species within species groups permitting positive identification of early stages, usually the most difficult to separate. The identification of the larvae of *E. fallax,* which are sampled more frequently than the adults, has expanded the distribution of the species to areas within the Indian Ocean; previously it was known only from Southeast Asian seas.

The study of evolutionary trends in planktonic copepods as expressed by morphology, distribution, and behavior is being continued by Fleminger and Hulsemann. The principal approach is to test character divergence against geographical relationships among congeners in two groups of calanoid copepods, the genus *Labidocera* (family Pontellidae) and the genus *Calanus* (family Calanidae). Among a number of interesting developments during the year was the discovery of an unusually large number of speciation events within a planktonic genus occurring in the western tropical Atlantic and centering in the West Indies. The *wilsoni-mirabilis* lineage in the genus *Labidocera* has apparently radiated most extensively in the southern Caribbean as indicated by finding four new species, each from a different geographical locality within the region. Species of this lineage occupy surface waters protected from extensive offshore advection along tropical coastlines, around islands, and over shallow offshore reefs. This particular planktonic habitat has been too sparsely sampled in the Caribbean to judge the total diversity achieved by the *wilsoni-mirabilis* lineage. However, considering the ranges of the six species now known, two unique features appear to have generated the unusually high number of closely related species for so spatially restricted a region as the Caribbean. The unique features, hydrography, and a parasitic fungus, have been incorporated in a hypothesis to explain the unprecedented high diversity for a zooplanktonic taxon. Several new collecting expeditions have been scheduled to determine the extent of this swarm of species and to test the hypothesis. The results should illuminate processes of speciation and morphological divergence in planktonic crustaceans.

Mating in *Labidocera* was examined microscopically for the first time. Individual observations were made on about forty pairings of *Labidocera jollae* and one pairing of *Labidocera trispinosa,* both inhabiting coastal Californian waters. The observations confirmed speculations on the functioning of sexually modified morphological features in both sexes. Comparison with mating patterns in a related family provides a basis for understanding the adaptive significance of morphological differences distinguishing the two families. Sites of spermatophore attachment on the female abdomen (*Labidocera*) were discovered to be characterized by intense concentrations of integumental glands. Comparisons between sets of species differing within geographical relationships showed a pattern of interspecific variation attesting to the importance of these glands in barriers to interspecific hybridization.

Studies on the taxonomy and distribution of *Calanus* were highlighted by resolving questions about the North Atlantic distribution of *Calanus helgolandicus.* A reproductively active population of *helgolandicus* was found in shelf and slope waters of North America living between Cape Hatteras and the New York Bight. This population provides a source for the previously unexplainable sporadic records of the species across the North Atlantic Drift. Comparison of North Atlantic and North Pacific *Calanus* distributions and interspecific morphological divergences indicates fundamental differences in the distribution of *Calanus* habitats in the two oceans, qualities that reflect differences in circulation patterns of high fertility waters of the mixed layer between the two oceans.

Information on the marine environment recorded in varved anaerobic sediments off the west coasts of North and South America is being examined under John Isaacs' direction by Andrew Soutar, Stanley Kling, and Peter Crill. In such accumulations where disturbance by burrowing organisms is essentially lacking, a faithful time series of various biological and geochemical variables can be resolved to approximately annual scale. Past work has shown that climatic information expressed in such measurements as temperature and rainfall is reflected by physical characteristics (e.g., variations in sediment thickness) and the flux of biological remains (fish scales, foraminifera, radiolarians, diatoms, and coccoliths). Man's impact on the environment has been imprinted via trace amounts of various chemicals (e.g., mercury, lead, and halogenated hydrocarbons). Such results suggest inquiry into the sedimentary record for clues to understanding the present environment. The cumulative nature of the record aggregates seasonal fluctuations in a way not practically obtainable by conventional shipborne sampling techniques (plankton nets, water samples, etc.). Comparison of cores from the Santa Barbara and Santa Monica Basins, for example, reveals a biological imprint characteristic of each basin. A locally characteristic dominance hierarchy in radiolarian assemblages is consistent over the last hundred years such that at no time does either basin come to resemble the others.

While the importance of high resolution sedimentary records as a sampling technique thus becomes apparent, the limited geographic distribution of natural occurrences (a few isolated areas in the world, primarily in high productivity regions) restricts their regional applicability. Accordingly, devices to simulate a sedimentary record are being developed. A newly designed particle interceptor trap is being built to acquire and preserve large samples of settling material under geochemically clean conditions. Traps are to be moored at various levels in the oceans for periods of several months and retrieved upon timed or acoustic command release. The technique outlined could be calibrated as a device for monitoring the marine environment. Samples from an earlier prototype give results consistent with records obtained from underlying sediments.

A scanning densitometer to measure and record varve thickness from X-rays of sediment cores has been built with control functions assigned to a microcomputer. The computer is also available for other data acquisition and analysis functions. A small portable keyboard, for example, has been set up as a tally counter of virtually unlimited capacity for recording individual observations. The device has proven to be more efficient than mechanical counters, and, in addition, eliminates the time consuming and error introducing step of keypunching manually recorded data.

The development of new instruments as discussed above to collect or process data for various projects continues to be an important part of MLR. Not all development projects are for the MLR research staff, but they usually are devices which will benefit MLR research. The MLR machine shop, under Duffrin, has been working on the sediment traps and improvements in the box corers for use in the varved sediments research.

Brown has developed and has in operation three new devices: the decade sampler, the manta net, and the magnetic release and actuator.

This decade water sampler was designed to measure microstructures. It does so by closing ten 450 ml water samplers simultaneously when activated by a messenger. The unit is 2 m in length and is deployed on a hydrographic wire. Particular attention was paid to having no contamination problems inherent in the design; thus, the sampler works essentially like a big suction gun. It was realized that an additional type of sampling might be possible with such a device, namely the sampling of unconsolidated sediments or nepheloid layers on the bottom of the ocean. The decade sampler was thus designed to operate as part of a free-vehicle system. In the free-vehicle mode it could go to the ocean floor, remain on the mechanical bottom for a number of hours to allow the sediments to come to equilibrium again after being disturbed by the landing of the sampler, take a sample, and return to the surface. In this manner, a closely spaced series of water and/or unconsolidated sediment samples could be taken with a known distance from the bottom. The design is such that additional collectors can be added between each of the others; thus, the spacing and number on the frame is adjustable.

The sampler has already yielded information on the microstructure of the chlorophyll maximum layer, showing it to be made up of layers a few centimeters thick of phytoplankton in the area off southern California.

The surface of the sea has come under increasing study as the importance of this interface with the air has come under closer scrutiny. A surface skimming net was devised to sample this surface layer in a manner not achieved by earlier neuston net designs. The objectives were to sample surface water quantitatively, keeping the scare effects to a minimum and being a surface follower. These requirements were met by the design of the manta net. Bongo nets, which have a 220 cm circumference, are used as the filtering part of the net and are towed by a frame with unique properties. The frame is steered by two paravanes to keep the net away from the ship so that it tows free of any scaring effects of either the ship wake or bow wire. A special wire bridle achieves the necessary steering angle, and two wings support the frame on the surface of the water like hydroplanes. The towing forces on the frame come from a submerged towing weight and bridle so configured as to keep the mouth of the net always on the water, no matter what the state of the sea or the speed of the ship. The submerged towing bridle also reduces the scare effect on the surface creatures, and the paravanes aid in the catch, as they keep the animals from escaping to the side of the net. This is the same action achieved by manta rays when they are feeding on the surface with their mandible extensions protruding ahead of their mouths, hence the naming of the net. The flow through the net is measured by a flow meter.

Catch results have been very gratifying, and have yielded some surprises in the kinds of small fish and squids that have been captured on the surface, even during daylight tows.

The problem of operating instruments in deep ocean waters is a source of constant concern. The magnetic release system transmits the force of a magnet from inside a pressure vessel to an outside keeper, holding the keeper in place. Upon the closure of a switch inside the vessel, the magnet is made to move and release its grip on the outside keeper. A trip hook attached to the keeper then activates the desired function. Thus, electrical systems are never exposed to the water or pressure since they are contained in the pressure vessel. Only magnetic force is transmitted by steel bolts through the pressure wall. All outside mechanisms are mechanical in nature and are not affected by water or pressure.

The first generation of magnetic releases was designed for use with a variety of free-vehicle systems, such as the pressure fish trap. Development problems revolved mostly around corrosion problems associated with using steel and aluminum in seawater. It was this problem that probably thwarted earlier development and caused some early failures. The corrosion problem was solved, and now the releases offer a whole new system of actuating underwater devices.

The opening/closing midwater trawl now uses this sytem which has eliminated all failures that might result from leaking wires, connectors, and solenoids. The bongo net now has a new magnetic mechanism to open and close the net without use of messengers. As a nonexplosive device, the release is a much less expensive unit to use for many free-vehicle systems since it requires no careful assembly, operation, or check-out system. Even rotary motion has been transmitted through the pressure wall and has been used to govern the movement of a drum on a large sediment trap.

The concept has now opened up a whole new way of activating underwater equipment.

During the past year the Ocean Technology Group under Sessions has been engaged in several programs. An improved digital-recording, free-vehicle current meter has been developed to extend the endurance of missions up to 6 months and overcome the data processing problems attendant to the large increase in capacity of information stored within the instrument during long term deployments. A solid-state flux-gate compass was developed for this instrument to remove the problems related to mechanical compasses common to our present day current meters. This current meter also incorporates hardware to permit placing the instrument in mooring lines of moderate loads without stressing the instrument.

A computer based data reading and editing capability has been developed to permit timely reading and processing of data recorded by current meters and other instruments which use this magnetic recording technique. This system is fully operational and permits the reading of several months of data in less than 15 minutes directly into the computer for automatic processing.

In order to overcome the shortcomings of most ocean current meters for near-surface measurements, this group has developed a new type of current meter utilizing a propeller with excellent characteristics. Much of the electronics are the same as the digital-recording, free-vehicle current meter, and several prototype units have been constructed for use in near surface profiling and mooring applications.

Acoustic recall of free vehicles has been developed and successfully tested. Several systems are now deployed in the equatorial Indian Ocean for durations of 4 months.

A low drag flotation package and mooring system has been developed for current meter measurements in high velocity equatorial regions. These systems are now operational and were installed early this spring on the equator by our group. A continuing program of operation for the next year is planned to keep at least two instruments in place at all times in order to obtain a continuous long term current record from the equator at a depth of 500 m.

A NORPAX program of measuring the thermal structure in the North Pacific Ocean in a north-south direction between Alaska and Hawaii utilizing U.S. Navy Fleet aircraft has been conducted for the past several years. Monthly flights between Adak and Honolulu and the onboard recording of data have been successfully maintained throughout the year by this group.

Instrumentation for the performance monitoring of the Tethered Float Breakwater program was designed and installed in support of the bay scale model during the past years. Data was continuously monitored over an approximate 8 month period and automatically recorded when events of significant magnitude, such as storms, occurred. These data permitted detailed analysis of actual sea performance of a large, scale model array. In addition to the Breakwater monitoring program, a general low cost wave monitoring network was conceived and used much of the hardware developed for the Breakwater program. Four stations were installed between Oceanside and Imperial Beach with data being automatically recorded twice daily at our central computer site. This information is computer processed and disseminated promptly on a monthly basis to interested agencies. This system is highly automated and designed to demonstrate the feasibility and economics of operating a network which can be expanded to provide very large area coverage.

Joseph L. Reid

NATIONAL MARINE FISHERIES SERVICE SOUTHWEST FISHERIES CENTER LA JOLLA LABORATORY

July 1, 1975, to June 30, 1976.

Fisheries research devoted to the objectives of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) continues as a central coordinating theme in the overall program of the National Marine Fisheries Service (NMFS), Southwest Fisheries Center (SWFC) laboratory in La Jolla, California, as it has for the past three decades. Under Reuben Lasker, Leader of the Coastal Fisheries Resources Division at the La Jolla facility, research emphasis has been placed on the causes of larval fish mortality and its effect on recruitment, areas of study increasingly perceived by fishery biologists as fundamental in solving problems of fishery biology.

The report which follows recounts highlights of work accomplished by the Coastal Fisheries Resources Division and records CalCOFI research activities undertaken at the La Jolla Laboratory.

During the above period a number of fruitful areas in larval fish research were investigated at the La Jolla Laboratory, notably the following: histology of starvation of larvae; oceanographic changes which affect the distribution of larval fish food; the determination and analysis of the kinds of food and feeding by larval northern anchovy, jack mackerel and Pacific sardine; analysis of mortality rates of northern anchovy embryos and larvae from 1951–1969 using CalCOFI data; the development of techniques for assessing the suitability of various water masses as feeding grounds for fish larvae; an investigation into invertebrate and vertebrate predators of fish larvae; simulation modeling of larval anchovy growth, behavior and prey microdistribution; the application of otolith-aging techniques to larval anchovy growth studies; and food chain studies of pesticide uptake by larval anchovies. All of these studies have been aimed toward understanding how pelagic fish larvae interact with their environment; ultimately, the data are intended to help explain the all-important stock and recruitment relationship.

Causes of Anchovy Larval Mortality

This year saw the culmination of several lines of research on larval fish. The work of Reuben Lasker and Paul Smith provided first order estimates of distribution, abundance, growth and survival rates of northern anchovy larvae and showed how this information could be used to analyze the causes of anchovy larval mortality.

By examining seasonal and annual variations in the degree of anchovy spawning against sea surface temperature, vertical temperature gradients, upwelling, the speed of the California Current, the flushing rate of the Los Angeles Bight and secondary production, they showed that the usual habit of the anchovy to spawn heavily in the southern California area in winter alters radically in some years. Results indicated that spawning appears to be a simple function of the biomass of adults and the annual record reflects little more complexity than the rapid increase in anchovy biomass over the past 25 years.

Lasker has now developed supporting evidence for his recent hypothesis that upwelling events and storms in the California Current are detrimental to anchovy larvae by diluting concentrations of their food. He has shown, for example, that the advent of storm systems and turbulent mixing of the upper 100 m during the month of March 1975 diluted the larval anchovy's food organisms to a degree where there was not enough food left to sustain first-feeding larvae in their natural environment from March through April. As a result, he predicted that the 1975 year class of anchovy had to be a very poor one, based on the occurrence of massive upwelling in the Los Angeles Bight during the anchovy spawning season and the poor nutritional content of the dominant larval fish food organism, *Gonyaulax polyedra*, present before upwelling occurred. This view has been borne out by subsequent fishery analysis by the California Department of Fish and Game.

Larval Fish Studies in New York Bight

Under a grant from the Brookhaven National Laboratory of the Energy Research and Development Administration (ERDA), Lasker and Scura began studies of the larvae of winter flounder, *Pseudopleuronectes americanus;* summer flounder, *Paralithchthys dentatus;* and scup, *Stenotomus chrysops,* in the New York Bight with the assistance of Geoffrey Laurence of the NMFS laboratory at Narragansett, Rhode Island, and Kathryn Dorsey of the La Jolla Laboratory. The rationale for this study was Lasker's work in the Los Angeles Bight which had shown that there are areas in the ocean where organisms of the proper size for first-feeding larvae congregate (i.e., in chlorophyll maximum layers). Although conditions and species of fish are quite different in the New York Bight, it was believed that similar techniques could be used to locate suitable larval feeding grounds on the east coast. The research strategy was to search for aggregations of possible food organisms at sea, collect samples of water from these areas and then introduce laboratory-produced fish larvae into the samples. If the larvae began feeding this would provide valuable clues as to the kinds and concentrations of food organisms necessary to characterize an area as a suitable one for larval fish survival.

Series of tests with first-feeding flounder, scup and anchovy larvae showed that, with certain modifications, each species could be used as a bioassay to determine whether feeding conditions in a body of water are suitable for a particular species of fish larvae. For example, it has been ascertained that anchovy larvae require approximately 280, 50-micron diameter particles a day, whereas flounders and scup are competent feeders on larger particles when they begin to feed and require only 10, 150 micron diameter or even fewer larger particles to satisfy their metabolic requirements.

It was shown that preference for certain kinds of food was evident in all species examined thus far. High levels of spiniferous dinoflagellates, *Ceratium tripos,* were ignored by flounder and scup larvae in the New York Bight during November and June, respectively, whereas nauplii and dinoflagellates (e.g. *Prorocentrum)* were taken by flounder, provided that the nauplii and dinoflagellates were in concentrations higher than 100/liter.

Scup preferred a smaller dinoflagellate, *Dinophysis acuminata,* to the larger *Ceratium* despite the predominance of the latter, while anchovy larvae in the Los Angeles Bight will not eat small diatoms, regardless of their abundance. An unusual finding was that scup larvae selected pine pollen grains, despite the extremely low concentration (0.01–0.04/L) of pollen in New York Bight water during June 1976.

Two instruments have been developed in conjunction with the studies of larval fish food patchiness in the New York and Los Angeles Bights to determine *in situ* concentrations of phytoplankton and microzooplankton (less than 1 mm in smallest dimension). A prototype model of a free-fall particle counter has been developed by John Brown of the La Jolla Laboratory and is scheduled for testing in the spring of 1977. This instrument is intended as a survey instrument for rapid measurement of *in situ* stratification and the distribution of particles by size throughout a 100-meter column. A dedicated computer accumulates numbers of particles per unit volume by 0.2 meter strata and by size of particle. The second instrument, already used successfully in the New York and Los Angeles Bights, was developed by Scura. It is deployed on a ship's hydrowire and provides information on relative particle distribution particle sizes between 50 and 500 μm) with depth using a rate meter. Water is delivered on board to provide specific particle concentrations when this is desired. The actual size and number of particles per unit volume is determined with a model Ta Coulter Counter aboard ship. Species composition is determined later in the laboratory from preserved samples with an inverted microscope.

Microdistribution of Small Planktonic Organisms Used as Food by Fish Larvae

Under the leadership of Lasker and Owen, an interdisciplinary multi-ship cruise was conducted in March 1976 with the NOAA research vessels, DAVID STARR JORDAN and TOWNSEND CROMWELL, to study the microdistribution of small planktonic organisms used as food by fish larvae in California coastal waters. Samples taken during this cruise with a 10-bottle vertical sampler have been analyzed by Owen for fine-scale depth differences in phytoplankton concentration, phaeophytin, detritus and microzooplankton patchiness. Because of the small distance first-feeding anchovy larvae can travel, this fine-scale distribution in their food may be a critical factor in larval survival. Owen found, for example, that adjacent bottles, 0.2 meter apart, can differ in phytoplankton content by as much as two times in the chlorophyll maximum layer. Horizontal patchiness was also investigated by constantly sampling with a plankton pump from two ships simultaneously as the ships approached one another.

Life Studies: Larval Fish

Basic to the objectives of the La Jolla Laboratory's Coastal Fisheries Resources Division is the ability to mature and spawn at will important pelagic marine fishes to provide fish eggs and larvae for laboratory experiments. Five important species have been successfully matured and spawned in the SWFC aquarium—the northern anchovy, Pacific sardine, Pacific mackerel, striped bass and Gulf croaker. During the past year, Roderick Leong of the La Jolla Laboratory, submitted a paper to the Fishery Bulletin describing the maturation of captive Pacific mackerel under different light-temperature conditions, the effectiveness of various hormones for induction of spawning, and a procedure for spawning mackerel on demand throughout the year. All of the experimental work on larvae at the Southwest Fisheries Center now depends on these techniques developed by Leong to provide living material.

Developments in Studies of Physiology of Fish Larvae

To provide the physiological information essential to an understanding of how much food fish larvae require in the sea, Hunter, assisted by Carol Sanchez, completed a study of the incubation time, rate of yolk absorption, onset of first feeding, and the effects of starvation on the survival, growth and food size requirements for Pacific mackerel larvae. Hunter and Sanchez determined that in order to survive and grow, Pacific mackerel larvae must feed on progressively larger prey as they grow, unlike the anchovy which can maintain itself on small particles until it is 6–7 mm in size.

Of particular interest were the findings on the vulnerability of first-feeding Pacific mackerel larvae to starvation. It appears that mackerel larvae must find food between 90 and 108 hours after hatching or between 40 and 58 hours after they absorb their yolk and begin to search for food. Although no larvae survived if fed 130 hours after hatching, they were able to eat one or more rotifers in a 4-hour period. The number of rotifers eaten, however, was about one-third of that ingested by unstarved larvae. Thus, starvation did not completely eliminate feeding behavior, but weakened the larvae to the extent that even at high food densities they were unable to eat a sufficient quantity of food to survive.

Hunter and Sanchez completed laboratory and field studies which demonstrated that >10 mm larval anchovies inflate their swim bladders each night and deflate them in the day. By swallowing air at the surface, the larvae could reduce their energy expenditure at night by floating and not swimming until the next morning.

Hunter also completed a study on the laboratory culture and growth of northern anchovy larvae. He found that growth in the laboratory on a number of cultured foods was equivalent to growth on a wild plankton diet. A significant finding was that *Artemia salina* nauplii could only be used as a food for larvae after the larvae had acquired a loop in their intestines as a precursor to the formation of a stomach. Without this loop, Hunter believes that the larvae do not retain the *Artemia* nauplii long enough to digest them and hence starve to death.

Hunter and Sanchez have also begun a study to determine the incidence of cannibalism and its importance as a source of egg and larval mortality in the anchovy. Examination of the stomach contents of adult anchovy captured in the areas of anchovy spawning indicate that the incidence of adults feeding on their own eggs ranged from 0 to 8% of the fish captured at night in a trawl sample. The number of eggs found in the stomach ranged from a single well-digested fragment of a chorion to over 700 eggs in good condition and obviously recently ingested. No larvae were found in any stomachs examined thus far although this was not surprising since laboratory work has indicated that digestion of the smaller larvae proceeds very rapidly (less than 2 hours) whereas eggs and especially the chorions may persist in stomachs from 6 to 8 hours. Recently ingested eggs could be staged and this work indicated that the fish had fed on the previous night's spawn rather than on those eggs released on the night of capture. This is of interest since ingestion of eggs at the time of spawning is more likely to be a density independent mortality whereas ingestion of the previous night's spawn is more likely to be density dependent mortality.

Otolith Aging Technique Developed for Fish Larvae

Until now it has been impossible to relate larvae taken in plankton nets to any criteria which could indicate what proportion of them are doomed to die. With the availability of an otolith aging technique for fish larvae developed last year at the La Jolla Laboratory, a method is now available to assess whether larvae in the ocean are growing optimally or not. D. Kramer, with the assistance of K. Plummer, recently completed a study of aging of anchovy larvae collected at sea by counts of daily increments on their otoliths. Although the larvae were collected at 15–16°C, the plot of size with age indicates that these 16°C larvae had a growth rate comparable to larvae reared at 14°C in the laboratory, indicating that food was limited for these larvae in the sea.

Histological Study on Effects of Starvation on Anchovy and Jack Mackerel Larvae

From a different point of view, Charles O'Connell has developed histological criteria for identification of starvation in early post yolk-sac larvae of the northern anchovy. This study is of major importance because it will make it possible to identify starving larvae in the sea, and thereby evaluate starvation as a cause of larval mortality. Eleven histological features were each graded on scales of poor to good, depending variously on the texture, shape and fullness of nuclei, cytoplasm, extracellular substance and cellular products and stores. The distribution of grades paralleled trends in survival data from this and other laboratory studies of the anchovy, demonstrating that conditions can be evaluated from histological parameters, which are largely independent of age and length over the range studied.

The order of importance of the histological features was estimated by a stepwise discriminant analysis. All 11 histological features were significant indicators of condition but those that best classified larvae as severely (irreversibly) emaciated, conditionally emaciated, or robust, were pancreas condition, trunk muscle fiber separation, notochord shrinkage, and liver cytoplasm. The discriminant analysis indicated that a larva should be evaluated on the basis of three or four features to insure a high percentage of correct classification to determine whether a larva was starving in nature.

Using a similar discriminant analysis, G. Theilacker has studied jack mackerel larvae and has found, as with the anchovy larvae studied by C. O'Connell, that the pancreas is significantly affected by food deprivation. The appearance of several other tissues in the mackerel larvae also seem to be related to starvation—brain nuclei becomes dark and shrink, muscle fibers separate, liver and gut nuclei are irregular and indistinct, and the kidney cytoplasm shrinks. Of these histological criteria, the changes in the pancreas, brain and muscle tissue seem to be consistent and the easiest to detect in starved larvae. An interesting finding made by Theilacker is that starvation may affect body form. Theilacker was able to relate five externally measured morphometric parameters to the histological features of starvation.

These morphological measurements may be a very sensitive diagnostic method (as well as less time-consuming than histology) for determining whether field-caught specimens of jack mackerel larvae are in a state of starvation.

Observations on Physical Condition of Anchovy Larvae

David Arthur, visiting scientist in the Coastal Division, has been studying the physical condition of all sizes of anchovy larvae using the relationship of body depth to length from CalCOFI samples from the years 1963 and 1965; 1963 was a very good year for survival of anchovy larvae while 1965 was a comparatively poor year. Arthur is attempting to correlate the distribution of larvae in good and poor physical condition with the oceanographic conditions for those years. Arthur has found that 6 mm larvae show differences in physical condition which can be correlated with the good survival years. He has also found striking differences in larval condition between very nearshore and offshore areas in the same year.

In a related study, Arthur has showed that there is a distinct difference in the number of microcopepods from onshore to offshore in the California Current. Twelve times as many nauplii per unit volume, on the average, occur near the shore as in the offshore zone. Highest densities found were 195/liter with an average of about 36/liter at those stations with the highest numbers. While the mass of an individual nauplius increased exponentially with increase in nauplius size, the numbers of nauplii decreased exponentially with size. A naupliar biomass maximum was found to occur with organisms 70 μm in width. Nauplii of this size are ingested at first feeding by sardine, anchovy, and jack mackerel larvae. According to Arthur, most larval fish have developed feeding tactics to utilize this small but important food resource at first feeding.

Mathematical Model Completed of Relationship Among Larval Anchovy Growth, Behavior and Microdistribution

A NOAA Research Associate in the Coastal Division until June 1976, W. Vlymen completed a mathematical model of the relationships among larval anchovy growth, prey microdistribution, and larval behavior, using as a base the extensive collection of anchovy larval data collected on CalCOFI cruises during the past 10 years. This simulation showed that nonlinear growth rates are functions of prey contagion, but that the highest growth rates do not occur at the highest levels of contagion, an unexpected finding.

Analysis of Potential Invertebrate Predators of Fish Larvae

Recognizing that a major cause of larval mortality may be the abundance of predators in the California Current region, A. Alvariño has been analyzing the plankton collections of the monthly CalCOFI cruises for 1954, 1956, and 1958 for Chaetognatha, Siphonophorae, Medusae, Ctenophora, Chondrophorae, and other zooplankters. Each species is identified, the number of individuals per species counted and measured. Data are also obtained on the number of organisms containing food in their digestive tracts. The food organisms are identified as well as their relative abundance in the sample. Alvariño has found that fish larvae, copepods and euphausiids appear in the digestive tracts of planktonic predatory species even though these prey may be absent or scarce in the same plankton collection. Sixty percent of the invertebrate predators found with food in their stomachs were found to have eaten fish larvae. Chaetognaths more frequently contain older larvae rather than yolk sac individuals. This may be because Chaetognaths digest yolk sac larvae very rapidly or that Chaetognaths can capture older fish larvae more successfully.

Mortality and Biomass Estimates for Commercial Pelagic Fishes

For almost 30 years, the Southwest Fisheries Center has participated in the California Cooperative Oceanic Fisheries Investigations with the Scripps Institution of Oceanography and the California Department of Fish and Game in determining the biomass of important commercial pelagic fishes by sampling their eggs and larvae through entire spawning seasons. Analysis of these results has also permitted P. Smith to make mortality estimates for larvae from year-to-year and biomass estimates for specific species, notably the northern anchovy, Pacific sardine, jack mackerel, Pacific mackerel, and hake. In 1976, the information obtained on CalCOFI cruises on the distribution of fish eggs and larvae has been corrected for biases inherent in the sampling and provided in tabular form by Smith for use in corrected biomass estimates.

There is a continuous analysis by Smith and J. Zweifel of the errors involved in using the numbers of larval fish caught by plankton nets for biomass estimates. In this connection, Zweifel has devised a weighted negative binomial model which eliminates most of the difficulties inherent in normalizing and linearizing larval catch data. He has devised a maximum likelihood estimate method for analyzing data collected in samples from contagious natural populations (e.g., eggs and larvae) when the vulnerability to capture is not constant. This discrete model permits the use of all plankton tows, and unlike analyses based on continuous distributions, shows that the number of tows in which no eggs or larvae would be expected is easily predicted from the model parameters. In addition, Zweifel has derived confidence intervals for the negative binomial distribution and showed that precise probability statements are possible for a wide range of sampling situations.

Marine Environment Assessment

Egg and larva surveys are one of the basic tools in fishery science for evaluating the kinds and amounts of fish resources. Since the beginnings of CalCOFI, a group of scientists at the La Jolla Laboratory has devoted its efforts to increasing the efficiency of such surveys by increasing the number of larval marine fish that can be positively identified and by training persons in their identification and description. Led by E. Ahlstrom, this group has compiled and curated an extensive reference collection used by fishery scientists from many nations for identification of larval fish. In addition, with the objective of training NMFS personnel and others in identification of fish eggs and larvae, a concentrated course was given by Ahlstrom in the spring of 1976. Twenty-one persons were enrolled in the class on a full-time basis and several additional persons audited the course. Ten of the participants were from foreign countries. During the course, 216 life history series were studied representing 98 fish families. This was the fifth time that this course has been presented by Ahlstrom.

A major accomplishment of the group during the past year was the preparation of a manuscript dealing with pelagic stromateoid fishes of the eastern Pacific: kinds, distribution and life history, by Ahlstrom, John Butler and Barbara Sumida. The paper had a dual purpose: to identify the kinds of pelagic stromateoid fishes present in the eastern Pacific together with their distribution and relative abundance and to describe the early life history stages of most of these.

In treating the life history stages, the authors followed the "dynamic approach", pioneered by Ahlstrom. Series of specimens of a species are selected by size from newly hatched larvae to juveniles, and these are studied for developmental changes in body form, pigment patterns, fin development, ossification, etc. The pelagic stromateoid fishes described belong to four families: Nomeidae (11 kinds treated in this manuscript); Tetragonuridae (3 kinds); Centrolophidae (4 kinds), and Amarsipidae (monotypic). The young of a number of the pelagic stromateoid fishes are associated with jelly fishes—this applies particularly to the centrolophids, of which the common form in the CalCOFI area is *Icichthys lockingtoni,* the medusa fish. The other common kind in the CalCOFI area is the squaretail, *Tetragonurus cuvieri.* Most of the pelagic stromateoids are typical species that enter the CalCOFI area only off southern Baja California, or offshore in the central water mass. However, a number of the species are common in the eastern Pacific, but especially *Cubiceps pauciradiatus,* which must be an important forage fish for tunas and billfishes.

Work also continued on the CalCOFI Atlas which will deal with the distribution of scorpaenid larvae for the years 1951–1969, the sixth such CalCOFI Atlas to be produced by this group. Rockfish larvae of the genus *Sebastes* are typically the third or fourth most abundant kind of fish larvae taken annually in CalCOFI plankton collections. Species identification is difficult because of the large number of species (over 65) occurring in California waters. Identification of some commercially important species had been accomplished by removing larvae from pregnant females and culturing them in the research aquarium of the Center to a point where they can be matched with larval series from CalCOFI plankton tows.

Seven other genera of scorpaenid fishes occur in the eastern Pacific, and their larvae have been identified using specimens from CalCOFI cruises and such wide-ranging expeditions as EASTROPAC.

The recent interest in rockfish off California illustrates the importance of the research on these species for which G. Moser has been principally responsible. As a result it is now possible to determine which species of rockfish are dominant spawners in nearshore California waters and when they spawn. J. MacGregor, working with California Department of Fish and Game (CF&G) biologists, has begun to examine rockfish samples collected by the CF&G partyboat sampling program. The purpose of this study is to obtain some of the basic data necessary to understand the life histories of the various species and to determine what problems are developing owing to the increasing fishing pressure directed at some of the species found in the CalCOFI region.

A study using Moser's species identifications will be carried out next year by MacGregor who will attempt to estimate spawning biomass of rockfish in the southern California area using larvae caught during past CalCOFI cruises.

Criteria for Management of Pelagic Fish Species

The information supplied by Ahlstrom's unit at the La Jolla Laboratory on the identification of fish eggs and larvae is essential for making biomass estimates of Pacific mackerel, jack mackerel, hake, saury, and other fish resources of the CalCOFI region. This year has seen an increased use of such larval fish information in establishing criteria for the management of pelagic fish species. For example, negotiations by the National Marine Fisheries Service, Northwest Fisheries Center with the Soviets and Poles have been based on information provided by Paul Smith for trends in hake eggs and larvae capture. In an administrative report, Smith pointed out that the hake population had apparently reacted to the fishery conducted on this species over the past 10 years by Soviet, and more recently by Polish trawlers. The primary effect noted was a curtailment in spawning on the southern half of the spawning grounds. Until 1965, half of all hake larvae were found north of Ensenada, Baja California, Mexico. After 1965, this proportion declined to less than 5% of the total larvae found. This phenomenon is reminiscent of the shrinking of the feeding grounds and spawning areas of the Pacific sardine prior to the rapid decline of the total stock. Important changes in the population of hake have thus been sensed by the spawning surveys, indicating that additional caution should be exercised in the management of the hake fishery.

This information was used for renegotiation of the U.S.-Polish bilateral agreement on fisheries by which the present Polish hake quota was reduced by 39%.

Biomass estimates of northern anchovy derived from egg and larva data are still the prime sources for information used to manage the northern anchovy fishery between Mexico and the United States. This year, the California Department of Fish and Game has relied heavily on the larval time series to indicate fluctuations in the major population.

The most recent plan presented to the Fish and Game Commission of the State of California to increase the commercial fishery on the stock was derived from larval abundance estimates produced at the La Jolla Laboratory. In the past, moratoria on fishing of the Pacific mackerel and Pacific sardine stocks was a direct result of scientific evidence provided to the Fish and Game Commission from egg and larva data as well as from small fish surveys conducted by the California Department of Fish and Game.

Hydroacoustic Surveys in the California Current

The La Jolla Laboratory has had an ongoing program of research into the use of underwater acoustics as a tool in assessing pelagic fish biomass in the California Current. The primary motivation for the rapid survey technique with sonar mapping of fish schools, a technique developed by Smith in 1970, has been the 20-fold changes in the central subpopulation of anchovy in a 16-year period. The rapidity of this change in the virtual absence of a significant fishery has emphasized the need for interim estimates between spawning surveys which are now conducted every 3 years.

Sonar mapping was conducted on a series of cruises aboard the NOAA research vessel JORDAN during the period from July 1975 through May 1976. A variety of techniques for determining numbers of schools, kinds of schools and sizes of fish were evaluated. On a number of occasions drop cameras were used by John Graves, SIO student, to determine the species of fish being observed and, in collaboration with the U.S. Navy, echoes from schools were recorded and analyzed by two signal processing systems aboard the JORDAN. With Van Holliday, Smith also used a bottom bounce technique inside the 100-fathom line to estimate the size distribution of gas bladder-bearing fish by resonant frequency analysis. Calibrations of the acoustic system on the Mexican research vessel, HUMBOLDT, and the California Department of Fish and Game vessel, ALASKA, were made using the facilities of the U.S. Navy's Sensory Accuracy Check Site (SACS) at Long Beach, so that these ships may proceed to make rapid comparable estimates of the schooled fish off the west coast. With Bret Castile, day, night and twilight vertical profiles were made in the California Current using multiple high-frequency volume reverberation. High frequency sonar is being investigated as a tool which may be used for detecting the vertical migration of very small organisms.

A report has been completed by Smith and Graves on photographic, visual, and acoustic observations of northern anchovy aggregations which can be used to estimate the impact of an anchovy school on its immediate environment. A representative concentration of northern anchovy in a school is 15 kg/m^2 live weight, 4.2 kg/m^2 dry weight or 1.68 kg/m^2 carbon. If the daily ration is of the order of 5%, this rate imposes a demand on the environment to provide food containing 84 g carbon per square meter of school per day. Since total primary production is of the order of 1 g/m^2 day in the anchovy habitat, the anchovy school must move so that an area hundreds of times its own is occupied and grazed each day.

In December 1975, the Coastal Fisheries Resources Division was host to a MARMAP (Marine Resources Monitoring, Assessment, and Prediction) Survey 3 (pelagic fish) acoustics workship, planned and organized by A. M. Vrooman, MARMAP Survey 3 Coordinator, Washington, D.C. (and formerly on the staff of the La Jolla Laboratory), and attended by representatives of acoustic fishery research groups from fishery research center in the Northwest, Southeast, and Northeast.

As one result of this meeting, Smith, with the assistance of his colleagues in the Coastal Fisheries Resources Division, California Department of Fish and Game, Instituto Nacional de Pesca of Mexico, and Van Holliday of Tracor, Inc., prepared a plan for MARMAP Survey 3 to institute and coordinate sonar mapping surveys, and to provide timely information on the status of northern anchovy stocks during the period of projected rapid increase in the Mexican fishery.

Retrieval System for CalCOFI Oceanographic Data Files

The tremendous volume of oceanographic and biological information collected during almost three decades of CalCOFI surveys has made it necessary to reorganize the material for more efficient and economic retrieval. During the past year the CalCOFI oceanographic data files of hydrocast data taken from 1950 through 1968 are being reassembled at the La Jolla Laboratory and converted from National Oceanographic Data Center card-image format to a packed binary format by Eber.

The converted files are to be reordered chronologically by cruise to facilitate a time series presentation of selected variables. A software package was developed by Eber to extract values of observed or computed variables for specific stations, depths, and cruises. The result is intended to be a display of the data in a printed tabular format and in the form of contour plots. The tables and contour plots will include long-term monthly means and standard deviations of selected variables, the number of observations and mean day for each monthly mean, the values of the individual variables and their departure from the long-term means.

It is intended to create a pooled regional file which can provide monthly and quarterly averages of the oceanographic variables in a format compatible with the CalCOFI biological files. The latter include the sized larvae of northern anchovy, Pacific sardine, Pacific mackerel, jack mackerel, and Pacific hake; fish eggs and unsized fish larvae; zooplankton volumes; and zooplankton functional groups such as copepods, euphausiids, etc.

Recreational Fisheries Program

In response to the stated intent of the Mexican government to promote an anchovy fishery and the well-publicized controversy between commercial and sportfishermen in California over the best use of the anchovy resource, a Recreational Fisheries program under the Acting Leadership of G. Stauffer was established within the Coastal Fisheries Resources Division as part of the planned reorganization of the La Jolla Laboratory which officially became a reality with the approval of the Central Office of NMFS in Washington in July 1975. The specific task given Stauffer and his staff was to provide stock assessments, stock monitoring and management information on commercial and recreational fish of the California Current for state bodies to manage fish stocks on an objective basis. The group also collaborates with Mexico in the collection of data on stocks common to the two countries, e.g., Pacific sardine and northern anchovy, and a variety of sportfish.

To this end, Stauffer, often in collaboration with Alec MacCall, California Fish and Game biologist detailed to the La Jolla Laboratory, has organized several workshops on various aspects of anchovy biology, arranged a symposium on the anchovy management challenge at the 1975 CalCOFI Conference, hosted by Reuben Lasker of NMFS, and produced numerous documents and working papers examining assumptions and data requirements for management of an anchovy fishery. One important conclusion is that a cooperative research program between California and Mexico is essential for developing standard formats for data collection and exchange.

Cooperative Fisheries Research with Mexico

Recognizing the problems inherent in the equitable sharing of fisheries resources, particularly the stocks of northern anchovy, CalCOFI scientists in the absence of a U.S.-Mexico bilateral fisheries agreement, have organized an informal collaboration with Mexico's Instituto Nacional de Pesca (INP) to obtain the best scientific information available for managing fish stocks through cooperative research. With the creation of an INP/CalCOFI Committee to chart policy, a Stock Assessment Committee to provide technical guidance and the formation of subcommittees on catch-per-unit of effort, eggs and larvae, acoustic surveys, aging and sampling to carry out various aspects of the agreed-upon program, scientists of the two countries have achieved a commendable level of joint effort during the past year.

Meetings of the various working panels were held at intervals. The Stock Assessment Committee which recommends courses of action for stock assessment and conservation of anchovy to their respective institutions, met in La Jolla in December 1975. Some important recommendations made to the INP/CalCOFI Committee were: increased activity in acoustics, aging and sampling of anchovies, a definition of catch-per-unit of effort, and an intensive examination of existing logbooks. In addition, a data management system for anchovy stock assessment was recommended with initial action to be taken by a new subcommittee which was established on data management systems.

The Egg and Larva Subcommittee of INP/CalCOFI met in early February 1976 at La Jolla to discuss cooperation between Mexico and the U.S. in stock assessment with egg and larva surveys. Recommendations were that a bi-national larval fish sorting center be considered in anticipation of the 1978 CalCOFI year, utilizing the resources currently available in both countries; that steps be taken to improve the training of technicians to improve standardization of hydrographic data and, recognizing the need for oceanographic expertise in analyzing fisheries problems, that oceanographers be assigned specifically to the FAO/INP/CalCOFI biology groups.

As a result of this growing cooperation in fisheries research through the mechanisms of INP/CalCOFI, Mexican scientists and fisheries students now routinely participate in CalCOFI biological, oceanographic and acoustic survey cruises sharing the data; training in the identification of fish eggs and larvae of the California Current has been provided to Mexican fishery biologists; there has been an increased exchange of scientific papers and information sharing between individual scientists and, at the level of the working scientist, reinforcement of the belief that the formulation of rational pelagic fishery policies requires that they work together to serve their mutual interests.

Izadore Barrett

REVIEW OF THE PELAGIC WET-FISHERIES FOR 1975

Total commercial landings of pelagic species reached a record high in 1975 when 190,075 short tons were landed (Table 1). The major contribution was again the anchovy, comprising 83% of the total. The lower landing of figures for 1974 reflected the late start made by the anchovy fishermen during the 1974–75 season. Landings of Pacific sardine and Pacific mackerel were minimal, due to the compliance by fishermen with the moratoria on these species. Jack mackerel landings were slightly up from 1974 although prices were lower in 1975. Market squid landings dropped considerably due to unavailability of the animals in Monterey Bay. Total landings of Pacific herring were only about half of those in 1974. This difference was due to the changing of harvest regulations in Tomales and San Francisco Bays.

TABLE 1

Landings of Pelagic Wet Fishes in California in Short Tons 1964–75

Year	Sardine	Anchovy	Pacific Mackerel	Jack Mackerel	Herring	Market Squid	Total
1964....	6,569	2,488	13,414	44,846	175	8,217	75,709
1965....	962	2,866	3,525	33,333	258	9,310	50,254
1966....	439	31,140	2,315	20,431	121	9,512	63,958
1967....	74	34,805	583	19,090	136	9,801	64,489
1968....	62	15,538	1,567	27,834	179	12,466	57,646
1969....	53	67,639	1,179	25,961	85	10,390	105,307
1970....	221	96,243	311	23,873	158	12,295	133,101
1971....	149	44,853	78	29,941	120	15,756	90,947
1972....	186	69,101	54	25,559	63	10,030	104,993
1973....	76	131,919	28	10,308	1,410	6,031	149,772
1974....	7	82,585	67	12,729	2,630	14,452	112,470
1975....	3	158,510	144	18,390	1,217	11,811	190,075

Northern Anchovy

The 1974–75 anchovy season began in the northern area on August 1, with a price to the fisherman of $42.50 per ton, which dropped to $30.25 per ton at season's end. The Monterey-based fleet consisted of 15 boats, two of which were purse seiners; and the remaining, lampara boats. Fishing effort was moderate until March when prices fell and unfavorable weather prevailed. The final landings totaled 6,669 tons.

The San Pedro-based fleet did not begin fishing until November when the price dispute with the canneries was resolved, although Port Hueneme boats fished as soon as the season opened on September 15. The San Pedro fleet numbered 38; of these, three were lampara and the rest purse seiners. Fishing effort was restrained by daily limits imposed by the canneries, although the quota of 100,000 tons was filled by May 2, when the Fish and Game Commission allowed an additional 15,000 tons with no additional limitations or provisions. At the conclusion of the season, the southern area fishermen caught 9,918 tons of the additional allowed 15,000 tons. The combined total for the two areas amounted to 116,587 tons of anchovies (Table 2).

TABLE 2

Anchovy Landings for Reduction in the Southern and Northern Permit Areas 1965–66 through 1975–76 in Short Tons

Season	Southern Permit Area	Northern Permit Area	Totals
1965–66 A	16,468	375	16,843
1966–67 B	29,589	8,021	37,610
1967–68 C	852	5,651	6,503
1968–69 D	25,314	2,736	28,050
1969–70	81,453	2,020	83,473
1970–71	80,095	657	80,752
1971–72	52,052	1,374	53,426
1972–73	73,167	2,352	75,519
1973–74 C	109,207	11,380	120,587
1974–75 E	109,918	6,669	116,587
1975–76 F	135,615	5,295	140,906

A = November 12, 1965 through April 30, 1966.
B = October 1, 1966 through April 30, 1967.
C = September 15, 1967 through May 15, 1968.
D = August 1 through May 15.
C = August 1 through April 30 in southern permit area.
E = August 1, 1974 through May 15, 1975.
F = August 1, 1975 through May 15, 1976.

Age analysis of the sampled catch indicated an unusually high percentage (9.6%) of fish from the 1970 year-class (age group IV). This year-class contributed significantly to catch during the 1971–72, 1972–73, and 1973–74 seasons. The dominant year-class for the 1974–75 season was the 1972 year-class (age group II), consisting of nearly 40% of the sampled catch.

The 1975–76 season opened in the north with moderate fishing effort. The Monterey fleet numbered 5 purse seiners and 2 lampara boats. Initial anchovy price was quoted at $28 per ton. Final landings totaled 5,291 tons.

The San Pedro-based fleet numbered 50 boats consisting of 7 lampara and 43 purse seiners. The increase in boats reflects a serious interest in the anchovy fishery. The southern area fishermen began fishing promptly with the price established at $30 per ton. Considerable fishing effort was expended during the fall although daily limits were imposed. Fishing locations shifted from San Pedro Channel to waters off Ventura during November. Large concentrations of anchovies were observed in this area during an earlier acoustic survey conducted by the ALASKA. Final southern area landings totaled a record 135,615 tons (Table 2).

Pacific Sardine

The 1974 moratorium on Pacific sardine limited landings to 7 tons in 1974 and 3 tons during 1975. These landings allowed by law, represent an incidental catch in mixed loads. All indications imply the sardine population is still in a depressed state.

Pacific Mackerel

Compliance of the fishermen to the 1972 Pacific mackerel moratorium resulted in total landings of 67 tons and 144 tons during 1974 and 1975 respectively.

Presently, increased numbers of Pacific mackerel appeared in jack mackerel loads. The fishermen are allowed up to 18% by weight as incidental catch. These observations and others imply an increasing population of Pacific mackerel.

Jack Mackerel

Jack mackerel landings for 1974 remained below average, totaling 12,729 tons. A possible cause for the decline is the emphasis towards the more profitable bluefin tuna and bonito. Fishing areas centered near San Clemente Island and Cortes Bank. Jack mackerel price stabilized at $115 per ton in 1974, but dropped to $85 in 1975.

TABLE 3

Commercial Landings of Jack Mackerel in California in Tons 1963–75

Year	Annual landings	Mean annual landings
1963	47,721	
1964	44,846	46,284 (1963–64)
1965	33,333	41,967 (1963–65)
1966	20,431	36,583 (1963–66)
1967	19,090	33,084 (1963–67)
1968	27,834	32,209 (1963–68)
1969	25,961	31,317 (1963–69)
1970	23,873	30,386 (1963–70)
1971	29,941	30,337 (1963–71)
1972	25,559	29,589 (1963–72)
1973	10,308	28,082 (1963–73)
1974	12,729	26,802 (1963–74)
1975	18,390	26,155 (1963–75)

The 1975 landing reached 18,390 tons with the majority of the total being caught in the last 5 months (Table 3). Availability of the fish and increased cannery orders accounted for this renewed interest. Fishing areas included Santa Catalina Island, San Clemente Island and Cortes Bank.

Market Squid

Market squid landings during 1974 reached 14,452 tons but fell to 11,811 tons in 1975. This decrease was the result of low landings in the Monterey area. Squid prices ranged from $40 to $200 per ton during both years with the common price ranging between $60 to $80 per ton.

Pacific Herring

During 1974, herring landings totaled 2,630 tons while 1975 landings amounted to 1,217 tons. The decrease in catch was due to a change in harvest regulations in Tomales and San Francisco Bays.

John S. Sunada

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Part II

SYMPOSIUM OF CALCOFI CONFERENCE

LA JOLLA, CALIFORNIA
DECEMBER 9, 1975

THE ANCHOVY MANAGEMENT CHALLENGE

CALIFORNIA'S VIEW OF ANCHOVY MANAGEMENT

ROBERT G. KANEEN
Marine Resources Region
California Department of Fish and Game

Thank you very much, Mr. Chairman, for inviting me to speak to you this morning at this, the 1975 CalCOFI Conference. As I understand it, this actually marks the 38th year we have had such meetings—22 annual sardine conferences, followed by 16 CalCOFI Conferences beginning in 1960.

I appreciate the opportunity to relate and discuss some of the views we have regarding anchovy management. There are sometimes conflicts between the wishes of the scientists and the decisions of management because management must consider both sociological and political problems. Consequently, the reasons for contravening decisions are not generally revealed.

In 1940, when I started working for the Department, we had a rather large sardine industry and fishery. At that time, concern was developing for the resource because of doubts in the scientific community as to the ability of the resource to support current catches. I know that after World War II the industry and fishermen complained about fishing and that shortly thereafter the Marine Research Committee was organized for the purpose of coordinating and funding additional scientific research on the sardine to determine the reasons for its decline. Today, we all know that we were not successful in properly controlling the sardine fishery or coming up with timely and convincing explanations for its decline. This history is still in the minds of many of our constituents, and is often related in letters we receive from the public. I am not telling you anything new, but it is history that has a bearing on the attitudes of user groups, the public, legislators, commissioners, and others who are involved in making the final decisions. In other words, management of the anchovy reduction fishery must "walk in the shadow" of the sardine fishery.

The title of this talk is, "California's View of Anchovy Management." Some have the definite opinion that maybe the title should be "California's View of Anchovy Mismanagement." I expect if you talk to working biologists, they would probably think that the anchovy resource has not been managed properly simply because sufficient catch has not been permitted relative to population dynamics information. I suspect that if you speak to the sportsmen, chances are good that they would say the same thing, that the title of my talk should be our view of "Anchovy Mismanagement," but for different reasons. In their view far too many anchovies are now being harvested. Likewise, I suspect the chances also are good that if you speak to a commercial fisherman, he would say that it is being mismanaged and agree with the reasons given by the scientists. If you spoke to the processor, chances are very good that you would also get the view that the title of this talk should be "California's View of Anchovy Mismanagement." It would seem that since so many are apparently dissatisfied, we have not managed the resource properly; however, let's review the decision making process and factors having a bearing upon the resources' utilization.

A brief view of organizational structure within the Department is probably in order. The Marine Resources Region is the management arm of the Department and is responsible for field work, monitoring the catches, contacts with the public, and other activities directly related to management. Research is conducted by Operations Research Branch (ORB) under the direction of John Radovich. The Region works together with the Research Branch (ORB) on certain research programs in which field data and observations can be obtained more expeditiously by our field personnel. It is the Region's primary responsibility to make management recommendations which are relayed to Sacramento headquarters.

The Director, with the assistance of Marine Resources Branch, arrives at a decision and makes recommendations to the Fish and Game Commission, which is responsible for management of the anchovy reduction fishery. For your information, the Fish and Game Commission is composed of 5 commissioners appointed by the Governor to 6-year terms and has direct responsibility for the rules and regulations governing the reduction of anchovies including closing the season on 48 hour notice, if deemed necessary. In his recommendations to the Commission, the Director is guided primarily by biological information supplied by my office, the Region, based not only on our work but that of the National Marine Fisheries Service right here in La Jolla. The Director also is guided by a series of general policy statements in the Fish and Game Code adopted by the Legislature. General objective and policy statements are contained in Code Section 2014, which states that California is to conserve its natural resources and to prevent willful or negligent destruction of birds, mammals, fish, or amphilia. The Department must (Code Section 1000) expend such funds as are necessary for research and field investigations and diffuse such statistics and information as shall pertain to conservation, propagation, and protection, etc. I would like to read Code Section 1700, which is more specific.

> 1700. It is hereby declared to be the policy of the State to encourage the conservation,

maintenance, and utilization of the living resources of the ocean and other waters under the jurisdiction and influence of the state for the benefit of all the citizens of the state and to promote the development of local fisheries and distant-water fisheries based in California in harmony with international law respecting fishing and the conservation of the living resources of the oceans and other waters under the jurisdiction and influence of the state. This policy shall include the following objectives:

(a) The maintenance of sufficient populations of all species of aquatic organisms to insure their continued existence.

(b) The recognition of the importance of the aesthetic, educational, scientific and nonextractive recreational uses of the living resources of the California Current.

(c) The maintenance of a sufficient resource to support a reasonable sport use, where a species is the object of sport fishing, taking into consideration the necessity of regulating individual sport fishery bag limits to the quantity that is sufficient to provide a satisfying sport.

(d) The growth of local commercial fisheries, consistent with aesthetic, educational, scientific, and recreational uses of such living resources, the utilization of unused resources, taking into consideration the necessity of regulating the catch within the limits of maximum sustainable yields, and the development of distant-water and overseas fishery enterprises.

(e) The management, on a basis of adequate scientific information promptly promulgated for public scrutiny, of the fisheries under the state's jurisdiction, and the participation in the management of other fisheries in which California fishermen are engaged, with the objective of maximizing the sustained harvest.

The Fish and Game Commission has established its own policies for management of the commercial industry and, more specifically, the management of anchovies. Briefly, the Commission policy prescribes that it foster and encourage the development and expansion of the commercial fishing, fish packing, and preserving industries so that our resources may be fully developed in the public interest without endangering the resource. They are clearly obligated by their policy to protect existing uses of the anchovy and to consider the issuance of all anchovy reduction permits when scientific evidence indicates that the resource will not be endangered.

I believe the Commission has been consistent with the original statements it made on the development of the anchovy resource. In 1967 the Commissioners stated that they would seriously consider any increase in anchovy reduction quotas when the industry clearly demonstrates it has the need and capability of utilizing increased tonnages. My recollection is that the CalCOFI Committee originally recommended that 200,000 tons could be taken in an experiment to increase the sardine population. This 200,000 tons represented about 10% of the total anchovy spawning biomass at that time and was thought to be sufficient to produce a measurable change in the anchovy/sardine system. The Commission authorized a quota of 75,000 tons for reduction with the promise that if the quota was reached during the fishing season, the commercial fishing industry could come back to the Commission and additional tonnages would be considered (Table 1).

TABLE 1

California Anchovy Landings for Reduction

Season	Landings (tons)	Zone Quotes (Tons)		Total
		Northern	Southern	
1965–1966	16,843	10,000	65,000	75,000
1966–67	37,610	10,000	65,000	75,000
1967–68	6,503	10,000	65,000	75,000
1968–69	28,050	10,000	65,000	75,000
1969–70	83,473	10,000	130,000**	140,000
1970–71	80,752	10,000	100,000*	110,000
1971–72	53,426	10,000	100,000	110,000
1972–73	75,519	10,000	100,000	110,000
1973–74	120,587	15,000*	120,000**	135,000
1974–75	116,587	15,000	115,000**	130,000

* Quota increased by Fish and Game Commission

** Quota increased by emergency action of Fish and Game Commission for only that season

The Commission has been particularly cautious with the anchovy resource because of the fears of many, particularly sportsmen, that the resource would not be properly managed and would fail like the sardine did years ago. In addition, the Legislature directed the Commission to prevent overexpansion of the reduction industry (Fish and Game Code Sec. 8079).

8079. The Commission shall, whenever necessary to prevent overexpansion, to insure the efficient and economical operation of reduction plants, or to otherwise carry out the provisions of this article, limit the total number of permits which are granted.

During the heyday of the sardine industry, production and plants increased without significant controls with the inevitable result that once people's money and jobs were involved, it became exceptionally difficult to enact legislation to curtail the catch. This lack of flexibility to curtail the catch has been recognized in anchovy management plans. Again, the Fish and Game Commission can and has stopped the anchovy reduction fishery in 48 hours.

In retrospect and considering the public's distrust of the State's ability to control the reduction fishery, the considerable agitation that prevailed in the 1960's, and the doubts of many as to the accuracy of our population estimates, the course of the Commission may have been the most prudent. Presently, public opinion appears to have improved with less emotional reaction and agitation to quota increases, and more belief that the State intends to safeguard the resource.

In light of this apparent improved public acceptance, let me now discuss some of the views that we in the Department have on anchovy management and what we would like to see in the future.

First, we will be guided by state policy as expressed in the Fish and Game Code and by the Fish and Game Commission. These policies govern recommendations made to the Commission. We are interested in seeing that the anchovy resource is managed so that the reduction industry has an opportunity to increase production in a manner consistent with other beneficial uses such as live bait for sportsmen and food for predators, including sportfish.

One area of great concern for many years and for which we now see a pressing need, is a cooperative management program with Mexico, for the harvest of all marine species that move between southern California and Baja California, including anchovy. This management should be for the mutual benefit of our two nations. I am pleased to see the many representatives of Mexico here, many of whom are presently working closely with our staff. If we don't work together, but go our separate ways, there can only be chaos and the probable eventual elimination of valuable resources.

We have been following with great interest and satisfaction the cooperation that has been occurring between our scientists. You are to be complimented for this sincere effort and I encourage you to continue since success in scientific cooperation will help in the attainment of management agreement within the appropriate governmental process.

In 1967, during the CalCOFI Conference, Walter Shannon, then Director of the Department, stated that we have been unable to convince the public that we know how to manage the anchovy resource effectively. We had recommended that 200,000 tons be harvested, but only 75,000 tons were authorized. Since 1967, increased demand for fish meal and attainment of quotas by the industry have influenced the Commission to increase quotas, as they stated they would, to 130,00 tons for the 1974–75 season. I believe there has been decided improvement in the attitude of the public relative to their confidence in our ability and willingness to manage the anchovy resource, and that the Commission will continue to authorize reasonable requests for reduction quota increases. There is little question but that the combined landings of Mexico and California will soon, exceed 200,000 tons. It must be strongly emphasized that if we fail to develop agreements for reasonable harvest quotas between Mexico and California, there is a strong possibility that valuable renewable resources may be endangered. It is difficult to foresee the effects that extended jurisdiction will have upon the management and harvest of the anchovy resource. Both Mexico and the United States are contemplating the establishment of greater authority over their coastal resources. Deliberations between the U.S. Federal Government and the states on possible management regimes are now going on. It is expected that the U.S. law will provide that any surplus not utilized by our domestic industry can be used by foreign nations that have established historical fishing rights off our shores. This emphasizes further the need for refining our understanding of the anchovy population and developing an agreement between our countries on the allocation of the central stock.

I believe that through cooperative CalCOFI programs definite progress has been made in improving our understanding of the anchovy resource. In addition, we have made progress in bringing to the sportsmen and other groups the fact that we have the will and knowledge to manage the anchovy resource and are capable of taking the proper measures for safeguarding the stocks should circumstances demand it.

We still need, however, to improve our methods of obtaining timely estimates of the size of the resource. Timely estimates of the resource size should be clear and concise and should be disbursed to the sportsmen and public regularly in order to offset some of the erroneous ideas that develop within their ranks.

The recent anchovy workshop is a step in the right direction. A review of our mutual research and management programs can only result in improving the understanding of the anchovy population and the ability to manage it wisely.

THE MEXICAN VIEW OF THE BASIC RESEARCH NEEDS FOR THE MANAGEMENT OF THE ANCHOVY FISHERY

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The northern anchovy is now considered to be the largest unexploited fishery resource of North America, largely because CalCOFI has brought attention to the vast resources of the California Current system. The work of CalCOFI, covering more than 20 years of data collection and analysis, provides a vast amount of information on the northern anchovy, *Engraulis mordax.*

OBJECTIVES

Mexico urgently needs to avoid overexploitation of its few valuable species and must increase and diversify the total catch. The realization of this fact has caused us to focus a great part of our research efforts on the more abundant resources, especially those of the California Current system. Thus, the growing national protein needs, and more specifically the need to have accessible food items for the great majority of the Mexican population, have been the most powerful stimulus for Mexico to develop the anchovy fisheries off Baja California.

Research on the California anchovy was undertaken before the fishery began and has offered scientists the possibility of analyzing an unexploited resource, as opposed to most other exploited fisheries. Thus, we may try to forecast the possible effects of an expanded fishery on the resource.

Since the development of this fishery is among the most important social objectives for Mexico, we intend to exploit the resource rationally. To prevent ourselves from permanently disturbing the self-perpetuating capabilities of the resource, we expect to obtain the greatest amount of the resource, for the longest possible time, with the broadest possible security margin.

RESEARCH PATTERNS

Because of the research efforts of CalCOFI over the past several years, there is a vast amount of information available, which obviates the need for considerable time and research efforts for Mexican scientists. Because of this, our first efforts have been focused on gathering as much information as possible on the abundance of the anchovy resource, the actual status of its populations, some technological aspects of catch and product processing, and economics.

Three main research areas to be studied now and in the future are: 1) acoustic surveys, 2) analysis of the fishery-resource interaction, and 3) egg-larva surveys. Four central areas of investigation must support these three research areas: 1) general biology of the anchovy and other related species, 2) the environmental conditions of the area under study, 3) catch and product processing technologies, and 4) economics.

Because of the varied nature of the research areas involved in the program, it seems logical to expect results at different times. We are assuming that the results will follow this order:

1) Research on a very short time scale. Results will be derived from the acoustic surveys, which should give us fast information on abundance and distribution of anchovy schools;

2) Midterm results. These will come largely from the different analyses of the fishery-resource interaction; and

3) On a long term basis. Egg and larva surveys can yield relevant information on distribution, abundance, variations in time or space, self-perpetuating capabilities, and other characteristics of the populations.

Clupeoid fish populations have proven fragile under a heavy exploitation scheme. The world has seen more than one instance in which the collapse of the fishery has been fast and, up to this time, not entirely reversible. Furthermore, in some cases, the fishery has simply disappeared at the normal levels of exploitation. Most of the time, the causes of such declinations have not been fully elucidated, particularly because there has been a lack of necessary information collected before the collapse. Because of this, we are not only seeking to make the anchovy resources for exploitation available, but we also will gather information to prevent those causes of decline known to have been present in other similar fisheries.

We also will be compiling biological, oceanographic, and meteorological data to be correlated with general populations characteristics. The Peruvian experience seems to demonstrate that there are many factors in addition to those normally considered that may account for major variations in the abundance or availability of the resource. Furthermore, there is evidence that the northern anchovy may undergo considerable fluctuations regarding its catchability because of vertical and/or horizontal movements. On the other hand, traditional models have proven, until now, to be poor predictors, which results in poor forecasting abilities. That is why we are planning on high speed data collecting systems. In Mexico's favor is the fact that the fishery is barely beginning and has the potential to be a huge one. We must keep in mind other countries' experiences, and thus avoid the consequences of an insufficient information base.

In addition to a good information base, data have to be accessible and standardized for their utilization. Because of this, we are developing computer files and retrieval systems to be generated at the same time the information is collected.

ACOUSTIC SURVEYS

In the early stages of our program, we are focusing our attention at providing the industry with relevant information to widen the fishery operations and increase the catch. All our efforts in acoustic surveys are geared towards giving and receiving information as fast as possible. Thus, cruise reports will be generated when the ship arrives in port, and relayed to the industry to let them know the actual distribution and abundance of anchovy schools. These reports should prove useful in determining trends of distribution and abundance of the resource, a necessary base for assessing the building of processing plants at sites other than Ensenada. It is more than probable, however, that this will change in the future. Up to the present time, anchovy schools have been sufficiently abundant in the accessible areas near Ensenada and the major factor limiting the boats from getting a good catch is the boat's storage capacity. However, a major change will soon occur because 30 new anchovy boats are being built. This will mean more than a two-fold increase in the actual fishing potential (Presently, there are 29 medium-aged, low cost and tonnage boats).

Such an increase will probably necessitate an expansion of fishing areas. The growing need to furnish information to the fishing fleet forces us to consider, within our research, the use of automatic recordings of acoustic surveys, as well as automatic processing and fast information capability.

Several members of our staff are devoting a good part of their time to developing and adapting such recording systems. In addition, we have the valuable support of experts and consultants from FAO.

FISHERY STATISTICS ANALYSIS

The activities related to fishery statistics analysis are devoted, at the present time, almost entirely to the development of information systems which may yield, at the beginning of the fishery, an understanding of the increasing fishery-population relation, as well as the problems implied in its control. Essentially, this information system implies the use of fishing log cards, per boat landing records, and sampling of the commercial catch, as well as a complete inventory of boats. Up until now, our sampling procedures, including the forms used, closely follow those developed by the California Department of Fish and Game. However, to be able to adequately meet industry requirements, relying on fast collection and accessibility of data, we are developing new options. Regarding the fishing log, we are working on a form that can be easily used by the skippers who will need no special training; additionally, such a form will be compatible with our automatic data processing system, to avoid unnecessary transcription. Thus, we are working on mark-sense cards which will be read, in the future, by an optical card reader located at our Ensenada Station and transmitted daily, if necessary, to the central files in Mexico City. If this system proves feasible, we would have, by the end of each month, a complete record of all the operations of the fleet that could be reported within 2 weeks to the industry.

Concerning landing data, we have devoted some effort to describing the information flow of the industry, based on records of landing for each particular boat. It is possible to obtain copies of such records; however, this will necessitate the revision of all the forms and transcription to codification sheets. We are thus looking for a design to develop this information system based on mark-sense cards, to be completed by the industry. In the future, our staff will use similar systems in sampling the commercial catch.

This system development, we hope, will have the following two important results: 1) the compiling, from the beginning of the fishery, of readily accessible, up-to-date, and standardized data; 2) by means of monthly or bi-weekly bulletins, we will be able to inform the industry what is actually happening. We are convinced that, in the future, the control of the fishery will depend mostly on the mutual understanding between the fishing industry and the research and control agencies. We want to have them on our side and have them understand, as much as possible, our recommendations.

Of course, all the other activities involved in the program, such as general biology, oceanography, technology, and economics will have, as much as possible, similar information systems.

ICHTHYOPLANKTON SURVEYS

Our activities in the field of ichthyoplankton surveys follow closely the methods and techniques developed by CalCOFI. This type of work yields very important results but, unfortunately, with a considerable lag in time. Ordinarily the delay in total sample analysis ranges from 1 to 2 years. Furthermore, the inherent difficulties of the work, together with the fact that on a long term basis this activity becomes routine and to many people boring, caused many trained personnel to leave this work, with the subsequent need to train new people. On the other hand, automatic sorting or processing of the samples seems, at the present time, far from yielding satisfactory results. No efforts have been made by us up to the present time to modify this type of work in any way.

Nevertheless, we consider this work to yield very important results, especially if we look at the new evidences pointing to the possibility that the strength of a particular year class may not depend so much on the abundance of the breeding stock as on the general environmental conditions under which the larvae develop.

Even if the predictive value of these activities is limited by the considerable time lag between collecting and analyzing the samples, their analytical value is very great. However, we should determine whether we are really collecting all of the necessary information with the intensity and coverage that could yield best results.

FUTURE PERSPECTIVES

Until a very short time ago, the anchovy was considered a potential resource of relatively low economic yield, mainly because most of the fishing effort was directed toward catching a few valuable species. However, a major breakthrough has occurred in recent years, probably due to 1) the demonstration that the stocks of highly valuable species are already overexploited; 2) that the anchovy potential represents the most abundant North American underexploited resource (information mostly resulting from CalCOFI research); and 3) the collapse of the Peruvian anchovy fishery, that opens a market for fish meal. As a result, the fishing industry (including the Government owned Productos Pesqueros Mexicanos) has turned to this potential and is beginning a major incursion into this fishery. As a result, we should expect a developing industry very soon.

Once the development of the industry begins, it can be foreseen that in a few years there will be enough fishing potential to catch the resource's annual yield, as well as plant capacity to process the products by the various technological alternatives available.

Our short term objective is for the industry to develop such capacity in the most orderly, controlled, and efficient manner possible.

In addition to the normal working lines mentioned above, we are working on technologies for catching and product processing. Such activities use all the available methods to locate and evaluate anchovy schools. To increase the efficiency of the fishery, product processing is a major objective at the present time. For both lines of work we are being adequately supported by experts and consultants from the FAO Fisheries Development Project. Other experts will soon come to support economics work and other lines of inquiry.

We are confident that this work will help in the development of an adequate capacity of exploitation. Nevertheless, we must always bear in mind that a great majority of the world fisheries, if not all, follow inevitably the path of overexploitation, impulsed by the inertia of development. Especially in the case of clupeoid fishes such overexploitation may easily lead to an irreversible decline of the stocks. Our actual knowledge seems insufficient to explain adequately what are the actual causes of this decline; however, one could easily point at excessive fishing effort as a facilitating factor.

Taking this for granted, we should search for an adequate fishing regime that will allow us to exploit the resources to the fullest during the high abundance years, without jeopardizing the self-perpetuating capabilities of the stocks during poor recruitment years. This may imply an exploitation level lower than that normally considered as maximum sustained catch. Furthermore, it may require optimal distribution of effort in a very large area and through successive years.

Indeed, such effort distribution will require adequate control of fishing operations at all future landing ports, including not only catch and effort records, but catch composition as well as general biological, hydrographic, and meteorological data.

This mean. a considerable amount of work to train the people to collect such records, sample the catch, locally process the samples, and compile the resulting information in general archives as soon as possible.

Furthermore, the Californian, as the Peruvian, experience points to the possibility of a close correlation between environmental conditions and population abundance and availability. To be able to cope with this need for data, it will prove necessary to continue regular oceanographic and ichthyoplankton cruises. It also is obvious that in some way we will have to contribute to the development of a meteorological outfit that should be sufficient for fishing and research purposes.

I hope that, in the context of the preceding discussion, it has been clearly established that one of the main objectives of this program is to build, based on other countries' experiences, a good, fast and reliable information system. However, this is only part of the story. We are gathering data that we assume relevant to the fishery, although there is no way of knowing if we are actually collecting all the necessary information. To improve this state of knowledge, we have to jump from the mere adaptation of methodologies into the fields of basic research.

Not long ago, the collaborative program between INP and CalCOFI was based on CalCOFI teaching the established procedures to our Mexican staff. Most of these procedures dealt with acoustic surveys, egg-larval work, oceanography, age determination, and so forth. However, we have started work on other new areas, and specifically on the integration of the results from these studies. The integration of these activities has proven to be the most difficult of the vast majority of research programs. Thus, the INP/CalCOFI Steering Committee decided to join efforts by establishing several standing committees on egg and larvae surveys, acoustic surveys, catch and effort, age determination and, above all, the stock assessment working group.

To be effective, one of the first requirements of these groups is that information should be readily available to all research people participating. On a short term basis, we believe that the following areas of research are among the most urgent:

a) adequate evaluation of quantity and distribution in time/space of the anchovy schools, including the methods to estimate such characteristics;

b) determination of the breeding mechanisms, as well as the recruiting process, including the parent/progeny relation;

c) age and growth, including the age distribution of the commercial catches; and

d) standardization of the fishing power, and determination of the effect of the fishing effort on the natural populations.

It should be made clear that many other research areas will have to be looked at in the near future, including the possible population-environment relations, product processing technologies, etc. Furthermore, research on the above mentioned areas involves investigation of many partial works.

One of the major problems that the developing fisheries may find is the availability of anchovy schools in areas within reach of the fleet. Obviously, the greater the fishing power, the more we should expect that the capabilities of ports to process catches will be inadequate. An alternative to building faster and larger boats with many days-at-sea capability is developing other ports of landing. Although the industry itself would tend to distribute fishing power throughout the total potential area, this process might be inefficient and easily lead to overinvestment. Assessments should be made so that this process may occur with the maximum possible efficiency.

On the other hand, horizontal movements of the schools that take them far from the coast, as well as the vertical movements that keep them in deeper layers, may permit the fleet to fish only part of the year, while the rest of the year they are either tied to the pier or catching something else. Efficient research will have to be done in order to know if more powerful boats could continue their operation throughout the year.

One question that worries all of us is what will be the regulatory procedures in the future? Were it not for the fact that any regulatory scheme will need information collected from the beginning, it seems too early to elaborate on this. However, the normal regulatory procedures of closed seasons or areas, quotas and so on seem to be inefficient to varying degrees, especially in the sense that they promote the underutilization of fishing power. In one way or another, they are all restrictive in the sense that not all the fishing potential of the fleet can be used.

Thus, it seems logical to consider other regulatory schemes that could be used. Unreal as they may appear at first, their application would heavily depend on the willingness of the industry and early planning. One such scheme could be based on the following factors:

1) The control of the fishing fleet to prevent it from going beyond the optimum fishing capacity. As we mentioned earlier, this may imply that the actual potential should be under that which is normally considered necessary to obtain the maximum sustained yield, especially to prevent overfishing during poor recruitment years. Besides, the number and individual fishing power of boats is not the only means of increasing total fishing potential. Technological advances on fishing gear and methods may considerably increase the fishing power. Because the fishery will be catching a product of relatively low commercial value, overinvestment prevention is a must.

2) Optimal distribution of effort in time and space. Heavily dependent upon fishing fleet mobility, it would require a high predictive capability. Although the technical difficulties seem unsurpassable at this time, we believe it's worth trying.

3) Adequate selection of the catch in terms of age or sizes. Clearly, this regulation may prove far more difficult to use than in a trawl fishery, since the selectivity function of the net may be totally nullified by the fact that anchovy schools are massive and contain mostly single-age groups. This will probably necessitate the selection of schools before the catch. Perhaps a good knowledge of differential distribution might help, or perhaps acoustic methods now developing will reach this advanced state of recognition. At any rate, the cost and willingness to use any of these improvements will be critical.

We are fully aware of the fact that the relationship between industry-research and regulation groups is always difficult and that most of the time fishermen are not only reluctant, but totally opposed to regulatory procedures. However, if that is the case, we could select the normal regulatory options, and the information obtained would benefit those as well.

The previously mentioned considerations take us to one very clear point: it is indispensable to increase, on a short term basis, our research capabilities. Until now, most of the work has been undertaken by individuals directing small groups of people. If the different problems mentioned are to be worked out, we'll need a greater number of researchers.

Training has been supplied, up to the present time, on a very limited basis. Furthermore, our collaborative program with CalCOFI, as I said before, has been concentrated towards learning specific techniques. This program, however, will prove insufficient in the near future. We feel that formal training in fields related to fisheries biology needs urgent consideration.

Anchovy schools are distributed along a very large area. It is highly unlikely that an isolated research institution will have all the necessary means to cover the whole area. One of the most successful areas of collaboration to date has been that of combined and complementary cruises. We hope that this line of work will not only continue, but be increased in the future.

I would like to end with a final remark. We have an unequaled opportunity to work with a fishery that, for all practical purposes, is only beginning. Although this a clear advantage, there is also an enormous responsiblity involved. Failure to assess properly the development of this industry might lead to the same serious consequences that have been suffered by others.

There are many aspects in which the industry and regulating agencies will have to be assessed from the start. I believe that one of the most powerful aids in integration and assessment is model making. Models, even crude and rudimentary, have the great advantage of making us know what pieces of information are most needed and, in a way, give us a greater insight into the problem.

I hope that our new strengthened collaborative program will pay considerable attention to this problem and that our interaction will result in the elaboration of a powerful theoretical framework. We know the capability of the people we are dealing with. We only hope that we will contribute with some good ideas, as our sets of data are still small, to this joint venture of establishing the scientific basis for northern anchovy fishery management.

RESEARCH AND MANAGEMENT IN SOUTHEAST ATLANTIC PELAGIC FISHERIES

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ABSTRACT

The South and South West African pelagic fisheries have been subject to serious declines in their most valuable fish population, *Sardinops ocellata.* In both fisheries the anchovy, *Engraulis capensis,* has become important. The history of the fisheries is described and subsequent progress discussed. Adequate legislation has been available as a basis for resource management, but until 1970 was not employed at critical periods in the fisheries history, since scientific input was lacking. Methods of past and present management are discussed and advantages of the present system noted. Recent research has shown that problems in these pelagic fisheries are multidisciplinary and that the most rewarding approach to solution is through integrated multidisciplinary research. A period of large scale survey work has highlighted many of the disadvantages of population biology and focussed on the need for rapid ways of detecting adverse change within the fisheries. Future work is described which concentrates on survey work giving rapid stock size estimates whilst producing valuable input in conventional monitoring of fishery statistics.

INTRODUCTION

Those of us involved in pelagic fish research in other parts of the world owe a considerable debt of gratitude to those workers in the United States who previously established the guidelines and have subsequently maintained the lead in so many aspects of this work. It may be possible to discharge our debt today in some small way by informing you on the history and problems of two related pilchard fisheries in the Southern Hemisphere (Figure 1), by describing a different management approach towards exploitation control and by mentioning a few new twists in established research method.

The fisheries are both located in the upwelled component of the Benguela Current System on the west coast of southern Africa and in the main located at about 35°S and 22°S respectively (Figure 2). The southern fishery, on a quota of 360,000 metric tons, is based upon six fishing harbors in the vicinity of Cape Town, whilst the northern fishery on 820,000 tons quota is based at Walvis Bay and to a limited extent at Lüderitz. In addition, an Angolan pilchard fishery makes a variable catch on the same *Sardinops ocellata* complex as the Walvis Bay fishery. Foreign and South African floating factories have made considerable catches on the South West African stock during a few years in the mid-sixties (Figure 3). A small catch is made off Durban during the annual pilchard migration (Baird, 1971).

Both the Cape and South West African pilchard populations have suffered declines, but the South West African group have apparently recovered. The Cape pilchard cannery industry has been replaced by a multispecies fishery where canning has declined, whilst in South West Africa, canning of pilchard is of paramount importance in the now multispecies fishery. In both fisheries the pilchard catch has declined and effort been diverted into anchovy and maasbanker in the north, and anchovy, maasbanker, mackerel, redeye, and lanternfish in the south.

Management strategy has changed. At the time of the Cape pilchard decline there was ample legislation but only a limited scientific basis for management action, whereas more recently the scientific input has allowed a firmer approach to exploitation control in both fisheries.

In the past, management action tended to be optimistic and expansionist; whereas recently, management has tended to be conservationist and both fisheries are at the moment tightly controlled.

Management of the pilchard stock in the multispecies South West African fishery has been successful and single stock management strategies will probably be applied to the Cape fishery in future.

The approach of the Sea Fisheries Branch to research has been through well known population dynamics and biological techniques as well as egg and larval and aerial/acoustic methods in more recent years. In the future, an increased committment to survey work is anticipated, with remote sensing techniques providing a substantial input to more conventional techniques. The aerial/acoustic techniques used at the Branch show increasing promise and are likely to be further developed.

HISTORY AND MANAGEMENT OF SOUTH AFRICAN ADMINISTERED PELAGIC FISHERIES

It is the present intention of management authorities to control pelagic resources in a conservative manner commensurate with the concept of maximum sustainable yield. However, the rate of exploitation will be controlled within the latter limit by economic realities which will also give expression to the view of the state regarding equitable and just distribution of the yield of the resource among various parties sharing in its exploitation. In practice, the Sea Fisheries Branch acts in terms of simplier guidelines of establishment of potential yield whilst more complex problems are referred to a higher authority on an *ad hoc* basis (Report 1971). The Sea Fisheries Branch is responsible to the Department of Industries whose duty it is to coordinate information into policy form for submission as policy proposals to the Minister of Economic Affairs (Figure 1). Subsidiary information is derived from the Fisheries Development Corporation of South Africa Ltd. (finance to fishing industry, construction and maintenance of fishing harbors, and technique development), the Fishing Industries Research Institute (processing practice, product development, and fault detection and advice), and the Fisheries Development Advisory Councils (statutory bodies carrying representation from all interested parties within the industry and responsible directly to the minister) together with a measure of scientific input from universities and museums.

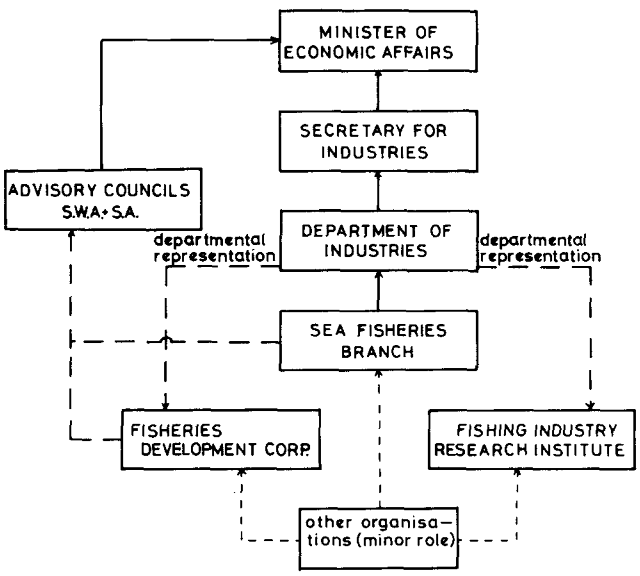

FIGURE 1. Management structure for South African fisheries.

Although not well integrated, the system works well and relatively recently the Advisory Councils have been good forums for discussion leading to development of rational resource exploitation.

South African multispecies pelagic fishery

From the beginning of the 19th century onwards, there was a considerable cottage industry for the export of dried and smoked fish (principally snoek, *Thyrsites atun*). Towards the end of that century considerable interest was focussed upon fisheries after an American schooner, ALICE, arrived off the Cape in 1890 and made large catches of mackerel and maasbanker with a purse net. This caused a local furore which resulted in an act (20 of 1890) which prohibited the use of purse nets along the Cape coast. A Commission of Enquiry was set up in 1892 to enquire into sea fishing and its formal report was the foundation for future legislation. The immediate result was the Fish Protection Act of 1893 which provided for closed seasons and size limits and repealed the 1890 act against purse nets.

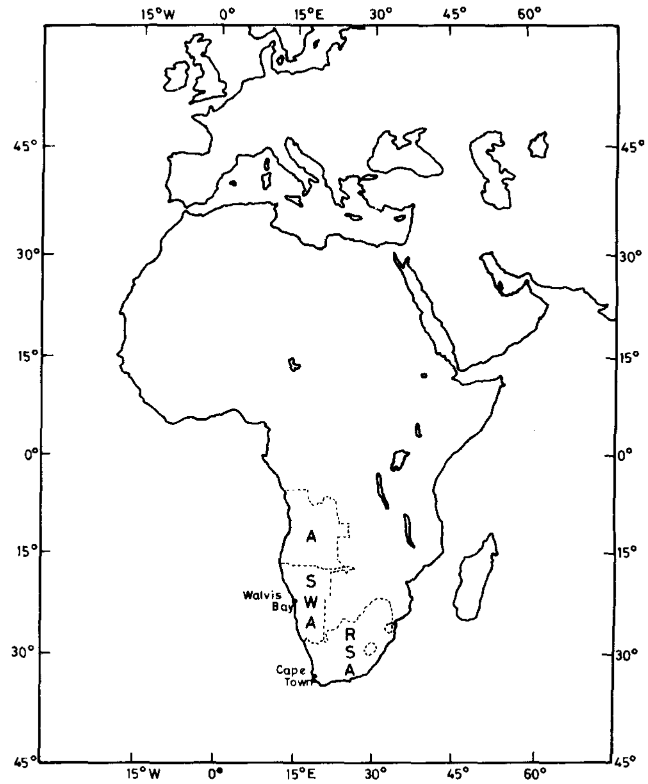

FIGURE 2. Location of pelagic fisheries off southern Africa.

Research commenced in earnest in 1896 when J.D.F. Gilchrist was appointed as marine biologist to the Cape Government, and in 1897 the first steam trawler research vessel, PIETER FAURE, was delivered. The Cape Government repealed most existing legislation with ordinance 12 of 1911 which provided for licensing of craft and gear, and empowered the Cape Administration to prescribe seasons and methods of fishing for various species. A fisheries advisory board was set up with Gilchrist as chairman.

There was a gap in research between 1905 and 1920 when the survey restarted with another steam trawler, PICKLE. At this time Gilchrist recorded that anchovies and pilchards occurred in abundance and were the principal food of the snoek. In 1924 the central government of the Union of South Africa took over financial responsibility for fisheries from the Cape Government, making this the concern of the Department of Mines and Industries. This was followed in 1929 by the formation of the Departments' Division of Fisheries and Marine Biological Survey, with a new research trawler, AFRICANA.

Perhaps the pelagic fishery dates from 1935 when the example of California was followed and some local entrepreneurs experimentally canned pilchards; but at any rate, in 1939 the demand for canned fish began to rise both locally and abroad. Italian fisherman made lampara type nets and caught shoal fish in Saldanha Bay. In 1940, 2,000 cases were packed on government contract at Lambert's Bay, and in 1941 the fishery began to expand despite problems with gear, poor cannery equipment, and a lack of tinplate. As the pelagic catch increased, 1943 was considered a record year with a pilchard landing of approximately 5,500 tons. The Fishing Industry Development Act of 1944 created the Fisheries Development Corporation and made the Department of Commerce and Industry responsible, through the Division of Fisheries, for the administration of the Sea Fisheries Act of 1940 relating to standards for export, control, and administration.

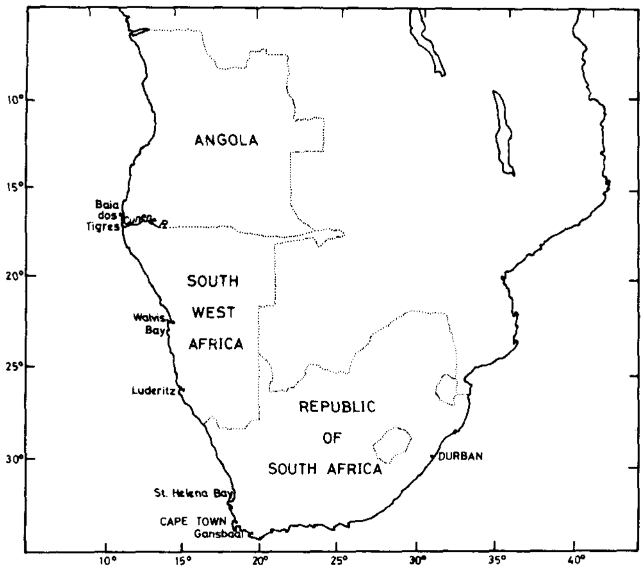

FIGURE 3. Detailed location of pelagic fisheries.

In 1944 the first plant for making fishmeal from pelagic fish began operating. By then pilchards were 55% of the total fish pack, and the cannery industry was getting organized. Experiments with gear in 1947 showed that a purse seine net was too heavy, so light pursed lampara nets were used, and successfully, for a number of years. Approximately 55,000 tons of pilchard was caught in 1948. The industry grew rapidly and by 1950 there were 13 factories catching over 80,000 tons of pilchards.

In 1950 the fishery was controlled by a comprehensive act and brought under investigation by the Division of Fisheries in a "Pilchard Research Programme." The 1950 legislation and its effects have been summarized by Du Plessis (1959) who noted that the control measures were not unilaterally enforced by the state but adopted after consultation with the processors and fishermen. The following measures were adopted:

- A minimum mesh size of 38mm between knot (mesh changed in 1956 to 32mm on introduction of synthetic materials).
- Limitation of processing plants; by 1953 the overall capacity limit of 221 metric tons/hour was reached.
- Provisions were made for closed seasons.
- Boat limitation was introduced, and no increase in numerical strength or total boat hold capacity was permitted.
- Limitation of installation of canneries (effective after 1953).
- Quotas were adopted and became effective in 1953 with a 250,000 ton (226,900 metric) combined pilchard and maasbanker quota, until 1958.

Unfortunately no distinction was made between pilchard and maasbanker catches, but it is possible to separate the catch records. The period 1950–58 saw considerable technological change as echosounders and winches were introduced and net size increased.

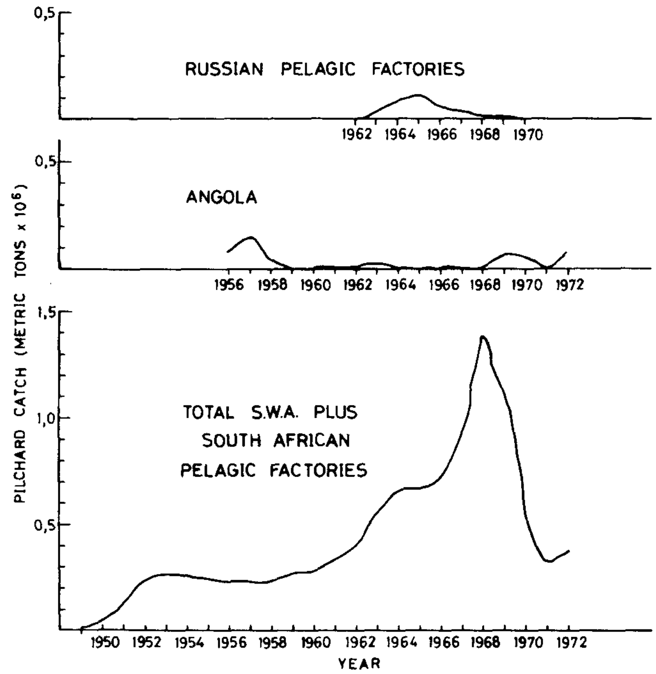

FIGURE 4. Southwestern Africa pilchard catch 1950–1972 from all data sources available.

The Pilchard Research Program which commenced in 1950 utilized all the resources of the Division and, from 1957, those of the South West African Administration Laboratory in Walvis Bay. Most of the work conducted has been published by David Davies in the Investigational Report Series of the Division and summarized in Davies (1957). The work covered distribution, associated species, reproduction, size, growth and age, feeding, migration, disease, and predators. Buys (1959) studied the hydrographic environment and commercial catches in St. Helena Bay and discovered a relationship between the annual average temperature from 0–50m and the pilchard catch the following year, and a relationship between the average value at 20m with maasbanker catches the following year. However, despite the strong correlation, Buys regarded the evidence as of little predictive value.

In 1953 a Boat Limitation Committee was set up to advise on numbers of vessels to be allowed into the fishery. Nevertheless the committee's advice was not accepted by the government on several occasions (Report 1971, para. 493).

The pilchard/maasbanker quota remained at 226,900 between 1953 and 1958 whereafter it was raised. In practice the quota was not applied rigorously as factories were permitted to fish all season whether or not quotas were filled. Other conservation measures introduced in 1950 were also of varying value. The imposition of a closed season occurred over the period when minimal catches were made in any case. The limitation on processing plants was seldom effective as the plants rarely received raw material in excess of their capacity, but the government unilaterally awarded extra licenses in 1965 increasing total processing capacity by 20% (Report 1971, para. 496). The restrictions on nets had only a limited effect, for all cotton nets were replaced by synthetics between 1950 and 1956 and the lighter weight and better handling qualities of synthetics increased the efficiency of the gear. Nets also became larger as vessels of progressively greater size were built (Stander and Le Roux, 1968).

In 1965 the government granted concessions for two fishmeal factory ships to operate outside the 12 mile limit of South Africa and South West Africa, placing no limit on the processing capacity or the fleets serving them. The vessels commenced operation in 1966 and 1967 and considerably increased the effort available in the South African and South West African fishery. It is recorded that the Commission of Enquiry Into the Fishing Industry regarded the increases in capacity allowed in 1965 as inordinately generous and that this increase set in motion an unhealthy trend in the fishery (Report 1971, paras 496-8).

As the pilchard catch began to decline after 1963, the fishery began to diversify with increasing catches of anchovy, *Engraulis capensis,* from 1964; redeye herring, *Etrumeus teres,* also from 1964; and principally one species of lanternfish, *Lampanyctodes hectoris,* from 1970 (Centurier, Harris, 1974). In 1971 the total catch was fixed by quota at 362,000 metric tons, and raised in 1972 and 1973 to 380,000 metric tons. In 1974 the quota was initially reduced to 365,000 metric tons but, during the season, was raised to 400,000 metric tons, with the provision that all mackerel catches made further than 25 n. miles offshore would be excluded from the quota. During the period 1964–75, the overall catch has remained approximately constant (Figure 5).

Aerial spotting commenced in 1967 but has only functioned as an aid to the deployment of fleets, rather than for the tactical deployment of fishing vessels, and as such is probably underutilized.

South West African Pilchard Fishery

There had been an inshore fishery for snoek for a number of years at Walvis Bay when, in 1922, a factory ship operated at Walvis Bay. The 1,481 ton SHERARD OSBORN acted as a processing plant for pilchards caught by catching vessels. Pilchards were canned, oil and meal were produced, but the venture was a failure. The first legislation affecting the South West African industry was promulgated immediately: Proclamation 18 of 1922 referred to the protection of seals and fish in territorial waters, closed seasons and size limits, and as such was the basis for future legislation.

In 1947 a snoek cannery in Walvis Bay began experiments with canning pilchards and producing meal and oil from whole fish and offal. By 1948 the catch exceeded capacity and a modern plant was ordered from the U.S.A. Three canneries incorporating fish-meal and oil plants were operating by 1949 when the South West Africa

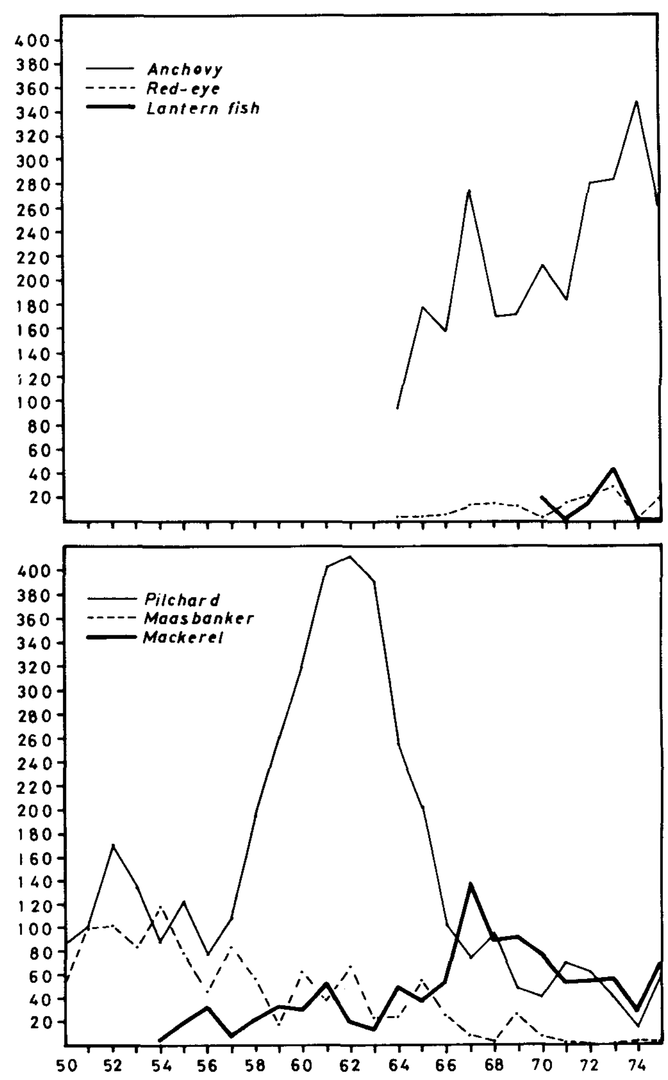

FIGURE 5. South African pelagic catch 1950–1975.

Administration decided that controls were required. In 1949 the Union of South Africa Parliament passed the South West Africa Amendment Act giving the territory the same powers as the four provinces of the Union. The South West Africa Administration, however, retained the right to legislate in certain domestic matters. In mid-1949 the Sealing and Fishing Ordinance was passed which gave the South West Africa Administration considerable powers over the fishing industry. Every vessel and factory had to be licensed; the maximum catch of any species could be fixed by notice in the *Government Gazette;* the number and capacities of fishmeal and oil plants in any defined area could be limited; the use of floating factories would be prohibited; taxes would be applied; there would be closed seasons and sanctuaries; and statistics would be collected from fishermen and factory owners.

The Marine Research Laboratory recruited a scientist in 1950 and research work commenced in 1952 following the launch of a small research vessel. By 1952 the fishing fleet consisted of about 100 boats and the administration imposed boat limitation restrictions to the effect that each factory could have 24 boats unless it already had more, in which case the number should be reduced in the course of time. At this time processing had expended to six large plants and in 1953 the reduction plants were limited to six with no single plant exceeding 30 tons/hour. In addition, catch quotas were applied, and a closed season introduced from 15 November to 28 February.

Incidentally, this total catch quota of 226,800 tons was not based upon scientific evidence derived from the fishery but from assumptions derived from the history of the California pilchard fishery. To enable the factories to adjust to the lowered catch, a temporary additional quota of 22,700 tons was granted for 1954, so the 226,800 ton quota became operative in 1955. The gross aggregate tonnage of the factories' vessels was restricted in 1954 to 495 tons for larger and 328 tons for smaller factories and during 1955 the number of vessels in the fishery declined.

The closed season covered the period when pilchards had spawned and were close to the harbor but in poor condition for canning, and with a low oil yield of about 2 gal/ton. Although this restriction was later removed, the bulk of the catch was still made in the mid-year period when fish condition was good and oil yield up to 18 gal/ton could be expected.

These conservation measures operated for 5 years, and had some impact: catches were tailored to production programs, production was streamlined, and waste began to be eliminated. The industry became stable and predictable. During this period of stability the administration realized that the yield of this now very valuable fishery should be scientifically evalulated, so in 1956 the Marine Research Laboratory at Walvis Bay started a tagging program to provide material for stock assessment and migration studies. The tagging program extended from 1956 to 1967 but no effective results were available until 1970.

The stable period ended in 1959 as a feeling grew that a larger catch could be taken from the pilchard stock. The South West African Administration associated itself gradually with this line of thought and at the insistence of the industry began to increase quotas progressively (Report 1971, para. 524).

In 1961 another cannery opened with a new quota, and further increases gave a quota of 626,000 tons by 1963. At this time it was felt necessary to safeguard the resource from international pressure, so the Territorial Waters Act (87 of 1963) extended the South and South West African territorial waters to 6 miles plus a 6 mile contiguous fishing zone.

In 1964 the quota was increased to 653,000 tons as two new factories opened, one in Walvis Bay and the other at Lüderitz. A concession on gear also was made with one vessel from each factory being allowed to use small mesh anchovy nets (11mm stretched mesh) in an attempt to commence an anchovy fishery. Quotas did not change in 1965 and 1966, but this period was the turning point in the history of the stock.

In 1966 a South African floating factory began operation off South West Africa and two further licenses were granted, against the wishes of the South West African Administration. A second floating factory with 18 catchers began operating in 1967 whilst the first floating factory increased its catchers from six to nine.

The South West Africa Administration was alarmed by this development and granted a special quota of 8,700 tons per factory partly to satisfy insistent demand and partly to raise money for research through a special research levy of R5,00 per ton on the special quota. In addition a new 90,355 ton quota was granted. This was followed by a further 90,355 ton quota in 1968, but the disagreement between the two authorities was settled by stabilization of South West African quotas at ten quotas of 81,650 tons plus 5,400 ton research levy quota and by limiting the South African floating factories to two, which had to operate outside the 12 mile contiguous fishing zone.

The factory ships were placed on a 499,000 ton quota for 1969 and 454,000 for 1970. This decision, however, was reviewed in 1969 and the factories were requested to withdraw in 1970.

In 1967 and 1968 the pilchard catch rose to 1 million and 1.5 million tons respectively. With all out efforts by the floating factories and land based factories, the catches in 1969 fell to around 1 million tons, and then in 1970 when no floating factories operated, to approximately 450,000 tons.

By this time most organizations connected with the fishery feared that a major decline had occurred, so a special research program was created and given access to the substantial funds accumulated by the Research Levy Fund since 1967.

The new program was referred to as the Cape Cross Program and represented a departure from traditional research methods. The sectional approach to research was replaced by an integrated multi-disciplinary approach involving accelerated sampling of the catch, a large scale egg and larvae program (South West African Pelagic Egg and Larvae Survey—SWAPELS), aerial research with night-viewing devices and airborne radiation thermometry, an acoustics program using a high frequency echosounder and integrator, genetics and fecundity studies, hydrobiological surveys, and so on (Cram and Visser, 1972, 1973; Cram, 1974). Having gained the confidence of the head office of the Department of Industries initially, heavy funding from the Research Levy Fund allowed a considerable investment in capital and running expenses which gave a good yield in terms of the conservation of the pilchard.

As a first result of accelerated research, in 1971 the ten established factory quotas of 81,650 tons were split on a 33%:66% basis giving a 27,215 ton pilchard quota and 54,435 ton "other species" quota, with the provision that the factory closed on filling its pilchard quota. The object was to reduce effort on pilchard whilst increasing effort on other species in order to retain the economic viability of the fishery whilst conserving the pilchard stock. In the same legislation, a 6 month closed season was proclaimed from 1 September to 31 March, and the area in the north where the juveniles predominated in experimental catches was closed to fishing. These restrictions were internationally broadcast through the International Commission for South East Atlantic Fisheries (ICSEAF), and member states were requested to act in accordance. Although cumbersome and open to abuse, this regulatory mechanism works well through an intensive inspection system which ensures that most catches delivered to the jetties are examined and sampled by government inspectors. These samples are the basic scientific data extracted from the catch. The split quota caused an increase in cannery efficiency as a "tally" system was developed to spread the pilchard quota over the entire season, boats only being allowed to present a fixed amount of fish (tally) to the factory for each trip. This eliminated gluts and scarcities and allowed the development of an optimal cannery program. Between 1971 and 1975 the split quota has been progressively readjusted from a 33:66 basis to 50:50.

There is a strong contrast between management styles in the 1960s and 1970s characterized by the attitude to quota increases. In the 1960s optimism was the keynote in expanding fisheries, and management was virtually by consent in a situation where scientific advice was absent or equivocal. In particular, economic argument had force and tended to prevail; it has been reported that, despite the existence of ample legislation, the effect of conservation orientated regulations was minimal. Concessions and quotas were relatively freely awarded until the industry itself became aware of disconcerting signs and began to insist upon scientific work being undertaken. This system of management did not work.

During the 1970s with declining or uncertain fisheries and better scientific advice, the government felt able to take an aggressively conservation-minded attitude, especially in South West Africa where sudden and strong action apparently became necessary. Both the South African and South West African pelagic fisheries are virtually national fisheries, not tightly controlled by the Department of Industries with regard to the fixed wetfish price (irrespective of species), the fixed selling price of all products, and the extensive legislation covering all aspects of catching and processing. At the moment, stability appears to exist.

CURRENT RESEARCH

Research on South African pelagic stocks has always proceeded along conventional lines, building up biological information with which catch data can be quantitatively analysed. Hydrobiological and egg data have been acquired, but their employment as management tools has been minimal. The yield of the Cape multispecies fishery has been recently established through an analysis of catch-per-unit effort and effort, and the sizes of component stocks

TABLE 1

Cape Pelagic Fish Catch 1949–75 *

Year	Species						Total
	Pilchard	Maasbanker	Mackerel	Anchovy	Redeye	Lantern fish	
1949	17,279	3,367	–	–	–	–	20,647
1950	86,075	49,154	–	–	–	–	135,229
1951	101,064	99,357	–	–	–	–	200,421
1952	171,066	101,572	–	–	–	–	272,638
1953	133,147	84,552	–	–	–	–	217,699
1954	88,304	118,137	4,044	–	–	–	210,481
1955	121,994	78,822	20,228	–	–	–	221,044
1956	76,512	45,752	32,670	–	–	–	154,934
1957	108,568	84,615	7,364	–	–	–	200,547
1958	194,857	56,415	21,580	–	–	–	272,852
1959	260,181	17,676	33,088	–	–	–	310,945
1960	318,032	62,926	30,985	–	–	–	411,943
1961	402,318	38,935	52,398	–	–	–	493,651
1962	410,249	66,649	20,355	–	–	–	497,253
1963	390,660	23,168	13,201	–	–	–	427,029
1964	255,022	24,241	50,244	92,395	2,474	–	424,376
1965	202,669	55,294	39,470	117,685	2,052	–	477,170
1966	113,565	26,288	54,899	157,234	4,501	–	356,487
1967	73,448	8,552	138,864	275,839	12,676	–	509,379
1968	94,100	1,318	90,106	169,793	13,504	–	368,821
1969	48,582	25,772	92,845	171,241	12,804	–	351,244
1970	41,059	7,522	77,740	214,713	2,931	18,203	362,168
1971	65,168	1,603	54,279	184,839	14,267	2,575	322,731
1972	62,108	960	55,594	280,229	20,000	15,238	434,129
1973	41,861	257	56,728	283,489	26,520	42,560	451,415
1974	16,649	1,616	30,898	348,898	792	334	398,782
1975	57,787	804	67,951	261,500	17,781	58	405,881

* Thousands of metric tons.

are approximately determined from virtual population analysis. The bulk of this work is published in the Investigational Report Series of the Sea Fisheries Branch. In South West Africa, research proceeded along similar lines with the emphasis on acquisition of catch and basic fish biological and hydrological data. A tagging experiment from 1957 to 1968 yielded stock sizes and migration patterns. This work is published in the Research Reports of the Marine Laboratory of the South West- Africa Administration as well as the Investigational Reports mentioned above. In 1970 research rapidly expanded in an integrated multidisciplinary program (Cape Cross Program) of which little has been formally published; however, the four informal reports generated by this program will be published fairly soon.

a decline began. The decline in mature fish anticipated that of the total owing to good recruitment and heavy mortality on mature fish over a period of a few years. The total abundance index declined severely after 1963. After 1965 anchovy nets with 11mm mesh size were widespread, so the size compositions before and after this date are not comparable.

The abundant year class or classes arose from years when the spawning biomass was low or declining, thus larval survival must have been good. The high levels of abundance in 1960–63 are sensitive to the estimate of fishing effort. If hold capacity as an index of effort underestimated the rate of increase in effort, the real level of abundance may have been much lower than suggested. Since good effort data are only available from 1964, the existing effort data from 1957–61 can only be qualitatively examined.

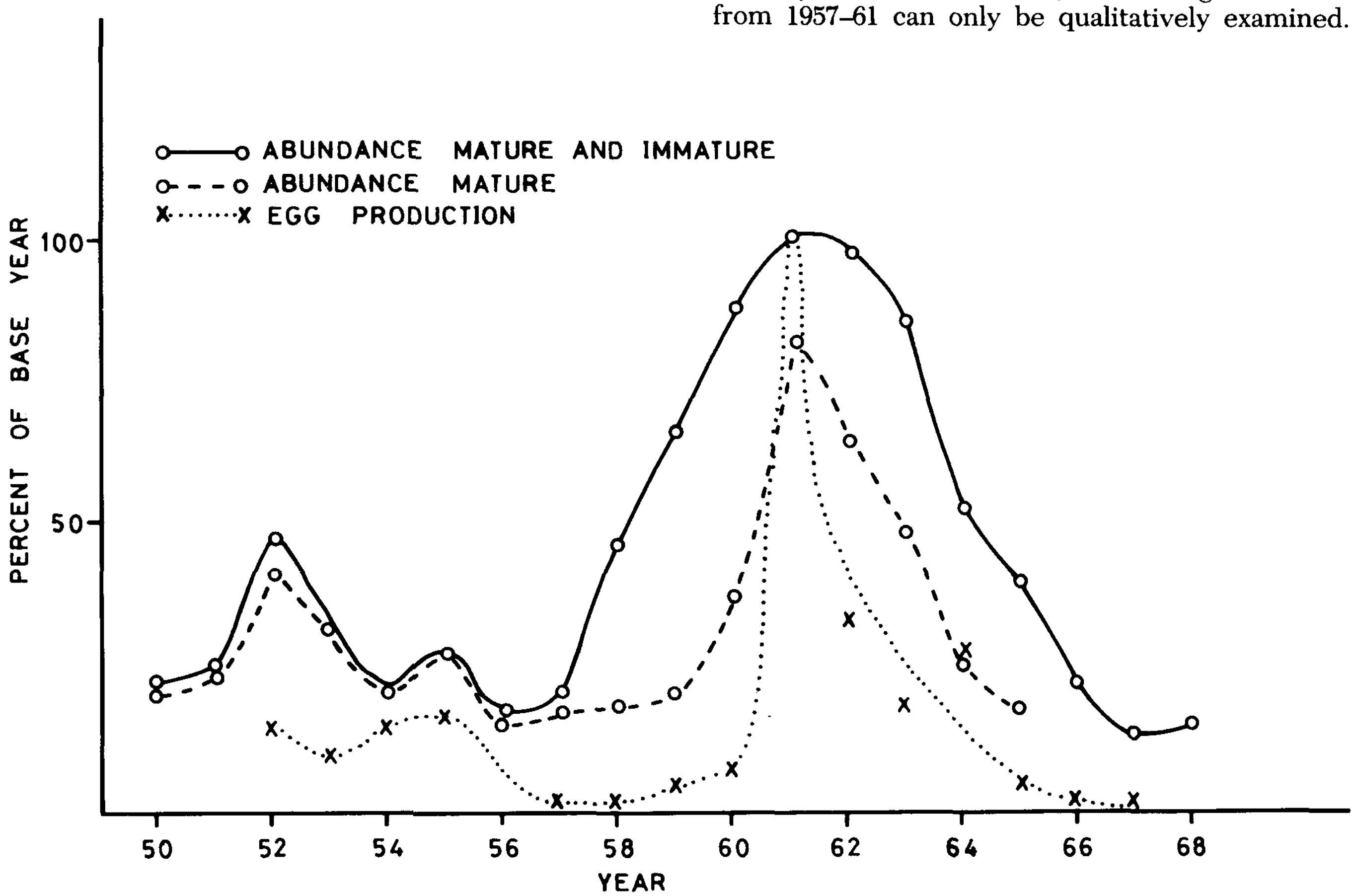

FIGURE 6. Pilchard and Pilchard egg abundance during the period 1950–1968.

South African Multispecies Pelagic Fishery Population Biology

Newman (1974) reviewed trends in the fishery and landings by species were derived from this work (Table I and Figure 5).

From 1950 to 1957 most of the catch was sexually mature and the stocks remained fairly constant. In 1958–59 the total pilchard abundance index increased due to good recruitment (Figure 6). The index increased to a peak in 1960–61 and thereafter

There is information to confirm that an increase in pilchard abundance took place in 1958–61. Du Plessis (1959) and Stander and Le Roux (1968) commented on the large proportion of young fish in the size composition data for 1958. In 1957 the fish had a modal length of 16cm which moved to 19cm in 1958, consistent with the growth data presented by Davies (1958) and Baird (1970).

Innovations such as echosounders were introduced before the decline commenced, but others such as

TABLE 2
Changes in Characteristics of the Fishing Fleet*

Year	Hold capacity **	No. boats	Mean hold capacity	Notations
1950........	4.8	150	32	–
1951........	6.4	183	35	–
1952........	7.3	197	39	–
1953........	8.3	229	36	–
1954........	8.5	225	38	–
1955........	8.3	228	36	Echo Sounder introduced
1956........	8.2	222	37	–
1957........	8.2	210	39	–
1958........	8.5	201	142	–
1959........	8.7	105	52	–
1960........	8.3	143	58	Echo Sounder 100%
1961........	9.3	131	71	
1962........	9.8	122	81	
1963........	10.9	127	86	Power blocks
1964........	11.4	126	90	
1965........	11.7	125	94	Fish pumps
1966........	11.9	125	95	Sonar Introduced
1967........	14.3	135	106	
1968........	14.5	130	112	
1969........	14.5	129	113	
1970........	14.5	113	129	

* From Newman (1974)
** X 10^3 short tons

power-blocks, sonar, and fishpumps were introduced after 1961 (Table 2). There was a trend towards fewer, larger vessels, a trend which continued until 1966. In the late 1960s aerial fish spotting commenced. All the above would tend to increase efficiency of effort in terms of hold capacity. From 1962 the catch per ton capacity declined rapidly confirming a decrease in abundance.

From 1964 onwards effort was diverted into anchovy, and the pilchard decline was compensated for by the increase in anchovy (Table 1). The evidence led to the empirically derived assumption that a multispecies yield of between 400,000–500,000 could be expected and that it was not likely to be increased by expending further fishing effort.

An assessment of fishing effort, stock abundance, and yield for the South African multispecies pelagic fishery has been published in abstract form (Newman, Crawford, and Centurier-Harris, 1974). The multispecies catch per boat lunar month was used to calculate the fishing power of individual vessels for each year from 1964 to 1972 using Robson (1966) methodology. Fishing power for each year was regressed against vessel storage capacity, horsepower, age, and net dimensions to evaluate the effects of these parameters on fishing power. Storage capacity was shown to have a significant effect on fishing power in most years. Vessel horsepower and age were important in the earlier and later years respectively. A dummy variable in the regression equation showed that the change from 32mm to 11mm mesh size improved boat efficiency by 64% while fish pumps increased fishing power by 36% and sonar, 18%.

A two dimensional array of catch per boat fishing season (7,16 lunar months) arranged by boat and year was used to calculate catch per standard boat fishing season for the period 1964–72. This catch per unit effort (CPUE) estimate and annual total catches were used to determine the total effort in each year, which was then adjusted for the introduction of fishing aids to produce an improved CPUE time series.

Effort increased from 800 to 1,500 standard boat lunar months between 1965 and 1972 while the CPUE of all species declined from 600 to 290 metric tons per standard boat lunar month in the same period. Plots of CPUE on effort of the previous year showed empirically that a yield of about 360,000 metric tons can be expected from the stocks, and that an increase in effort would not be advantageous and may have a detrimental effect.

The abundance of pilchard from 1953 to 1972 was estimated by virtual population analysis. Strong recruitment in 1955 and 1956 led to a rapid increase in population resulting in a stock size of 2.4 million metric tons in 1959. Thereafter the stock declined because of heavy fishing and more normal recruitment. In 1972 the population was at 11% of its peak value in 1959. These large fluctuations confirm CPUE information of Stander and Le Roux (1969).

Virtual population analysis shows that anchovy stocks have remained fairly stable between 1964 and 1972 at about 600,000 metric tons. There is no evidence that anchovy stocks have increased as the pilchard declined. Blanket net catches show some increase after 1959, but this is when the pilchard were most abundant (Newman, Crawford, and Centurier-Harris, 1974).

Aerial/Acoustic Surveys in South West Africa

Since 1971 the Branch has been attempting to develop aerial/acoustic methods of stock size measurement (Cram 1972, 1974). Work has centered upon development of survey strategy and measurement methods. Initially it was thought that aerial and acoustic methods could be used separately, but observations on *Sardinops ocellata* shoal groups showed that extreme patchiness of shoals, their mobility, and the tendency of fish to avoid survey vessels may invalidate results of quantitative acoustic surveys on the stock. These errors can be reduced considerably by employing a survey strategy in which aircraft delimit areas of high fish occurrence into which aerial and acoustic observations are concentrated at the expense of areas of low fish occurrence. The technique calls for aircraft sensors to obtain horizontal dimension data whilst the vessel's acoustic gear makes synchronous measurements of shoal thickness and fish packing density on as many shoals as possible within the shoal group (Cram and Hampton, 1976).

The sources of error in the aerial/acoustic method have been critically examined and distinctions have been drawn between biased and unbiased sampling errors and errors of physical measurement. Sources of sampling bias have been examined on the basis of experience in the fishery from 1970 to 1975 and, where possible, quantitative arguments were used. Statistical sampling errors have been estimated from the variance in aerial and acoustic samples taken from integral subpopulations of the total stock.

A tentative error limit of ± 50% is fixed on estimates of relative apparent abundance, but no estimate has been made of error limits in absolute determinations of apparent abundance as the necessary experimental work on the acoustic target strength of *Sardinops ocellata* is not yet complete.

Aerial observation of pilchard shoals has had an impact upon attitudes towards other aspects of research, particularly ecology. When the location of the bulk of the stock is known, it is possible to relate occurrence of shoal groups to environmental conditions, spawning groups to shoal groups, and to relate fish distribution to distribution of effort in the fishery. Pilchard shoals are very variable in size, from super shoals of many kilometers length to small shoals of a few meters length. Shoals may be ribbon like, crescentic, or round; the ribbon shaped ones usually being the largest (Cram & Agenbag, 1974). Anchovy shoals size appears to differ with age groups: younger fish tending to form large shoals, and adult fish smaller shoals (Schülein, Sea Fisheries Branch, personal communication). The few observations available suggest that sizes of shoals may be very variable.

In the multispecies fishery, identification of shoals is always a problem, particularly so when the relatively small anchovy shoals are entrained by a large pilchard shoal group. Experienced observers are at an advantage, but are not infallible. With improved TV equipment and a National Marine Fisheries Service (NMFS) type drop camera it may be possible to determine more reliably the difference between anchovy and pilchard shoals when they are closely adjacent.

Ichthyoplankton Surveys in South West Africa

Since 1971 egg and larvae research has been an important part of the research program in South West Africa. A large scale survey program ran for 2 years between August 1972 and April 1974 during which monthly cruises were conducted between August and April to coincide with the spawning patterns of the major pelagic species. The horizontal distribution of pilchard eggs was adequately delineated throughout the survey area.

Two separate seasonal and geographical spawnings were found: one in a southern inshore area peaking during August to September at 13,0°C to 16,6°C, the other in a northern offshore area peaking during February and March at 16,5°C to 22,0°C (Figure 7).

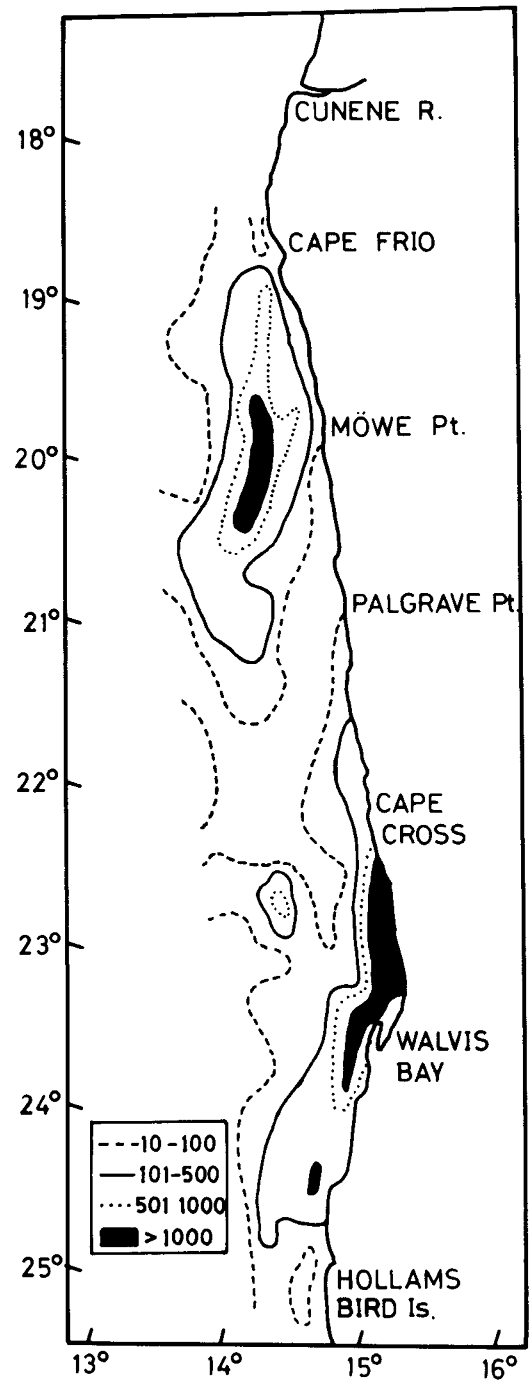

FIGURE 7. Spawning group distribution.

Pilchard eggs collected in bongo net samples were sorted into development stages, and the abundance of each stage was divided by stage duration to give numbers produced per day. Using these values the instantaneous coefficient of loss per day Z was calculated from

$$\frac{N_2}{N_0} = c^{-Zt}$$

where:

N_0 = initial number of eggs
N_2 = number surviving to the next stage in t days
t = mean stage duration.

Egg mortalities of 87% and 89% were derived for the two survey periods.

The stock size of the adult pilchard was determined from egg production and calculated at 1.7 million metric tons for 1972/73 and 2.3 million metric tons for 1973/74. The sources of error associated with this type of estimate are well known. The main contribution to the variance in the stock estimate is variability of egg distribution in space and time.

This problem was examined by taking 20 replicate bongo net tows in a 5 x 5 nautical mile area of high egg occurrence. The distribution of pilchard egg count showed a large number of tows with zero counts on one bongo unit in conjunction with high counts on the second bongo unit.

A probable explanation for the great differences in some catches is that the samples bordered on the peripheries of egg patches which, it would seem, are sharply delineated. As the mean of counts for the area will be influenced by the number of zero counts, within-tow observations were pooled. An analysis of the mean number of eggs per haul gave confidence limits of 0.68–1.36 at 95% level, which are in accord with the "half or double rule" reported by Silliman (1946).

Anchovy eggs were found in the summer months, December to April, in the northern area. Spawning appeared to be continuous, but eggs were most abundant in January and February in water of surface temperatures 17°C to 22°C. In contrast with other areas containing pilchard and anchovy stocks, *Engraulis capensis* is frequently found in warmer areas than *Sardinops ocellata.*

Embryos of the South West African pilchard, *Sardinops ocellata,* obtained at sea have been incubated from blastodisc stage to hatching at 27 different combinations of salinity, temperature, and dissolved oxygen (salinity range: 33–36°/₀₀ Temperature range 13–22°C, Oxygen range 1.5–1.7ml/1). Observations on rate of development, survival of eggs until hatching, viable hatch, percentage of malformations, and dimensions of newly hatched larvae were made. The combined effect of salinity, temperature, and dissolved oxygen on rate of development and larval survival was examined using multiple regression techniques. Pilchard eggs were defined as euryphaline, euryoxic, and stenothermal. Survival was maximum or near maximum within the range 16–21°C and 33–35°/₀₀ salinity where the dissolved oxygen exceeded 1.5ml/1. Decrease in dissolved oxygen content associated with increase in temperature caused retardation of development.

Mean larval length at hatch was 3.59mm. The growth of the larvae during the yolk sac stage and the efficiency of yolk utilization were also determined. Larvae increased in length for 3–5 days after hatching, after which time there was a progressive decrease in size, probably owing to starvation. In trial 24 (35°/₀₀, 18°C,5.2ml/*l* O_2) individual larvae reached their maximum length. Growth rate, taken as the increase in length in millimeter per day, showed a linear correlation with temperature. In an additional experiment, the mean ages at which embryos and larve attained five definite morphological and physiological stages were observed at 10 different constant temperatures (11–22°C).

The average time for morphological development of the eggs decreased exponentially with increasing temperature. Incubation time (fertilization-hatching) ranged between 118 hours at 11°C to 30 hours at 22°C. Below 13°C a functional jaw and retinal pigmentation failed to develop.

The rate of development of the round herring egg, *Etrumeus teres,* also was determined and incubation time was found to vary from 135 hours at 11°C to 30 hours at 20.5°C (O'Toole and King, 1974).

TABLE 3

Species and Percentage Composition of Larvae taken in South West Africa Ichthyoplankton Surveys

Species	Percentage	
	Survey 1*	Survey 2**
Pelagic larvae		
Goby, *Sufflogobius bibarbatus*	66.6	60.0
Anchovy, *Engraulis capensis*	16.6	1.9
Pilchard, *Sardinops ocellata*	3.7	17.5
Mesopelagic larvae		
Myctophid and Gonostomatids	4.5	12.4
Maasbanker, *Trachurus trachurus*	3.12	4.9
Hake, *Merluccius capensis*	1.3	0.9
Soles, *Austroglossus microlepis* *Dicologlossa cuneata*	3.0	1.5
Others	1.1	0.8

* 1971–72.
** 1972–73.

All fish larvae were extracted from the SWAPELS samples and identified as far as possible to species level (Table 3). Those belonging to commercially important groups were measured to the nearest millimeter. Larvae of the following families were represented in the catches: Clupeidae, Engraulidae, Gonostomatidae, Myctophidae, Gadidae, Merluccidae, Carangidae, Trichiuridae, Scorpaenidae, Triglidae, Gobiidae, Blenniidae and Soleidae.

Pilchard larvae were widely distributed over the research area and correspond well with the egg distribution already outlined. They were most abundant at surface temperatures of 14.0°C–16°C in spring and at 18–21°C in summer. Larvae were particularly numerous during January, February, and March in waters of 18–21°C. The geographic limits of anchovy larval distribution were not delimited to the north or to the seaward of the research area. It is assumed that considerable spawning must have occurred further north and west of latitude 18°S. Larvae were more common in night hauls with peak abundance occurring from midnight to 0200 hours (O'Toole, Sea Fisheries Branch, person. comm.).

Environment off South West Africa

The distribution of conservative and non-conservative properties of sea water off South West Africa showed great similarity to that reported by Hart and Currie (1960) and Stander (1964). It was therefore apparent that since 1970 no large scale departures from normal oceanographic conditions had occurred.

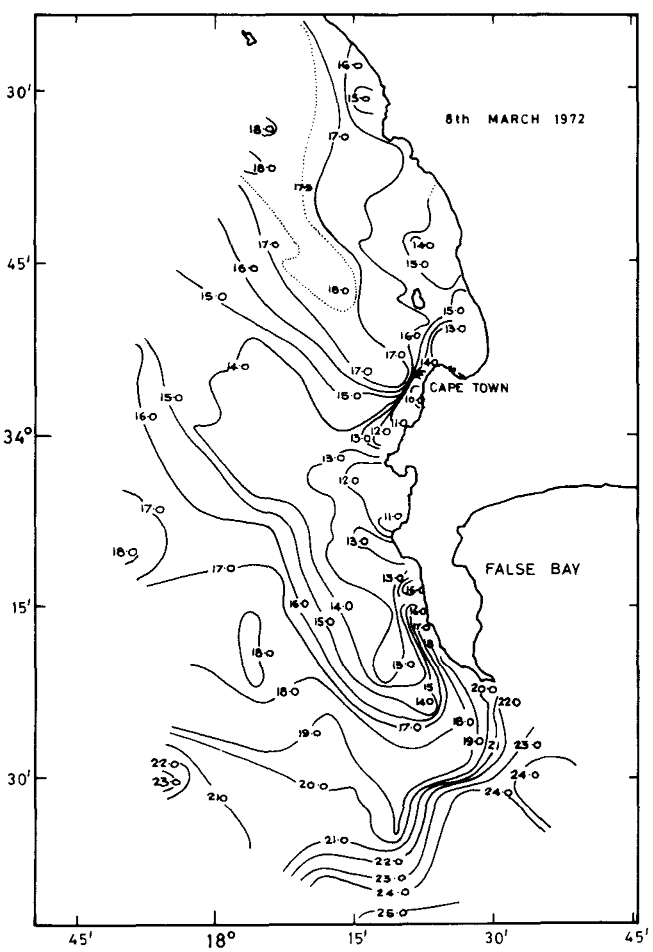

FIGURE 8. Southern end of the Benguela Current upwelling component.

Airborne radiation thermometry (A.R.T.) provided more detailed information on surface temperature distribution throughout the Benguela Current system, particularly on the coastal upwelling zone. The southern end of the upwelling component of the system exists in the region of Cape Town and is noticeable for the intense thermal gradient formed during periods of active upwelling (Figure 8).

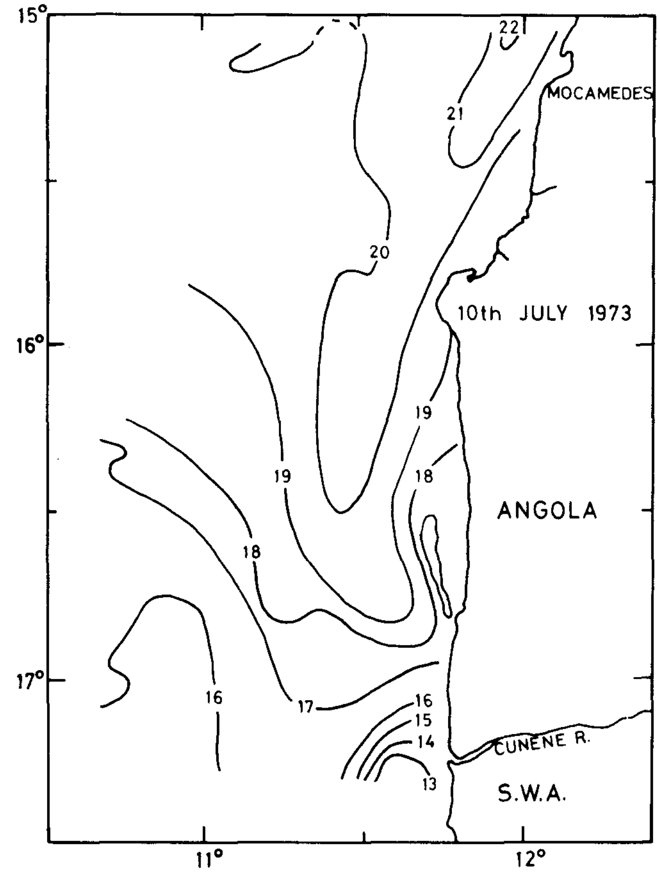

FIGURE 9. Northern end of the Benguela Current upwelling component.

A quantitative relationship between surface temperature and local wind direction and velocity has been derived for the area near Cape Town, and W. R. H. Andrews has shown that a relationship exists between surface wind stress and the distribution of numerous properties in deeper water. Based on these relationships A.R.T. data up the coast have been interpreted as showing that the coastal upwelled component of the system is very responsive to variations in local wind stress. Coastal upwelling occurs in about seven semipermanent sites between the northern limit near the Angolan border (Figure 9) and the southern end near Cape Town. Seasonal migrations of the South Atlantic atmospheric high pressure system cause changes in the coastal winds which provide year long refreshment to the surface waters by upwelling. Although upwelling winds blow intermittently over the whole year in the entire area, their effect is focused on certain areas in a seasonal manner. In summer, when the high migrates south, coastal pressure gradients are enhanced in the south and weakened in the north, so upwelling is at a maximum in the south and reduced in the north. In winter, the high migrates north and upwelling is at a maximum in the north and a minimum in the south. In the center of the system near Lüderitz there appears to be more constancy. Although refreshment by upwelling is constant, it is seasonably and geographically separated and, at present, the biological implications of this situation are unknown.

zooplankton being offshore. Pilchard shoals avoid the dense *Fragilaria karstenii* tending to be found in less dense phytoplankton and zooplankton mixed areas (Figure 11). Anchovy do occur in the *Fragilaria karstenii* areas although both anchovy and pilchard are rarely caught in he high zooplankton (low phytoplankton) areas. *Fragilaria karstenii* is usually very abundant around Walvis Bay, particularly in the upwelling center south of Walvis Bay, and seems to be the preferred habitat of the goby, *Sufflogobius bibarbatus.* Extensive goby catches have been made with purse seine nets in this area, but the quantities were not recorded separately from other species.

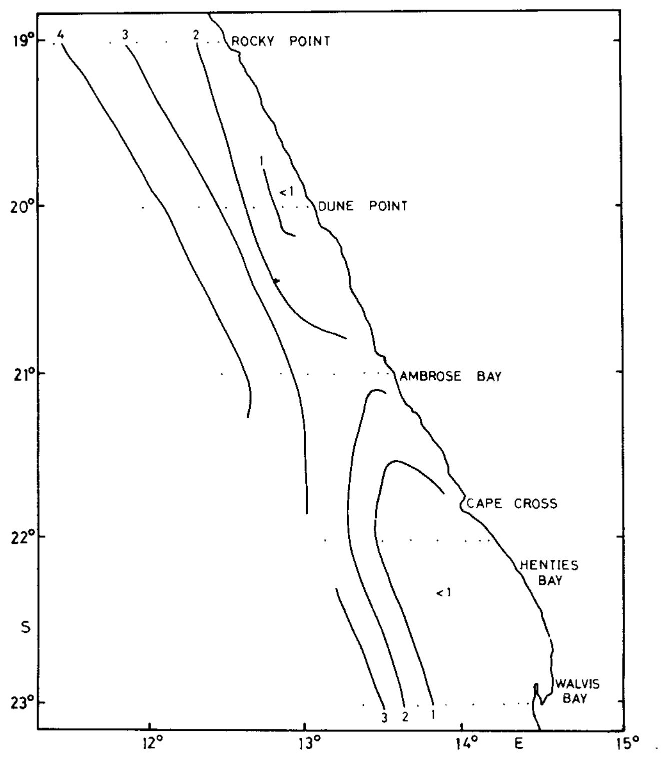

FIGURE 10. Dissolved oxygen (ml/l) at 50 m for June 1973.

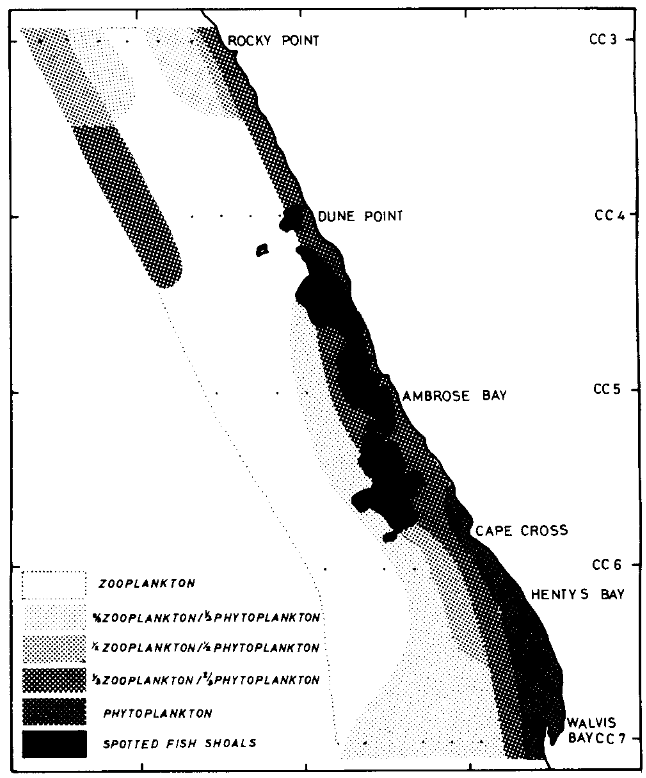

FIGURE 11. Plankton and fish shoals (April 1972).

Planktology and other hydrological investigations have been accomplished to examine distributions and as part of an ecological study on pelagic fish. The ecological work implies that salinity and temperature of the coastal zone are rarely unsuitable for pelagic fish, but that their distribution can definitely be limited by the dissolved oxygen content and dense phytoplankton (principally *Fragilaria karstenii*). Oxygen content values of less than 1 ml/1 are common in deeper water throughout the fishing ground and can occur up to the 5m depth (Figure 10). Areas of low oxygen content tend to be devoid of catch and, dependent upon their position and persistance, can have a considerable influence on fish availability (Visser *et al.,* 1973; Wessels *et al.,* 1974).

Phytoplankton and zooplankton occur in zones approximately parallel to the coast: the densest phytoplankton being close inshore and densest

The concept of the intermediate zone of phytoplankton/zooplankton and oxygen content is doubtless an oversimplification. However, it served as a useful first concept with which to interpret data, and combined with the fishspotter data led to ideas of fish shoal ecology, using the shoal group as a biological entity, which is useful input to availability studies.

Feeding Studies on South West African Pelagic Fish

A start was made on a study of feeding selectivity in pilchard and anchovy in South West Africa and it was found that the gill raker mechanism of the post-larval fish is such that filter feeding is impossible. Particulate feeding occurs until a length of 100mm is achieved in pilchard and 80mm in anchovy after which diatoms dominate the diet. Below these sizes competition for food could occur with the extremely abundant goby larvae constituting an important source of competitive pressure on food organisms (King and McLeod, 1977).

Population Genetics of the South West African Pilchard

Nongenetic characters, such as time (season), water temperature, and locality separate spawning groups of pilchard along the south and west coasts. Tagging work indicates that there is little migration between the major stocks of pilchard in South and South West Africa (Newman, 1971). In South West Africa, ecological and seasonal differences separate two spawning groups. A preliminary genetics project showed that genetic imbalance occurred in all three regions sampled (two in South West Africa, one in the Cape). The regional samples showed different proportions of alleles. The simplest model suggests that the species contains several stock units breeding in isolation which is continuous over generations in spite of much physical mixing on the sampled fishing grounds.

South West African Pilchard Population Biology

Research on the South West African pilchard stock has centered upon the need to quantify and explain the decline which happened in recent years. (Table 4).

TABLE 4
South West African Pilchard and Anchovy Catch 1947–1975 *

Year	Pilchard	Anchovy
1947	0.9	
1948	2.7	
1949	8.0	
1950	46.7	
1951	127.2	
1952	225.8	
1953	262.2	
1954	250.6	
1955	227.1	
1956	227.9	
1957	227.5	
1958	229.1	
1959	273.5	
1960	283.3	
1961	343.5	
1962	397.4	
1963	555.2	
1964	635.9	
1965	661.0	0.6
1966	712.0	2.6
1967	932.2	24.8
1968	1,363.9	161.2
1969	1,010.7	226.1
1970	513.7	188.9
1971	324.0	187.8
1972	373.5	136.6
1973	408.1	295.5
1974	561.6	252.8
1975	561.4	200.5

* Thousands of metric tons.

When available estimates of stock size are considered with the pilchard catch over the same period, three notable points emerge, which have had important impact on management (Figure 12):

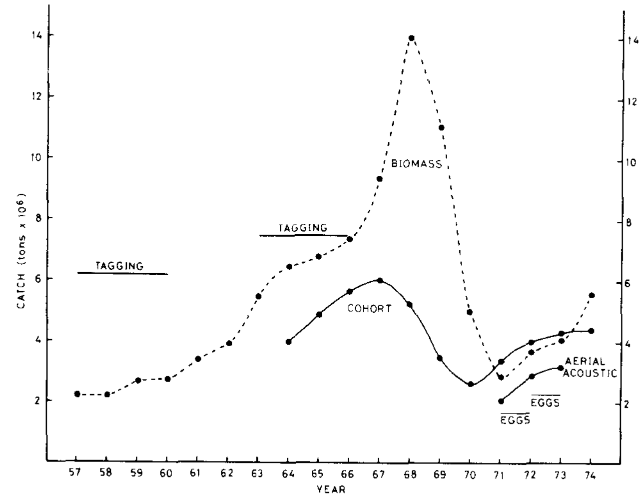

FIGURE 12. Stock size estimates and catch (Pilchard).

1. The 1957–60 and 1963–66 estimates of stock size are high in comparison with all other (later) estimates.
2. The stock size trend from 1961 to 1974 shows a relationship with the trend in catch.
3. All estimates from 1970 onwards display the same trend with approximately similar values.

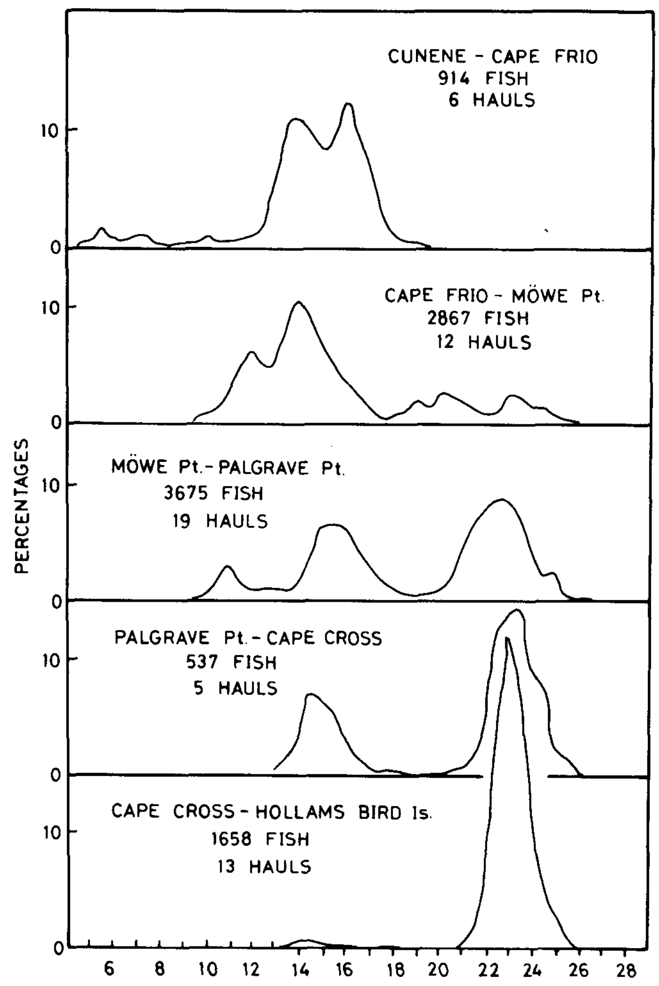

FIGURE 13. Percentage frequency distribution per area. Experimental catches September–December 1970 (Schülein).

Tagging Experiments

Stock size estimates of 6.25 million tons (1957–60) and 7.50 million tons (1963–66) were derived from an analysis of returns from a tagging experiment conducted by the South West Africa Administration Marine Laboratory (Newman, 1970). The analysis showed that emigration of tags from the catch area of the fishery was negligible.

Recent work on the distribution of *Sardinops ocellata* has demonstrated that the stock is widespread latitudinally (Figure 13). The assumption can be made that this is the usual distribution due to the Angolan fishery performance and aerial work accomplished between 1970 and 1974, which showed no change in distribution. Furthermore, this widely distributed population is subdivided into two spawning populations (Figure 7) with different ecological preferences (King, 1974). Fecundity studies show that samples taken during the spawning periods are significantly different in successive months, but cannot be separated consistently into northern and southern groups either temporally or spatically. Representatives of all groups can be captured at Walvis Bay (Le Clus, 1974). A preliminary muscle esterase genotyping experiment indicated that subpopulations could occur within the South West African population (Thompson and Mostert, 1974).

Considering that the recovery area for tags (Figures 14, 15) was only a small proportion of the area within which the shoal groups nomadically move, it is likely that emigration is a very significant factor, particularly so if tags were placed in representatives of a northern spawning group. Although the increase in the fishing area after 1964 has increased the likelihood of more effective tag recapture, emigration is probably a significant source of bias reducing the tag returns of the same landings and thus tending to inflate the estimate of stock size.

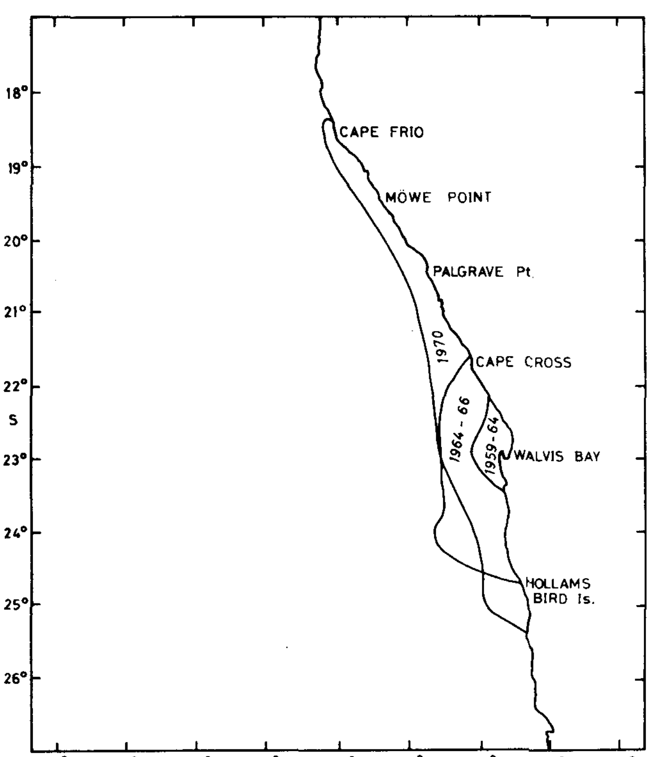

FIGURE 14. Increasing fishing area (from Baird, Newman, Ratte, Schülein, 1973).

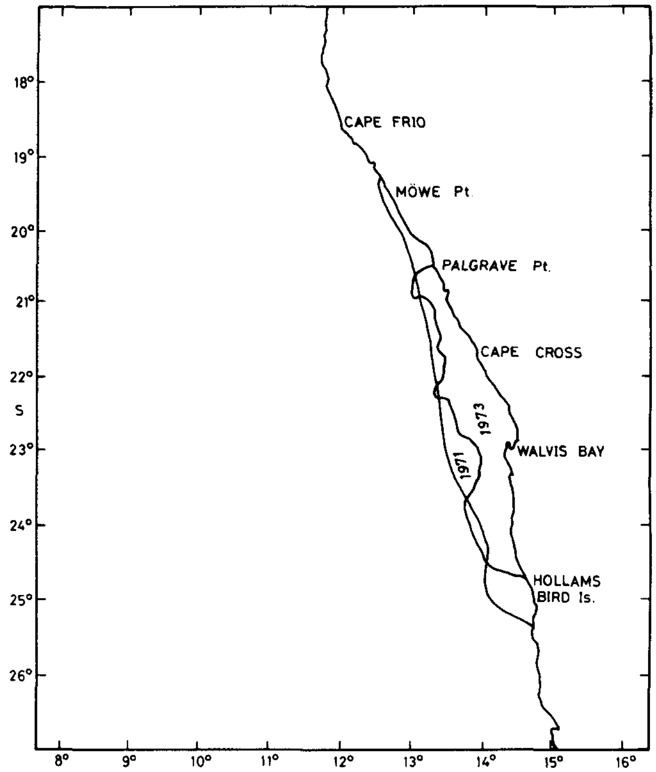

FIGURE 15. Decreasing fishing area.

A second important source of error concerns estimates of initial tagging mortality. Unfortunately, no experimental work was done on *Sardinops ocellata* and a value of 40% was used, derived from work done on *Sardinops caerulea,* being the mean value for fish greater than 18.5 cm. However, the range of values reported by Clark and Janssen (1945) was 20% to 70% with very great variation between groups of tagged fish. From the description of the methods used by Clark and Janssen and some knowledge of the method used on *Sardinops ocellate* it is highly likely that at least similar variation occurred.

Using a Petersen population estimate,

$$\frac{C}{B} = \frac{R}{M}$$

where:

C = the catch
B = biomass
R = tag returns
M = number of fish tagged,

the catch, tag-returns, and a range of initial tagging mortalities from 20% to 70% give ranges of biomass from 8.1 – 3.1 million tons for 1957–60 and 8.8 – 3.3 million tons for 1963–66 (Table 5). The figures for 40% are very similar to that reported by Newman (1970). The estimates of initial tagging mortality do not include an estimate of sustained mortality due to tagging, which is likely, and would serve to reduce estimates of stock size.

TABLE 5
Range of Pilchard Biomass Estimates, with Various Initial Tagging Mortalities, in Millions of Tons

	Percent initial tagging mortality		
Years	20%	40%	70%
1959–60	8.1	6.1	3.1
1963–66	8.9	6.4	3.3

Baird, Newman, Ratte, and Schülein (1972) point out that the estimates of total mortality for the period 1967–71 (Table 6) are higher than that of 0.7 calculated for the period 1963–66 by means of tagging (Newman 1970). The general decline in both 6/5 and 7/6 year-classes is consistent with a progressive decline in stock size over the period.

TABLE 6
Instantaneous Pilchard Mortality Rates, 1967–71

	Total mortality at age		
Year	5/4	6/5	7/6
1967	-	1.99	2.44
1968	0.30	1.85	2.26
1969	0.74	1.60	1.25
1970	0.26	1.34	2.22
1971	0.67	1.08	1.86

The discrepancy in calculated mortality rates for the consecutive periods by a factor of between 1.5 and 3.5 could be the result of an underestimate of mortality from tag returns. Tag return data were lumped to give a mortality rate reflecting average conditions. This procedure masked the rapidly increasing second year recovery rates and possibly resulted in an underestimate of mortality giving an inflated estimate of stock size.

The apparent effect of the high 1966–68 catches on the population suggests a fairly high rate of exploitation, indicating that the effect of a probable high tagging mortality outweighs the effect of bias through emigration. Taking into account sustained tagging mortality and a low estimate of total mortality, the population during the period 1957–66 may have been lower than that reported, somewhere nearer the level of 3 million tons indicated by the 70% initial tagging mortality level. No deductions can be drawn as to the contribution to the estimated stock size from the putative northern population.

Stock Size Trend 1961–74

The trend in population size from 1961 to 1974, as derived from virtual population analysis (Schülein, Newman, and Centurier-Harris (1975), is that the biomass apparently increased in the period 1964–1967 quite rapidly whilst the catch increased slowly at first, then rapidly to 1968, whereafter both fell abruptly until they picked up in 1970 and 1971 respectively (Figure 16). The large increase in catch was led by quota relaxations, yet, despite a doubling of the catch between 1966 and 1968 from 0.75 to 1.5 million tons, the population is reported to have been increasing. This is possible, provided that a large year-class passed through the fishery. The values of stock size from 1964 to 1967, 4.5–6.0 million tons, are lower than those quoted for the period 1963–66 from the tag return data, 6.25 to 7.50 million tons, which have been previously questioned, and could be interpreted with the aid of reported recruitment patterns. In 1963 an el Nino type situation resulted in anomalous hydrographic and biological conditions in the fishing area. Stander and De Decker (1969) reported on these conditions, observing that oil yield was depressed and that larval survival would be impaired. Despite the anomalous conditions, the fishery maintained its catch and a strong recruitment occurred.

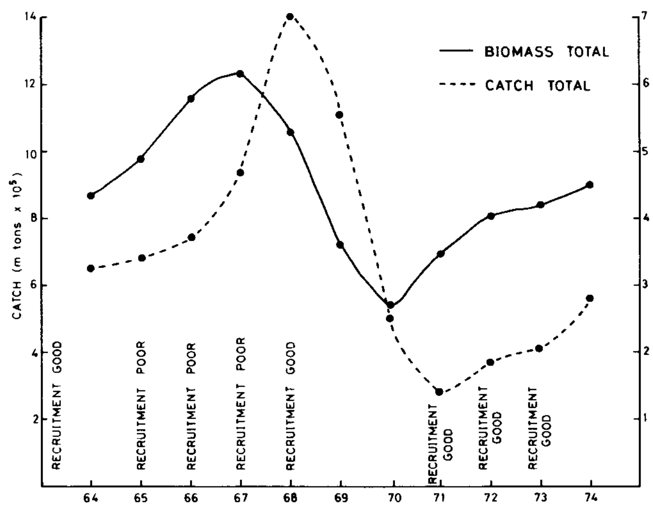

FIGURE 16. Trends in Pilchard catch and biomass (Schülein, Newman, and Centurier-Harris, 1975) with added annotation for recruitment.

A study of data on environmental conditions and oil yield, and possible larval survival and recruitment has led to the development of an empirical model stating that oil yield is an indicator of environmental suitability, and the state of the environment dictates larval survival and hence later recruitment (Schülein, 1974). Using the 1963 anomaly which was associated with low oil yield, Schülein suggests that as recruitment occurs at ages from 2 to 4, the poor recruitment experienced from 1965 to 1967 was the result of high larval mortality in 1963. Thus the extremely rapid increase in catch from 1966 to 1968 took place at a time when the stock could have been reduced by poor recruitment in 1965–1967 (Newman, 1970) which exaggerated the effects of heavy fishing and lead to the decline of 1969–70.

Recruitment was strong in 1963 (Newman 1970), weak between 1965–67, and strong again in 1968–69 and 1971–73 (Schülein 1974). The effects of strong recruitment in 1963 were visible in 1965–66, but by 1967 the fish responsible were about 6 to 8 years old, and not well represented in the catch, less than 20% by weight in recent years (Schülein, Newman, and Centurier-Harris 1975). On the other hand the poor recruitment of 1965 and 1966 may have resulted in a net loss to the population, which could have resulted in a declining population after 1963. Newman (1970) reported from the analysis of tag return data that the population size was declining from 1963 to 1966, but not severely.

If the stock size levels reported for 1964–67 are too high, the source of bias should be sought in the manner in which the basic data are acquired, namely the manner in which the catch is made. As virtual population analysis (VPA) requires the total number of fish of each age caught per year, a value for the coefficient of natural mortality, and one year for which the fishing mortality rate has been independently estimated, bias can only exist in the catch data and the assumed value for the coefficient of natural mortality. In any case, an error in the mortality coefficient becomes reduced in the earlier years under consideration, so the bias, if any, should be sought in the catch.

For VPA to succeed, the catch must be made upon a discrete population or within a previously defined management area. The distribution of pilchards off South West Africa indicates shoal groups are spread along the entire coast (Figure 13). Schülein (1972) has shown that a latitudinal distribution of age exists throughout the entire coastal zone, with younger fish in the north and older fish in the south. As recruitment has previously been regarded as incomplete until age four, only this and older age classes were used in the VPA.

TABLE 7

Search Area by Year *

Year	1959	1960	1964	1965	1966
Search area (nautical miles)	899	549	548	2,110	2,771

* Newman 1970

Between 1959 and 1964, the fishing area was small, being less than 900 square nautical miles around Walvis Bay, so that many shoal groups were unlikely to be represented in the fishery. From 1964 the search area rapidly increased, until by 1970 the entire coastal zone was searched, thus incorporating more of the shoal groups into the fishery. This increase, from 900 (in 1959) to 2,800 (in 1966) and then to about 9,000 square nautical miles (in 1970) affected the basic data (Table 7). The estimates of stock size made each year in the changeable fishery may not be comparable, as each may refer to a different management area covering part of the range of the stock. The increase in population size shown for the period of increasing catches may refer more to increasing search area than to increasing abundance.

In 1968–70 the catch declined considerably and the search area expanded, nearly covering the approximate reported distribution of the stock. The catch was further reduced in 1971 when a restrictive quota was applied. At this time the stock probably commenced to increase in response to the good recruitment reported by Schülein (1974), indicating that the reduction in effort on pilchard came at an opportune moment.

A further indication that bias may exist in VPA estimates can be obtained from catch-per-unit-effort (CPUE) assessments which have been attempted from three sources: landings per gross ton of the fleet, the area which had to be searched to obtain the catch, and fuel utilization. The last two are interdependent.

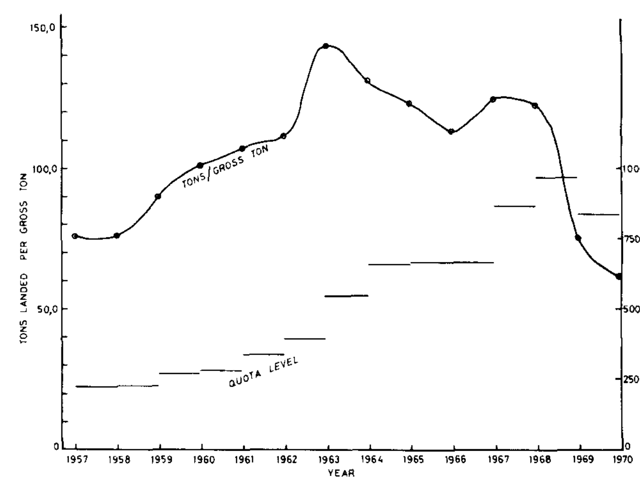

FIGURE 17. Pilchard catch-per-unit-effort (CPUE) index (Baird, Newman, Ratte, and Schülein, 1972) with added quota levels.

While trends in landings of pilchard per gross ton have been determined (Figure 17), gross fleet tonnage does not take into account increases in vessel efficiency, changes in vessel size, or alterations in the number of trips, but can give some indication of effort. From 1957 to 1963 the quota increases allowed the catch to rise and so did the landings per gross ton, indicating that the quotas prevented full utilization of effort. Between 1964 and 1966 the index declined despite freezing of quotas for that period, but in 1968 and 1969 the quotas were substantially raised giving an upsurge in the index before the decline in 1969 and 1970 associated with a slight quota restriction in 1969 and the failure to meet the quota in 1970. Baird, Newman, Schülein, and Ratte (1972) regard the 1970 index as unbiased as the quota was not filled, suggesting that this indicated a reduction in abundance of about 50% the level of 1964–68.

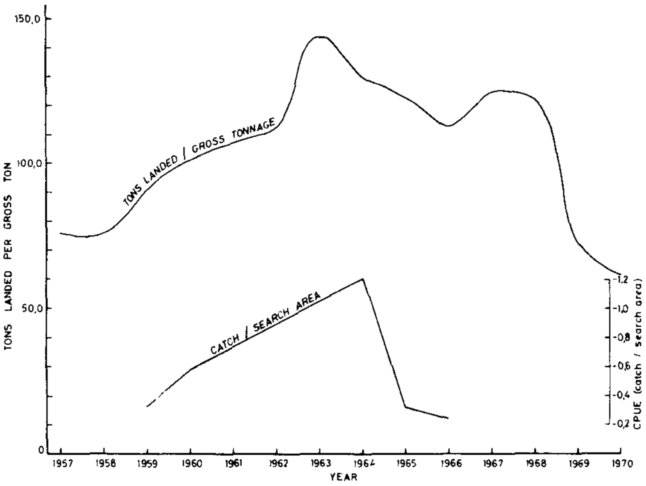

FIGURE 18. Indices of pilchard catch-per-unit-effort (CPUE).

In attempting to determine trends in stock size from either index, the effect of quota changes should be taken into account. A close relationship was demonstrated for landing/gross ton compared with quota levels, except for the period 1964–66 and after 1969 (Figure 18). During the period 1964–66 the landings/gross ton declined despite a period of quota stability. The landings/gross ton were compared with catch/search area (calculated from Newman, 1970, Tables I and V), although the catch/search area declined severely after 1964 (Figure 18). Additional CPUE information comes from landings/fuel issues and catch/search area (Figure 19). The landings/fuel issue data indicate that CPUE was high in 1964 but thereafter a consistent decline took place, recovering in 1970–72. The numerical level of the decline from 0.14 metric ton/liter in 1965 to 0.04 metric ton/liter in 1971 is similar to the levels calculated from tagging, 1963–66, and mortality estimates, 1970–72 (Newman and Schülein, 1973). Correspondence between catch per fuel issues and catch/search area would seem likely as they are interrelated: the greater the area searched, the more fuel used. These data could as easily be measures of availability as abundance, but probably combine indices of both. The problem is that it is impossible to extract the effect of availability, so the best interpretation of these CPUE data would be that availability and apparent abundance were changing during the period in question. The terms availability

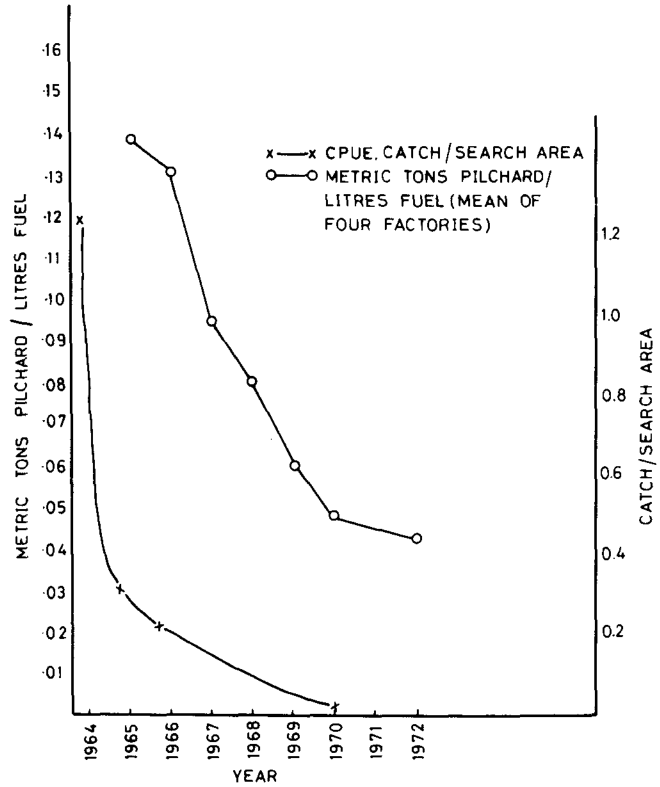

FIGURE 19. Catch-per-unit-effort (CPUE) landings/fuel issues (Newmand and Schülein, 1973) with added notation of CPUE catch/search area.

and apparent abundance are used according to Marr (1951).

As the canneries require fish in prime condition, cannery fish have to be caught as near to the factories as possible, and as the shoal groups are distributed near the coast over a considerable latitude this usually means traveling north to the nearest shoal group. It is usually unnecessary for any vessel to proceed further than the nearest catchable shoal group owing to information exchange by radio. During April 1972 the catch area was distributed at the southern end of one shoal group, while other shoal groups were present to the north (Figure 20). This localization of fishing effort renders CPUE analysis difficult, for the movement of shoal groups north and south will have a considerable impact on effort, probably greater than any short term change in abundance.

All CPUE indices show a decline from about 1964 to 1970 as may reevaluated virtual population analysis estimates. The important question becomes, "How severe was the decline?"

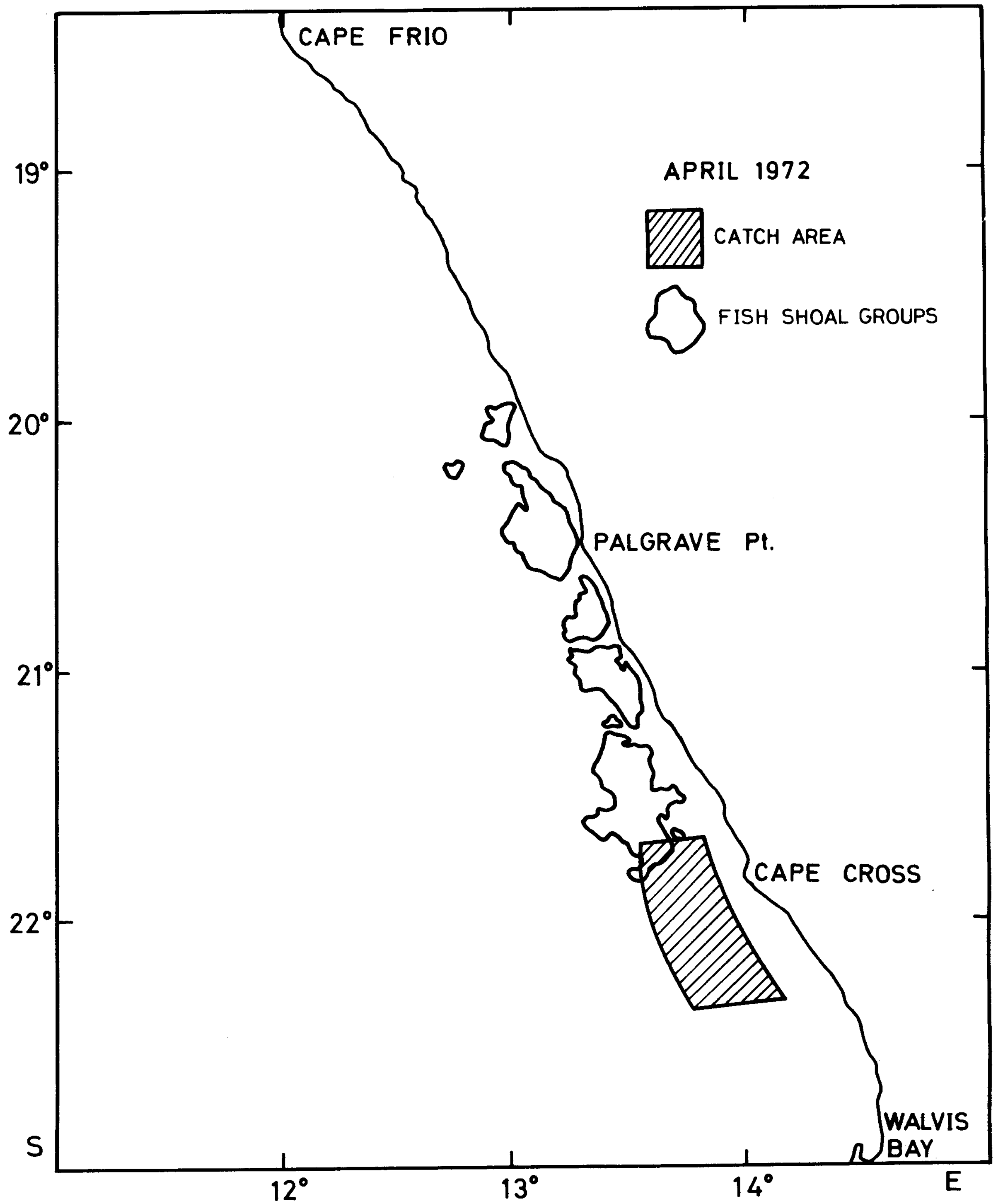

FIGURE 20. Pilchard school groups and catch area.

Current Trends In Stock Size

Estimates of population size have been made from aerial/acoustic data at 2.1, 2.9, 3.2 million metric tons for 1971/72, 1972/73 and 1973 respectively (Cram, 1972, 1974). No estimate of the variance in the estimates is available. Quantitative egg capture data gave two estimates of 1.7 and 2.3 million metric tons for 1972–73 and 1973–74 respectively. The estimates are subject to error giving a range of possible spawning population size from half to double the estimate (King, 1974).

Baird, Newman, Ratte, and Schülein (1972) suggested that increased fishing mortality in 1967–71 had a significant impact on the age structure of the population. In 1967, 55% of the landings consisted of fish 5 years and older, whereas in 1971 these age groups contributed 25%. The trend conforms except for 1970 when the value was 40%. The high proportion of older fish in the catch in 1970 and the trend of increased mortality (Table 4) suggest the depletion of the stock was neither sudden nor severe. Considering the suggested revision of stock estimates from tag return data and VPA for 1965–68 with the data for 1970 onwards, it would seem the decline in pilchard population size was real but not as serious as suspected and of the order of 30%, approximately from 3 million to 2 million metric tons and extending from about 1965 to 1970.

Subsequent to the restrictive quota on pilchard, the stock size is increasing because of good recruitment and is probably at a level of 3 million metric tons. The decline experienced between 1964 and 1970 is explicable in terms of recruitment variation exaggerated by a short period of high fishing mortality, and the stock can now be considered as recovered.

South West African Anchovy Population Biology

Engraulis capensis occurs from the Kunene River on the northern border of South West Africa to Cape St. Sebastian on the south coast of South Africa. Anchovy fishing started off Walvis Bay in 1963 when two vessels were equipped with 11 mm mesh nets to determine the anchovy fishery potential. Commercial fishing started the following year (1964) when two vessels from each of the eight Walvis Bay factories (and the Lüderitz factory) were equipped with 11 mm nets. Good catches by these boats suggested the possibility of full scale exploitation, and by 1968 all vessels were equipped with anchovy nets.

Prior to 1971 no accurate differentiation was made between pilchard and other species landed, but factory estimates indicate that the catch of anchovy (and other species) increased from about 575 metric tons in 1965 to 295,483 tons in 1973 (Table 3). Following the commencement of the new research program in 1970, accurate records of the anchovy landings were kept from 1971 onwards.

Age determination proved difficult initially as the otoliths were found to be blank in younger fish and finely cracked in older fish making the identification of growth zones very difficult. Scales therefore were used, which were hard to obtain through the commercial fishery as the action of catching and pumping stripped many scales off the fish. However, experimental fishing yielded suitable age material. The formation of new rings starts in May, thus fish spawned at the beginning of the spawning season (October) and at the end (April) will be 6 and 12 months old respectively before the first annual ring appears. The protracted spawning season is assumed to be responsible for the pronounced variation in lengths at age, particularly of 1 year fish. The mean length of 1 year old fish is 9.3 cm with a range 5.5-11.4 cm.

Fifty percent maturity occurs at 9.5 cm (0 to 1 year) and 100% maturity at 11.0 cm (2 years and older). The development of gonads starts in September and is continuous through to April. Eggs occur continuously within the plankton during this period.

The age composition of the catch has shown a similar trend to that in the Cape anchovy fishery. In 1971 the modal age group was 2 years, in 1972 the modal age was 0, and in 1973 the contribution of the 0 year class to the fishery rose considerably (Table 8).

TABLE 8

Age Composition in Numbers of Fish for the Commercial Anchovy Catch, Walvis Bay 1971–73 * and Cape 1965–67

South West Africa

Year	0	1	2	3	4
1971	17.3	11.4	41.9	26.3	3.1
1972	41.3	28.2	16.2	13.0	0.9
1973	56.9	27.2	11.9	6.1	2.5

South Africa

Year	0	1	2	3	4
1965	28.7	41.0	20.5	8.4	1.4
1966	68.6	20.6	9.4	1.4	
1967	73.5	22.5	2.6	1.4	

* Ratte, 1973

Schülein (1974) suggested that the good recruitment of 0 year anchovy in 1972–73 was partially due to favourable conditions for larval survival in 1972–73, based upon good oil yield values in those years.

TABLE 9

Total Instantaneous Anchovy Mortality*

Year	Age 1/0	2/1	3/2	4/3
1971			0.47	2.14
1972	0.38	0.56	0.22	2.67
1973	0.92	0.65	0.66	0.91

* Ratte, 1974

In 1971 when fishing mortality was low in the younger age classes, estimates of total mortality from catch curves were also low (Table 9). Later, between 1972 and 1973, the total instantaneous mortality rates of the younger age classes rose considerably. Using these mortality estimates, the catch averaged between 1971 and 1973, fishing mortality, and estimates of natural mortality between 0.8 and 0.4, the anchovy population size is estimated at between 0.5 and 1.0 million metric tons. The shift of modal age between 1971 and 1973 suggests heavy exploitation.

TABLE 10

Average Anchovy Length per Age Group

South African Stock

Age years	LC	Range LC
1	7.9	6.5–10.0
2	10.4	
3	11.9	
4	13.0	

South West Africa Stock

Age years	LC	Range LC
1	9.3	5.5–11.4
2	10.9	9.3–12.4
3	11.9	10.6–13.0
4	12.7	12.0–13.2

There is some evidence that the South West African and South African anchovy populations are separate. Meristic characteristics are identical, although the mean length and range for 1 year group is more than in the South African stock (Table 10). This could be attributed to the wider size range available in South West Africa and the arbitrary formation of growth rings on the scales particularly between May and October, rather than to faster growth. It is possible that a similar length and range exists in the South African stock.

The development of resting and immature gonads in the two areas occurs in September and continues until April, with peak activity in December, January, and February in South West Africa (Table 11). Spawning occurs in widely separate locations, within a range of surface temperatures from 13.3 to 22.0°C.

The change in age structure accompanying the South African anchovy fishery occurred without influencing the South West African stock, although the pace at which the 0 year group grew to prominance was less in South West Africa than in the Cape. The population in South West Africa was not fully exploited until 1972 whereas in the Cape the 0 year group predominated from 1966.

The presumably separate South West African anchovy population has been present in catchable concentrations since 1964, when the pilchard population was at its recent probable maximum. The catch increased rapidly as effort increased until effort stabilized in 1968. After a slight increase in 1969 the catch dropped slightly, until the good

TABLE 11

Comparisons of Gonad Development, Spawning, and Formation of New Annual Rings in *Engraulis capensis* in South East Atlantic

SOUTH AFRICAN STOCK

Month	Gonad development	Spawning occurrence	New rings forming
FIRST YEAR			
May			
June			X
July			X
Aug.			(max.)
			X
Sept.	X	X	X
Oct.	X	X	X
Nov.	X	X	X
Dec.	X	X	
SECOND YEAR			
Jan.	X	X	
Feb.	X	X	
March	X	X	
April	X	X	

SOUTH WEST AFRICAN STOCK

Month	Gonad development	Spawning occurrence	New rings forming
FIRST YEAR			
May			X
June			X
July			X
Aug.			X
Sept.	X		X
Oct.	X	X	(max.)
			X
Nov.	X	X	
Dec.	X	X	
SECOND YEAR			
Jan.	X	X	
Feb.	X	X	
March	X	X	
April	X	X	

recruitment of 1973 when the catch doubled. The anchovy stock thus exists in parallel with the pilchard stock, is relatively small, heavily exploited, and the fishery is recruitment dependent.

Problem Areas

Current research has been directed towards solving specific problems associated with management of the stocks. Many avenues of research have been explored and an almost unlimited amount suggested, but it seems that we still require very basic information on the fishery, as it is not yet possible to manage effectively all the valuable stocks presently exploited. Principal problem areas are the establishment of stock size and yield, single stock management in the multispecies fishery, and stock identity.

Pilchard conservation was promoted by the split quota system, but this produced its own problems through daily pilchard tallies, as each factory strove to spread its pilchard catch throughout the season in order to maximize its effort on anchovy. Inevitably this led to dumping of pilchards caught inadvertently or dumping following the location of an anchovy shoal. Dumping appears to have been a fairly common practice in the past, for the Commission of Enquiry into the Fishing Industry (Report, 1971) notes evidence that 10–50% of the catch was dumped. Furthermore, the commission noted that statistics of the factories in respect of fish delivered to them always were less than the amount supplied. The introduction of automatic scales and the inspectorate in 1971 should have solved the shore based problems, but nevertheless cast doubt on the value of commercial catch data. It also has been alleged that pilchard has been identified as anchovy on occasion to defeat the split quota regulations, increasing the element of doubt about the accuracy of catch figures. Assessment of effort is not easy owing to the spatial and temporal variation in distribution of effort in the multispecies fishery, and effects of availability, in particular, contaminate effort data. The fishing pattern on pilchard stocks is variable, the wider the search area the more younger fish are caught, thus recruitment varies. The recruitment pattern may vary asynchronously within components of the multispecies fishery, causing effort to be diverted to whichever species has strongly recruiting year classes. Most methods in population dynamics require a stable time series of data but these are not available at least for South West Africa.

The existence of these problems strikes at many assumptions made in calculating stock size and yield, preventing accurate estimates being made, and rendering difficult the management of single stocks in the multispecies fishery. The problem was solved initially almost arbitrarily when the 1970 quota was split 33/66% by weight. Since then, however, the pressure of small upward adjustment of the reduced pilchard portion was irresistible despite some objection from scientists. It has been difficult to produce a valid argument against the creeping upward adjustment of the pilchard quota as, for example, a 10% readjustment is extremely meaningful economically but scientifically undetectable, and may represent 50,000 tons of fish. This continual readjustment of the split quota has an adverse impact upon population dynamics as effort varies from year to year, and sometimes within a season.

Single stock management is an essential element of present and future management strategy, but hampered in South West Africa by a lack in ability to accurately assess stock size annually with known confidence limits, or to establish an accurate annual value for yield. In the Cape, the only current source of data is catch statistics, which are subject to previously mentioned sources of error and bias, compounded by the fact that up to five species are represented in the catch. Here the problems of single stock management are acute as the canning industry is very reduced and the most favoured species are either severely depressed (pilchard) or subject to excessive variations in availability (mackerel). Moreover, with the 0 year group anchovy predominating in the catch, it is likely that any pertubation in recruitment (*vide* the opposite of the 1973 occurrence in South West Africa) would have an unfortunate effect on the fishery. The main problem in the Cape would thus seem to be similar to that of South West Africa: management of single stocks to resuscitate a cannery industry, while maintaining the reduction industry at an optimum level.

The principal biological problem is fundamental to management strategy and research: the determination of population homogeneity. The work of the egg program, fecundity, population biology, genetics research, and tagging point to two separate geographical anchovy and pilchard populations, with subgroupings present in the latter species both in South West and South Africa. The existence of subpopulations in South West Africa severely complicates matters for, at the present, it is not known what proportion of each putative stock is represented in the fishery, and thus in the estimates of stock size. For the South West African pilchard, a knowledge of what proportion of which stock occurs where, will have a substantial effect on future exploitation of the resource when development occurs in the country. Similarly, in the Cape a resuscitation of the depressed pilchard stock will probably be facilitated by a thorough biological inventory to determine areas and situations within which conservation is required.

An important, though non-scientific, problem is the credibility and communication of research results to the industrial and management authorities. Experience has shown that scientific management advice to the authorities will be opposed by a powerful lobby using economic arguments augmented by their own interpretation of trends in the fishery. Scientific information is passed to the Department of Industries, which also receives industrial information from other sources, and is then formulated in a policy proposal for submission to the Minister of Economic Affairs. Since the varied information has to be collated by officials with economics and administrative qualifications, it has been essential that complex scientific appraisals be reduced to the minimum and preferably augmented by results of direct measurement techniques. It is a regrettable experience that the fishing industry tends to be aware of the shortcomings of its catch statistics and tends to be wary of esoteric statistical analysis of these data.

Lastly, the problem of uncontrolled foreign participation in the pelagic industry exists today.

Although the International Commission for Southeast Atlantic Fisheries (ICSEAF) has been in action since 1971, it has not focused much attention on the pelagic stocks. Foreign catch has been occasionally significant (Figure 3) and there is no legal apparatus to prevent a foreign fleet from catching outside the territorial or contiguous fishing zones.

FUTURE RESEARCH

Although there is a considerable armory of techniques and methods available within the many aspects of fisheries science, the Branch's pelagic research is, in general, only at first base. Such estimates of stock size and yield available are insensitive and inflexible, and therefore not well suited to managing fisheries subject to sudden change. The overriding problem is a lack of good basic data on the stocks and this should be reflected in our future work.

When faced with a choice of major strategies, that which provides the quickest, most precise management advice should be chosen. This would tend to eliminate strategies such as an ecosystem approach through ecological energetics which, while undoubtedly useful, is unlikely to influence the management of presently exploited pelagic fish stocks.

Population Studies

Whilst the collection and analysis of catch and effort data from logbooks will continue, survey capability must be developed to aid in single stock management within the multispecies fishery. Maximum sustainable yield, particularly when applied to a multi-species fishery, is an inflexible tool in a fishery subject to variable recruitment or alterations in fishing pattern. Estimates of stock size must become more accurate, and dependence on the catch reduced.

Survey input to population dynamics would possibly assist management through the differentiation of trends in availability and abundance. Routine aerial observations on shoal group location may allow the development of an availability index which, together with data on catch position from logbooks, may help to refine effort data.

The present aerial/acoustic methods will be enhanced through experimental work at sea which will lead to better estimates of the variance in stock size than presently available. Statistical sampling errors in aerial measurement of shoal surface area and acoustic measurement of mean surface fish density will be evaluated. Sources of bias need further study, particularly the variation in visibility of shoals from the air and the degree of avoidance of research vessels by shoals. A further source of bias in absolute measurements of stock size is target strength variation. A comprehensive experiment on live pilchard has been accomplished but the results are not yet available. This work will be continued with other species.

An important use of the aerial/acoustic strategy is prediction of pilchard recruitment. As recruitment to the present fishery is from 2 to 4 years, and complete at 4, 2 to 4 years are available for annual assessment of year class or size class abundance, and for observing their progress. The present aerial/acoustic strategy, when applied within the complete geographical range of shoal groups, will allow the estimation of biomass contribution from all fish which form shoals, and indications exist that this behaviour commences during the first year. Insufficient samples were taken during previous surveys (particularly in the north where young fish tend to be more common), but increased experimental purse seine catches supplemented by camera drops should give adequate size distribution data from enough shoals.

Although the "turnover" of anchovy is much faster, they may be amenable to a recruitment orientated aerial/acoustic survey as some evidence exists that 0 year shoals tend to be substantially larger than shoals of older fish. This possibility will be examined although, at this stage, the logistic problems in such a quick-fire survey are daunting.

Aerial/acoustic technology development will proceed. A possibility exists that a state-of-art system will be developed in conjunction with the National Fisheries Engineering Laboratory of the National Marine Fisheries Service (USA). The object will be to use the most advanced technology practicable for determining shoal dimension, mean surface density (number of fish/m^2 of shoal thickness), packing density (number of fish/m^3 of shoal), shoal thickness, and to detect fish shoals deeper than the visible range of the eye or bioluminescence sensors.

The future of the South West Africa pelagic egg and larva program (SWAPELS) is uncertain. Although estimates of pilchard stock size have been made, their accuracy is insufficient for any input to management other than support. Furthermore, these surveys are labor intensive and utilize considerable ship time. Gear problems, especially clogging, have characterized attempts to quantify anchovy egg collection.

No serious attempts have been made at predictions based upon larvae collections, although this is an area in which we will be largely guided by CALCOFI experience.

There are three approaches to using South West African Pelagic Egg & Larvae Survey: 1. for pilchard, anchovy, and maasbanker annual estimates of spawning stock size; 2. for all commercially valuable species once every 3 years; and 3. of the entire exclusive economic zone once every 5 years.

The only large scale alternative is to leave eggs completely and develop an 0 group prediction system using the resources that went into SWAPELS.

Biological Research

The genetic structure of the pelagic populations is not known. It is intended to use techniques of genetics on larvae and spawning adults from more areas in the geographic range of the pilchard and to test for more polymorphic isozyme systems in the species. This work should be extended to anchovy and other commercially exploited stocks.

It is by no means sure that all elements of the inshore pelagic stocks have been located. Surveys will be conducted in the semi-permanent upwelling areas to determine the existence of any other stock units.

Ecological Research

It is intended to use aerial observation in conjunction with shipborn research on shoal ecology to determine what factors principally control availability. The object will be to make availability trends more readily understandable to management rather than to derive a predictive model.

Competition of food is important to the qualitative recruitment model, based on oil yield being equivalent to environmental "quality." If good oil yield means good recruitment of both anchovy and pilchard, this will create additional competition unless it can be absorbed by the "suitable" environment. A feeding competition study will be evaluated. In this regard the high oil yield and its presumably associated anchovy 0 group recruitment in 1973 will be interesting to compare with pilchard recruitment between 1975 and 1977.

The bulk of the South West African anchovy stock appears to exist in warmer water than pilchard in contrast with the norm expressed by Longhurst (1971). Physiological studies may indicate whether the anchovies have an ecological advantage there, or in the Cape, if a general cooling of the environment occurs.

Research conducted since 1970 has indicated the presence of a large goby population (*S. bibarbatus*). The fish have featured in the purse seine fishery but the quantity is not known (Schülein, Sea Fisheries Branch, person. comm.). SWAPELS has generated much distributional data and a very tentative estimate of stock size in the 10^5 metric tons range (O'Toole, Sea Fisheries Branch, person. comm.) Acoustics cruise data show the goby population is widespread and extremely numerous. During a scattering layer study, target back scattering strength was determined which enables differentiation of gobies from the euphausiids with which they are frequently associated. Target strength is approximately known. Vertical migration and distribution of adults and larvae are known (d'Arcangues and Hampton, Sea Fisheries Branch, pers. comm.)

It is hoped to commence a quantitative study on the goby population in order to provide good base line data prior to the inevitable exploitation.

CONCLUSION

The Sea Fisheries Branch's strength in pelagic fish research is in the comprehensive logbook and inspection systems, the development of an aerial/acoustic method of assessing stock sizes, and the egg and larva program. Judicious interweaving of the best aspects of each technique with hydrobiological and other data will bring rational management of pelagic resources much nearer.

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THE LESSONS OF THE PERUVIAN ANCHOVETA FISHERY

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ABSTRACT

The outstanding features of the Peru upwelling system are high productivity and great variability. No large changes in the parameters of the anchoveta population were detected in the fishery and survey data analyzed in studies done before 1972, but because of deficiencies in the data such changes may have occurred and gone undetected. These studies might have been adequate in a less variable fishery, and even in the anchoveta fishery were useful in that they prevented an excessive increase in fishing effort. But because they did not allow for the possibility of large changes in the behavior of the population, they were of little value when recruitment failed in 1972. The stock's collapse in that year and its apparent failure to recover since are still not understood. In the light of this experience, future studies and management of anchoveta fisheries should take into account the potential for large changes in the parameters of the fish populations and in the meaning of the usual fishery statistics and survey data.

INTRODUCTION

Because of upwelling, the coastal waters of Peru are among the world's most productive. The chief direct consumer of this immense planktonic production is the Peruvian anchoveta, *Engraulis ringens* Jenyns, and it in turn is the chief forage item of the region's higher level consumers, including fish, birds, and marine mammals. In some years the normal processes of production and consumption are interrupted when upwelling ceases and warm surface waters advance to the coast with lethal effects on the native biota, a phenomenon called El Nino.

In the absence of a large market, no large scale fishery developed to exploit Peru's marine production until the second world war, when high demand and low supplies in the United States and elsewhere offered large profits from the export of canned tuna and bonito. After the war, as normal fishing operations resumed in the former belligerent countries, Peruvian exports were steadily displaced from foreign markets by cheaper domestic products, and in Peru the boats and factories that had been built during the war were increasingly idle.

Reduction plants had been installed in the canning factories to make fish meal from the leavings of the canning process, and beginning about 1950 some factory owners resorted to buying anchoveta for reduction to cut their losses when the canning lines were idle. This incidental activity soon became profitable in itself as world demand for fish meal increased and other supplies declined, in particular the California sardine. As new boats and plants entered the industry, the catch of anchoveta grew exponentially, doubling each year from 100,000 tons in 1955 to 3.3 million tons in 1960 (Boerema and Gullard, 1973).

At this point the Peruvian government, with technical assistance from the Food and Agriculture Organization of the United Nations (FAO), began to collect fishery statistics and conduct fishery investigations with the aim of rationally managing the resource. The first assessment of the fishery, done in 1965, showed that the stock was fully exploited, or nearly so, by the current annual catch of 8 million tons, and for the next few years the catch was limited to approximately this amount by closed seasons and quotas. Later studies, done after the population of fish eating birds had been reduced by some 75% during the 1965 El Nino, showed that the anchoveta stock could yield 10 million tons per year on the average. The quota was consequently raised in 1968, and the annual catch was around 10 million tons through 1971. While the annual quotas prevented excessive increases in the catch, they did not prevent and in fact encouraged excessive increases in the industry's capacity (catching and processing) since the companies with the largest capacities obtained the largest shares of the quota. As a result, the industry by 1971 was heavily overcapitalized.

At the end of 1971, the anchoveta fishery appeared to be a model of successful management, by biological standards if not economic ones. But then, within months, the population suffered two catastrophes. First it became clear early in 1972 that recruitment had practically failed, and after that the adult stock, crowded against the coast by the severe 1972 El Nino, was greatly depleted, either by heavy fishing or by a combination of heavy fishing and extraordinary mortality due to the extreme environmental conditions that then prevailed. By the middle of 1972 only a small part of the former stock appeared to have survived.

The stock of anchoveta did not recover rapidly after the collapse of early 1972, and since then the fishery has operated at a low level. After catching about 4.5 million tons in the first months of 1972, the fishery in effect remained closed until March 1973 when about 2 million tons were caught during a brief open season, but acoustic surveys and the composition of the catch showed that recruitment was again poor and the stock was still small. The fishery was again closed for the remainder of the year. In 1974 conditions were somewhat better and a catch quota of 4 million tons was filled. So far in 1975, a quota of 3 million tons has been taken in the first part of the year, and an additional 2 million may be allowed in the last few months. Acoustic surveys continue to show a stock size well below the average observed before 1972.

The record of anchoveta fishery can be interpreted in various ways. One is that the stock and its usual behavior were adequately described by the assessments done before 1972. In this case, the recruitment failure of 1972 was a freak event whose consequences were needlessly exacerbated and prolonged by excessive catches in 1972 and since. Another interpretation is that these assessments for one reason or another did not accurately represent the condition or behavior of the stock. In this case, there is no sure way to infer from the available data whether the catches before or after 1972 were too high or too low, or what should be the strategy for managing the fishery now.

The choice between these interpretations is still open. This paper will briefly describe the upwelling system and the natural history of the anchoveta, relate the ways in which the fishery was studied and managed, discuss the questions still outstanding, and finally draw from the Peruvian experience some advice for studying and managing other anchovy fisheries that may have some similar features.

THE UPWELLING ECOSYSTEM

Upwelling and Primary Production

The rate of upwelling along the coast of Peru varies seasonally with the strength of the southeast trade winds that blow nearly parallel to the coast. During the southern winter (June to September), when the winds are strongest, the upwelling is most vigorous and the zone of cold water along the coast is widest. During spring and summer upwelling slows and the zone of cold water narrows as the winds subside, usually to a minimum in March (Bjerknes, 1961).

In some years an extreme relaxation of the trade winds results in a virtual cessation of upwelling. The zone of cold water disappears along most of the Peruvian coast which is then subjected to tropical conditions causing major disruptions. This event, which is called El Nino, is simply the extreme case since the summer minimum of upwelling. It is not a well defined phenomenon, since the summer minimum can fall anywhere in the whole range of conditions between relatively strong upwelling and almost no upwelling. While the designation of El Ninos is therefore arbitrary in some cases, the most severe occurrences in this century have been roughly periodic, falling 6 to 8 years (or some multiple thereof) apart. Bjerknes (1966) proposed a mechanism of interaction between the oceanic and atmospheric circulations of the Pacific to account for the apparent cycle.

Up to a point, the rate of primary production and the density of phytoplankton vary inversely with the rate of upwelling, being lowest in winter and highest in spring and summer, although low values can also occur at the height of summer when upwelling is very weak. The low rates of primary production observed in winter presumably result from the deeper mixing caused by the strong winds in that season (Guillen, Rojas de Mendiola, and Izaguirre de Rondan, 1971).

Upwelling consists of the emergence from depth of distinct water parcels rather than a steady flow. Parcels well up across a zone extending several kilometers or tens of kilometers from shore, and each parcel is the site of a distinct biological succession as it moves offshore and gradually mixes with surrounding waters (Strickland, Eppley, and Royas de Mendiola, 1969). Succession does not proceed at the same rate in all parcels since plankton growth rates within an upwelled parcel depend on the concentration of organic chelators that sank from the surface layer into the parcel before it welled up (Barber *et al.,* 1971).

Because of the seasonal and annual differences in upwelling strength, and the patchiness of the plankton, the environment occupied by the Peruvian anchoveta is quite variable in both time and space, on both large and small scales. Moreover, its most extreme variations are as yet unpredictable, which will be important in considering the population dynamics of the fish and the performance of the fishery.

Life History of the Anchoveta

On a large scale, the distribution of anchoveta schools varies seasonally as upwelling strength varies. In winter, when the layer of cold upwelled water along the coast is relatively wide and deep, schools are usually small and scattered across a zone extending 200 km or more offshore and at depths to 80 m. In summer the schools are larger and restricted to a much narrower and shallower layer of water whose dimensions depend on the degree to which upwelling weakens. In most summers this layer is around 100 km wide, but in summers of weak upwelling it contracts to 20–40 km, and during severe El Ninos it disappears entirely along much of the coast (Jordan, 1971; Murphy, 1974). In summer the distribution of schools is often very contagious, large expanses of water being nearly devoid of fish while a few small areas contain great numbers of schools in varying proximity (Instituto del Mar del Peru, 1974a).

The catch rates of anchoveta purse seiners fluctuate seasonally as the distribution of schools changes. Fishing success is relatively low in winter, and usually high in summer when the fish are concentrated.

The first fish to approach the coast and concentrate in large schools after the winter dispersion are evidently the spawners, since the spring catches typically consist almost entirely of maturing and spawning fish despite the presence of a large number, even a majority, of immature fish in the population. The recruits produced in the spring spawning, which takes place roughly from August to October, usually first enter the catches in early summer (December or January). A second spawning, variable in strength and timing among years, produces a second smaller recruitment that normally appears in the catches between March and May (Chirinos de Vildoso and Alegre de Haro, 1969). It is not known how many times an individual may spawn each year.

At the time of first vulnerability to capture, and later during the following spring spawning, some recruits apparently school separately from mature fish, since schools caught in summer sometimes consist entirely of recruits (Saetersdal and Valdivia, 1964) and schools caught in spring consist entirely of mature fish. With those exceptions, anchoveta do not school by age, or by sex.

Some spring spawned recruits participate in the spring or summer spawning of the following year (when 1 year old), but their participation is highly variable among years. Clark (1975) found summer spawned recruits do not spawn until the year after (at the age of 2 years less a few months). The oldest fish in the catches are usually around 3 years old (Chirinos de Vildoso and Chuman, 1968) and 17 cm long, although older and larger fish also occur rarely.

Tagging studies (Jordan, 1972) and some anatomical differences (Rojas de Mendiola, 1971) indicate a division of the anchoveta off Peru into two stocks, with a boundary near 15°S, which also marks the transition from the oceanographic regime of northern Chile and southern Peru to the somewhat different regime further north. The southern stock provided 10–15% of Peruvian catches before 1972.

Predators of the Anchoveta

The major known consumers of anchoveta are fish, birds, and sea lions. Other animals such as squid may also feed on anchoveta, but no instances have been observed and reported.

Among the pelagic fish that prey on anchoveta, the most important commercially is the bonito, *Sarda chiliensis.* Annual catches of this fish rose steadily from a few thousand tons in 1940 to 100,000 tons in 1960, and have since fallen by half. Catch per effort has also declined recently, most sharply after the 1965 El Nino (Instituto del Mar del Peru, unpublished figures). It appears that the bonito population has been substantially reduced by fishing.

The fish eating birds that consume anchoveta have a long and colorful history, since their dried excrement, or guano, is a fine fertilizer which has been mined from the island rookeries off and on since Inca times. Partly owning to human activity (including the disruption of breeding by 19th Century operations and the enlargement of breeding grounds by fencing off headlands in this century) and partly to periodic mass mortalities during El Ninos, the size of the bird populations has varied greatly in the last few centuries. In the most recent period, the number of birds fell from an unprecedented maximum of 25 million in 1955 to 6 million after the 1957 El Ninos, recovered rapidly to 18 million in 1963 dropped to 4 million after the 1965 El Ninos, and then increased slowly to 6.5 million just before the 1972 El Ninos, which left between 1 and 2 million survivors (Jordan and Fuentes, 1966; Murphy, 1974).

Because the decline of the bird population is a mirror image of the increase in anchoveta catches during the same period, it has been argued that the fishery inhibited the growth of the bird populations by reducing the abundance of anchoveta (e.g., Ricker, 1970). But the changes in the total numbers of birds have resulted mostly from changes in the numbers of the historically most important species, the guanay, *Phalacrocorax bougainvillei.* This bird is a cormorant that unlike the other species chases fish underwater, including fish trapped in a purse seine, and since fisherman often locate anchoveta schools by sighting birds feeding, it is plausible that the guanay's poor performance in recent years is the result of mortality incidental to fishing operations rather than of scarce prey. In 1973 when anchoveta were certainly scarce but the fishery was closed almost the entire year, the population of birds increased (Instituto del Mar del Peru, 1974b).

The Biological Effects of El Nino

When upwelling ceases and warm oceanic water replaces cold nutrient rich water in the surface layer along the Peruvian coast, the density and productivity of the plankton fall to very low levels. Planktonic and nektonic species from the tropics invade the pelagic zone (Instituto del Mar del Peru, 1972). Anchoveta schools are hard to find near the surface, although dense concentrations may occur in places where some weak or sporadic upwelling persists (Jordan, 1959; Jordan and Fuentes, 1966).

The most conspicuous victims of El Nino are the fish eating birds which routinely suffer a 75% mortality when the anchoveta disappear. Whether the anchoveta or other fish are also subject to extraordinary mortality during El Ninos is unknown. The severe El Ninos and minor disturbances in the summers of 1957, 1963, and 1965 were all followed in the next summer by an extreme scarcity of adult fish in the catches, consistent with a heavy mortality during the disturbances, and Clark (1975) inferred from a study of virtual populations, and the changes in catch composition in 1971 and 1972, that the recruits of 1971 had perished as a group during the 1972 El Nino. On the other hand changes in catch composition could have been the result of some process (e.g., changes in selection according to age by the fishery) other than previous extraordinary mortality, and no masses of dead fish have been observed during or after any of the recent disturbances.

STUDY AND MANAGEMENT OF THE FISHERY

In 1960 when the catch of anchoveta was still growing rapidly, the Peruvian government established the Instituto del Mar del Peru (called the Instituto de Investigaciones de los Recursos Marinos until 1964) to conduct studies of Peru's fish resources and particularly the anchoveta fishery. Since 1960 the Instituto has been advised and assisted in its task of monitoring the fishery and training technical personnel by FAO which under various projects has provided visiting consultants, equipment, and formal instruction as well as resident advisors.

Since its beginning the Instituto has kept monthly records of the anchoveta fishery, including the size, composition, and activity of the fleet as well as the size and composition of the landings (by length, age, sex, and reproductive condition). It has also conducted synoptic surveys of the upwelling zone. Known by the general name EUREKA surveys, these have consisted of synoptic acoustic coverage of large parts of the coastal zone by chartered fishing vessels which in the course of traversing their transects sometimes made test sets to determine stock composition and collected plankton samples. Other surveys have been performed by the Instituto's research vessels.

The monthly fishery records collected by the Instituto served as the basic data for several studies and assessments of the fishery by personnel of the instituto and foreign experts.

Saetersdal, Tsukayama, and Algre (1965) did the first studies on fishing power and standardization of effort. They found that the catch per vessel trip increased with gross vessel tonnage, but that both the slope and intercept of the regression line varied seasonally. In particular, they noted a steep and nearly proportional relationship in months of good fishing, and a less steep and distinctly nonproportional relationship during months of poor fishing. Despite these variations, they recommended gross tonnage as an index of fishing power, and in subsequent assessments fishing effort was computed as the sum of products of gross registered vessel tonnage (GRT) and some measure of fishing time (either months of operation or number of trips).

Boerema *et al.* (1967) concluded from changes in catch per unit effort and catch composition that the fraction of deaths caused by fishing had increased from less than ¼ in 1961 to about ⅔ in 1964. They did not diagnose overfishing, but advised that further increases in effort would not substantially increase and might decrease the catch which was then around 8 million tons per year.

Murphy (1967, 1973), Schaefer (1967, 1970), and Gulland (1968) all fitted various surplus production functions to the records of catch and effort, and found the maximum sustainable yield of stock, to the fishery and the guano birds combined, to be around 10 million metric tons. The same result was obtained with longer series of data by a succession of panels of experts convened later under FAO sponsorship (Ricker, 1970, 1972).

There were other indications that the stock was at or near full exploitation after 1964. Several different computations (Boerema, *et al.,* 1967; Gulland, 1968) showed the fraction of deaths caused by fishing was around 0.5, considered to be the optimum. The composition of the catch in numbers also changed from a preponderance of adults to a preponderance of recruits, which raised fears that the spawning stock was becoming dangerously small.

On the basis of all these results, the government in 1965 imposed a catch quota and thereafter began to close the fishery in certain seasons for the purposes of limiting the total catch and, in summer, postpone for a month or two the capture of recruits. As mentioned earlier, these measures limited the catch without limiting the capacity of the fishing fleet and the processing plants which by 1971 were only about 50% utilized in catching and processing the quota.

In addition to the stock assessments by catch and effort methods cited above, on which the government's regulations were based, two histories of the fishery have been prepared by virtual population methods. Burd and Valdivia reconstructed the population in each month from the catch histories of individual recruit groups, choosing likely values for a constant rate of natural mortality and the rate of fishing mortality in the last month in which fish of a particular group appeared in the catch. Clark (1975) treated the virtual population in each month as an index of population size on the assumption that natural and fishing mortality varied proportionally. Both studies showed that the fishery was strongly selective with respect to age, and that the relative vulnerabilities of different age groups had changed after the 1965 El Nino. Neither study shed any light on the potential yield of the stock or the possible reasons for its collapse in 1972, except for Clark's inference that the El Nino of that year had caused a mass mortality of year old fish.

OUTSTANDING QUESTIONS

The Meaning of the Collected Data

By now there are several fairly long series of data on the anchoveta fishery, but known and suspected biases and errors in the data continue to frustrate attempts to infer confidently from fishery statistics the effects of fishing on the stock. The problems are the following:

(i) The reported landings have been treated as estimates of the total catch. But since small fish are often pulverized and lost in pumping operations at sea and in port, and are often under reported even if they do reach the plants, the reported landings are certainly less than the total catch. The ratio of true catch to reported landings is not known for any period, nor can it be assumed to have been constant when there were large changes in catch composition.

(ii) The length composition of the landings is biased because, for various reasons, small fish were less likely to be sampled than larger ones. The age composition of the landings, which was estimated by subsampling the length sample, shares this bias; in addition, the age data suffer from suspected inaccuracies in the otolith readings on which they are based.

(iii) A more serious problem for the purposes of current assessment and management is that, owing to differences in vulnerability to capture among age groups, the composition of the landings does not reflect the composition of the population. Nor do changes in the composition of the landings necessarily indicate changes in the composition of the stock, since the relative vulnerabilities of different age groups, while often consistent, can vary greatly among seasons and years. These variations are clear enough in virtual population studies, but such studies necessarily follow events by some years.

(iv) The catch per gross registered vessel tonnage (GRT) trip or GRT month has been treated as an index of stock abundance in the anchoveta fishery, but not without grave doubts discussed by Gulland (1968), Murphy (1973), Clark (1975), and the fourth panel of experts convened by FAO and the Instituto del Mar del Peru (Murphy, 1974). It is very likely that the catch per GRT trip is strongly influenced by factors other than total stock abundance. These factors include the areal distribution of the stock (including total area occupied, school size, and contagiousness of distribution), the incidence of vessel saturation, the proportion of the stock unavailable to the fleet, the distance at which the fishermen can detect schools, and the degree of cooperation among vessels. All of these are known or suspected to have varied greatly among seasons and years in Peru. On the other hand, the catch per trip is certainly buffered against changes in stock density, since low catch rates can be at least partly compensated by longer trips. For both reasons, it is doubtful that the accumulated series of catch per effort records can be regarded as an accurate record of changes in stock abundance.

(v) The observations collected during acoustic and plankton surveys are not affected by the peculiarities of the fishery, and in principle could provide unbiased estimates of stock size. In practice, however, it is a large and difficult task to estimate stock size, or even changes in stock size, by counting the eggs in the sea. The Peruvian survey results, and the present knowledge of the anchoveta's spawning habits, are certainly not adequate to the task.

Acoustic survey results probably provide the most trustworthy measures of stock size (Johannesson and Losse, 1973), but even these may be subject to error because of incorrect calibration of the equipment, or changes in the distribution and behavior of anchoveta, or changes in the abundance of other species in the pelagic zone.

Further work on acoustic surveys is now being done by FAO in Peru, and this work offers the best hope for devising a reliable, practical, and timely method of monitoring the abundance of the stock.

The Proper Strategy for Managing the Anchoveta Fishery

In the anchoveta fishery, and most others, the aim of management is to obtain something fairly close to the maximum surplus production by maintaining the stock at some optimum size, which can be achieved by regulating fishing. But surplus production is the difference between growth and recruitment on one hand and natural mortality on the other, and in Peru the determinants of this difference may change greatly in both the short term and the long term in response to factors other than stock size. It is very likely that the rate of natural mortality varies somewhat with oceanographic changes from year to year, and during El Ninos may be heavy, at least among some age groups. Aside from oceanographic effects, the rate of natural mortality has probably decreased since the start of the anchoveta fishery as a result of reductions in the populations of predators (guano birds, bonito, and other food fish). Clark (1975) concluded from a comparison of virtual stock sizes and acoustic estimates in the same months that natural mortality was negligible after 1965 until 1972, although it must have been quite high before the start of the fishing. Despite fairly steady recruitment before 1972, the recruitment failure of that year shows that reproductive success also can change greatly. The summer of 1971–72 may have been a rare exception; on the other hand, while the spawning stock did not decrease and probably increased from 1965 to 1971, the results of plankton surveys during the spring spawnings of those years, for what they are worth, show a steep and persistent decline in egg production (Murphy, 1974); and the recruitment failure of 1972 had already occurred before El Nino set in.

The potential for large changes in the parameters of the anchoveta population independent of stock size does not imply that stock size has no effect. Rather it implies that the effect of stock size depends on environmental and perhaps behavioral factors, so that different stock sizes would be optimum (i.e., most productive) in different conditions. At present, however, the factors other than stock size that influence natural mortality and reproductive success are largely unknown, and until these factors can be identified and predicted, it will not be possible to manage the fishery rationally.

The event of 1971–72 provides a case in point. By March 1972, when the fishery reopened after a 2 month summer closure, it was apparent to the

Instituto del Mar del Peru that there would be little recruitment. The instituto recommended that the fishery remain closed to conserve the spawning stock, but the government allowed the fishery to operate until June, by which time the stock was reduced to a very low level. It seems from this record that the adult stock was simply fished out. On the other hand, the stock was very large during 1971, and during that year the catch was restricted by quota. As a result, a large adult population was present at the start of the 1972 El Nino. If natural mortality did in fact drop close to zero after 1965, the adult stock present in late 1971 may have been substantially larger than at the start of earlier El Ninos, and this excess may have been indirectly responsible in part for the collapse of the stock when the plankton disappeared during the 1972 El Nino. In this case, the collapse of the stock resulted as much from insufficient fishing in 1971 as from excessive fishing in 1972.

To manage the stock properly under all the environmental conditions that occur in Peru, particularly during the next El Nino, the Peruvian authorities would need to be able to predict environmental changes and their effects on the stock. Variations in upwelling strength along the coast of Peru result from large scale changes across the Pacific Ocean, and may soon be predictable from leading indicators elsewhere, which could be monitored by satellites (Miller and Laurs, 1975). Learning the effects of such variations on the stock of anchoveta will, however, require a careful monitoring of the size and composition of the stock under all conditions. Does weak upwelling have any effect on natural mortality? Does the effect differ among age groups (eggs, larvae, juveniles, adults)? Is it density dependent? How do environmental conditions affect spawning activity?

ADVICE FOR A DEVELOPMENT ANCHOVY FISHERY

The doubts and questions that remain in Peru can serve to guide the study and management of anchovy fisheries elsewhere.

The first lesson to be drawn is that while it is essential to collect the basic fisheries data (catch, effort, and catch composition), it is also essential to find out what these data mean. In a purse seine fishery for a species that inhabits a variable environment, catch per effort and catch composition may be heavily influenced by variable factors other than stock size and composition, and these factors will need to be investigated and monitored to make the collected fishery statistics useful for purposes of assessment. This effort will periodically require some independent measure of the size and composition of the stock, e.g., systematic acoustic surveys with test fishing.

A second lesson is that the productivity of the stock may vary greatly, randomly or systematically, with factors other than stock size and composition. In this situation it will not be meaningful to estimate the usual population parameters and relationships from observations made in different periods; the values may have changed, and their averages may be useless or even dangerous for management purposes. Instead, an attempt should be made to relate population performance to environmental conditions as well as stock size from the start, so that eventually the fishery can be managed rationally as environmental conditions change.

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Part III

SCIENTIFIC CONTRIBUTIONS

5—77829

DWARF HAKE OFF THE COAST OF BAJA CALIFORNIA, MEXICO

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ABSTRACT

Dwarf hake found in southern California is compared to *Merluccius productus*, the common hake found along the western coast of the United States, through morphometric measurements, meristic counts, and the electrophoresis of tissue proteins from the eye lens, vitreous humor, and muscle myogens.

Dwarf hake differs significantly from *M. productus* to suggest it may be a separate species and does not interbreed with either *M. productus* or the rarer *M. angustimanus*.

INTRODUCTION

This study was initiated to investigate the possibility of more than one stock of hake living off the coast of California and Baja California, Mexico. *Merluccius productus* is the common hake which spawns from off northern California to the tip of Baja California (Ahlstrom and Counts, 1955; Kramer and Smith, 1970). Ginsburg (1954) indicated the range of *M. angustimanus* extended northward along the west coast of Baja California to Del Mar, California, but Ahlstrom and Counts (1955) found no evidence of eggs or larvae of any species other than *M. productus.*

MacGregor (1971) collected a number of small hake off southern Baja California in January 1970, for fecundity studies. The smallest maturing male he found was 119 mm standard length (SL) and the smallest maturing female was 125 mm SL. All males 129 mm SL and longer and all females 140 mm SL and longer were sexually mature. The size at which these hake were mature was less than half that reported by Best (1963) who found only one mature fish shorter than 400 mm total length (TL). This fish was a female 380 mm TL (about 336 mm SL) with small ovaries filled with maturing eggs.

We obtained 51 frozen specimens from the same sample taken by MacGregor on January 11, 1970, at 26°07' N, 113°07' W. After thawing, all the fish in this sample had a rather red skin color. The red color is not consistent however, and has not been observed in subsequent samples. Perhaps the red color was caused by abrasion during capture as the fish had virtually no scales left because they had to be picked out of over 3,000 lbs (1,360 kg) of pelagic red crabs, *Pleuroncodes planipes,* that were caught in the same trawl. The red color faded to grey-brown when the fish were preserved in formalin.

The age of 56 hake from this and subsequent samples was determined from an examination of otoliths. The mean length at age I was similar to the mean length Best (1963) found for *M. productus,* but age groups II through V were remarkably smaller (Table 1, Figure 1). Of the 393 individual fish which we have identified and measured, the largest was only 305 mm SL and 97% of them were 250 mm SL or less.

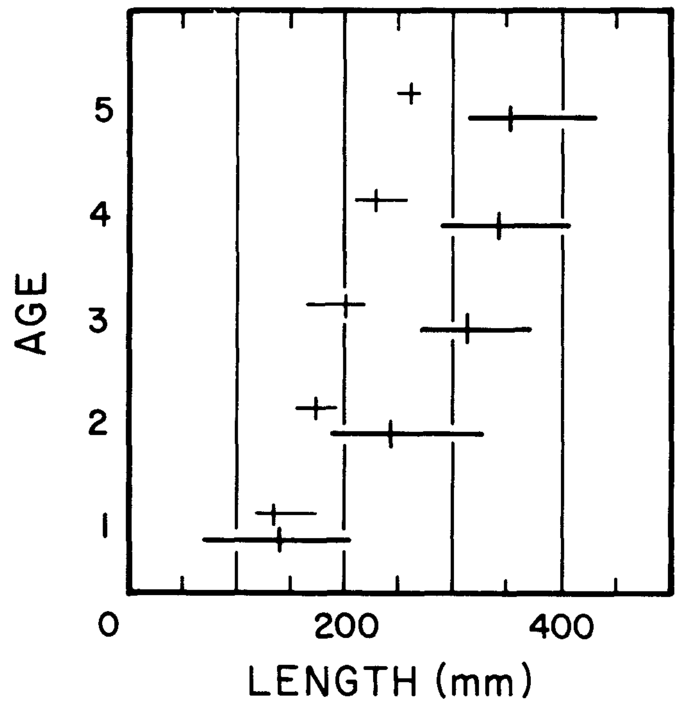

FIGURE 1. Length and age of *M. productus* (heavy bars) from Best (1963) and from dwarf hake (light bars).

From these data it appears that most of these fish are mature at age I and all are mature at age II. According to Best (1963), most *M. productus* are mature at 354 mm SL or age IV with perhaps a few of the larger age III maturing. The extremely small size at first maturity and the very slow growth rate has prompted us to refer to these small hake off southern Baja California as "dwarf hake."

TABLE 1
Mean Standard Lengths of *Merluccius productus* and Dwarf Hake by Age

AGE	Merluccius productus* Number	Mean SL (mm)	Range SL (mm)	Dwarf hake Number	Mean SL (mm)	Range SL (mm)
I	186	137.0	71–203	23	135.9	118–173
II	93	243.3	186–327	11	173.6	156–195
III	91	313.0	274–371	13	203.2	168–220
IV	9	342.2	292–407	7	231.0	214–260
V	10	351.9	318–433	2	261.5	253–270

* From Best (1963).

PROTEIN ELECTROPHORESIS

Electrophoresis of tissue proteins is an important tool for taxonomic studies. The form and structure of protein molecules are relevant sources of phylogenetic information (Sibley, 1962). Species differences in the electrophoretic patterns of muscle myogens of salmonoids were demonstrated by Tsuyuki and Roberts (1963). Tsuyuki et al. (1965) presented evidence for the virtual constancy and species specific nature of muscle myogens.

Electrophoresis of muscle myogens as well as eye lens and vitreous humor proteins was carried out in polyacrylamide gel columns according to the method described by Broome (1963). Muscle myogens of individuals of approximately 50 *M. productus* tested produced patterns similar to each other but different from the patterns observed from 30 dwarf hake (Figure 2). Proteins from these and other tissues were also electrophoresed in starch gel and in polyacrylamide gel slabs, and in all cases *M. productus* differed from the dwarf hake.

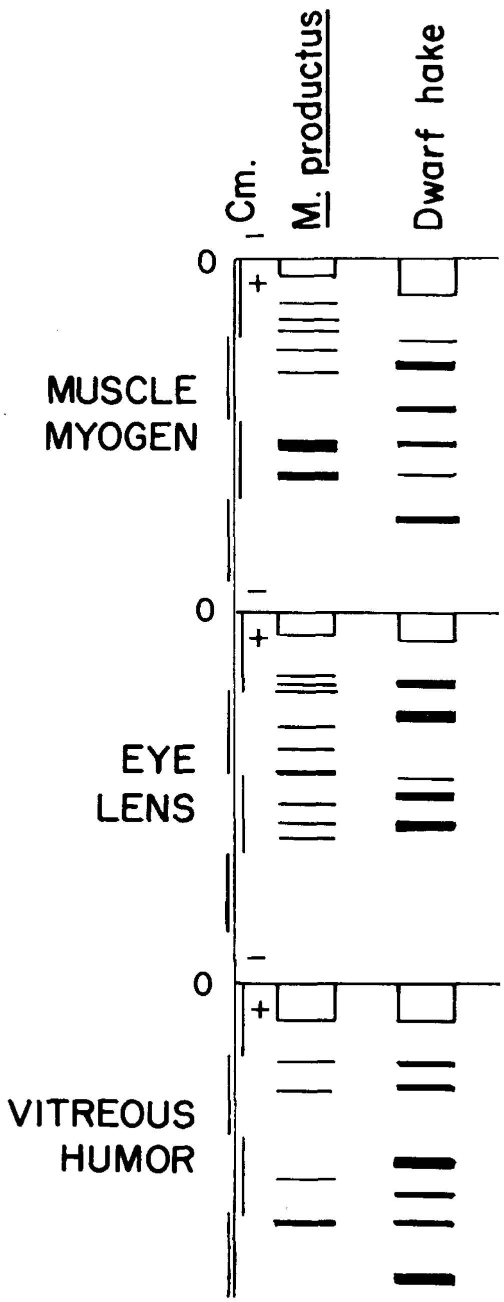

FIGURE 2. Protein patterns produced by electrophoresis in polyacrylamide-gel columns of tissues from *M. productus* and dwarf hake.

MORPHOMETRICS

We chose meristic and morphometric characters for this study according to those indicated by Ginsburg (1954) to be diagnostic for *M. productus* and *M. angustimanus.* All counts and measurements were made as he described.

Ginsburg (1954) indicated allometric growth for head length and pectoral length. Our data indicated essentially isometric growth for all the morphometric characters we examined except there did appear to be slight allometry in the snout to tip of pectoral fin for dwarf hake less than 100 mm SL (Figure 3). However, the calculated mean length of snout to tip of pectoral fin for all dwarf hake less than 100 mm SL was 52.59% SL and 52.56% SL for all those over 100 mm SL; the two are not significantly different (df = 230, F = 0.0095 ns).

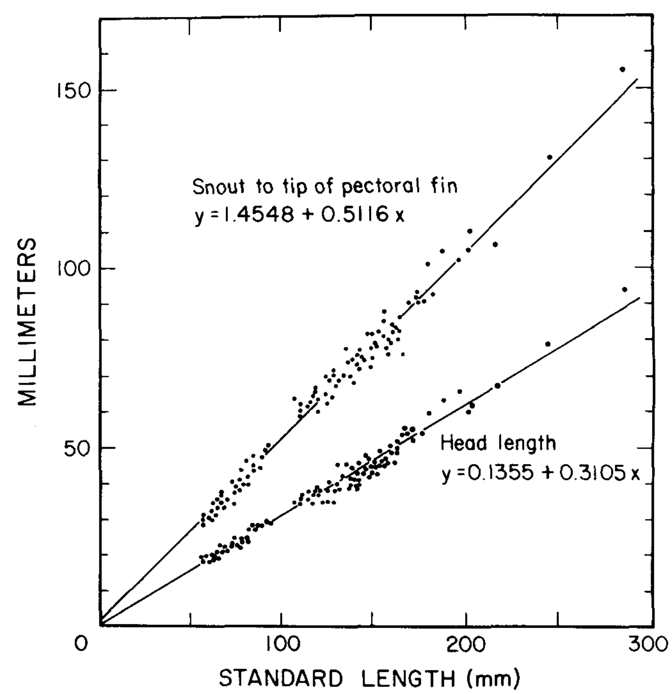

FIGURE 3. Snout to tip of pectoral fin and head length in relation to standard length for dwarf hake.

The morphometric measurements are expressed as percent of standard length (Table 2, Figure 4) and are graphically compared, as detailed by Hubbs and Hubbs (1953). The differences in the means between dwarf hake and *M. productus* are highly significant at the 0.01 level for all seven characters measured (Table 3), with dwarf hake having the largest percent of standard length for all characters.

TABLE 2

Morphometric Measurements of Dwarf Hake and *Merluccius productus* Expressed as Percent of Standard Length

Merluccius productus	N	Mean % SL	Range % SL	Standard deviation	Standard error
Snout to tip of pectoral fin	76	48.58	43.86–52.44	2.2945	0.2646
Pectoral fin length	76	19.67	11.59–23.08	2.0715	0.2376
Head length	76	28.76	25.64–33.33	1.3361	0.1498
Snout length	76	9.90	7.41–12.37	0.9761	0.1073
Maxillary length	76	13.54	10.77–17.46	1.2542	0.1438
Snout to anal fin insertion	76	45.01	37.70–50.77	1.8791	0.2243
Eye diameter	76	5.92	4.24–8.82	0.7395	0.0848
Dwarf hake					
Snout to tip of pectoral fin	231	52.57	45.78–59.26	2.3228	0.1466
Pectoral fin length	231	21.46	15.71–25.93	1.7453	0.1148
Head length	231	31.25	26.57–35.48	1.8356	0.1207
Snout length	231	10.41	8.55–13.16	0.9379	0.0617
Maxillary length	231	14.92	11.46–19.35	1.4898	0.0980
Snout to anal fin insertion	231	48.09	44.37–54.39	1.7690	0.1163
Eye diameter	231	6.58	5.33–7.94	0.5461	0.0359

fin ray counts were made from x-ray plates, gill raker counts were made directly from the fish. In nearly all cases the raker count was made from the first gill arch on the left side, in a few the left side was damaged so the right side was used. Only well formed rakers were counted, tubercles were not.

Ginsburg suggested that in some hake there might be a slight growth change in gill raker count. Since the mean standard length of our *M. productus* (218.5 mm SL) was almost twice that of dwarf hake (114.3 mm SL) we tested for growth changes. The mean number of gill rakers on the first gill arch was calculated for both species segregated into 100 mm SL size groups (Table 4). The differences in the means between size groups within either species were tested and found to be not significant at the 0.5 level.

TABLE 3

Comparison of the Means of the Morphometric Characters for Dwarf Hake and *Merluccius productus*

	M. productus % SL	Dwarf hake % SL	Difference % SL	df	F
Snout to tip of pectoral fin	48.58	52.57	3.99	306	169.03
Pectoral fin length	19.67	21.46	1.79	306	53.80
Head length	28.76	31.25	2.49	306	126.76
Snout length	9.90	10.41	0.51	306	19.63
Maxillary length	13.54	14.92	1.38	306	55.69
Snout to anal fin insertion	45.01	48.09	3.08	306	155.66
Eye diameter	5.92	6.58	0.66	306	69.33

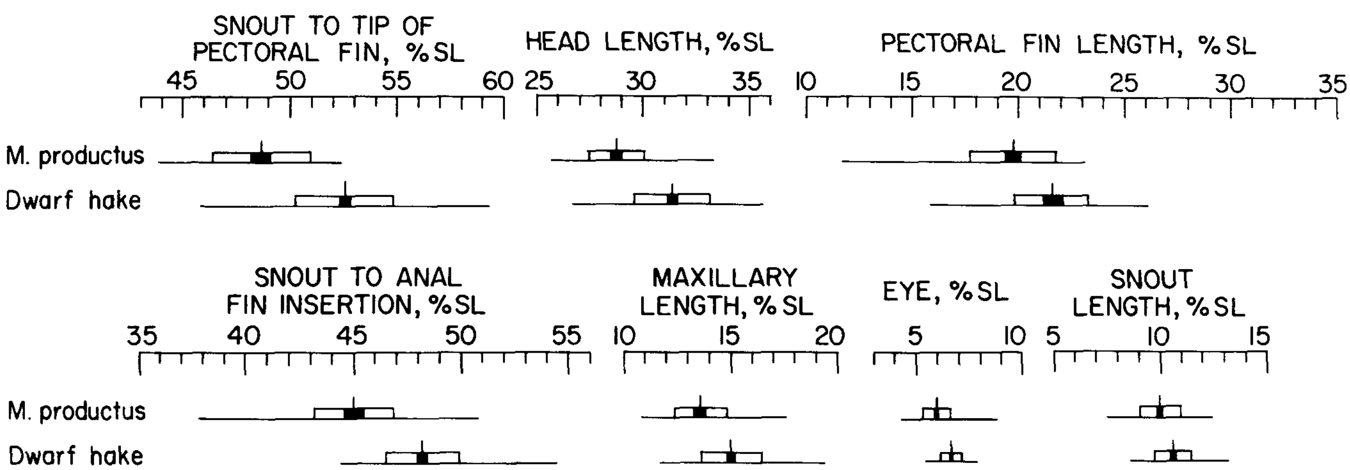

FIGURE 4. Graphic comparisons of morphometric data for *M. productus* and dwarf hake (see Table 1). The range is shown by the horizontal line and the mean by the vertical line. The solid bar represents two standard errors of the mean on either side of the mean. The open bar plus one-half of the solid bar represents one standard deviation on either side of the mean. Graphic method from Hubbs and Hubbs (1953).

Although these differences are all significant, the degree of overlap of each is so great (Figure 4) that none of the characters is very useful for field identification of individual fish; however, the combination of longer head and fin lengths and greater distance from snout to anal fin insertion gives the dwarf hake a more slender appearance than *M. productus.* In all the specimens we examined, both dwarf hake and *M. productus* had truncate or slightly emarginate caudals.

MERISTICS

In addition to the number of anal fin rays, second dorsal fin rays, and gill rakers on the first gill arch which Ginsburg (1954) indicated as the chief characters which separate *M. productus* from *M. angustimanus,* we counted vertebrae. Vertebral and

TABLE 4

Mean Numbers of Gill Rakers on the First Gill Arch of *Merluccius productus* and Dwarf Hake Segregated into 100 mm Size Groups

	Standard length 0–99 mm		Standard length 100–199 mm		Standard length over 200 mm	
	N	Mean	N	Mean	N	Mean
M. productus	0	—	37	19.54	62	19.37
Dwarf hake	95	17.26	131	17.36	5	17.20

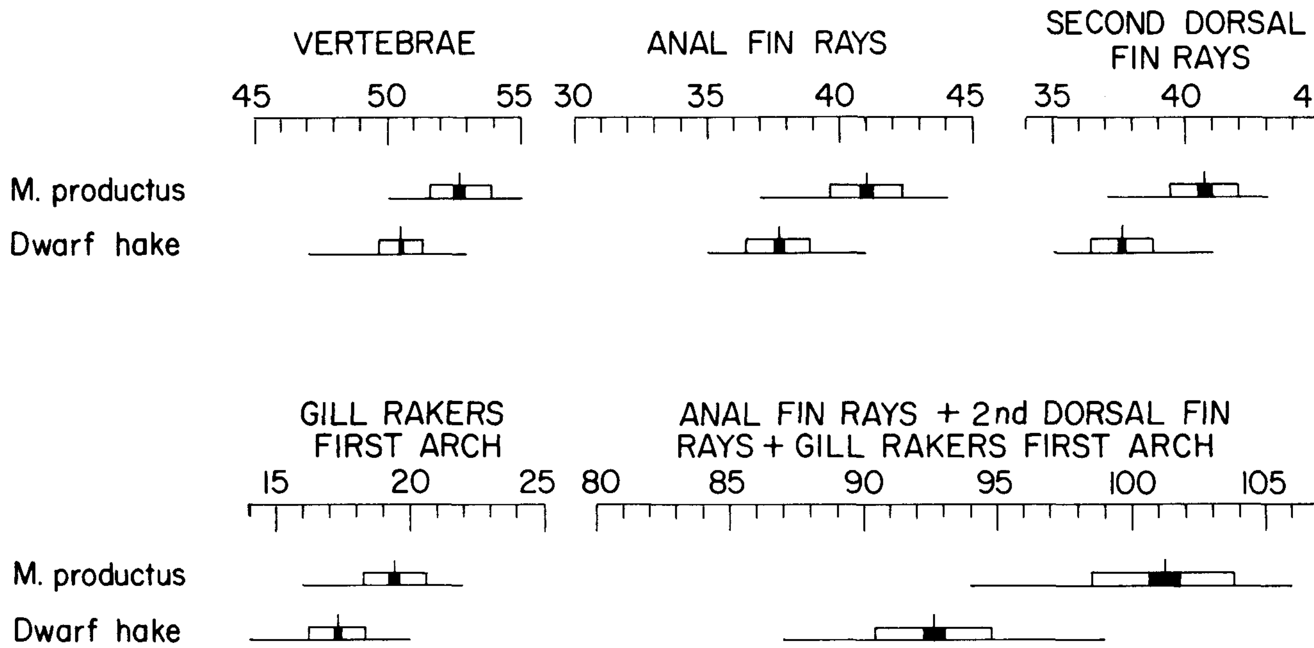

FIGURE 5. Graphic comparisons of meristic data for *M. productus* and dwarf hake (see Table 4). The range is shown by the horizontal line and the mean by the vertical line. The solid bar represents two standard errors of the mean on either side of the mean. The open bar plus one-half of the solid bar represents one standard deviation on either side of the mean. Graphic method from Hubbs and Hubbs (1953).

TABLE 5

Meristic Counts for *Merluccius productus* and Dwarf Hake

	N	Mean	Range	Standard deviation	Standard error
Merluccius productus					
Number of vertebrae	94	52.73	50–55	1.1563	0.1193
Anal fin rays	91	41.02	37–44	1.3497	0.1415
Second dorsal fin rays	93	40.69	37–43	1.3265	0.1376
Gill rakers upper limb	105	4.30	3–5	0.5904	0.0576
Gill rakers lower limb	105	15.10	13–18	0.9085	0.0887
Total gill rakers first arch	105	19.41	16–22	1.1985	0.1170
Anal + 2nd dorsal + total rakers	91	101.20	94–106	2.6759	0.2805
Dwarf hake					
Number of vertebrae	210	50.52	47–53	0.7959	0.0549
Anal fin rays	192	37.71	35–41	1.1794	0.0851
Second dorsal fin rays	175	37.58	35–41	1.2004	0.0907
Gill rakers upper limb	231	3.90	3–5	0.4913	0.0323
Gill rakers lower limb	231	13.43	11–16	0.8145	0.0536
Total gill rakers first arch	231	17.32	14–20	1.0767	0.0708
Anal + 2nd dorsal + total rakers	171	92.67	87–99	2.2566	0.1726

Dwarf hake have fewer vertebrae, anal fin rays, second dorsal fin rays, and gill rakers than *M. productus* (Table 5, Figure 5). The differences in the means for all of these characters are highly significant at the 0.01 level (Table 6). There is considerable overlap in the counts so no single character is very useful for field identification of individual fish; however, the sum of three meristic characters which are readily counted in the field, anal rays, second dorsal rays, and gill rakers on the

TABLE 6

Comparison of the Means of the Meristic Characters for *Merluccius productus* and Dwarf Hake

	M. productus	Dwarf red hake	Difference	df	F
Number of vertebrae	52.73	50.52	2.21	302	373.07
Anal fin rays	41.02	37.71	3.31	281	441.84
Second dorsal fin rays	40.69	37.58	3.11	266	381.08
Gill rakers upper limb	4.30	3.90	0.40	334	41.50
Gill rakers lower limb	15.10	13.43	1.67	334	287.23
Total gill rakers first arch	19.41	17.32	2.09	334	246.81
Anal + 2nd dorsal + total rakers	101.20	92.67	8.53	260	727.82

TABLE 7

Meristic Data From Samples Arranged From North to South

Sample number *	Latitude	Vertebrae		Anal rays		Second dorsal rays		Gill rakers		Anal + second dorsal + rakers	
		N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
1	38–34°N	25	53.04	23	41.35	25	41.24	25	19.64	23	102.04
2	33–30°N	25	53.08	23	41.17	25	40.92	25	19.80	23	102.00
3	29°N	25	52.52	23	40.78	25	40.20	25	19.60	23	100.96
4	27°N	25	50.76	23	38.22	25	37.52	25	17.24	23	92.43
5	26°N	25	50.72	23	37.00	25	37.24	25	17.64	23	91.83
6	25°N	25	50.56	23	37.74	25	37.80	25	17.12	23	92.65

* Samples 1, 2, and 3 are *Merluccius productus;* samples 4, 5, and 6 are dwarf hake.

first arch, is a good tool. If we had arbitrarily separated all the hake in our samples into two groups with this combination character, those with a sum of 96 or less as dwarf hake and those with 97 or more as *M. productus,* we would have misclassified only 6 *M. productus* out of 91 and only 8 dwarf hake out of 171, for a total identification error of 5.34%.

Frederick H. Berry,[1] a National Marine Fisheries Service (NMFS) Fishery Biologist formerly at this laboratory, proposed in an unpublished manuscript that all the eastern Pacific hake from Alaska to southern Chile were represented by two species. He concluded that *M. polylepis* from southern Chile was a valid species and the other four forms, *M. productus, M. angustimanus, M. gayi gayi,* and *M. gayi peruanus,* were a single species, *M. gayi.* He postulated that the meristic and morphometric characters which had been used to separate the last four merely reflected environmentally induced differences which varied clinally over the geographic range.

Our data did not indicate such a cline; instead, we found a distinct break in both morphometric and meristic characters in the area off Punta Eugenio, Baja California, or about 28° N. We can demonstrate this by using the method described by Rothschild (1963) for graphic comparisons of meristic data.

The procedure requires samples of equal size for comparison of any single character; therefore, after we arranged our samples in geographic order from north to south, we selected randomly from the larger number of fish to produce sample sizes equal to the smallest. We counted the mean number of vertebrae, anal fin rays, second dorsal fin rays, gill rakers on the first gill arch, and the combination of anal rays plus second dorsal rays plus gill rakers for each sample arranged from north to south (Table 7).

An analysis of variance was performed for each of these characters and in all cases F was found to be highly significant at the 0.01 level (Table 8).

The ranges, means, and one ω interval on each side of the means were plotted (Figure 6). ω is a single valued parameter for judging the significance of multiple comparisons of the observed differences using Tukey's procedure (Steele and Torrie, 1960)

[1] Berry, Frederick H. (MS) Taxonomy of the eastern Pacific hake *Merluccius.*

TABLE 8

Analysis of Variance for Meristic Data From Samples *

	df among samples	df within samples	F
Number of vertebrae	5	144	48.60
Anal fin rays	5	132	65.95
Second dorsal fin rays	5	144	63.67
Total gill rakers first gill arch	5	144	35.15
Anal + 2nd dorsal + total rakers	5	132	145.81

* See Table 7.

for $\alpha = 0.01$. A mean beyond one ω interval on either side of the mean of another sample is significantly different from that sample at the 1% level. For all 5 meristic characters tested, there is a sharp break between samples 3 and 4 or at about 28° N, which does not fit Berry's clinal theory.

The morphometric and meristic data, the size at first maturity, and the differences in tissue proteins

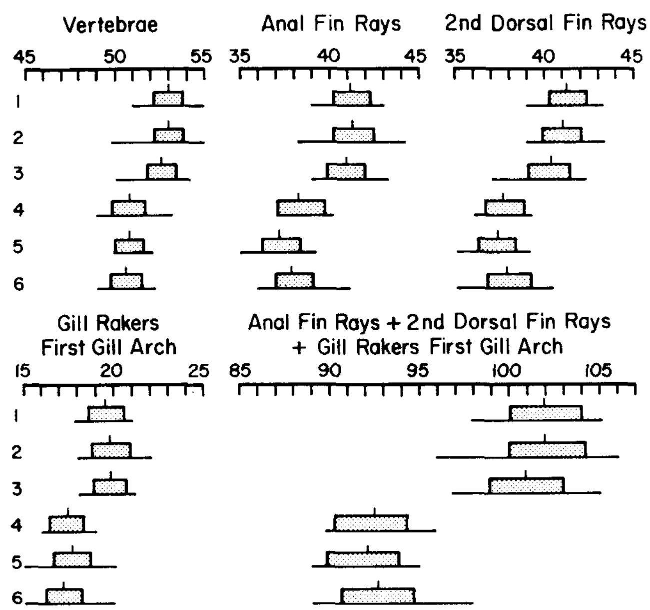

FIGURE 6. Graphic comparisons of meristic data of samples arranged from north to south. Samples 1, 2, and 3 are *M. productus,* samples 4, 5, and 6 are dwarf hake. The horizontal line represents the range, the vertical line the mean, and the solid bar represents one on either side of the mean. Graphic method from Rothschild (1963).

are convincing evidence that the dwarf hake is a species distinct from *M. productus.* However, we are not convinced that the dwarf hake is *M. angustimanus.* We have examined the specimens from off Del Mar, California, and Santo Domingo, Baja California, that Ginsburg (1954) used in his description of *M. angustimanus* and find that they fit our description of dwarf hake. Dwarf hake do not quite fit the original description of *M. angustimanus* by Garman (1899). He found 110 lateral line scales, and although we find it very difficult to get an accurate count on our specimens, the range is much higher, 125 to 150, with an average around 135. Garman's illustration and description indicates extremely long pectoral fins reaching to the fifth anal ray or beyond. Dwarf hake have relatively long pectorals but they seldom reach to the fifth anal ray and frequently do not even reach to the anal fin insertion. Garman did not count vertebrae, but C. Mathews [2] (MS) found from 45 to 49 vertebrae with a mean of only 47.02 for *M. angustimanus* from the Gulf of California; dwarf hake have from 47 to 53 vertebrae with a mean of 50.52. Out of the 83 *M. angustimanus* Mathews examined, only 2 had more than 48 vertebrae, and out of 210 dwarf hake, we found only 3 with less than 49. To adequately compare dwarf hake and *M. angustimanus* we would need to obtain fresh *M. angustimanus* from Panama suitable for electrophoresis; a series of specimens from which to take counts and measurements, and we would also need to examine Garman's type specimen, which is beyond the original scope of this paper.

CONCLUSIONS

1. There are two stocks of hake off the coast of Baja California, Mexico; *M. productus* to the north and dwarf hake to the south. The primary division between the two stocks is in the area of Sebastian Viscaino Bay or about 28° N, with some overlap in the range of the two. One dwarf hake was taken off Del Mar, California, 33° N, and one sample of 4 *M. productus* was taken off San Hipolito Bay, 27° N.

2. Dwarf hake and *M. productus* are approximately the same size at age I but subsequent growth of dwarf hake is much slower than in *M. productus.* The maximum observed size of dwarf hake is 305 mm SL. The maximum reported size of *M. productus* (Best, 1963) is 800 mm TL (707 mm SL).

3. Most dwarf hake are mature at age I, and all are mature at age II. Most *M. productus* mature at age IV with perhaps a few of the larger age III mature.

4. Dwarf hake are distinctly different from *M. productus* in electrophoretic patterns produced from proteins of the eye lens, vitreous humor, and muscle.

5. Morphometrically, dwarf hake differ from *M. productus* by having longer heads, longer pectoral fins, larger eyes, longer snouts, greater distance from snout to tip of pectoral fin, and greater distance from snout to anal fin insertion.

6. Meristically, dwarf hake have fewer vertebrae, anal fin rays, second dorsal fin rays, and gill rakers than *M. productus.*

[2] Mathews, C. (MS) Meristic studies of the Gulf of California hake, with description of a new species.

ACKNOWLEDGMENTS

We thank Pat Arasmith for her technical assistance, and Geoffrey Moser, both from the National Marine Fisheries Service, La Jolla, California, for his review and valuable comments and to Richard Rosenblatt, Scripps Institution of Oceanography, for permitting us to examine hake specimens from the Scripps collection.

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RECURRENT GROUP ANALYSIS OF HYPERIID AMPHIPODS FROM THE NORTH PACIFIC CENTRAL GYRE *

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ABSTRACT

A preliminary analysis of the hyperiid amphipod assemblage of the North Pacific Central Gyre is presented. "Recurrent group" analysis indicates the existence of such amphipod groups in the gyre. These groups frequently include congeners, a result unexpected in light of the "competitive exclusion" principle. More detailed analysis indicates how these congeners, although occurring together, may be dividing up space differently and so coexisting.

INTRODUCTION

This is a report of preliminary results of a detailed analysis of the hyperiid amphipod assemblage of the North Pacific Central Gyre community. The research is part of an intensive, long term investigation, under the leadership of Dr. J. A. McGowan, into the structure ("what lives there and how are the animals distributed in time and space?") and function ("how do the organisms interact, and what are the control mechanisms of the area's biology?") of the gyral community.

The North Pacific Central Gyre was selected as an appropriate site for investigating a pelagic ecosystem because of a-priori reasons to feel that it is a genuine ecosystem in the classical sense (Odum, 1959): a nearly closed system of highly co-evolved organisms, regulated by in-situ processes. The major circulation patterns of the Pacific seem to have remained essentially unchanged since at least the pliocene (Riedel and Funnell, 1964), and the gyre has therefore had a long period of evolution in which to fine tune its internal workings and arrive at some sort of long-term stability. The gyre is a much better approximation to an ideal "closed" system than are most oceanic study areas; at least it is not beset by massive horizontal advection, and it gives indications that its biology is controlled by in-situ processes rather than advective events (McGowan, 1974).

The first step in analysis of any system should be to determine "What is out there and where is it located?" This question is the basis for my current work on gyral hyperiids. Other aspects of gyral ecology are under intensive investigation: copepods (McGowan and Walker, in prep.), microzooplankton (Beers, Reid, and Stewart, 1975), chaetognaths (Lyons, in prep.), nutrients (Eppley et al. 1973), phytoplankton (Venrick, 1971, 1972), mesopelagic fishes (Barnett, 1975), physical microstructure (Gregg and Cox, 1972), primary productivity (Eppley et al. 1973), patchiness (Haury, 1973; Wiebe, 1970, 1971), and other parameters.

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METHODS

Over the last decade a large number of month long cruises have been made by Scripps Institution of Oceanography to 28° N, 155° W, about 600 km north of Oahu; this site was selected in expectation that is would be representative of most of the gyre. The cruises cover most seasons of the year, and all used the same central sampling plan and equipment in order to permit direct comparisons. Most sampling procedures are done in intensive replication. Cruises involved with this investigation of the North Pacific Central Gyre are: Climax I (Sept 1968), Climax IIA (Aug 1969), Aries IX (Sept 1971), Cato I (June 1972), Southtow XIII (Feb 1973), Tasaday I (June 1973), Tasaday II (July 1973), Tasaday III (Aug 1973), and Tasaday XI (Mar 1974).

My data are from cruise Climax I during which two parachute drogues were deployed at ten m depths about 10 km apart and a ten day series of around-the-clock depth stratified bongo net (S.I.O. 1966) tows was made between them (see S.I.O. 1974 for drogue tracks and details of sampling plan). Six depth ranges were covered (0–25, 25–50, 50–75, 75–100, 100–350, and 350–600 m); depths were monitored using a Benthos time-depth recorder. Nets were opened at the bottom of a depth range, fished obliquely upwards, and closed at the top of the range; nets were closed automatically by a frame-mounted flowmeter after fishing 400 m^3 per side. All nets were 505 u mesh with 333 u cod ends, and all tows were at a nominal 2½ kts.

I have identified and counted all hyperiid amphipods from 79 of these Climax I bongo samples (one sample = one side of a bongo frame). For the present analysis all samples were designated either "day" (0600–1900) or "night" (2000–0500). All "day" samples taken at the same depth were considered replicates regardless of date taken, as were all "night" samples at a given depth.

RESULTS AND DISCUSSION

Structural Overview of the Hyperiid Assemblage

From analyses of zooplankton catches made in the same area with the Isaacs-Kidd plankton trawl (505 u mesh, 3 m x 3 m mouth), we know that hyperiids rank fifth in overall numerical abundance of major taxa in the gyre (Table 1). They comprise some 5–7% of total individuals in the macrozooplankton (i.e., zooplankton caught by 505 u nets) and are therefore a major portion of the community.

TABLE 1.

Overall Rank-Order of Numerical Abundance of Major Taxa in the North Pacific Central Gyre *

1. COPEPODS	7. "jellies"
2. EUPHAUSIIDS	8. PTEROPODS
3. CHAETOGNATHS	9. DECAPODS
4. OSTRACODS	10. FISH LARVAE
5. AMPHIPODS	11. HETEROPODS
6. THALIACIANS	12. POLYCHAETES

* From samples collected with the Isaacs-Kidd plankton trawl (505 u mesh, 3 m x 3 m mouth) in open oblique nighttime hauls from 0–300 m at 28° N, 155° W.

I have found representatives of over half (13 of 21) the world's hyperiid families, over half (42 of 71) the world's genera, and about ⅓ of the world's species (83 of approximately 300) in these samples. Lumping counts from all samples, a total of 14,851 individuals was taken, with overall abundances ranging from 1 to 3695 individuals per species. Individual samples contained from 1 to 38 species and from 1 to 658 individuals.

Wiebe (1971) studied the ability to accurately rank species (in terms of numerical abundance) using samples consisting of varying numbers of individuals. Accuracy of ranking is a function not only of sample size but also of the underlying community structure, especially degree of dominance and patchiness. However, his results suggest that with nearly 15,000 animals we can be fairly certain of the first 10 to 15 ranks. If we deal mainly with the top 10 to 15 hyperiid species, we are including 75–85% of the total individuals (Figure 1), and what is happening within that group is basically "what is going on among amphipods in general."

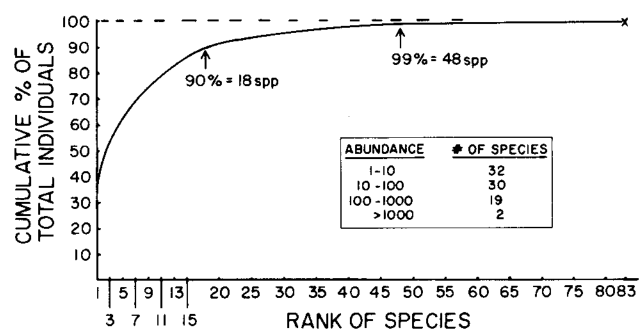

FIGURE 1. Cumulative percentage curve of hyperiid amphipod fauna from the North Pacific Central Gyre; totals for 79 bongo net tows are used. Grand total individuals = 14,851.

Relationships Among Hyperiid Species

As previously stated, this community has had a long time to evolutionarily fine tune its internal workings. The series of cruises listed above has shown that many factors, from primary productivity to rank order of abundance (abbreviated ROA) of species within major taxa, tend to be relatively constant within the gyre. Therefore, when we try to examine the internal workings of any portion of the community we are probably looking for subtle shifts and changes in internal structure. We must at present use rather unsubtle sampling (bongo net tows integrate over a horizontal distance of hundreds of meters) and statistical techniques (generally rank-order statistics). Because we must seek out subtle effects with unsubtle techniques, small changes or non-spectacular results (which might otherwise be viewed with skepticism) may have to be accepted as being true indicators of what is actually going on within the community.

In general, species (particularly small planktonic organisms) must encounter one another in order to interact, and it is in the interactions of species that one may seek control mechanisms for the ecosystem if it is in fact regulated by in-situ processes. An appropriate question is, then, "what species occur together?" If we know this, then we may further examine those sets of co-occurring species, hoping to answer such questions as "How do similar species manage to co-exist in an apparently physically unstructured environment?"

To aid in sorting out such groups of co-occurring species from a large mass of data (here 83 species and 79 samples), we have a technique available called "recurrent group analysis," Regroup for short (Fager, 1957). The object of this technique is to locate and identify groups of species which are commonly part of one anothers' environment ("part of" in the sense of being caught in the same bongo tow).

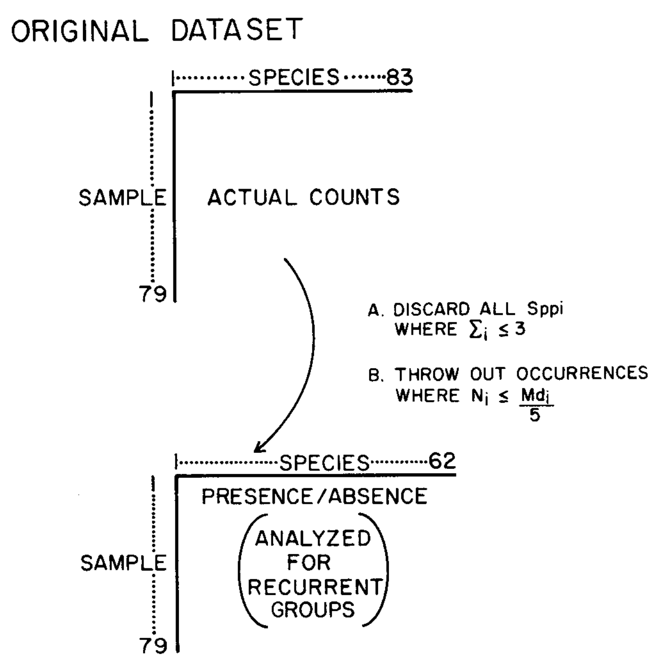

FIGURE 2. Original raw-data matrix of hyperiid species and their occurrences by samples, and the data matrix as reduced for recurrent group analysis.

Regroup calculates an index of affinity (ranging from 0.0 to 1.0) for every possible species pair. This index is based on presence and absence data arranged by sample (i.e., what species occurred in what samples; Figure 2). If we assume as a null hypothesis that species co-occur purely at random (i.e. that there is no pattern to nature), program AFFIN (Fager, MS) can calculate probability levels for affinity indices. For instance, the probability of "affinity index of sp. X and sp. Y being greater than 0.70 due strictly to chance" is less than .002 (Figure 3). Probability levels ("P") for indices of affinity depend on the number of occurrences for each species, and must be calculated anew for each new set of data.

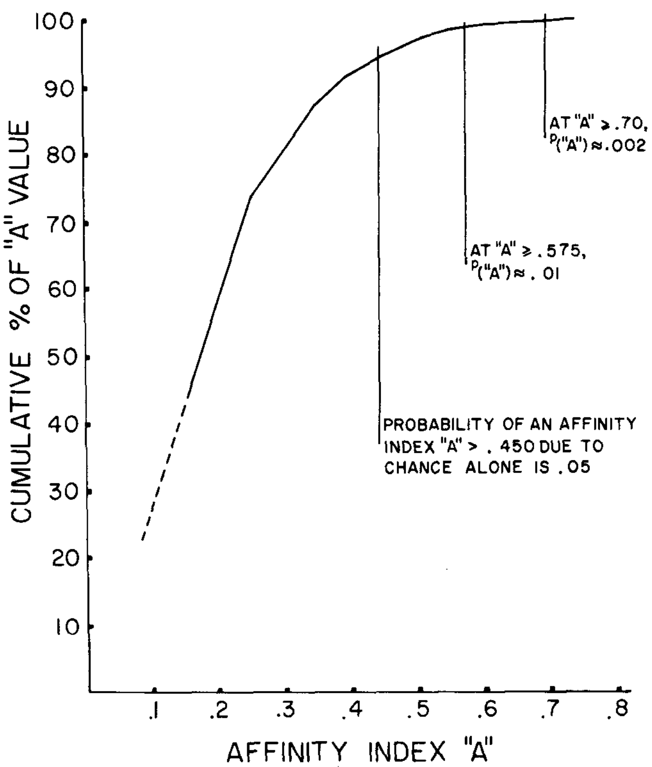

FIGURE 3. Cumulative percentage curve for indices of affinity assuming random associations of species in samples. Generated from the reduced data matrix of Figure 2.

Regroup forms the largest possible group of species within which all species have an affinity index greater than, say, 0.575 (P about .01 for present data) for one another. This represents a stringent grouping criterion; each species must have a high affinity index for all others in the group in order to be included. The idea is to sort out closely knit groups of species, (recurrent groups), wherein the rate of co-occurrence is much larger than can be expected due to chance alone. However, this does not require that all members of a group be present whenever any one member is present, merely that the rate of such occurrences be very high. Once the largest possible such group has been formed, it is removed from the analysis and the Regroup procedure applied to the remaining species to check for the existence of other groups. In Regroup, a species not included in a group may still be an "affiliate" of the group if that species has affinities only with group members.

It is unreasonable to include some species in such an analysis, particularly very rare species; all species for which the total caught was three or fewer were eliminated (Figure 2). In addition, contamination, minor net leakage, and so forth call into suspicion very low occurrences of otherwise common animals. To adjust for such problems, all species counts where "number of sp. X caught" was less than "20% of the median for sp. X" were reduced to zero. This cleans up the data considerably and allows us to seek clear cut patterns.

We do in fact get such recurrent groups among the hyperiids. Regroup analysis of the final data matrix (Figure 2) produced six groups, containing from two to seven members per group (Table 2). These groups are remarkably clearcut. In Regroup analysis of copepod data from samples taken during the same Bongo series, most groups had affiliates as well: no such affiliates were found for any amphipod group.

TABLE 2

Membership of Groups as Determined by Recurrent Group Analysis

Group #	Species ID #	Overall ROA*	Species	
I	6	11th	*Brachyscelus crusculum*	
	20	16th	*Hyperietta luzoni*	CONGENERS
	23	10th	*Hyperietta stephenseni*	CONGENERS
	24	2nd	*Hyperietta vosseleri*	CONGENERS
	29	5th	*Lestrigonus bengalensis*	
	35	18th	*Lycaeopsis themistoides*	
	52	13th	*Phronimopsis spinifera*	
II	7	12th	*Anchylomera blossevillei*	
	13	9th	*Eupronoe armata*	CONGENERS
	15	4th	*Eupronoe sp "A"*	CONGENERS
	26	3rd	Hyperioides sibaginis	
III	2	22nd	*Amphithyrus bispinosus*	
	32	17th	*Lestrigonus schizogeneios*	
	44	8th	*Paratyphis parvus*	
IV	53	14th	*Phrosina semilunata*	CONFAMILIALS
	56	1st	*Primno rectimanus*	CONFAMILIALS
V	25	7th	*Hyperioides longipes*	
	61	15th	*Scina sp "A"*	
VI	60	6th	*Scina sp "B"*	
	76	25th	*Vibilia armata*	

* Rank-order of numerical abundance (for lumped counts from 79 samples).

The hyperiid groups did not necessarily consist only of very high-ranked species, nor did all the high-ranked species group together. For instance, Group I includes species whose overall ROA were 11, 16, 10, 2, 5, 18, and 13 (Table 2). Group II included ROAs 12, 9, 4, and 3. The most common species was *Primno rectimanus*[1], which grouped in Group IV. Group IV consists of only two species, the other of which is *Phrosina semilunata:* these two species are confamilial and quite similar morphologically.

The three most abundant species fell into different groups. There is a tendency for at least some members of each group to be close relatives. Group I includes three very similar congeners, Group II includes a pair of very similar congeners, and Group IV consists of similar confamilials (the only two species of that family found in the gyre). It is frequently the case that morphological similarity implies functional similarity. If this is true for hyperiids, a tendency for similar species to occur together is disturbing, for ecological theory states that two species cannot do overly similar things at the same place and time or one will be eliminated in the resultant competition. These groups therefore warrant closer examination.

TABLE 3

Overall Rank-Orders of Abundances by Species within Depth*

Depth	Species ID # (Group I only) 6	20	23	24	29	35	52
A) Day							
0–25 m	2	4	3	5	1	6	7
25–50	6½	6½	2	1	3½	5	3½
50–75	4½	6	2	1	3	7	4½
75–100	5	2	3½	1	7	6	3½
100–350	5	6	2	3	4	7	1
B) Night							
0–25 m	2	6	5	1	3	4	7
25–50	4½	4½	3	1	2	6	7
50–75	7	4	5	1	2	6	3
75–100	6	2	5	1	4	7	3
100–350	5	4	2	1	7	6	3

* Ranks were obtained by summing all replicates at a time/depth, and ranking those species-sums within the time/depth. Numbers of replicates are given in Table 4.

Because it is the largest group, I will deal only with Group I for detailed analysis. The least sensitive question one might ask is, "Does the group as a whole exhibit a tendency towards internal ROA stability across depths?" This is really asking, "Did Regroup select a batch of species, based on presence/absence, which appears to have even stronger internal structure?" The answer is 'yes' for Group I for both day and night. Using the Kendall Concordance ("W") test for five sets of seven ranks (Table 3) to check the null hypothesis "there is no agreement over depths as to ROA within Group I", we must reject the hypothesis for both day ($W = .414$, $p \leq .05$) and night ($W = .485$, $p \leq .01$). Despite some impressive changes in within-group ROA of individual species from depth to depth (e.g., during the day, species #29 is ROA 1 at the surface but ROA 7 at 75–100 m) there is an overall significant ($p < .05$) agreement as to ROA.

[1] *Primno rectimanus = Primno latreilleri.*

A more detailed question is to ask whether there is repeatability of intragroup ROA at a given time of day and depth. This may again be checked using Kendall Concordance: the null hypothesis is "there is no agreement between replicates at a time and depth as to rank order of abundance of Group I species." There is very highly significant ($p < .01$) agreement between replicates at each time and depth (Table 4), and we reject the null hypothesis for all times and depths. In other words, the "replicates" at a time and depth, which often include samples taken on different dates within the 10-day sampling period, do in fact appear to be replicates of a constant condition.

TABLE 4

Analysis of Group I for Agreement between Replicates as to Rank-Order of Abundance at a Time/Depth

Depth	Day n*	W*	P*	Night n	W	P
0–25 m	8	.74	< <.01	7	.63	< <.01
25–50	7	.46	<.01	5	.65	< <.01
50–75	11	.44	< <.01	4	.62	< <.01
75–100	9	.51	< <.01	4	.65	< <.01
100–350	7	.63	< <.01	6	.67	< <.01

* n = Number of replicates at time/depth. W is the Kendall Concordance statistic calculated for n sets of seven ranks. P is the approximate probability that such a W value might be due to chance alone.

Another question of interest is "Do the various Group I species agree on where, horizontally (i.e., in which tows) to be abundant?" Because there is agreement on overall ROA structure within the group, we expect the answer to be 'yes'. If any one species becomes more abundant they must all become more abundant, or else the ROA agreement should fail to appear. Null hypothesis is "there is no agreement among species as to where (i.e., in which replicate) to be abundant." Again we test using Kendall Concordance; there is significant agreement ($p \leq .05$) on where, horizontally, to be abundant in only six of ten time/depths (Table 5). Due to the problems of multiple testing, only $P \leq .01$ should be regarded as truly statistically significant, reducing the number of positive agreements to four. This implies that while there exists an overall trend towards such agreement, it is not very strong; this in turn implies that multispecies patchiness is not particularly pronounced.

TABLE 5

Analysis of Group I for Agreement between Species as to Where (in which replicates) to be Abundant

Depth	Day n*	W*	P*	Night n	W	P
0–25 m	8	.34	∾.01	7	.38	<.01
25–50	7	.63	< <.01	5	.40	<.01
50–75	11	.15	>.20	4	.05	>.20
75–100	9	.33	∾.01	4	.11	>.20
100–350	7	.31	∾.05	6	.22	∾.20

* n = Number of replicates at time/depth. W is the Kendall Concordance statistic calculated for seven sets of n ranks. P is the approximate probability that such a W value might be due to chance alone.

Searching further for structure we may ask, "Do the species of Group I agree on a depth at which to be most abundant?" This requires re-ranking of the average abundance data; ranks are now *within* each species *across* depths (Table 6). For both day and night we accept the null hypothesis "there is no agreement among Group I species as to the best depth (i.e., depth of maximum abundance) at which to be caught". (Kendall Concordance test for seven sets of five ranks: day W = .266, p = .10; night W = .078, p ≃ .50). We must then accept the inverse, that the species of Group I find different depths to be "best", which implies that vertical as well as horizontal patchiness is not very strongly multispecific. This is the first clue to the puzzle of recurrent groups containing congeners.

TABLE 6

Group I Species Ranked (Within Each Species) as to Average Abundance at Each Time/Depth

A) Day

Depth	Species ID# (Group I only) 6	20	23	24	29	35	52
0–25 m	1	4	5	5	1	4	5
25–50	3	2½	3½	2	2	1	3
50–75	2	2½	2	1	3	2	2
75–100	4	1	1	3	4	3	4
100–350	5	5	3½	4	5	5	1

B) Night

Depth	6	20	23	24	29	35	52
0–25 m	1	4	2	2	2	1	3
25–50	2	5	5	1	3	5	5
50–75	4	2	3	3	1	2	4
75–100	3	1	4	4	4	3	2
100–350	5	3	1	5	5	4	1

Looking for evidence of diurnal vertical migration is even more enlightening. A species may exhibit "normal" (upwards at night) vertical migration, lack of vertical migration, or "reverse" (downwards at night) vertical migration. The seven species in Group I are as evenly split as is possible among the three alternatives (Table 6): three species (ID nos. 6, 20, 52) show no migration, two species (ID nos. 23 & 29) show reverse migration, and two species (ID nos. 24 & 35) show normal migration. What is most interesting is that each of the three congeners does one of these three distinctly different things, thus providing evidence for the separation of roles which theory requires of closely related species found living together.

CONCLUSIONS

A number of fairly firm conclusions may be stated even at this preliminary stage in the analysis.

1. A species list has been generated for the gyre.
2. There are recurrent groups of amphipods in the gyral community.
3. These groups can and do include congeners.
4. The groups have a significantly consistent internal rank structure both within and across depths, but much more so within depths.
5. Both horizontal and vertical patchiness appear not to be strongly multispecific in nature.
6. There is evidence, from within Group I alone, of normal, reverse, and absence of diurnal vertical migration.
7. The ecological problem of coexistence of morphologically very similar congeners may yield to detailed examination of spatial and temporal distributions.

There appears to be an enormous amount of structure to the community in spite of the superficial homogeneity of the environment. The gyral community is a finely tuned system and we badly need better ways of examining it, but detailed analyses of existing samples and data can yield considerable insights.

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HIDROLOGIA COMPARATIVA DE LAS BOCAS DE DOS ANTIESTUARIOS DE BAJA CALIFORNIA

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ABSTRACT

During spring and summer of 1975 four samplings were carried on, two at the mouth of San Quintín Bay and two at the mouth of Estero de Punta Banda, with the objective to study the variation of temperature, salinity, dissolved oxygen, pH, and some meteorological variables as functions of time in diurnal cycles. This is part of a study that intends to give an infrastructure for the development of mariculture in the antiestuaries of Baja California. To study San Quintín Bay and the Estero de Punta Banda will allow us to make comparisons with the objective to find common characteristics that can be extrapolated to other antiestuaries. In this report we also present some results from a recent sampling made in fall.

Estimaciones de la Productividad Orgánica Primaria

P (mg C m^{-3} día^{-1})

	San Quintín	E. Punta Banda
PRIMAVERA	39.9 A2	9.9 A2
VERANO	23.6 A2	7.2 A2

RECONOCIMIENTOS

Agradecemos al Antonio Novelo el habernos permitido utiliza sus instalaciones en el Estero de Punta Banda. Agradecemos a los compañeros Gilberto Gaxiola Castro, Sila Nájer Martínez, Bernando P. Flores Baez, Felipe Salinas, Artemio Gallegos, Salvador Galindo Bect, Talpa Lara, Lucía Vargas, Claudia Valdez, Enrique Parra, Refugio González, Luis A. Galindo Bect y Marcos Miranda Aguilar, su valiosa colaboración en los trabajos realizados.

INTRODUCCION

La Hidrología de Bahía San Quintín y el Estero de Punta Banda ha sido estudiada con el objetivo primordial de proporcionar una infraestructura científica para el desarrollo de maricultivos (Acosta Ruíz y Alvarez Borrego, 1975; Lara Lara y Alvarez Borrego, 1975; Alvarez Borrego, Ballesteros Grijalva y Chee Barragán, 1975; y Alvarez Borrego y Chee Barragán, 1975). El énfasis hasta ahora había sido el determinar la distribución espacial de diversos parámetros ecológi cos físico-químicos y su cambio en función del tiempo a lo largo de ciclos anuales; además de estudiar los parámetros relacionados con la productividad orgánica primaria. Avarez Borrego y López Alvarez (1975) presentaron algunos resultados sobre la determinación de biomasa por grupos taxonómicos de fitoplancton. Para un mejor entendimiento de los procesos que afectarán a cualquier grupo de especies que se cultiven en lagunas costeras semejantes a Bahía San Quintín y al Estero de Punta Banda, es necesario tener un mejor conocimiento de la dinámica de los mismos, el campo de la velocidad de corrientes y su compleja fluctuación en función del tiempo. Este campo dependerá de las mareas, la geometría de la laguna costera, especialmente su batimetría, los vientos y los efectos termohalinos de incremento de la temperatura y evaporación. Del campo de la velocidad depende la renovación del agua donde se esté realizando el cultivo, y por lo tanto el suplemento de alimento, sobre todo en el caso de cultivos de macro-algas y de moluscos filtro-alimentadores.

Redfield, Ketchum y Richards (1963) indicaron el poco conocimiento que se tiene sobre la hidrología de sistemas antiestuarinos, comparado con los ampliamente estudiados sistemas estuarinos. Las especulaciones que se han hecho sobre los sistemas antiestuarinos, en que la evaporación es mayor que cualquier aporte de agua dulce, se han basado en el conocimiento del mar Mediterráneo. Por ejemplo se especulaba que el contenido de nutrientes tendería a disminuir en el sistema antiestuarino con respecto al océano abierto adyacente, debido a una circulación termo halina que produciría en la boca una corriente en el fondo hacia afuera, de agua con mayor salinidad; y en la superficie, una corriente hacia adentro de agua con menor salinidad. Alvarez Borrego y Chee Barragán (1975) demostraron que a lo largo de todo el año la concentración de nutrientes en Bahía San Quintín aumenta de la boca hacia el interior, es decir, es mayor en el interior de la Bahía que en el océano abierto adyacente.

El objetivo del presente trabajo es el determinar la hidrología de las bocas de dos sistemas antiestuarinos en Baja California, Bahía San Quintín y el Estero de Punta Banda, y su cambio estacional a través de un año. Esto nos podrá permitir en el futuro hacer cálculos de flujo y balances de materiales, sobre todo de fitoplancton y de nutrientes en solución. Al estudiar simultáneamente dos sistemas antiestuarinos podemos realizar comparciones que quizás nos permitan establecer características lo suficientemente comunes para ser extrapoladas a cualquier otro sistema antiestuarino.

En este trabajo se presentan de una manera preliminar, los resultados obtenidos de los muestreos de primavera y verano de 1975; incluyendo salinidad, temperatura, oxígeno disuelto, pH y condiciones meteorológicas. Además, se presentan resultados obtenidos recientemente en otoño en San Quintín.

El estero de Punta Banda es una laguna costera localizada a lo largo de la orilla sureste de la Bahía de Todos Santos (Acosta Ruíz y Alvarez Borrego, 1974). Su boca se encuentra aproximadamente a 8 millas náuticas del mar obierto. Fuera de la Bahía de Todos Santos, al suroeste de Punta Banda se encuentra una zona de surgencias (Chávez de Ochoa, 1975). La boca del Estero no es mayor de 150 m en mareas bajas.

Bahía San Quintín se localiza a 200 km al sur de Ensenada, Baja California Norte. En el mar abierto inmediatamente al sur de la entrada de la Bahía ocurren surgencias intensas (Dawson, 1951). La boca tiene un poco más de un kilómetro de ancho (ver Chávez de Nishikawa y Alvarez Borrego, 1974).

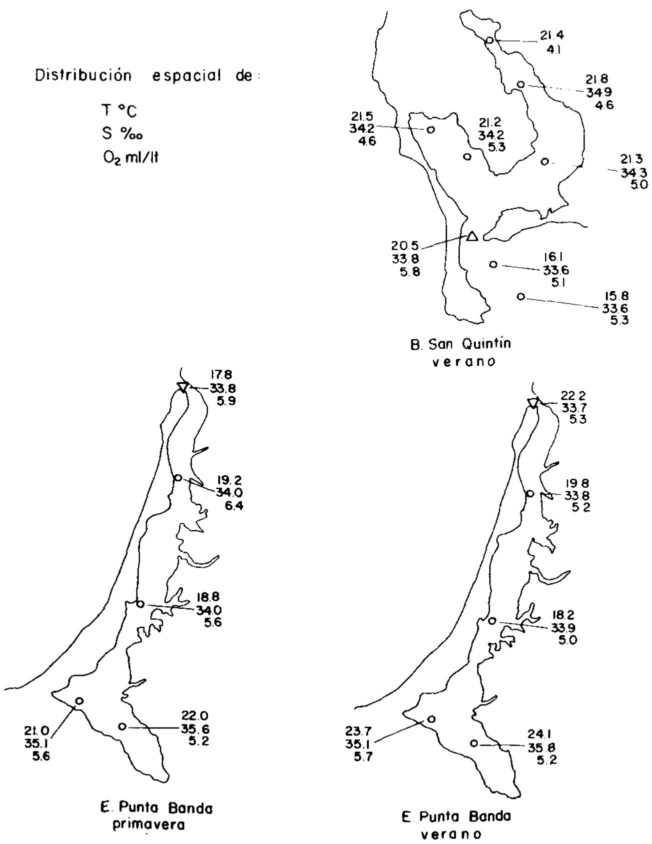

FIGURA 1. Localización de la estaciones de muestra en Bahía San Quintín y en el Estero de Punta Banda, mostrando la distribución espacial de temperatura, salinidad y oxígeno disuelto.

MATERIALES Y METODOS

Se realizaron dos muestreos en cada boca en Mayo y Agosto, para estudiar las condiciones de primavera y verano. En cada muestreo se anclaba la embarcación "SIRIUS I" de 35 pies de eslora, propiedad del CICESE, a manera de plataforma fija. Se tomaron muestras cada hora por períodos de 26 horas tratando de incluir un ciclo de radiación solar y de mareas. Además, en primavera se muestrearon 4 estaciones hacia el interior del Estero de Punta Banda, y en verano se muestrearon estaciones hacia el interior de ambos lugares (Figura 1). En San Quintín se muestreó el 7 y 8 de Mayo, y el 14 y 15 de Agosto; y en el Estero de Punta Banda el 26 y 27 de Mayo, y el 27 y 28 de Agosto. El muestreo reciente, que corresponde a otoño, se realizó el pasado 26 y 27 de Noviembre.

Se colectaron muestras de agua de supervicie y de fondo para determinaciones de temperatura, salinidad y oxígeno disuelto. Y solamente de superficie para pH. No fue posible tomar datos de pH en verano debido a fallas en el potenciómetro. En el muestreo reciente de Noviembre se determinó la dirección e intensidad de la corriente en la supervicie y aproximadamente a un metro del fondo. Además, se tomaron datos de temperatura ambiental y dirección e intensidad del viente para los propósitos del presente trabajo.

La salinidad se determinó mediante un salinómetro Beckman, modelo 118 WA200; la temperatura mediante termómetros reversibles y termómetro de cubeta; el oxígeno por el método macroWinkler descrito por Strickland y Parsons (1965); el pH utilizando electrodos de vidrio y un potenciómetro Orión, de bateris, modelo 401 y las corrientes mediante un correntómetro tipo Savonius.

La colecta de agua de fondo se hizo con botellas Nansen recubiertas con teflón y la de superficie con botellas Van-Dorn. Antes de realizar cada muestreo se leía la profundidad mediante una ecosonda y en base a ésto se situaba la botella de fondo aproximadamente a 1 m del mismo. La profundidad media en la boca de San Quintín es de cerca de 9 m y en el Estero de Punta Banda 7 m.

La intesidad y dirección del viento se midió con un anemómetro Kahlsico modelo 03 AM 120. La salinidad se determinó en el laboratorio, mientras que el resto de las propiedades se determinaron en el campo. Las gráficas de mareas se construyeron con datos del calendario publicado por la Secretaría de Marina, con su corrección por tiempo y espacio para el lugar estudiado.

RESULTADOS

En general la variación de temperatura y salinidad a través de un ciclo diurno tuvo tendencias más claramente marcadas en Bahía San Quintín que en el Estero de Punta Banda (Figura 1). Especialmente notable es la alta correlación entre estos parámetros ocurrida en primavera en Bahía San Quintín. En el Estero de Punta Banda se aprecian cambios bruscos de los valores, mientras que en Bahía San Quintín en general la variación fué suave. En Bahía San Quintín, en verano, alrede dor de las trece horas se detectó un fenómemo más claramente mostado por la temperatura pero corroborado por la salinidad (Figura 2) consistente en una anomalía que aumentó los valores de ambas propiedades con especto a la tendencia general de variación. El cambio brusco más marcado en el Estero de Punta Bana occurio a las seis horas en primavera. En general la temperatura fué mayor en la superficie que en el fondo, con diferencias hasta de más de 3°C en San Quintín en verano, y hasta más de 4°C en el Estero. Las diferencias de los valores de salinidad, de superficie y de fondo no son tan notables como las de temperatura.

Con relación a la salinidad, la columna de agua fue menos homogénea en San Quintín que en el Estero. La salinidad ue en general igual o mayor en la superficie que en el fondo. En verano en Bahía San Quintín se detectó una inversión en el gradiente de temperatura, en la columna de agua, de las 18:00 a las 23:00 horas del primer día; a las 03:00 horas; de las 06:00 a las 07:00 horas y de las 14:00 a las 18:00 horas del segundo día, con temperaturas mayores en el fondo que en la superficie (Figura 2). Esto implica que hubo una inversión en el gradiente de densidad. Pra corroborar ésto, se tuvo especial cuidado en las mediciones de temperatura realizadas recientemente en San Quintín (Figura 3); en efecto, una vez más se detectaron temperaturas en el fondo un poco mayores que en la superficie. Aunque no presentamos las gráficas de sigma-t, los resultados indican que en algunas ocasiones las fuertes corrientes de marea provocan temporalmente el que se encuentre agua en la superficie de mayor densidad que en el fondo.

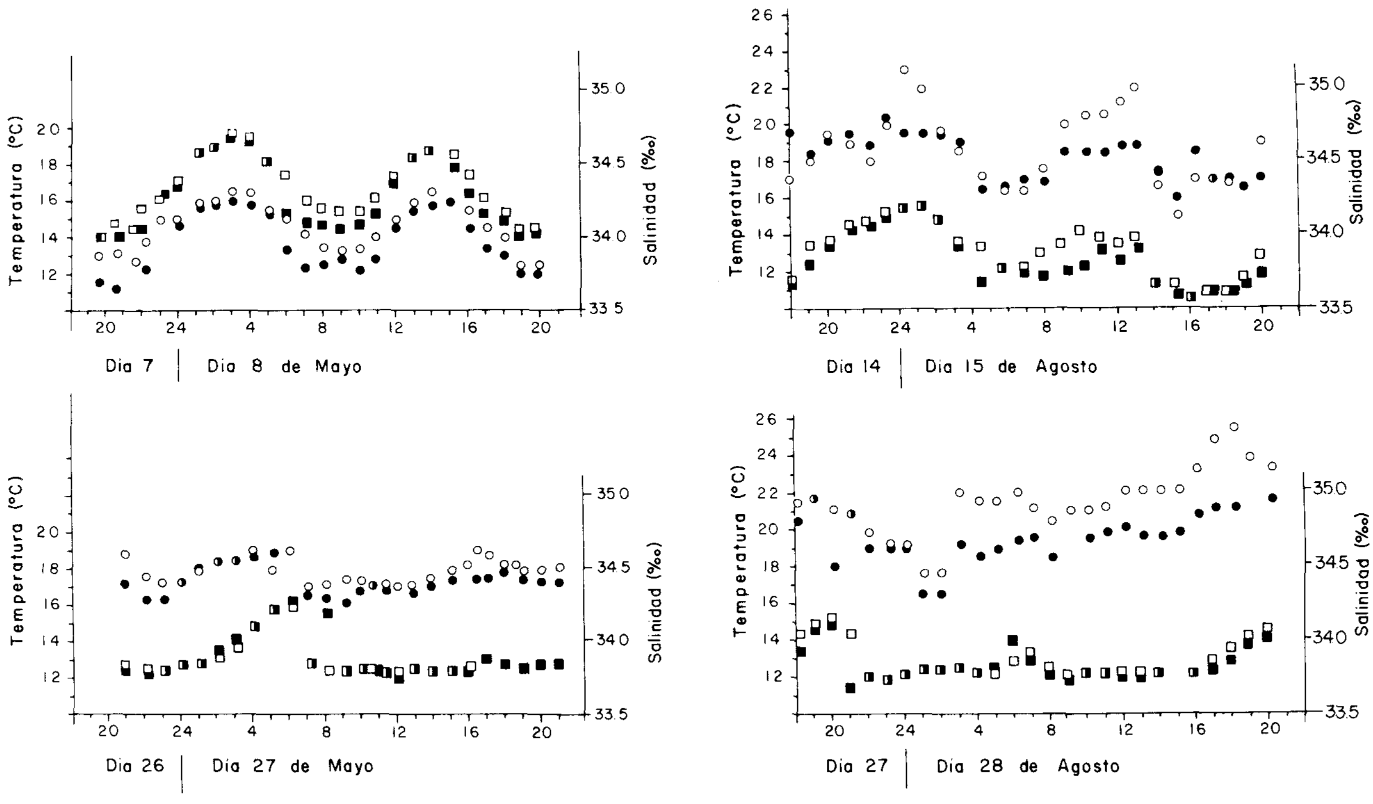

FIGURA 2. Variación de temperatura y salinidad en las bocas de San Quintín y el Estero. Círculos y cuadros claros representan valores de superficie y los oscuros de fondo.

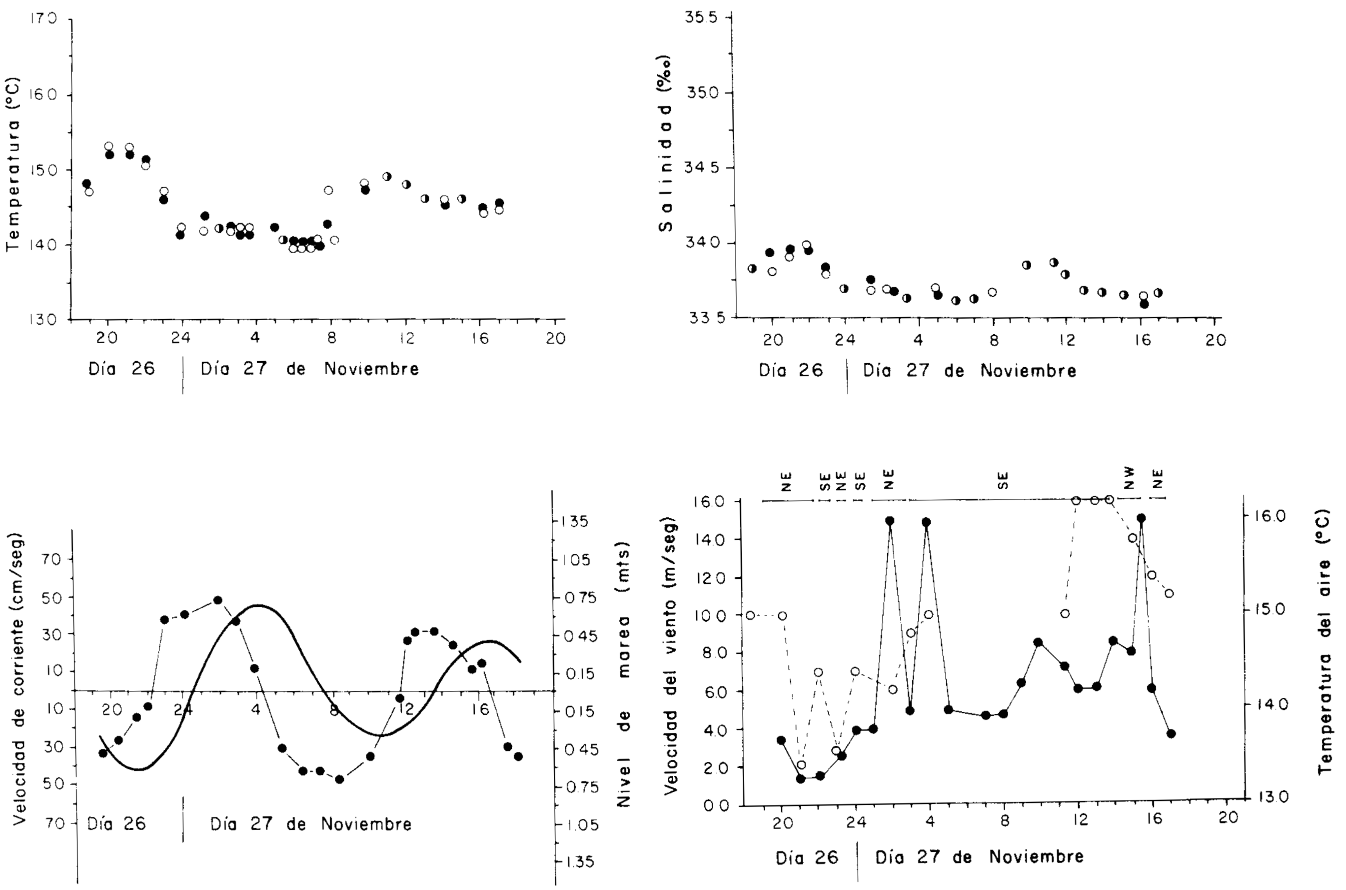

FIGURA 3. Variación de temperatura, salinidad, velocidad de corrientes, marea, velocidad del viento y temperatura del aire en la boca de San Quintín en el muestreo reciente de otoño. Círculos claros representan valores de superficie y los oscuros de fondo.

Contrario a la salinidad y temperatura, la variación de oxígeno disuelto fué más irregular en San Quintín que en el Estero (Figura 4). El pH fué casi invariable en el Estero de Punta Banda, mientras que en San Quintín su variación fué claramente marcada, con una alta correlación con la salinidad, temperatura y oxígeno disuelto (Figuras 2 y 4).

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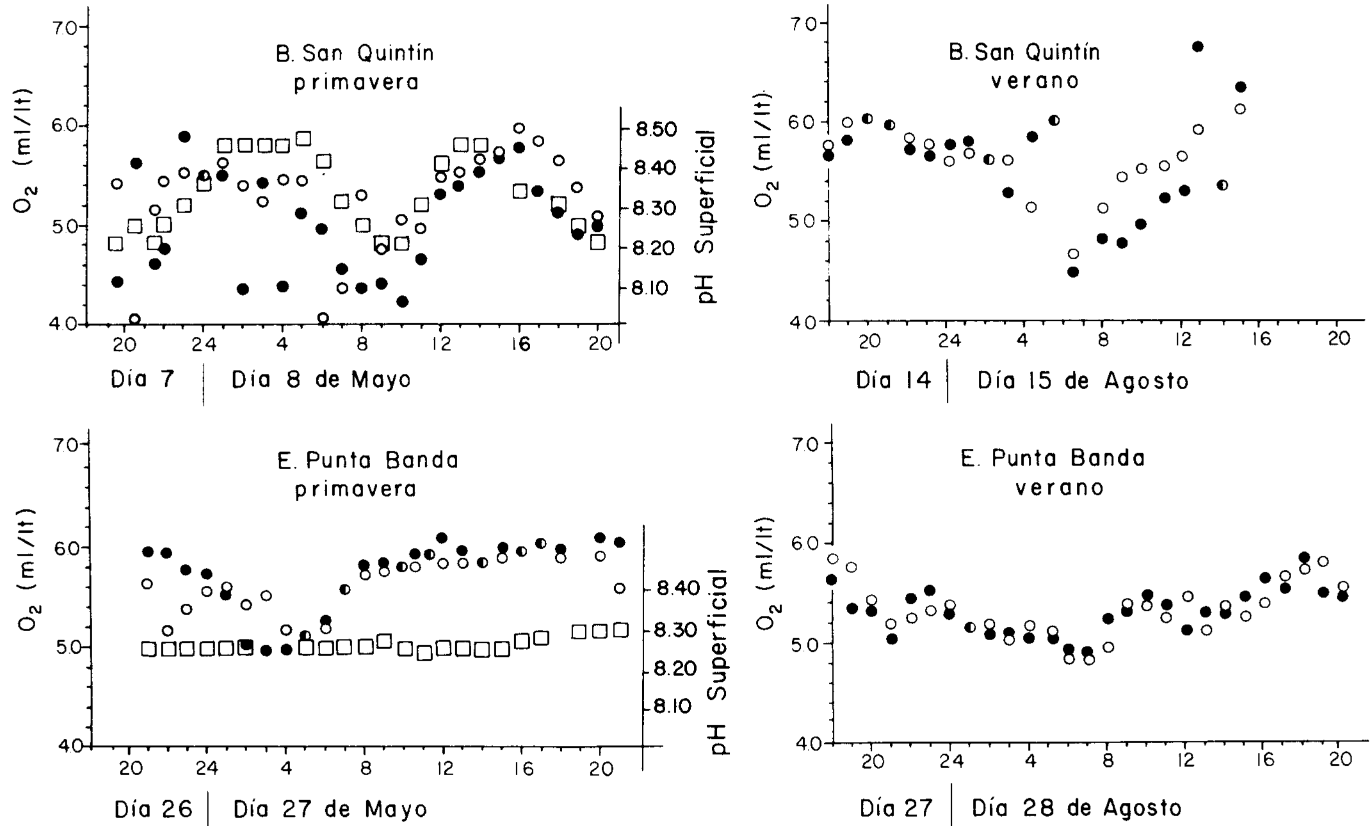

FIGURA 4. Variación de oxígeno disuelto y pH en las bocas de San Quintín y el Estero. Círculos y cuadros claros representan valores de superficie y los oscuros de fondo.

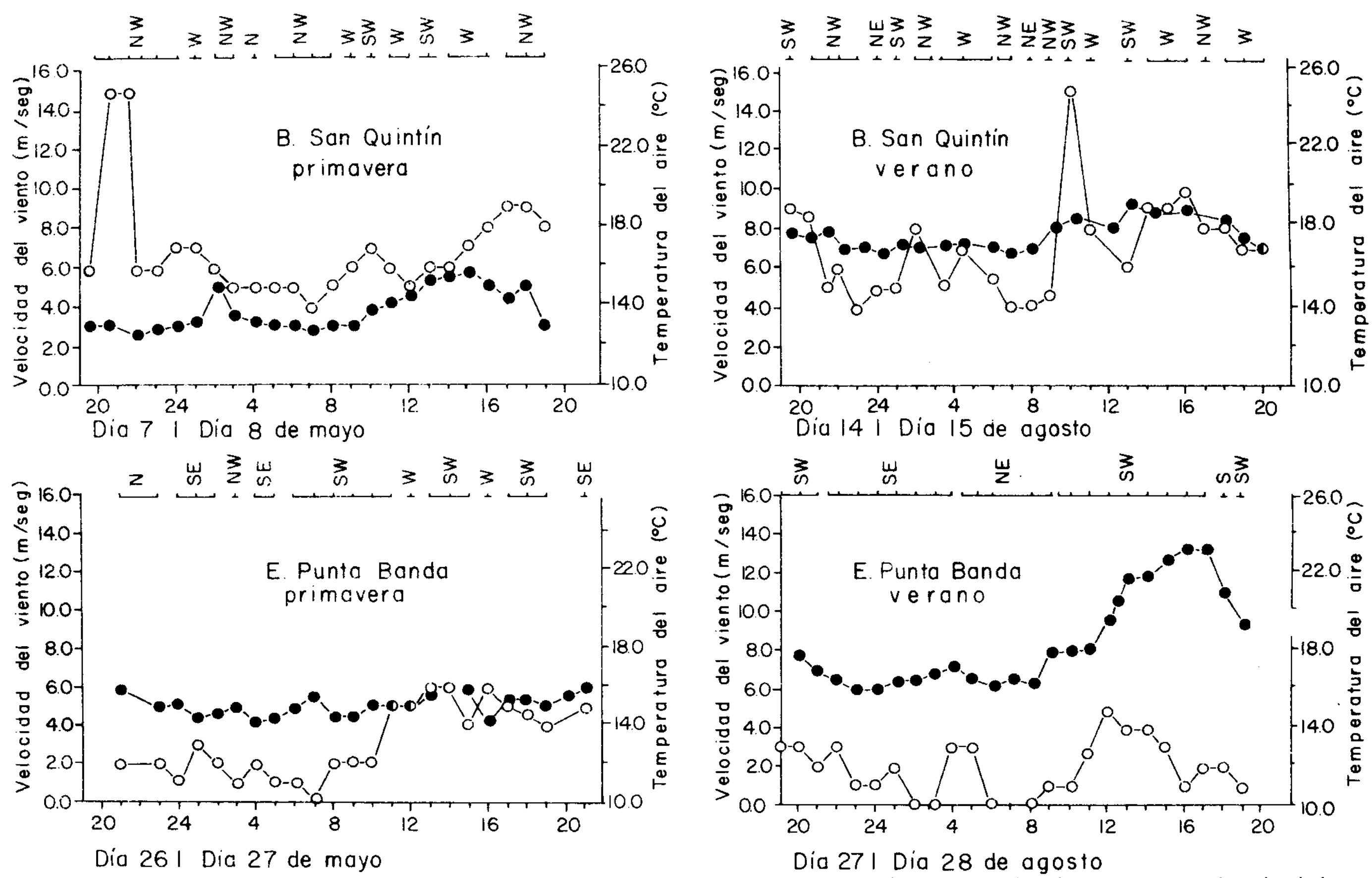

FIGURA 5. Variación de la velocidad del viento y la temperatura del aire en San Quintín y el Estero. Círculos claros representan la velocidad del—viento y los oscuros la temperatura.

DISCUSIONES

Resultados obtenidos anteriormente han mostrado que la salinidad y temperatura generalmente tienden a aumentar de la boca al interior de estos dos antiestuarios (Acosta Ruíz y Alvarez Borrego, 1974; y Chávez de Nishikawa y Alvarez Borrego, 1974). De acuerdo con ésto, al estar midiendo estas variables en las bocas, en función del tiempo, debe haber una correlación estrecha con la marea, con la salinidad y temperatura aumentando en reflujo y viceversa. En efecto, en el muestreo de primavera en San Quintín se detectó una correlación casi perfecta entre la temperatura, la salinidad, la marea, y también el oxígeno y el pH (Figuras 2 y 4). Sin embargo, en los demás casos no es evidente este tipo de correlación. Existen diversos factores que pueden causar variaciones irregulares de estas propiedades, v.g.: calentamiento y evaporación no uniforme en el interior de los antiestuarios debido a una batimetría irregular, con canales y bajos; la presencia de corrientes a lo largo de la playa en el exterior de las bocas; las condiciones cambiantes en la zona oceánica adyacente a las bocas, como los cambios producidos por una sugencia; y conrelación a la concentración de oxígeno, el oleaje variable de acuerdo con las condiciones de los vientos. Cabrera Muro (1972) y Contreras Rivas (1973) detectaron una corriente paralela a la play frente a la boca del Estero de Punta Banda, con dirección norte. Los cambios bruscos de temperatura y salinidad detectados en algunas ocasiones en la boca del Estero, tales como el ocurrido a las 6 de la mañana en primavera (Figura 2), son seguramente debido a este tipo de corriente paralela a la playa, que provoca el desplazamiento del agua que sale del Estero, de tal manera que al comenzar a subir la marea entra agua "nueva" no mezclada, y se registra en la boca una súbita disminución de temperatura y salinidad. Algunas de las anomalías registradas en San Quintín (Figura 2) pueden deberse también a este tipo de corrientes a lo largo de la playa.

El intenso oleaje que comúnmente ocurre frente a la estrecha boca del Estero, aundado a las fuertes corrientes de marea (más fuertes en el Estero que en San Quintín, por lo estrecho de la boca del primero), son causantes de la mayor homogeneidad de la columna de agua en el Estero. En general, en ambos lugares, la columna de agua es más homogénea durante el reflujo.

Seguramente la presencia de surgencias en la zona oceánica adyacente a laboca de San Quintín son la causa de que se hayan registrado temperatures más bajas que en el Estero, en el agua y en el aire. Vientos persistentes del noroeste registrados en San Quintín (Figura 4) pueden haber causado estas surgencias.

La experiencia adquirida coneste trabajo preliminar nos enseña que dificilmente se pueden obtener conclusiones fuertes con series de tiempo tan pequeñas. Por lo cual, futuros muestreos deben abarcar períodos del orden de unas dos otres semanas, en lugar de un día.

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PARAMETROS RELACIONADOS CON LA PRODUCTIVIDAD ORGANICA PRIMARIA EN DOS ANTIESTUARIOS DE BAJA CALIFORNIA

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ABSTRACT

The Center for Scientific Research and Higher Education of Ensenada has started this year a series of activities that have as an objective to build a scientific infrastructure for the rational development of mariculture in Baja California. An important part of this objective is to develop methodologies to estimate the available food for species under cultivation in coastal lagoons. This implies the knowledge of physical, chemical, and biological aspects of these ecosystems. In this paper we report some preliminary results of the phytoplankton biomass changes, represented by the chlorophyll "a" concentration variation, at the mouths of two antiestuarine systems, San Quintín Bay and Estero de Punta Banda; and we discuss some of the problems to be solved in order to use the chlorophyll-light method to estimate the organic primary productivity in coastal lagoons.

INTRODUCTION

El desarrollo de maricultivos en lagunas costeras deberá llevarse a cabo en el futuro con el objetivo lógico de obtener rendimientos máximos por unidad de área. Para ésto se hace necesario el tener un buen conocimiento del alimento disponible para las especies a cultivar se. Esto es muy complejo en sistemas dinámicos donde las corrientes de marea aunadas a intensos gradientes de variables como temperature y salinidad, provocan cambios fuertes en el orden de horas. De particular importancia es no solamente el evaluar la cantidad de alimento presente en un momento dado en una cierta localización, sino los flujos del mismo.

Ryther (1969) ha expresado que la producción de moluscos, si dependiera solamente del alimento producido en el agua donde están creciendo, tendría un promedio no mayor de 150 kg por hectárea por año (expresado en peso de carne sin concha). Cultivos intensivos en áreas pequeñas pueden producir cosechas anuales de 5,000 a 500,000 kg por hectóra por año (peso de carne), dependiendo del método de cultivo. Estas altas cosechas resultan de la concentración en una área pequeña del material orgánico producido en una región mucho más grande.

Un aspecto de suma importancia es el hecho de que los moluscos bivalvos, al filtroalimentarse del material en suspensión, no approvechan por igual las diferentes especies de fitoplancton (Loosanoff, comunicación personal). Debido a ésto, no basta determinar la productividad orgánica total, sino que es necesario ser discriminatorio determinando por lo menos las biomasas parciales por grupos de especies.

Relacionados con el objetivo de determinar el alimento disponible para especies a cultivarse en una laguna costera como las que se encuentran en el noroeste de Baja California, existen básicamente cuatro aspectos importantes que estudiar: la producción orgánica primariar fitoplancton en la laguna costera que se trate; la biomasa de fitoplancton por grupos taxonómicos; el aporte neto del exterior a la laguna, de biomasa de organismos planctónicos y su distribución en el interior de la misma; y la producción orgánica primaria por pastos marinos y sus epifitas. En un futuro se deberá tender al establecimento de policultivos; pero, si en un principio el interés principal es cultivar organismos filtroalimentadores, los tres primeros factores son los más importantes.

Actualmente, el Centro de Investigación Científica y de Educación Superior de Ensenada, en colaboración con la Unidad de Ciencias Marinas de la Universidad Autónoma de Baja California, desarrollan un programa de investigación de Bahía San Quintín y el Estero de Punta Banda. Este programa incluye el estudio de variables hidrológicas (temperatura, salinidad, concentración de oxígeno disuelto, pH, fosfatos, nitratos, y velocidad de corrientes), meteorológicas (temperatura de bulbo húmedo y bulbo seco, velocidad del viento, radiación solar, y porciento de nubosidad) y biológicas (concentración de clorofilas y sus productos de degradación, y biomasa de fitoplancton por grupos taxonómicos).

En este reporte se presentan algunos resultados de variables relacionadas con la productividad orgánica primaria en las bocas de estos sistemas antiestuarinos y se discute la posibilidad de adaptar el método de clorofila-luz para su utilización en lagunas costeras.

Acosta Ruiz y Alvarez Borrego (1974) y Chávez de Nishikawa y Alvarez Borrego (1974), han presentado con anterioridad descripciones de estos dos cuerpos de agua, por lo cual no es necesario repetirlo aquí.

MATERIALES Y METODOS

Se realizaron dos muestreos en cada boca, en mayo y agosto, representativos de primavera y verano. En cada muestreo se anclaba la embarcación "SIRIUS I", de 35 pies de eslora, a manera de plataforma fija. Se

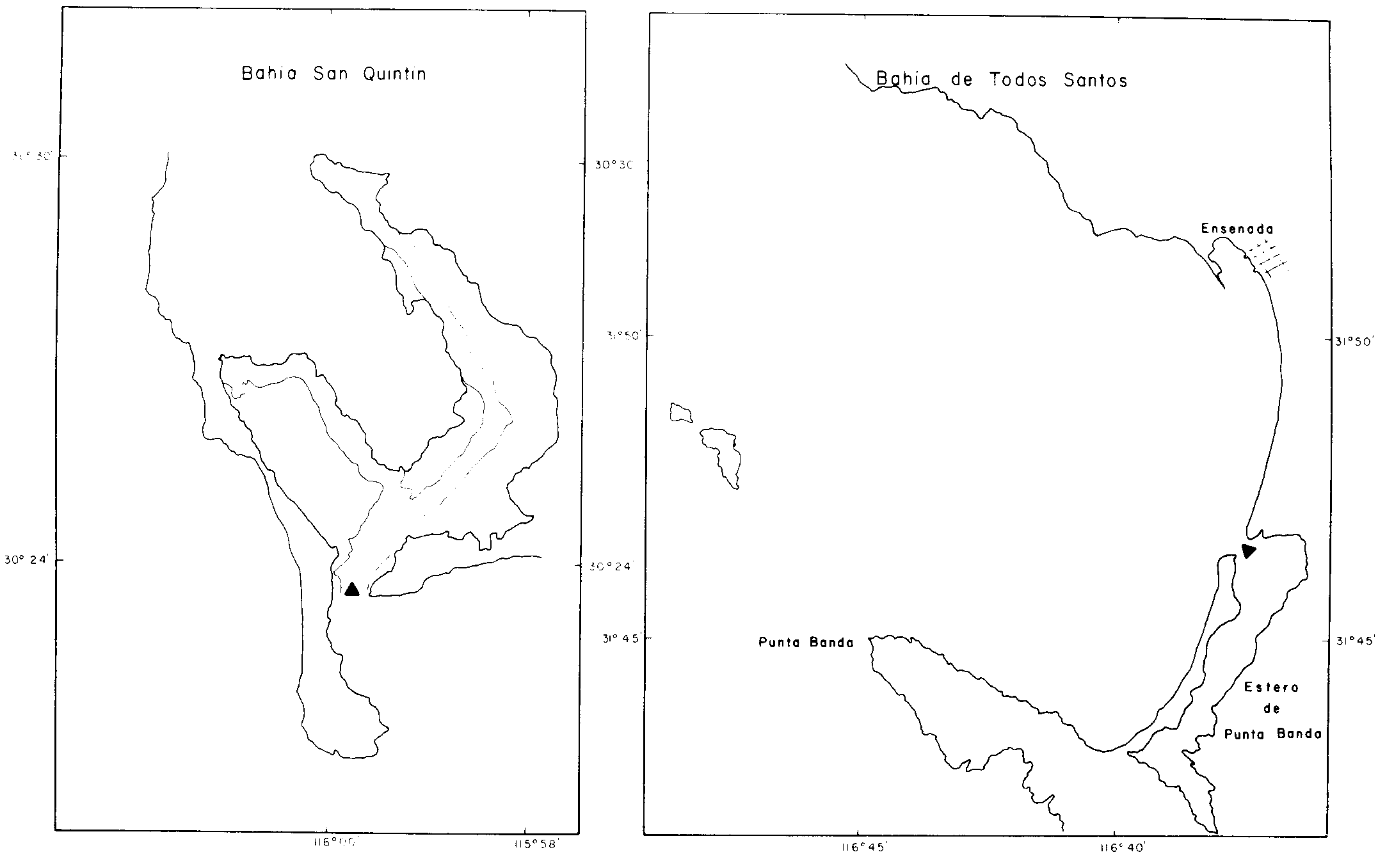

FIGURA 1. Localización de estaciones.

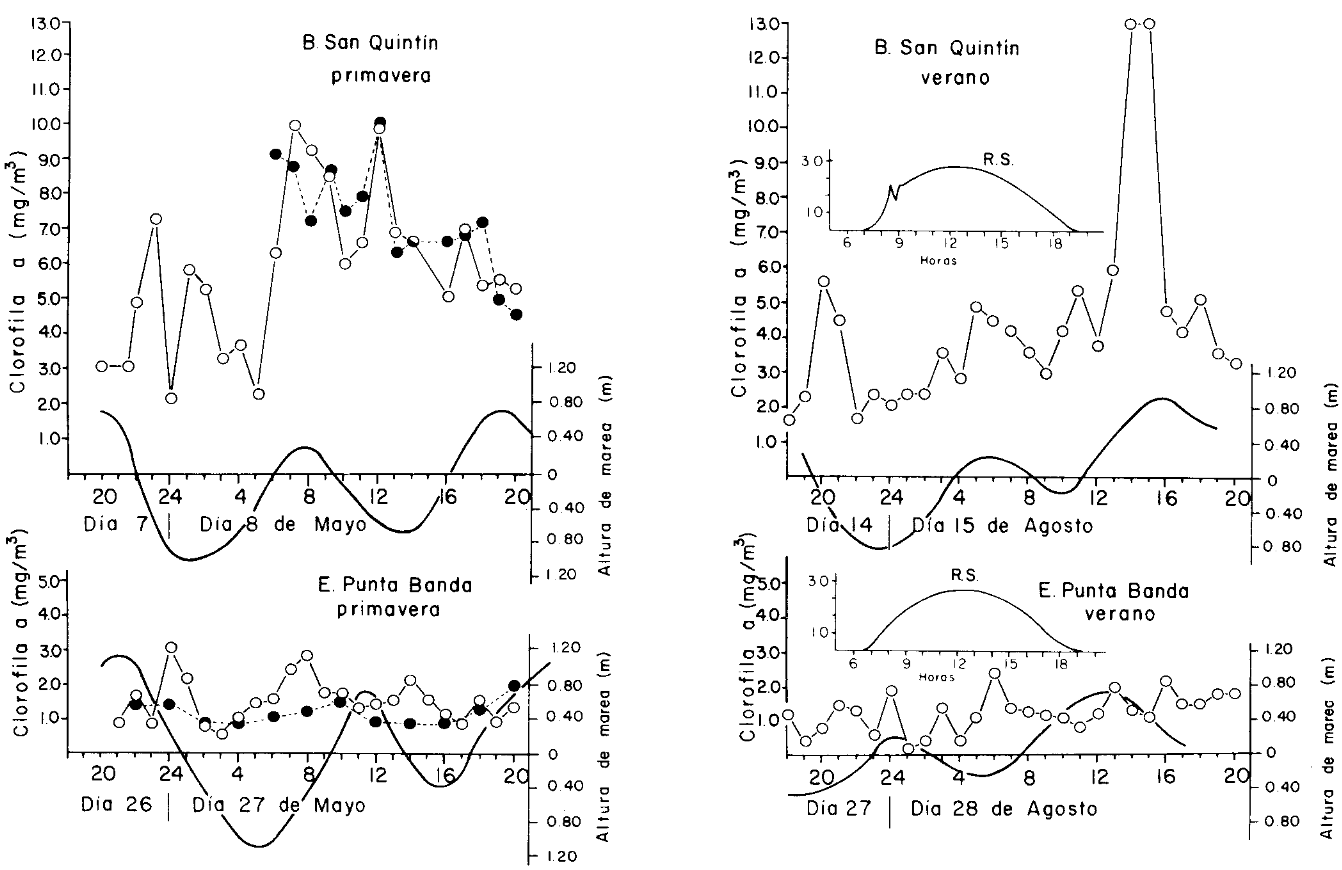

FIGURA 2. Ciclo de variación diurna de la concentración de clorofila "a" en mg/m³. (○ muestras de superficie, ● muestras de fondo). R.S. = Radiación solar en grs —cal cm $^{-2}$.

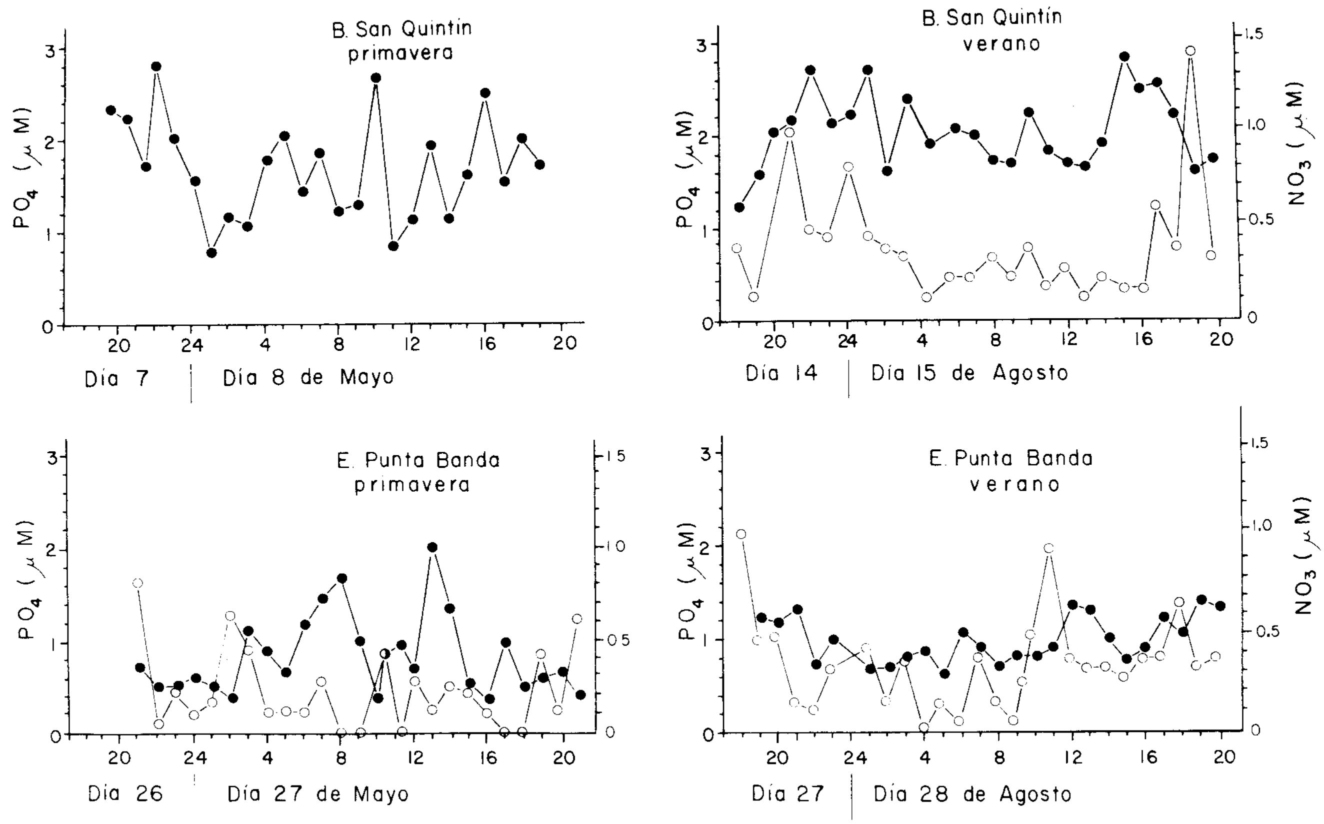

FIGURA 3. Ciclo de variación diurna de la concentración de nutrientes M. (○ fosfatos, ● nitratos).

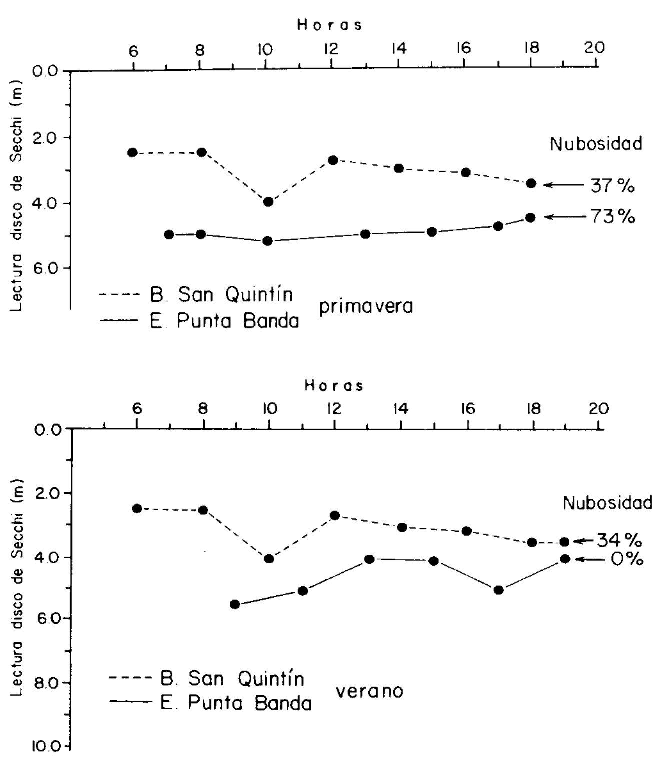

FIGURA 4. Profundidad del disco de secchi.

tomaron muestras cada hora por períodos de 26 horas, incluyendo unciclo completo de irradiación solar y de mareas. Además se muestrearon cuatro estaciones en el interior del Estero de Punta Banda en primavera y verano (Figura 1). Para el objetivo del presente trabajo, se tomaron muestras para el análisis de clorofila "a," fosfatos, y nitratos.

En primavera se determinó la clorofila "a" en muestras de superficie y de fondo. Al no encontrar una diferencia significativa entre—los dos niveles, se optó por muestrear solamente en la superficie en las siguientes colectas. Las determinaciones de clorofila "a" y nutrientes se realizaron por los métodos espectrofotométricos descritos por Strickland y Parsons (1963), utilizando un espectrofotómetro UVVIS Coleman Hitachi, modelo 139.

Además se tomaron lecturas de disco de Secchi y se midió la irradiación solar mediante un actinógrafo de gráfica contínua, marca—Kalsico No. 01AM100.

RESULTADOS

En la boca de Bahía San Quintín la clorofila "a" presentó una mayor concentración y un rango más amplio de variación que en la boca del Estero de Punta Banda (Figura 2). Se aprecia también en ambos lugares una mayor concentración en primavera que en verano. En general, la variación en ambos lugares en función del tiempo fué irregular, con variaciones abruptas sin correlación aparente con factores como la marea o el ciclo de irradiación solar. La distribución espacial de clorofila en el Estero de Punta Banda es muy homogénea con valores que uctúan entre 0.7 y 1.7 mg/m^3.

La concentración de fosfatos y nitratos es mayor en Bahía San Quintín que en el Estero de Punta Banda (Figura 3), con rangos de variación casi iguales para primavera y verano. Al igual que la clorofila "a," la variación de estos dos nutrientes en función del tiempo fué irregular, con cambios abruptos hasta en una hora.

La profundidad del disco de Secchi fué siempre menor en Bahía San Quintín que en el Estero de Punta Banda, aún en primavera con 73% de nubosidad en el Estero y sólo 37% en Bahía San Quintín (Figura 4).

DISCUSIONES

Glooschenko, Curl y Small (1972) estudiaron la variación diurna de la concentración de clorofila "a" en las aguas costeras frente a Oregon. Su conclusión fué que la concentración máxima de superficie occurrió a menudo alrededor de media noche y el mínimo coincidió con el máximo de intensidad de luz. La fotoinhibición fué responsable de las bajas concentraciones durante el período de luz y la declinación de la concentración después del máximo en el período de oscuridad se debió a que las células acabaron sus reservas de algún precursor de clorofila o de algún substrato proveedor de energía. Lara Lara y Alvarez Borrego (1975) observaron que en general la distribución superficial de clorofila "a" en Bahía San Quintín es tal que los valores disminuyen de la boca hacia el interior de la misma. De acuerdo con lo anterior, al determinar la variación diurna de clorofila "a" en la boca de San Quintín, se esperaría el efecto combinado de la variación por efecto de irradiación solar y por el efecto de mareas. Este último causaría el que se presentaran mas bajas concentraciones cuando la marea esta bajando y viceversa.

Nuestros resultados muestran (Figura 2) que estos dos efectos se ven oscurecidos por la variación no periódica debida quizás a una distribución en forma de manchas de poblaciones de fitoplancton.

Los más bajos valores de concentración de clorofila y de nutrientes en el Estero de Punta Banda, con respecto a los de San Quintín, izá se deban a que la boca del Estero de Punta Banda está situada a unas 10 millas náuticas de la zona de surgencia de Punta Banda, fuera de la Bahía de Todos Santos (Chávez de Ochoa, 1975), mientras que la boca de Bahía San Quintín se encuentra inmediatamente adyacente a una área de surgencias intensas (Dawson, 1951). Esto causa también el que las aguas del Estero de Punta Banda sean más transparentes (Figura 4).

De acuerdo con nuestros resultados, el uso del método de clorofila-luz para estimar la productividad orgánica primaria en un punto determinado de este tipo de lagunas costeras, es válido solamente cuando se toma en cuenta la variación de la concentración de clorofila en función del tiempo. El tomar la concentración de clorofila de un momento dado como representativa para todo el día, podría causar un error en la estimación de la productividad primaria de hasta un orden de magnitud.

Small, Curl, y Glooschenko (1972) presentaron una versión revisada de la ecuación original de Ryther y Yentsch (1957). La modificación principal consiste en tomar en cuenta el cambio de concentración de clorofila en función tiempo. La nueva ecuación estima la producción primaria para intervalos de dos horas, de la siguiente manera:

$$P_{d2} = R_{d2} \cdot C_{d2} \cdot A_2$$

donde: P_{d2} es la fotosíntesis para un incremento de dos horas del período de luz a la profundidad d (expresada en g C m^{-3} [2 hrs.]$^{-1}$); R_{d2} es la fotosíntesis relativa para un incremento de dos horas a la profundidad d (R m^{-3} [2 hrs.]$^{-1}$); A_2 es la razón máxima fotosíntesis/clorofila para un incremento de dos horas (g C hr^{-1} [g Clorofila "a"]$^{-1}$). En condiciones de saturación de luz, A_2 es el número de asimilación (Small, et al, 1972).

La ventaja del método de clorofila—luz para estimar la productividad orgánica primaria rutinariamente, en lagunas costeras como Bahía San Quintín y el Estero de Punta Banda, sobre otros métodos como los de Carbono-14 y Oxígeno, consiste en que no tendrían que realizarse incubaciones, teniendo solamente que tomarse una muestra de agua para su posterior análisis en el laboratorio. Incluso, se podría de terminar la concentración de clorofila "a" de una manera contínua, por fluorimetría, utilizando una lancha con motor fuera de borda.

Las desventajas con que todavía cuenta el método de clorofila luz, de acuerdo con la versión originalmente presentada por Ryther y Yentsch (1957) y mejorado por Small, Curl, y Glooschenko (1972), en cuanto a su aplicación a lagunas costeras como las nuestras, estriban principalmente en el desconocimiento que se tiene de la distribución espacial de A_2 y su cambio en función del tiempo. Además, un problema que quizás es menos grave pero que no debe dejar de considerarse, es que la R_{d2} de Small, Curl, y Glooschenko (1972) fué calculada asumiendo que la curva promedio R:I de Ryther (1956) es aplicable a las poblacio nes fitoplanctónicas de la zona de surgencia frente a Oregon; queda por determinarse el que dicha curva sea aplicable a las poblaciones fitoplanctónicas de nuestras lagunas costeras. De acuerdo con los resultados de Ryther y Menzel (1959), la misma especie de fitoplancton puede comportarse de maneras diferentes con respecto a la relación R:I de acuerdo al acondicionamiento que presente a la luz.

Utilizando las curvas "fotosíntesis relativa : radiación total diaria" de Small, Curl, y Glooschenko (1972) y nuestros resultados de concentración de clorofila se obtuvieron las estimaciones de productividad orgánica primaria, para el metro cúbico superficial, que se presentan en la tabla I. Estas estimaciones se presentan en función de A_2 que deberá determinarse en el futuro. Los coeficientes de A_2 fueron mayores para San Quintín que para el Estero de Punta Banda, y en ambos lugares fueron mayores en primavera que en verano.

Bannister (1974) ha presentado en su forma más completa, un tipo de ecuación que pretende proveer una mayor fundamentación teórica para el desarrollo futuro de una teoría general de la dinámica de fitoplancton. Este tipo de ecuación, que es mas bien aplicable a lagos, introduce el concepto de eficiencia cuántica y la partición del coeficiente de extinción de la luz en dos componentes, uno dependiente y otro independiente de la concentración de clorofila. Existen en el momento, desventajas fuertes que impiden la aplicación de este tipo de ecuación a las estimación de la productividad orgánica en lagunas costeras. Se debe asumir que la concentración de clorofila no variá con el tiempo; el determinar los valores de la eficiencia cuántica implica básicamente el mismo tipo de problemas que la determinación de A_2; y es muy difícil determinar los dos componentes del coeficiente de extinción de luz. Algunos de estos factores fueron mencionados por el propio Bannister (1974).

RECONOCIMIENTOS

Agradecemos a los oceanólogos Luis Galindo y Marcos Miranda, a los estudiantes de la Escuela Superior de Ciencias Marinas, Talpa Lara, Enrique Parra, Refugio González y Lucía Vargas por su valiosa ayuda en los muestreos de campo. Agradecemos al Sr. Antonio Novelo su desinteresada ayuda permitiéndonos utilizar las instalaciones de su motel en Estero Beach, durante los muestreos.

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CORRIENTES GEOSTROFICAS EN EL GOLFO DE CALIFORNIA EN LA SUPERFICIE Y A 200 METROS, DURANTE LAS ESTACIONES DE INVIERNO Y VERANO.

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ABSTRACT

Oceanographic data from several cruises made by CalCOFI into the Gulf of California, between 1956–1965, were used to make dynamic topographic charts for the determination the geostrophic circulation at surfaces (0 db) and 200 db (decibars) relative to the 500 db level.

In winter, the outflow was observed most of the time on the side of Baja California Peninsula, with velocities of 40 cm/sec on the surface level and 25 cm/sec on the 200 m level, both at southwest of Tiburon Island.

In summer, the surface circulation and 200 m depth circulation was to the northwest. On the surface, the velocity was 35 cm/sec, and the water flowed into the Gulf on the east side and along the central axis.

EXTRACTO

Datos oceanográficos provenientes de diversos cruceros realizados (en su mayoría) por CalCOFI dentro del Golfo de California entre 1956 y 1965, fueron utilizados para la elaboración de cartas de topografía dinámica para determinar la circulación geostrófica en las superficies de 0 y 200 db (decibares) relativas al nivel de los 500 db.

En la época de invierno, el agua salió del golfo por el lado de la península de Baja California en la mayoría de las veces, observándose velocidades de 40 cm/seg en la superficie y de 25 cm/seg en el nivel de los 200 m, ambas al suroeste de Isla Tiburón.

En verano, la circulación superficial y de 200 m fué hacia el noroeste, con velocidades hasta de 35 cm/seg en la superficie, en la que el agua paració entrar al golfo por el lado este y a lo largo del eje central.

OBJETIVO

El presente trabajo tiene la finalidad de describir la circulación de las aguas en las partes central y sur del Golfo de California, desde Isla Tiburón hasta la zona de entrada en un estudio que cubra las dos principales estaciones del año, invierno y verano.

Las aguas del Golfo de California son importantes para la industria pesquera de México, porque poseen una alta productividad biológica que se extiende por todo el golfo y una gran diversidad de peces de interés comercial. Un conocimiento básico de las corrientes es especialmente importante, ya que pueden correlacionarse con la distribución temporal y espacial de las larvas de peces y poblaciones de pláncton.

Debido a que la existencia de datos es insuficiente, además de que no están igualmente distribuidos a través de las estaciones del año (Table 1), únicamente se consideran las diferencias entre las condiciones de las principales estaciones, verano e invierno, siendo apenas el inicio de una investigación a detalle, hasta que no se tengan más datos para poder dar una discusión más sistemática de cambios estacionales.

	INVIERNO	PRIMAVERA	VERANO	OTOÑO
1956	● ●			
1957	●		● ●	
1958				
1959				
1960				
1961				
1962				
1963	●			
1964				
1965			●	

TABLA 1.
Tabla de Frecuencia de Cruceros Hidrograficos, Dentro del Golfo de California, Incluidos en este Estudio.

DATOS

Para la realización del presente trabajo se contó con datos provenientes de diversos cruceros oceanográficos dentro del Golfo de California efectuados por CalCOFI desde 1956 hasta 1965 (Tabla 2). Con los datos de las anomalías de alturas dinámica de dichos cruceros, dados en metros dinámicos, se construyeron cartas de topografía dinámica. Wyllie (1966) publicó estas mismas cartas para los años de 1956 a 1961 en un atlas que contiene cartas de flujo geostrófico en la superficie y a 200 m de profundidad para la región de la corriente de California, en donde incluye nueve cruceros dentro del golfo. Algunas de las cartas que integran el presente trabajo han sido ligeramente modificadas de aquellas publicadas por Wyllie.

CRUCERO	FECHA	BARCO	PROPIEDADES OBSERVADAS
CCOFI 5602	6 FEB.- 18 FEB. 1956	BLACK DOUGLAS	T °C, S ‰, O_2
CCOFI 5612	24 NOV- 21 DIC. 1956	HORIZON	T °C, S ‰, O_2
CCOFI 5702	8 FEB.- 25 FEB. 1957	SPENCER F. BAIRD	T °C, S ‰, O_2
CCOFI 5706	7 JUN.- 23 JUN. 1957	STRANGER	T °C, S ‰, O_2
CCOFI 5708	9 AGO.- 27 AGO. 1957	STRANGER	T °C, S ‰, O_2
CCOFI 6311 (EL GOLFO)	9 NOV.- 7 DIC. 1963	A. AGASSIZ	T °C, S ‰, O_2, PO_4, SiO_3, NO_2
CCOFI 6505 (EL GOLFO II)	14 MAY.- 17 JUN. 1965	A. AGASSIZ	T °C, S ‰, O_2, PO_4, SiO_3, NO_2

TABLA 2
Lista Cronologica de Los Cruceros Hidrograficos Dentro Del Golfo de California Que Integran Este Estudio.

METODOS

Uno de los métodos indirectos para la medición de las corrientes en el mar es la presentación de cartas de topografía dinámica en las que se muestran los desniveles de las superficies isobéricas. Este procedimiento es el método dinámico y fué primeramente usado por Sandström y Helland-Hansen en 1903 (Pirie, 1973). Una carta de topografía dinámica representa la corriente o flujo geostrófico de las aguas sobre una superficie usobárica.

Para la determinación de las corrientes geostróficas en el mar es necesario conocer la variación del volúmen específico a lo largo de una superficie isobárica. El gradiente horizontal del volúmen específico implica que las superficies isobáricas se inclinen con respecto a otras superficies más profundas, las cuales tienden a aproximarse a una superficie de nivel (Reid, 1959) estableciéndose un declive geopotencial en las superficies superiores. Este declive puede ser encontrado conociendo la variación del volúmen específico sobre la capa isobárica, siempre y cuando a una profundidad dada, una superficie se mantenga horizontal (La Fond, 1951). Las corrientes geostróficas están esencialmente en función del declive geopotencial. En estas condiciones se puede determinar la corriente en la superficie isobárica superior, relativa a cualquier corriente posible en la superficie inferior, la cual se supone que está a nivel y es tomada como referencia. Uno de los problemas que pueden originar errores en el cálculo de las corrientes geostróficas es la selección de la superficie isobárica de referencia adecuada (Reid, 1959; Warsh y Warsh, 1971) tomando en cuenta que la calidad de los datos de temperatura, salinidad y presión (profundidad) es aceptable. En este caso se optó por tomar la su perficie de 500 db de acuerdo a otros autores (Roden y Groves, 1959; Wyllie, 1966; Griffiths, 1968; Alvarez, 1974) y en virtud de que hay muchas estaciones que no sobrepasan a los 500 m de profundidad.

En intervalo de los contornos fué de 0.04 m din. (metros dinámicos) en el nivel de 0 m y de 0.02 m din. en el de los 200 m.

Cada contorno representa la línea a lo largo de la cual se desarrolla una corriente. La dirección del flujo, indicada por las flechas, se determino en el supuesto de que la corriente tiende hacia la derecha y en ángulos rectos al gradiente dinámico en el hemisferio norte.

La velocidad de la corriente puede estimarse aproximadamente con la ayuda de un gráfico que aparece en lado izquierdo de todas las cartas que integran el presente trabajo.

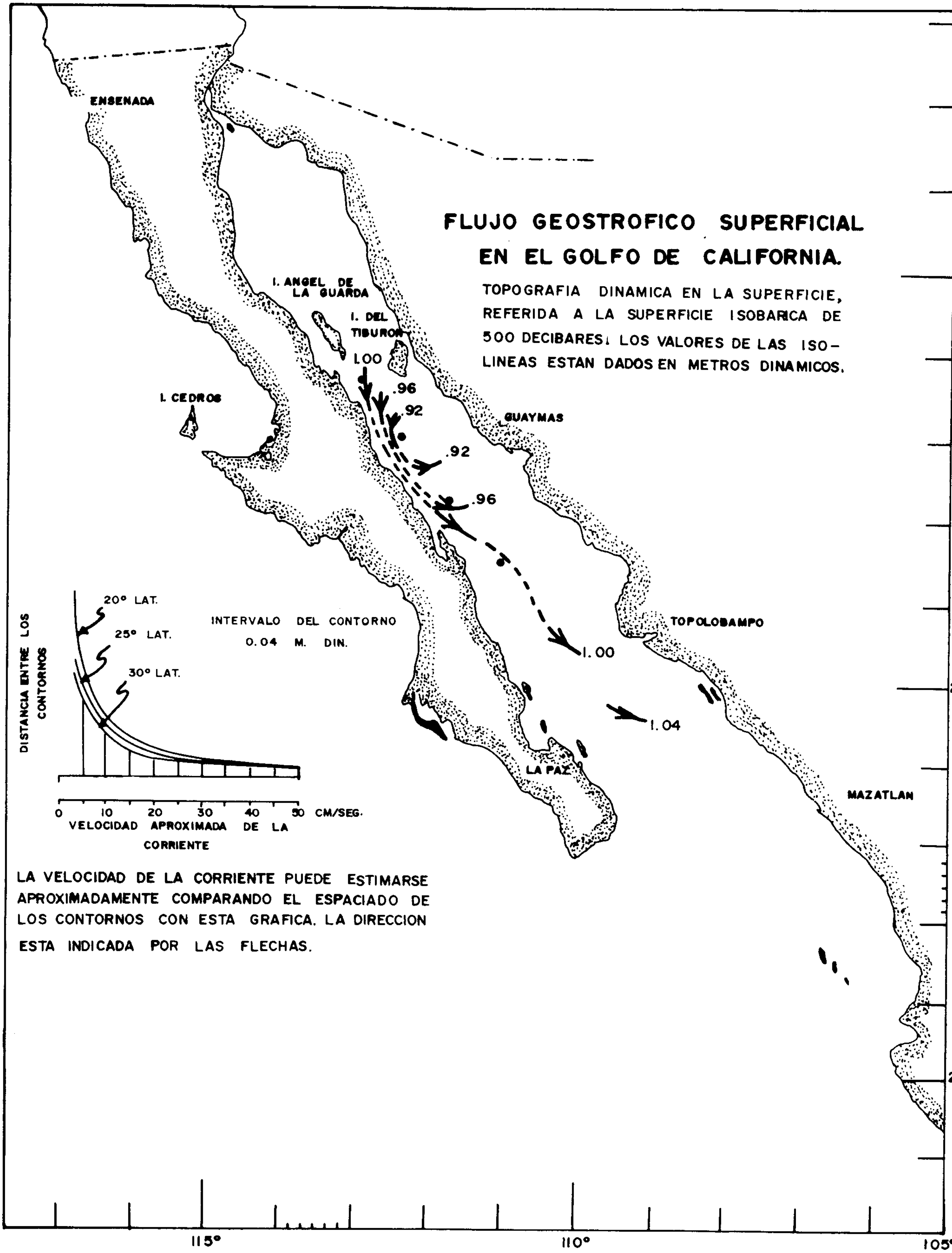

Figura 1. Flujo geostrofico superficial en el Golfo de California—noviembre de 1963.

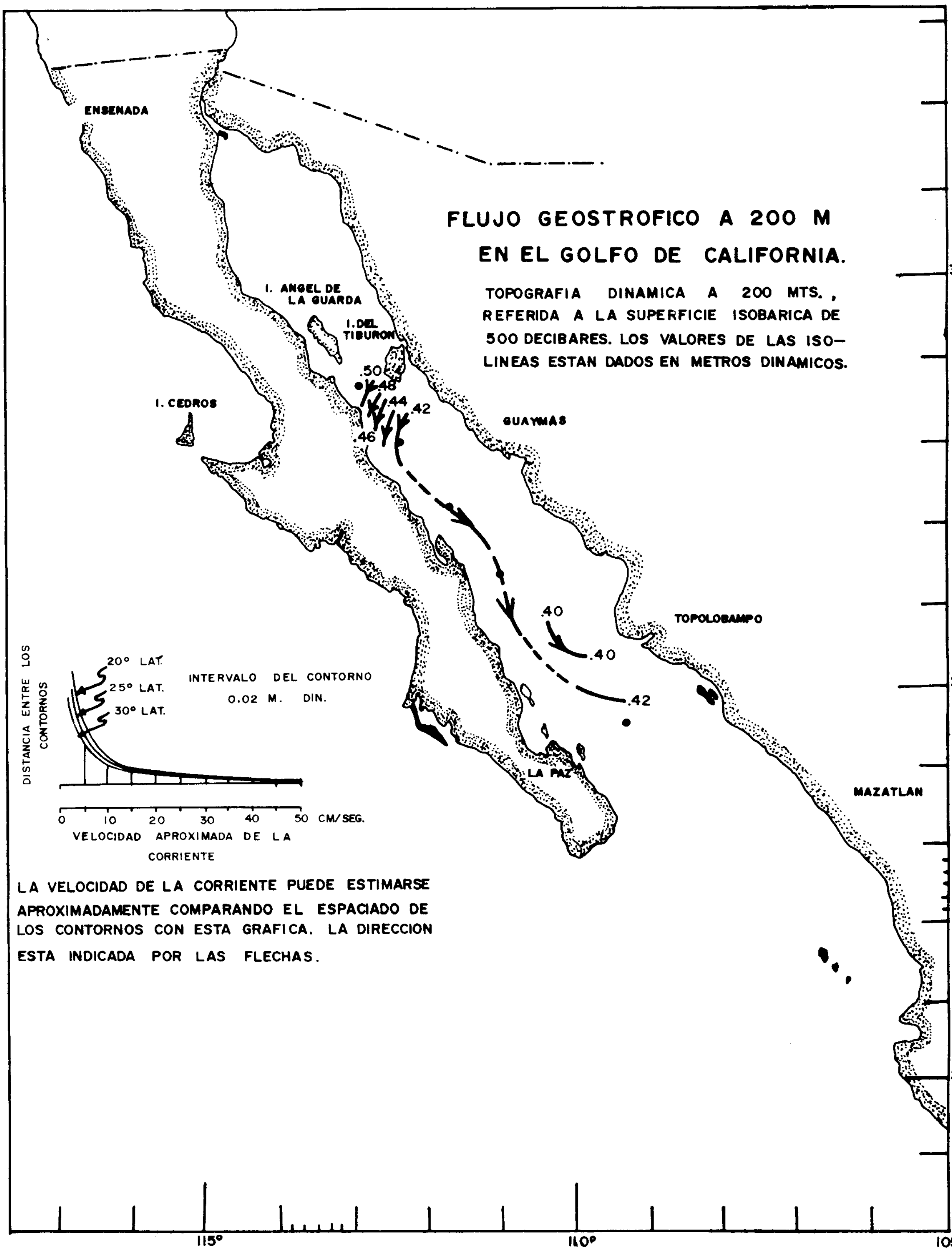

Figura 2. Flujo geostrofico e 200 m en el Golfo de California—noviembre de 1963.

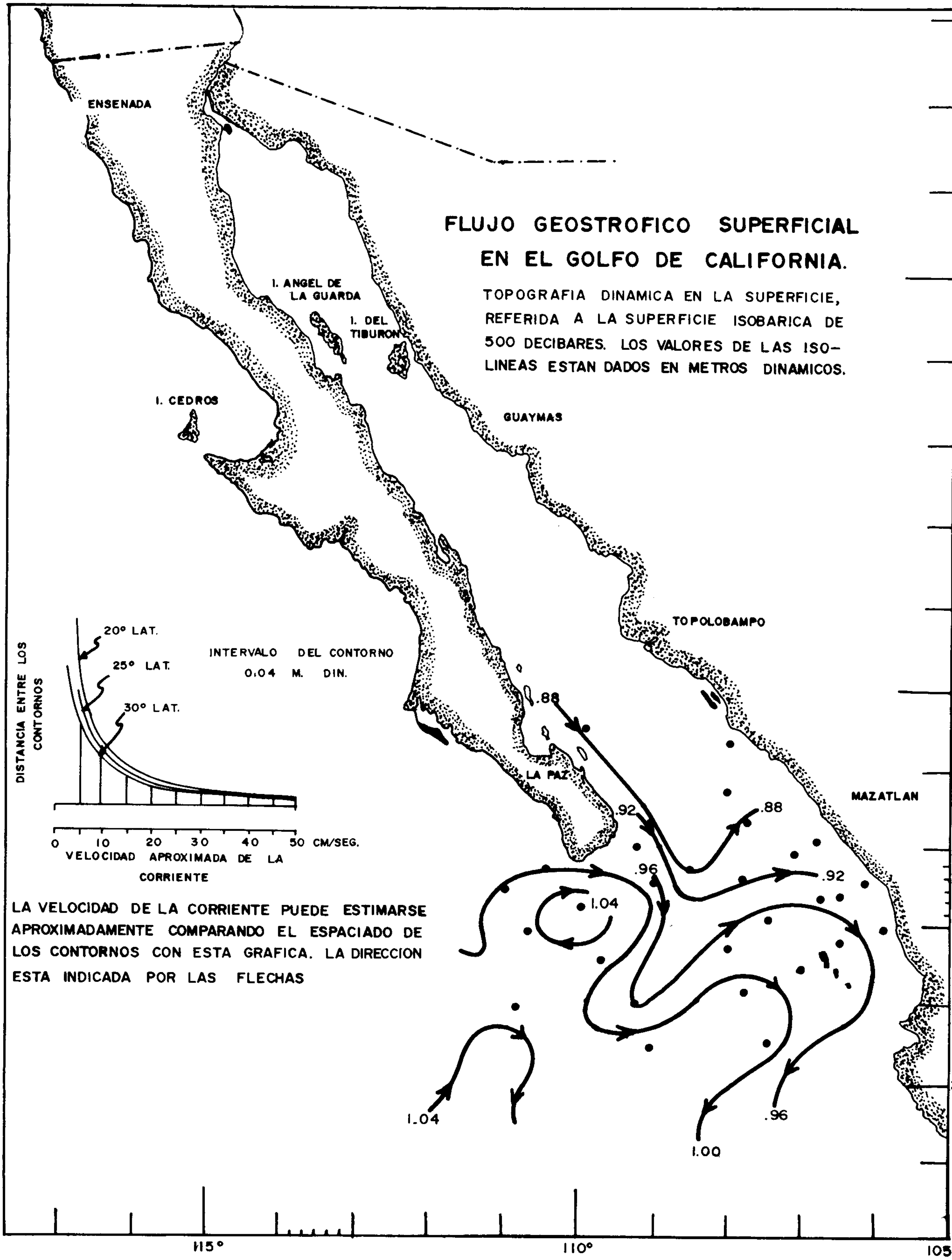

Figura 3. Flujo geostrofico superficial en el Golfo de California—noviembre y diciembre de 1956.

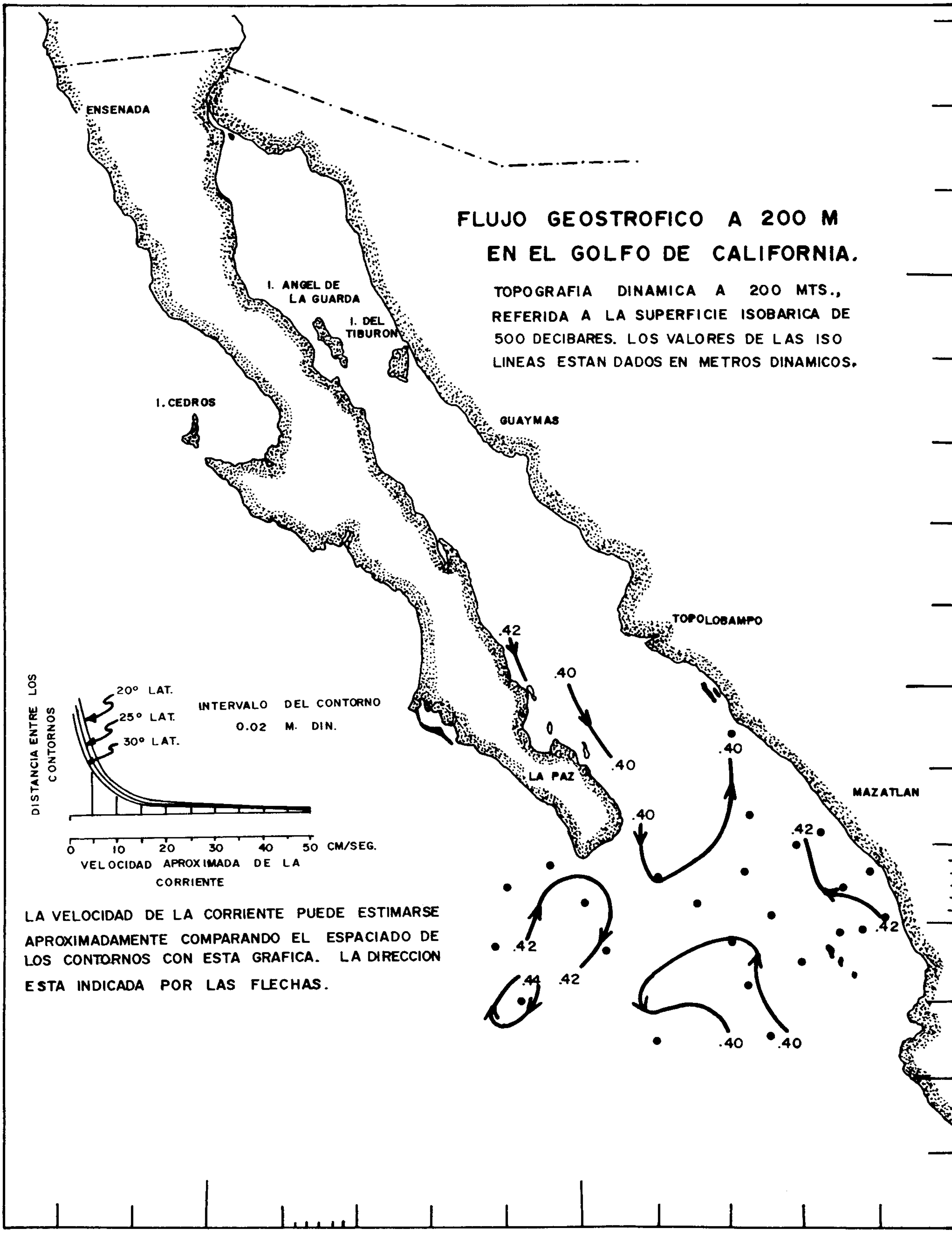

Figura 4. Flujo geostrofico a 200 m en el Golfo de California—noviembre y diciembre de 1956.

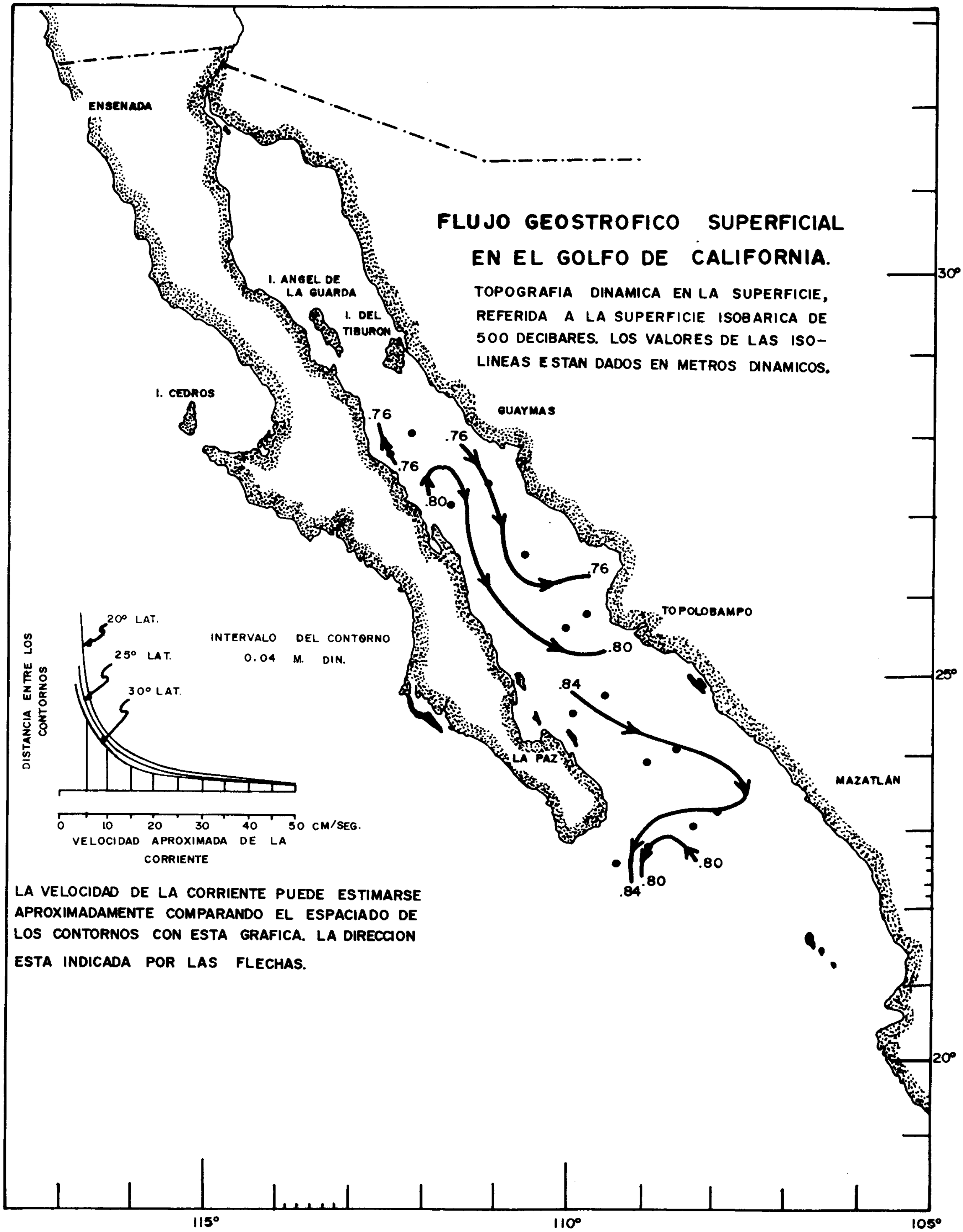

Figura 5. Flujo geostrofico superficial en el Golfo de California—febrero de 1956.

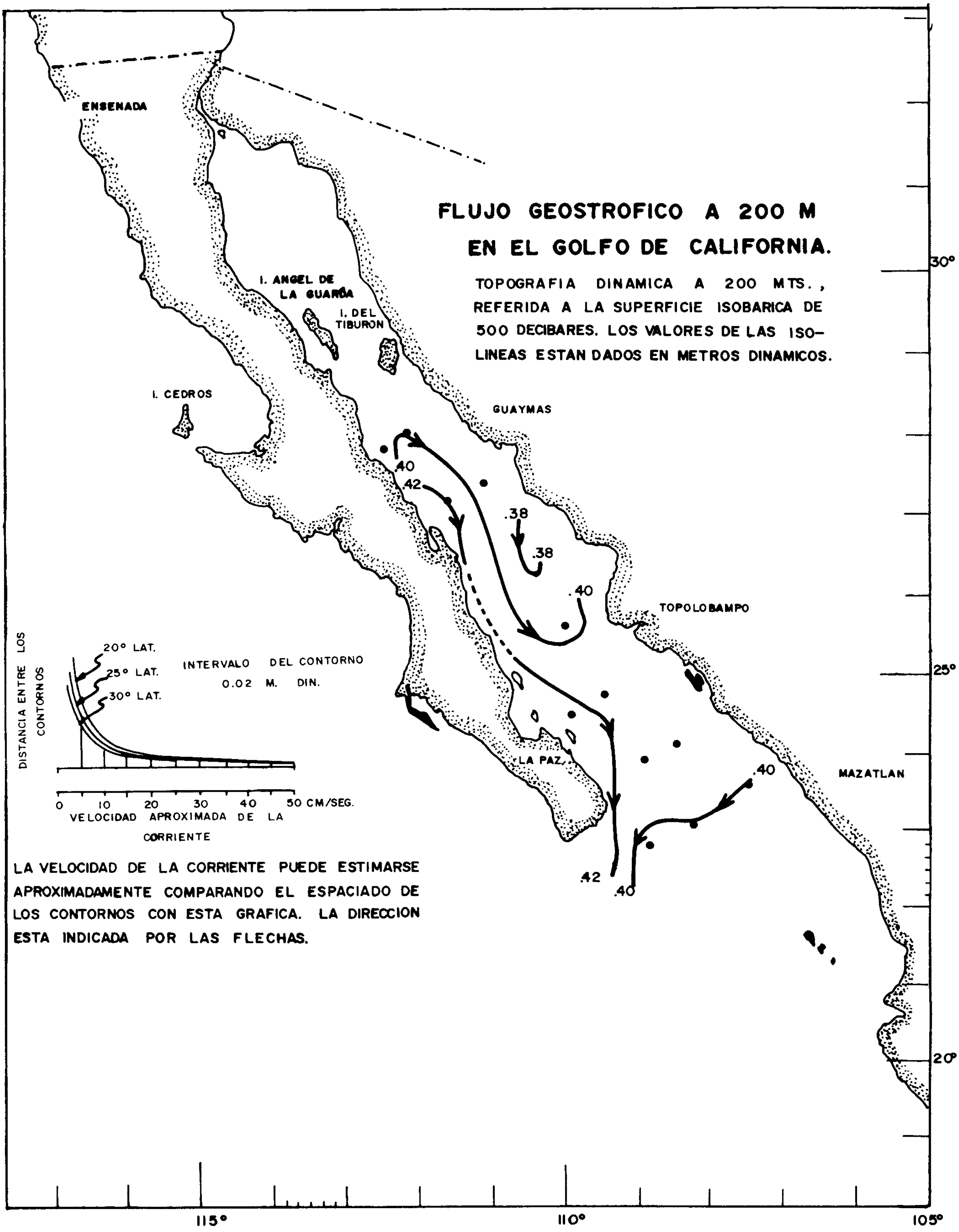

Figura 6. Flujo geostrofico a 200 m en el Golfo de California—febrero de 1956.

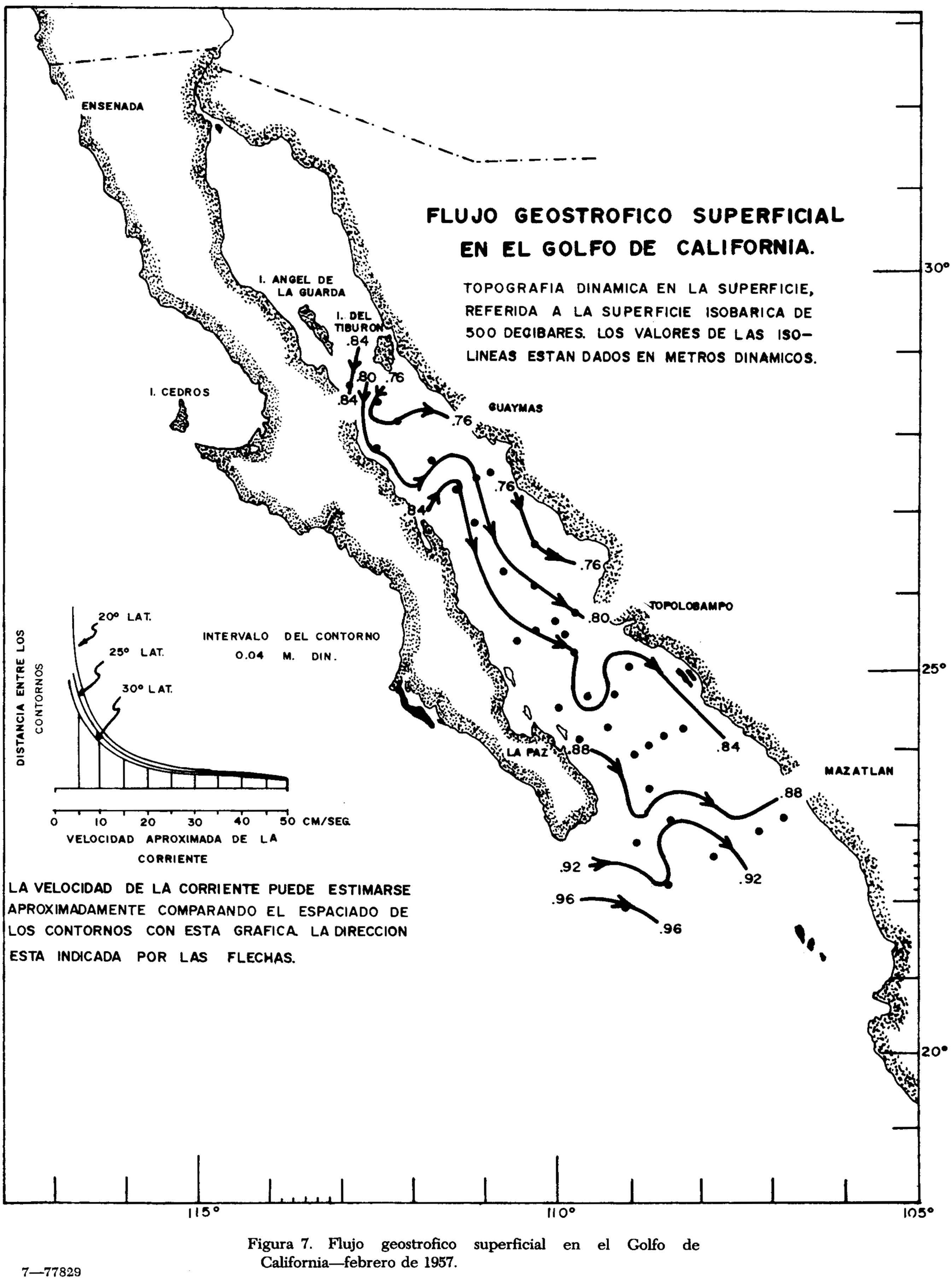

Figura 7. Flujo geostrofico superficial en el Golfo de California—febrero de 1957.

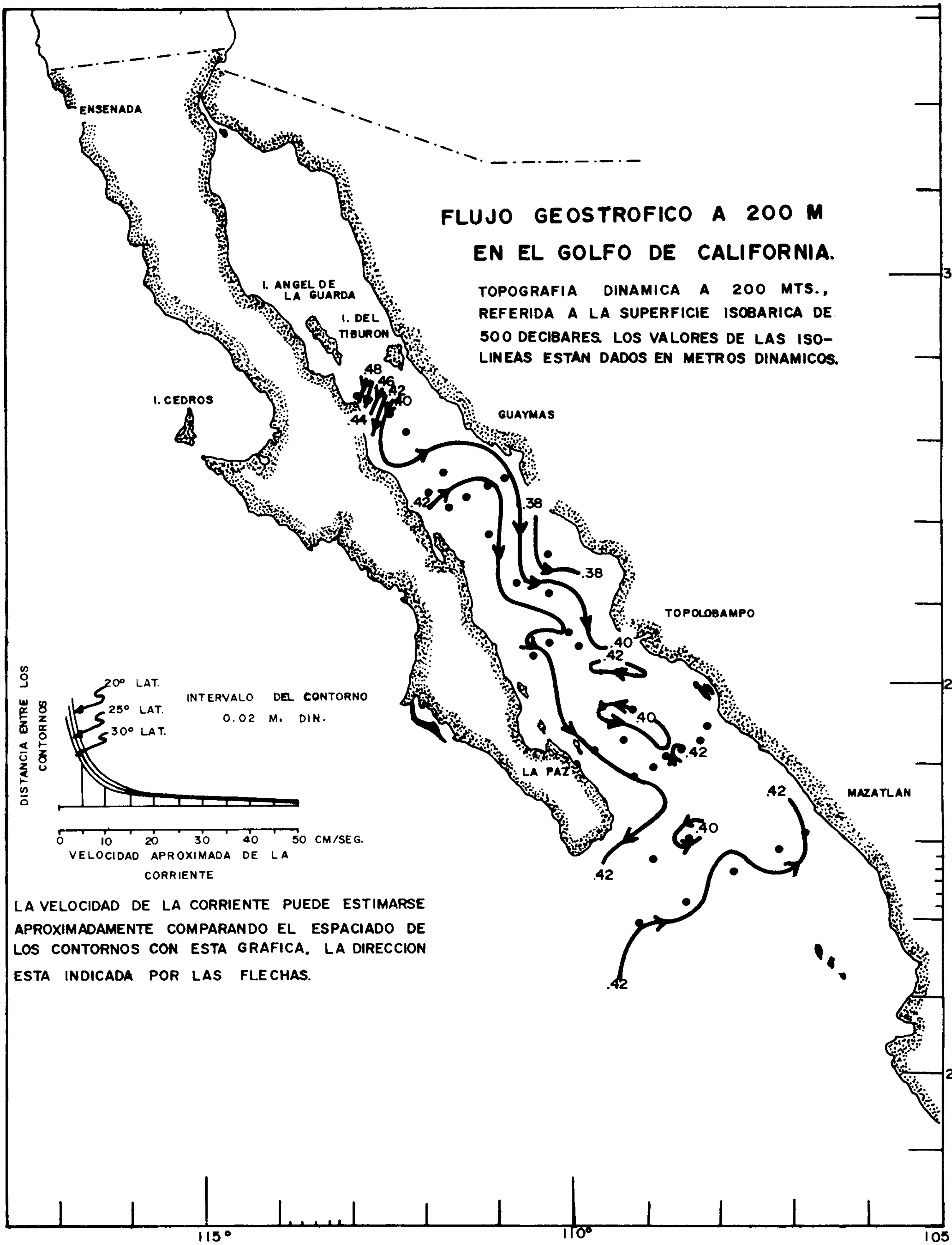

Figura 8. Flujo geostrofico a 200 m en el Golfo de California—febrero de 1957.

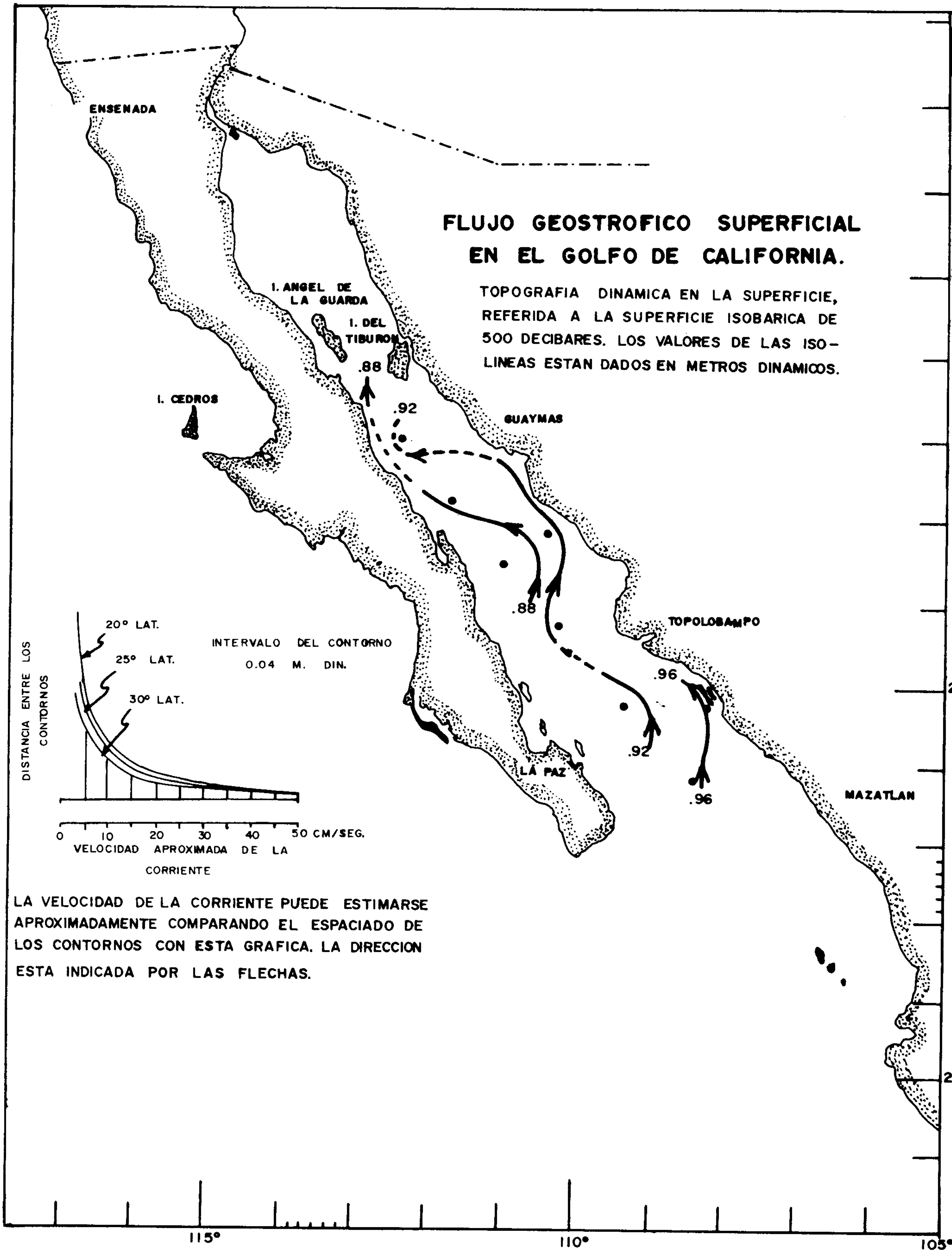

Figura 9. Flujo geostrofico superficial en el Golfo de California—mayo y junio de 1965.

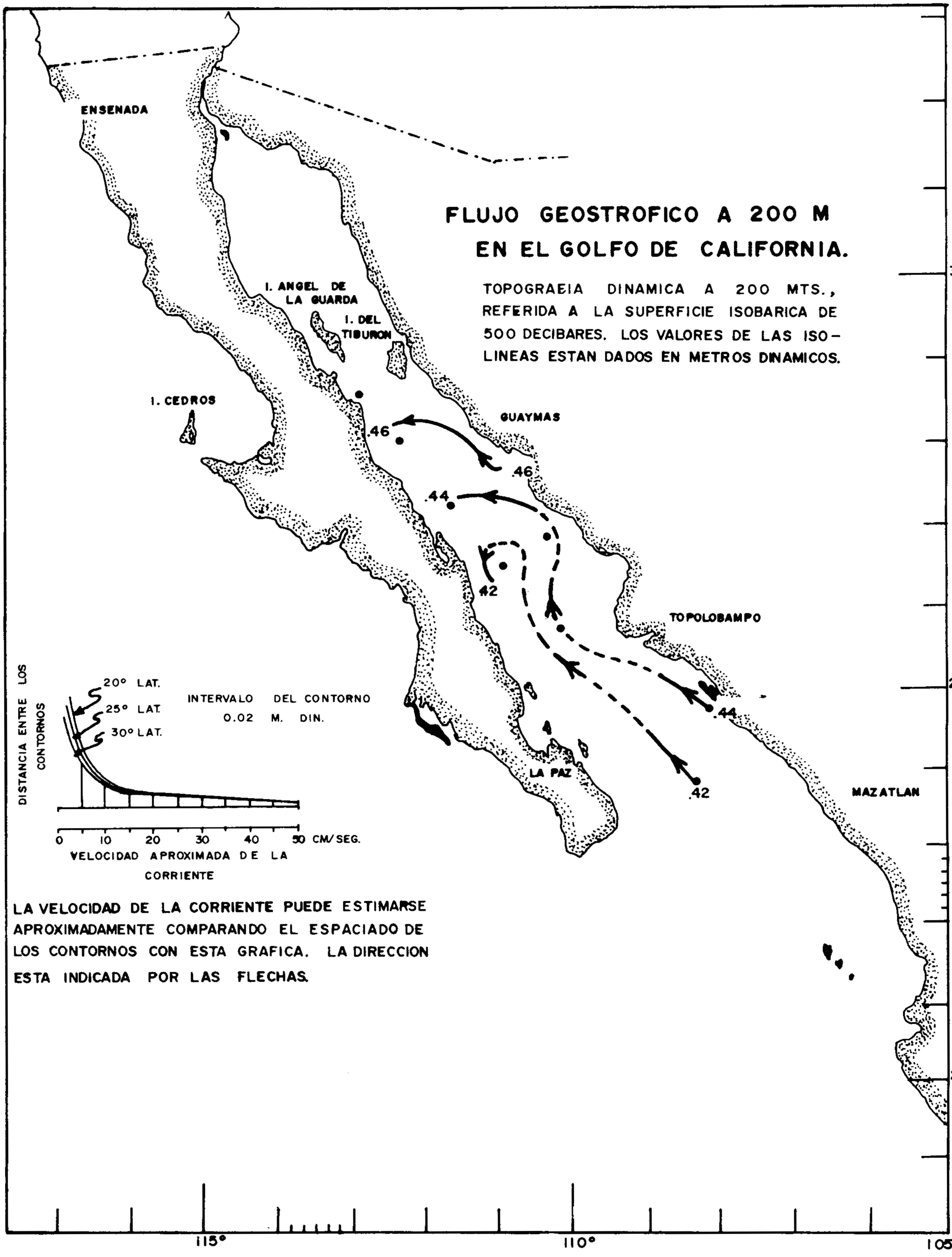

Figura 10. Flujo geostrofico a 200 m en el Golfo de California—mayo y junio de 1965.

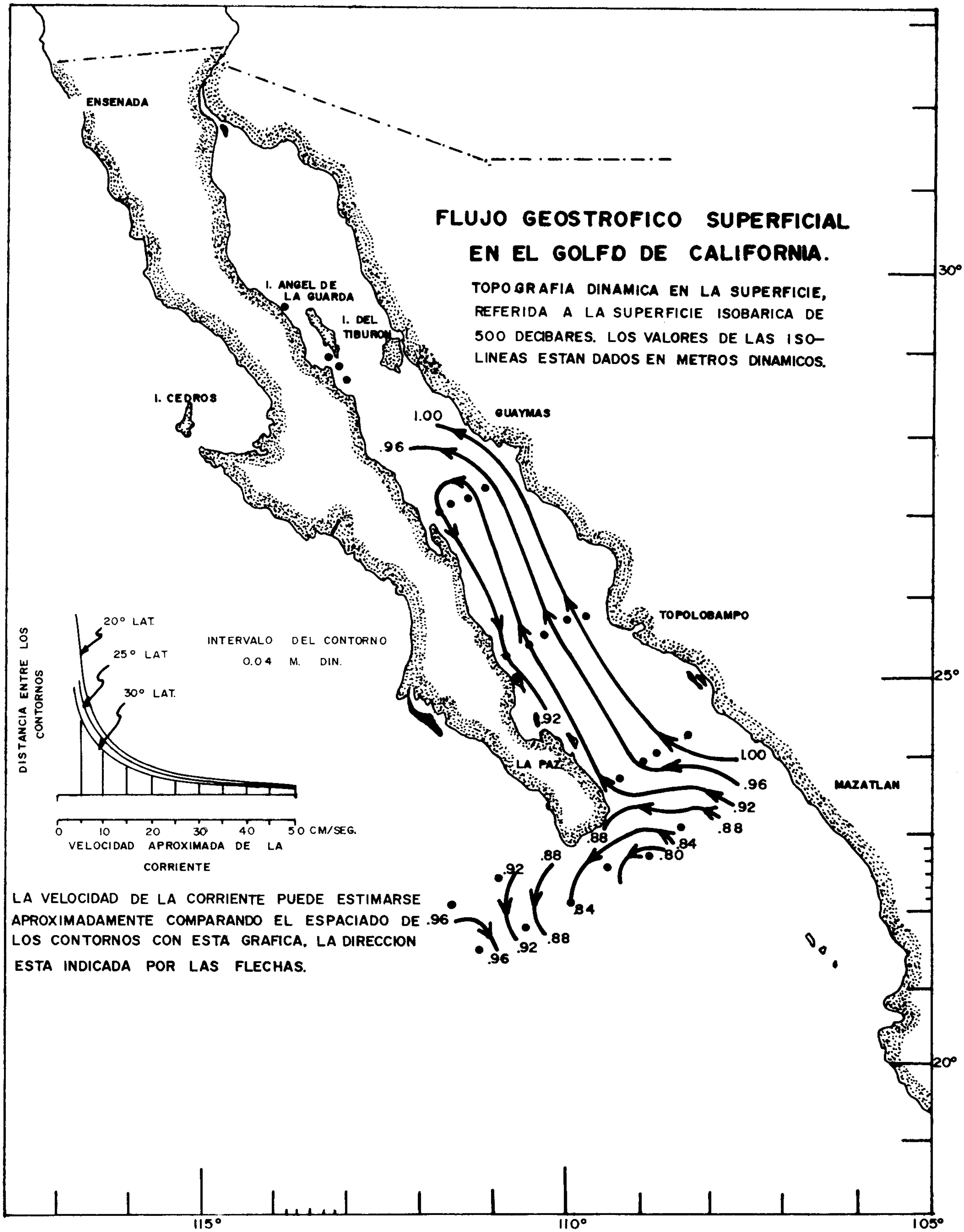

Figura 11. Flujo geostrofico superficial en el Golfo de California—junio de 1957.

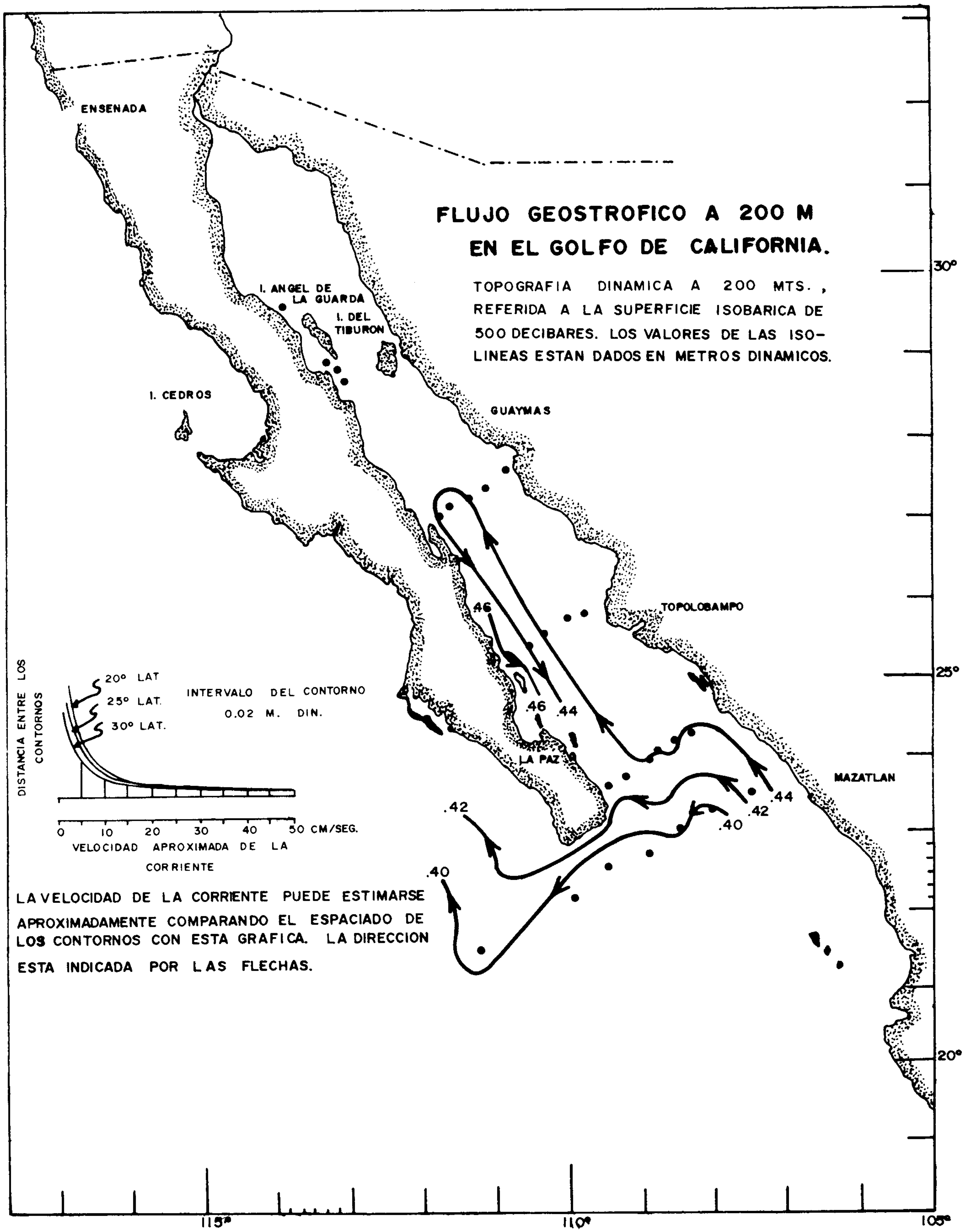

Figura 12. Flujo geostrofico a 200 m en el Golfo de California—junio de 1957.

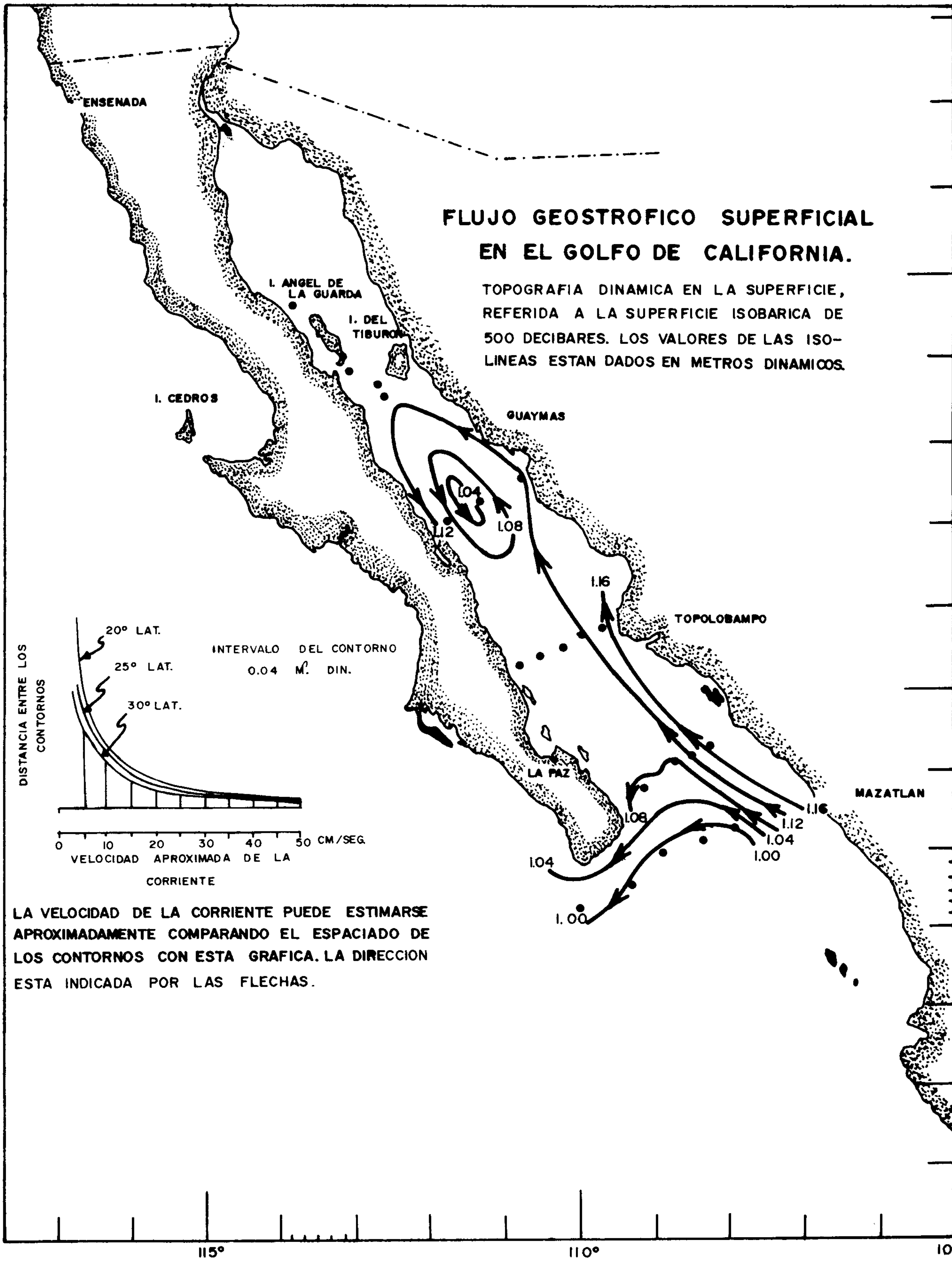

Figura 13. Flujo geostrofico superficial en el Golfo de California—agosto de 1957.

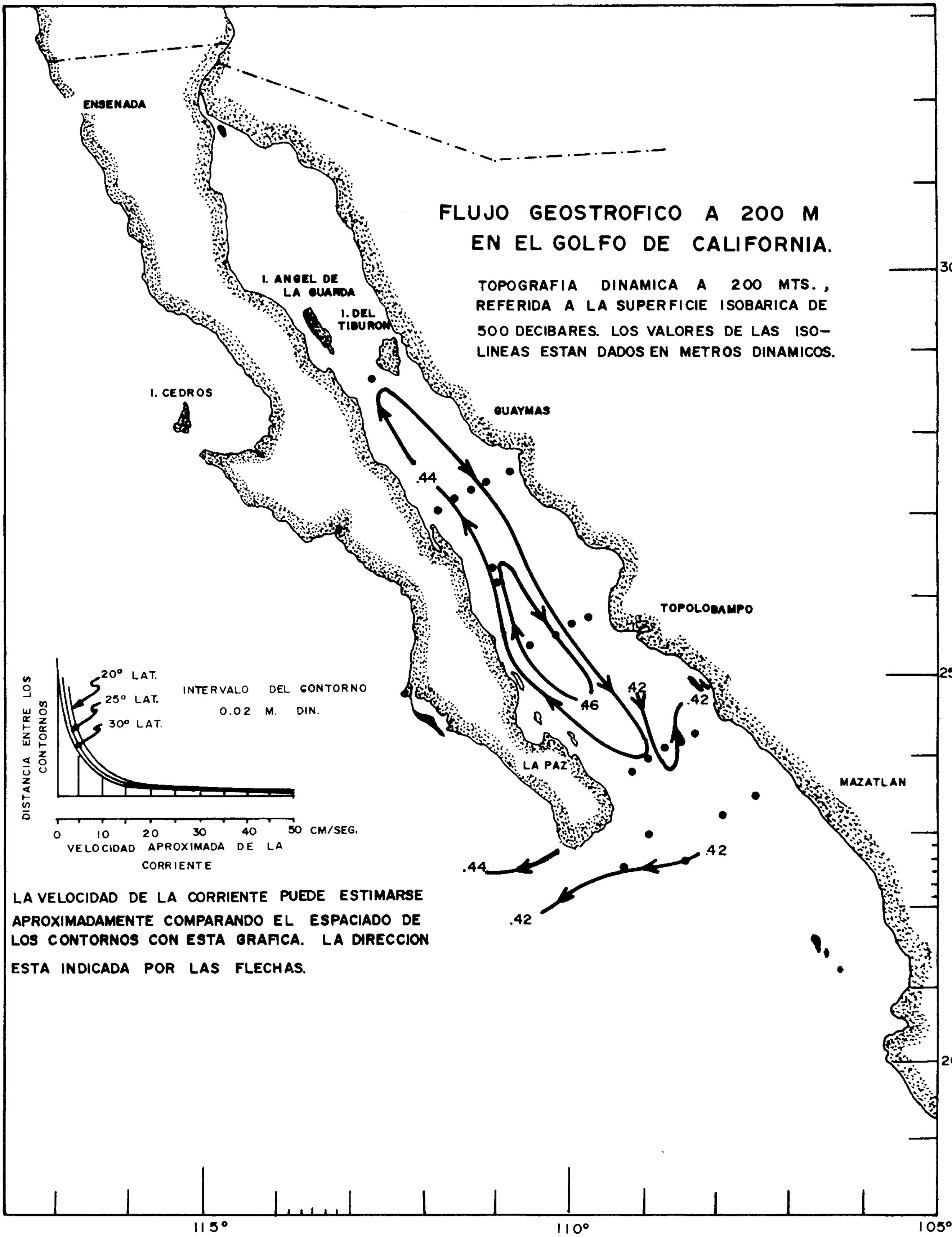

Figura 14. Flujo geostrofico a 200 m en el Golfo de California—agosto de 1957.

RESULTADOS

Invierno

Se tuvieron datos para todos los meses de invierno, excepto para el mes de enero.

Para el mes de noviembre de 1963 se tuvieron una serie de estaciones oceanográficas situadas casi a lo largo del eje central del golfo, con las que pudo observarse muy vagamente un flujo con tendencia hacia el sureste, tanto en la superficie de 0 m como en los 200 m (Figuras 1 y 2).

En noviembre y diciembre de 1956 la circulación en la superficie se mantuvo hacia el sureste, por el lado de la Península de Baja California, desde la latitud 25° N hasta alcanzar la zona de entrada en la latitud 22° 50′ N, en donde toma una dirección hacia el este, dirigiéndose contra la costa de Sinoloa. (Figura 3). La velocidad observada en este nivel fué de 40 cm/seg en la boca por el lado de la península. En el nivel de los 200 m también se observó un flujo hacia el sureste, pero con velocidades más lentas (Figura 4).

En febrero de 1956 (Figura 5) la circulación superficial sepresentó hacia el sureste con una velocidad aproximada de 16 cm/seg frente a Guaymas, disminuyendo considerablemente en la boca hasta presentarse una corriente casi nula, pero en la zona de entrada frente a Cabo San Lucas, se observó una velocidad de 35 cm/seg con dirección hacia el sur. En el nivel de los 200 m (Figura 6) se observó la misma tendencia de la corriente hacia el sureste, con velocidades aproximadas de 15 cm/seg frente a Cabo San Lucas, y de 9 cm/seg cerca a Guaymas y un flujo muy débil en la boca.

En febrero de 1957 la velocidad de la corriente superficial alcanzó hasta 35 cm/seg al sur de Isla Tiburón, y 23 cm/seg a la altura del paralelo 27° N con dirección de flujo hacia el sureste (Figura 7). Entre La Paz y Topolobampo la circulación fué débil, y en la boca fué de 4 cm/seg. En la zona de entrada, la tendencia fué hacia el este con velocidades de 10 cm/seg y 17 cm/seg. En el nivel de los 200 m, la dirección de la corriente fué también hacia el sureste con una velocidad máxima de 25 cm/seg al sureste de Isla Tiburón (Figura 8). En la latitud 26° 30′ N se observaron velocidades de 15 cm/seg, y en la boca de 5 cm/seg con dirección hacia la parte exterior del golfo por el lado de la peninsula. Frente a Cabo San Lucas, la dirección de la corriente fué hacia el suroeste. Entre las latitudes 24° N y 25° N se observó un giro con movimiento en sentido contrario a las manecillas del reloj.

Verano

En mayo y junio de 1965 la corriente superficial y de 200 m fué hacia el noroeste. Fué observado un flujo superficial desde los 24° N hasta los 27° N cerca a Guaymas, con velocidades de 20 cm/seg y 9 cm/seg (Figura 9). En el nivel de los 200 m se apreci una velocidad aproximada de 10 cm/seg en la latitud 25° 30′ N, pareciendo fluir a lo largo del eje central cerca a Topolobampo hacia la parte central del golfo (Figura 10).

En junio de 1957 fué notable la observación de corrientes superficiales hacia el noroeste con velocidades mayores de 20 cm/seg fluyendo desde la boca hasta la latitud 28° 30′ N (Figura 11). La velocidad máxima que se pudo estimar fué de 25 cm/seg frente a Cabo San Lucas, dirigiendose hacia el suroeste. En la profundidad de 200 m, la dirección de la corriente también fué hacia el noreste, fluyendo casi a lo largo del eje central desde los 24° N hasta los 26° N, de donde se regresa hacia el sureste paralela a la costa de la península con velocidad de 10 cm/seg en la latitud 25° N (Figura 12). En este nivel se observó un flujo frente a Cabo San Lucas, dirigiéndose hacia el suroeste con velocidades de 17 cm/seg.

En agosto de 1957 la circulación superficial fué hacia el noreste, con velocidades de 35 cm/seg en la boca, entrando por el lado este del golfo, y de 15 cm/seg, que es la velocidad media de un giro con movimiento en sentido contrario a las manecillas del reloj, observado en la latitud 27° 30′ N (Figura 13). En el nivel de los 200 m se observó un gran giro con movimiento en el mismo sentido a las manecillas del relój con velocidad aproximada de 15 cm/seg en la latitud 25° N (Figura 14).

DISCUSION

Las corrientes geostróficas deducidas en el presente trabajo son relativas, ya que está relacionadas a cualquier movimiento posible sobre la superficie de 500 db. Todos los datos de velocidades son valores observados. La circulación superficial y de 200 m fueron semejantes, presentándose velocidades más lentas en el nivel de los 200 m (Roden, 1964). Se pudo observar que la velocidad de la corriente disminuyó con la latitud, presentándose velocidades más grandes al suroeste de Isla Tiburón, posiblemente influenciadas por las corrientes de mareas, que son comunes en esa área (Roden, 1964), las cuales representan una complicación en el uso del cálculo geostrófico para la determinación de las corrientes (Stevenson, 1970).

Durante la época de invierno, la circulación geostrófica fué predominante hacia el sureste, cuando los vientos soplan del noroeste, paralelos a la costa este del golfo. Estos vientos alejan las aguas superficiales de la costa este (Roden, 1958), apilándolas contra la costa de Baja California, las aguas más densas de lascapas inferiores reemplazan a las menos densas de las aguas superficiales, produciendo desplazamientos ascendentes, dando como resultados las surgencias que son caracteristicas en el lado este de la región. Cuando el campo de densidad alcanza una condición estable, las corrientes resultantes, suponiendose un equilibrio geostrófico, se desarrollan hacia el sureste, con las aguas más densas en la parte este y las menos densas en el lado oeste (Alvarez, 1974). La circulación hacia el sureste en invierno están, razonablemente de acuerdo con la circulación superficial generalizada del golfo para esta época, con velocidades entre los 35 cm/seg y 40 cm/seg en noviembre, diciembre y enero. Para esta época, Roden (1972) observó velocidades comunes de 40 cm/seg y 50 cm/seg en el área de entrada del golfo. La circulación en el nivel de los 200 m fué semejante a la superficial, pero con velocidades más lentas. La velocidad observada en este nivel fué de 25 cm/seg al suroeste de Isla Tiburón, la cual fué disminuyendo con la latitud.

La circulación en el verano también coincide con la circulación generalizada del golfo para esta época, es decir, que las corrientes tienden hacia el noroeste desde la boca hasta la latitud 28° N, cuando los vientos soplan del sureste (Roden, 1964; Hubbs y Roden, 1964), repitiéndose posiblemente el mismo mecanismo que en el invierno pero en forma inversa, ya que existen evidencias de surgencias en el lado oeste (Roden y Groves; 1959). El agua superficial pareció entrar al golfo por el lado este en la mayoría de las veces, y la de los 200 m a lo largo del eje central Roden y Groves (1959) concluyen que el agua entra al golfo con más frecuencia por el lado este, concentrada cerca de los 100 m de profundidad, conclusiones que son dadas en base a la distribución de la salinidad. Las velocidades en el nivel superficial mayores de 30 cm/seg son pocas veces presentes para los datos de este estudio, aunque se observó una velocidad de 35 cm/seg en agosto de 1957. En el nivel de los 200 m, la velocidad máxima observada fué de 10 cm/seg en la mayoría de las veces. Frente a Cabo San Lucas, la corriente se presentó paralela a la costa, con dirección hacia el sur-suroeste durante todo el verano, estando de acuerdo con Hubbs y Roden (1964) con velocidades hasta de 25 cm/seg. En agosto de 1957 se observaron giros en la circulación superficial y en los 200 m. El giro superficial se desarrolló en sentido contrario a las manecillas del relój, y el de los 200 m en el mismo sentido a las manecillas del relój. El remolino superficial fué observado en la latitud 27°30'N, y el de los 200 m desde los 24° N hasta los 28° N. Estos giros parecen indicar flujos inversos, esto es, el que agua superficial circula hacia el sureste por el lado oeste y hacia el noroeste por el este. En el nivel de los 200 m la circulación es invertida.

CONCLUSION

Existe mucha diferencia en la circulación entre el invierno y verano. En invierno la circulación es completamente hacia el sureste y en el verano la circulación se invierte. Parece ser que las velocidades más grandes se observaron con mayor frecuencia en invierno que en verano. Existe la evidencia de que los vientos son los responsables de la circulación superficial dentro del golfo (Hubbs y Roden, 1964). La velocidad de la corriente en el nivel de los 200 m fué más lenta que en el nivel superficial. En el invierno, la velocidad fué superior a 35 cm/seg en la superficie, y de 15 cm/seg en los 200 m. En el verano, la velocidad en la superficie fué menor a los 35 cm/seg, y en el nivel de los 200 metros alcanzó hasta 10 cm/seg.

En el invierno pudo observarse que la velocidad disminuyó hacia el sureste, y en el verano hacia el noroeste, esto es, que la velocidad disminuyó en dirección al flujo. En el verano, el agua superficial entró al golfo por el lado este en la mayoría de los casos, y en el invierno el flujo hacia el exterior se observó por el lado de la península.

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CLIMATOLOGY OF UPWELLING RELATED PROCESSES OFF BAJA CALIFORNIA

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ABSTRACT

Marine surface data are used to describe large scale features of upwelling and certain related processes off the west coast of Baja California. The offshore-directed component of sea surface Ekman transport, computed from the wind stress distribution, is considered an index of coastal upwelling intensity. Upwelling appears to be strongest south of 30°N latitude, from March to June. Departures from randomness in the offshore Ekman transport signals include the annual and diurnal periodicities, an energetic irregular rhythm in the "event" frequency range (several day to several week periods), and two types of persistence. A short-term persistence appears to be related to the duration of synoptic scale atmospheric disturbances, while a much longer-term persistence may be related to a feedback mechanism between the upwelling and the overlying wind stress field.

The longshore current field is highly correlated seasonally with the upwelling cycle. Strong equatorward surface flow is indicated during the spring upwelling maximum; during the fall there is generally a poleward component of flow. Wind stress curl distributions indicate a tendency for the surface wind drift to be convergent (negative curl) in the offshore region. From Punta Baja to Punta Eugenia the convergent area extends to the coast. Areas of divergent surface drift (positive curl) extend several hundred kilometers off the coast north of Punta Baja and south of Punta Eugenia. From a "Sverdrup transport" point of view, this pattern is consistent with evidence of separate cyclonic gyral circulations north of Punta Baja and south of Punta Eugenia.

INTRODUCTION

Coastal upwelling is a highly fluctuating process which can have important effects on fishery resources. The role of upwelling in bringing nutrients into the surface layers where they are available for organic production is widely recognized. A related process that may enhance production is the dispersion of grazing organisms by the diverging surface waters, thereby reducing grazing pressure on the phytoplankton stock. In addition to these effects at the very base of the food web, upwelling can alter the temperature distribution, field of motion, stratification, and other characteristics of the physical environment, affecting marine organisms at various levels of their life processes.

At the Pacific Environmental Group we are developing descriptions of upwelling phenomena to aid fishery researchers in accounting for such effects. To be most useful these descriptions should have continuity over the broad space scales and long time scales involved in fishery work. In addition it is desirable that they be continually updated and hindcast over past periods for which knowledge of a fishery is available. Our approach, consequently, has been to avoid basing our work on dedicated observational programs but rather to try to construct a useful descriptive system from observatons routinely reported by ships at sea, weather stations, etc.

Our collocation with the U.S. Navy's Fleet Numerical Weather Central (FNWC) in Monterey, California, provides access to a broad data base including archived historical data, analyzed meteorological products, and real time reports. Several data sources have proven most fruitful. The National Climatic Center's file of marine surface observations has been useful in defining the climatological seasonal cycles. This file contains over 38 million individual ship reports, dating back into the nineteenth century. Similar real-time ship reports continue to be delivered via the international data networks. To describe variations from normal seasonal conditions we have used the analyzed products, notably the surface atmospheric pressure analysis, produced by FNWC. Finally, the U.S. Naval Oceanographic Office ship drift file, which is a compilation from ships' log books of differences between dead reckoning position and accurately detemined position, has been useful as an indication of the seasonal variability of the ocean surface flow field.

Our major focus is the upwelling region off western North America. However, since the data sources are global the methods developed should be applicable to other regions, depending on the density of available data. At this stage much of our work is qualitative. Our goal is to model quantitatively many of the processes which would be useful environmental inputs to fishery management systems for upwelling regions, and to define and develop practical indicator systems to make these inputs operational.

THE SEASONAL CYCLES

To define seasonal variations, long-term composite monthly distributions of various properties were assembled from ship reports contained in the National Climatic Center's file of marine surface observations (TDF-11). After preliminary gross error checks, similar to those described by Bakun, McLain, and Mayo (1974), climatological scalar properties were compiled by computing the arithmetic means of all available reports within a specified 1-degree square area and long-term (1850–1970) month. Similarly, resultant mean vector quantities have been computed as the arithmetic means by north and east components for all reports in the area. A mean value for any month and square is therefore formed from a data set that is independent of all other months and squares. No attempt has been made to smooth the fields, either by removing data which do not appear to fit the distributions or by applying objective smoothing procedures. The mean values were contoured by machine, and "bulls eyes" in the contours, even where they possibly reflect erroneous data, were left in the figures as indications of the general degree of consistency of the composite fields.

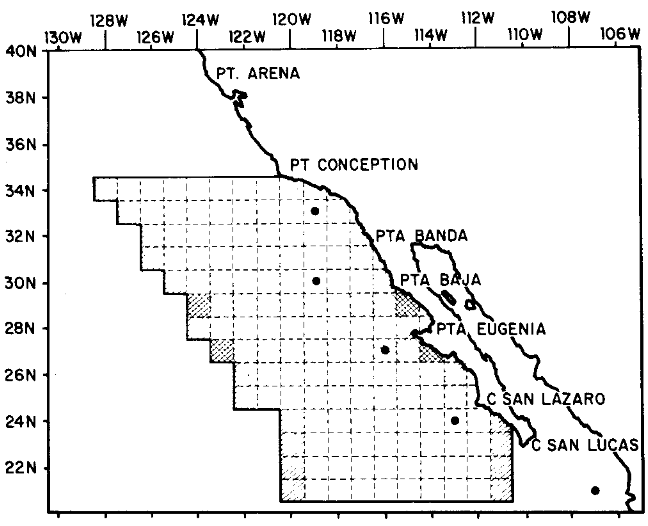

FIGURE 1. Chart of the Baja California region. The grid of 1 degree squares is used for summaries of ship observations. Shading indicates nearshore and offshore lines of selected squares parallel to the coast and lines extending westward from the coast south of Punta Baja and Punta Eugenia used for displays of time-space sections. Large dots indicate 3 degree grid intersections used to compute time series properties.

Approximately 400,000 individual reports are available for the area defined by the grid off southern California and Baja California (Figure 1). The number of reports per 1-degree square per month varies from less than five (in May in the southwest section of the grid), to 3500 (in May off Los Angeles). The spatial distribution of observations is biased in that "ship of opportunity" reports are generally confined to coastwise shipping lanes. The highest density of reports is found within 3 degrees of the coast and north of 30°N latitude. Significant temporal bias may exist, since approximately 50% of the total available observations have been taken since 1945. Nevertheless, the coherence of the resulting vector and scalar fields indicates that our composite distributions can be used to describe the dominant seasonal cycles in upwelling related processes. Moreover, comparisons between our monthly sea surface temperature fields and those of Robinson and Bauer (1971), for example, show good correlation.

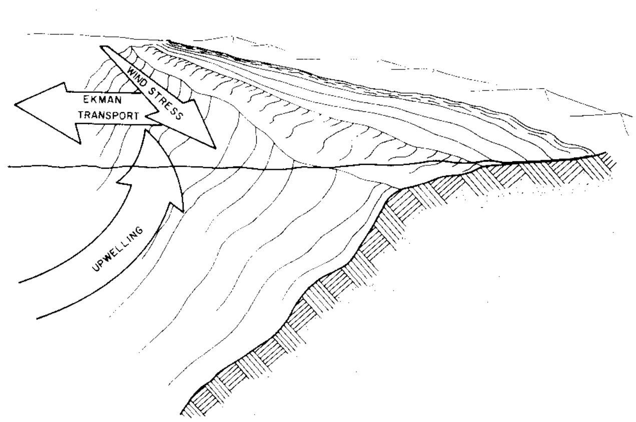

FIGURE 2. A conceptual diagram of the coastal upwelling process. The coast of the continent is represented in cutaway view with the ocean to the left of the figure. Offshore transport in the surface Ekman layer of the ocean due to stress of the wind is replaced by upwelling from depth.

In a simplified view of the coastal upwelling process, equatorward wind stress parallel to the coast induces flow in the surface layers of the ocean which is deflected offshore by the earth's rotation (Figure 2). When this occurs over a wide expanse of coast where longshore horizontal surface flow cannot compensate for that driven offshore, the balance is maintained by upwelling of deeper water. Wooster and Reid (1963) approximated the wind-driven offshore flow as Ekman transport and showed that this "index of upwelling" explained in general the observed features of coastal upwelling in broad diffuse eastern boundary currents such as exists off Baja California.

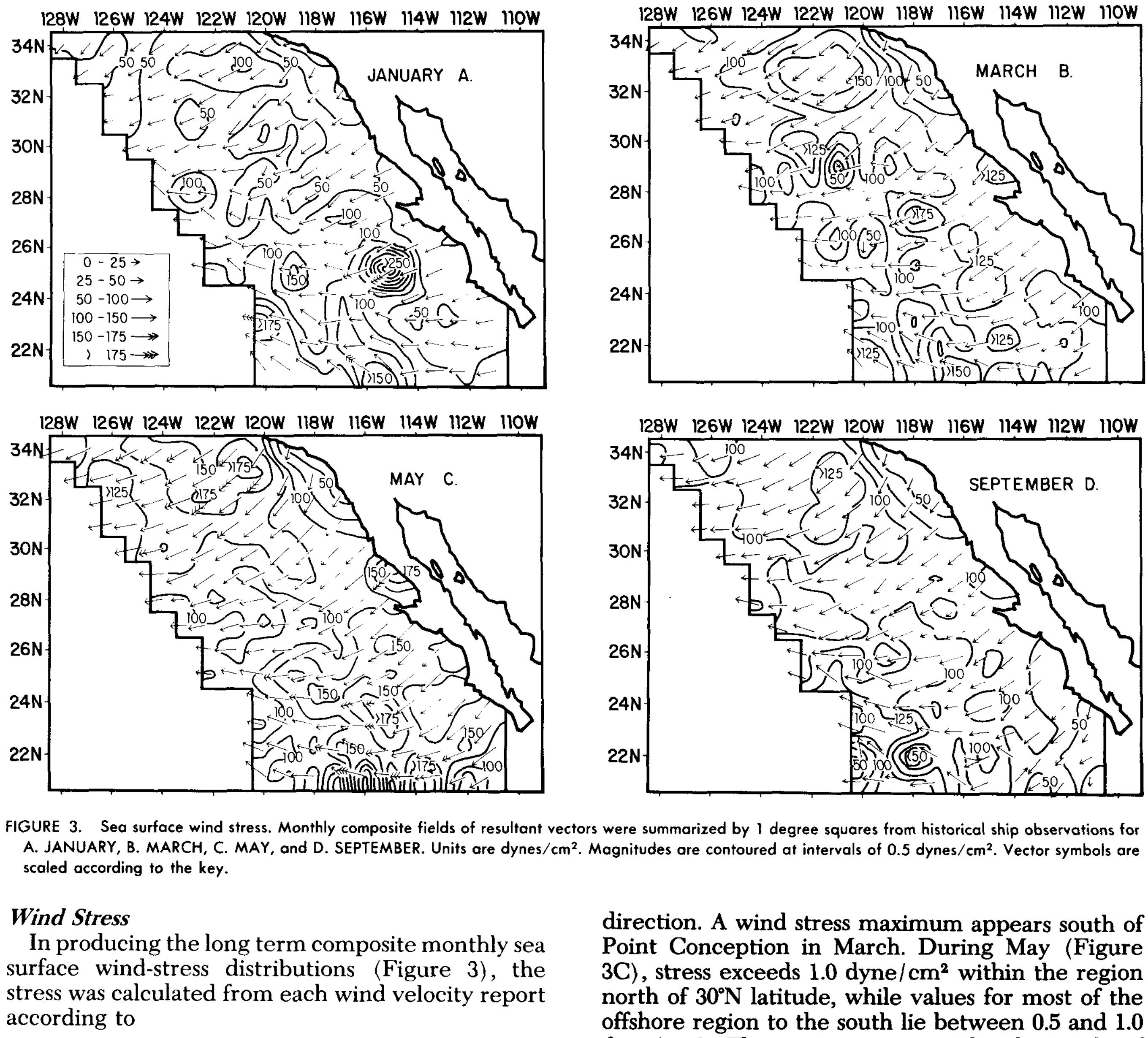

FIGURE 3. Sea surface wind stress. Monthly composite fields of resultant vectors were summarized by 1 degree squares from historical ship observations for A. JANUARY, B. MARCH, C. MAY, and D. SEPTEMBER. Units are dynes/cm². Magnitudes are contoured at intervals of 0.5 dynes/cm². Vector symbols are scaled according to the key.

Wind Stress

In producing the long term composite monthly sea surface wind-stress distributions (Figure 3), the stress was calculated from each wind velocity report according to

$$\tau = \rho_a C_D |\vec{v}| \vec{v} \quad (1)$$

where:

$\vec{\tau}$ denotes the stress vector

ρ_a is the density of air which was considered to have a constant value of 0.00122 g/cm³

$|\vec{v}|$ is the observed wind speed

$\vec{v}$ is the observed wind velocity vector

C_D is an empirical drag coefficient.

A constant drag coefficient of 0.0016 (Denman and Miyake, 1973) was employed.

The fields show the tendency for an equatorward component of stress to parallel the coast of Baja California, which implies conditions favorable for upwelling throughout the year. Most of the seasonal variability appears in magnitude rather than in direction. A wind stress maximum appears south of Point Conception in March. During May (Figure 3C), stress exceeds 1.0 dyne/cm² within the region north of 30°N latitude, while values for most of the offshore region to the south lie between 0.5 and 1.0 dyne/cm². The maximum immediately north of Punta Eugenia is a consistent feature during the spring. The mean distributions for January and September (Figures 3A and 3D) indicate relaxed conditions. Typical values of surface stress are less than 0.5 dyne/cm². A region of minimum wind stress is indicated along the coast from Point Conception to Punta Banda. This feature corresponds in location to the cyclonic eddy which dominates the ocean surface circulation in the Southern California Bight (Reid, Roden, and Wyllie, 1958).

Surface Wind Transport

Our estimates of the transport in the surface layer of the ocean due to the stress of the wind are based on Ekman's (1905) theory which leads to the following equation for the total integrated mass transport of pure drift currents:

$$\vec{V}_E = \frac{1}{f}\vec{\tau} \times \vec{k} \quad (2)$$

where:

$\vec{V}_E$ is the total mass transport resulting from an applied local wind stress

f is the Coriolis parameter

$\vec{k}$ is a unit vector directed vertically upward

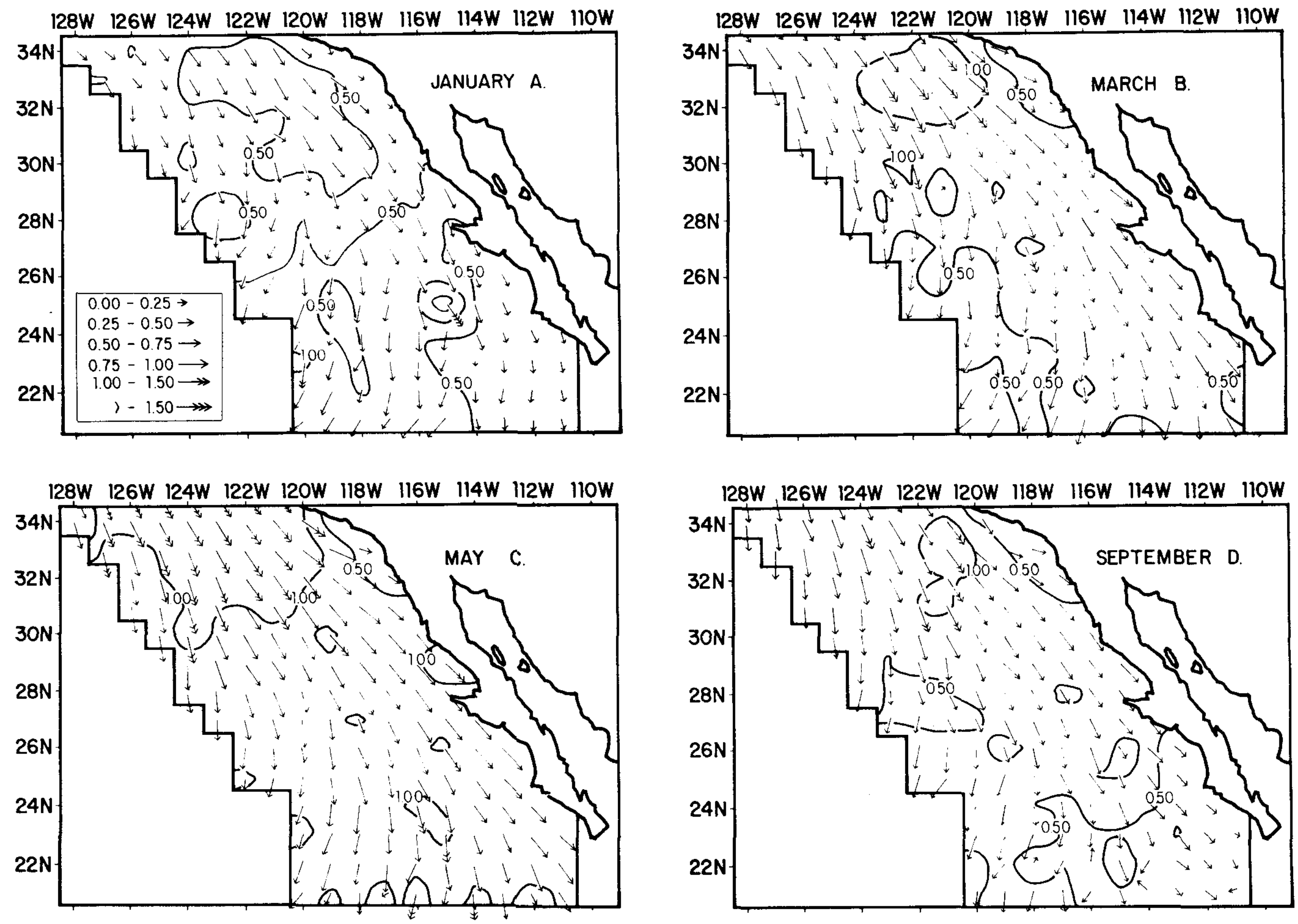

FIGURE 4. Surface Ekman transport. Monthly composite fields of resultant vectors were summarized by 1 degree squares from historical ship observations for A. JANUARY, B. MARCH, C. MAY, and D. SEPTEMBER. Units are metric tons per second per 100 meters coastline. Magnitudes are contoured at intervals of 25 units. Vectors symbols are scaled according to the key.

The relationship implies that the integrated transport is directed 90° to the right of the wind stress in the northern hemisphere.

Composite monthly fields of Ekman transport (Figure 4) were calculated by applying equation (2) to the mean distributions of surface wind stress. The mean transport is directed offshore throughout the year. Accordingly, our conceptual model (Figure 2) indicates strong upwelling in regions of coastal divergence in March and May (Figures 4B and 4C). During these months local maxima in the surface transport appear north of 30°N latitude, immediately north of Punta Eugenia, and south of 24°N, where the decrease in the Coriolis parameter leads to corresponding increases in the computed Ekman transport. Offshore gradients in the surface transport may contribute to convergences and divergences, thereby altering the distributions of organisms.

The seasonal cycle of Ekman transport (Figures 5 and 6) within the selected 1-degree squares adjacent to the coast (Figure 1) indicates the general seasonal pattern of local wind forcing of coastal upwelling. The degree of correspondence in general shape and position of the contours of absolute magnitude in the vector time series (Figure 5) with the contours of magnitude of the offshore component (Figure 6) illustrates the primarily offshore direction of wind driven surface flow off Baja California, implying some degree of upwelling on average throughout the year. Strongest upwelling appears to occur from March to June, and along the coast from 20°N to 30°N.

A maximum is apparent north of Punta Eugenia at 28°N latitude. From September to December, offshore transport weakens, and changes sign in September at 21°N. July and August, and January and February appear to be transition periods.

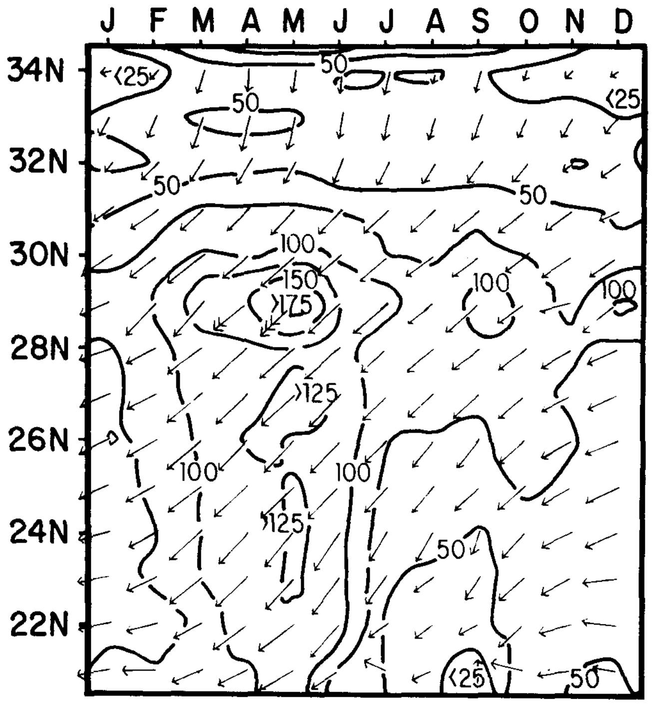

FIGURE 5. Seasonal cycle of Ekman transport near the coast. Resultant vectors were summarized by month for the group of selected 1 degree squares adjacent to the coast shown in Figure 1. Units are metric tons per second per 100 m coastline. Magnitudes are contoured at intervals of 25 units. Vector symbols are scaled according to the key in Figure 4A.

In addition to the surface Ekman wind drift, the ocean surface flow field also contains geostrophic components. Sverdrup, Johnson, and Fleming (1942, page 501) describe a linkage by which the accumulation of denser upwelled water near the coast and the transport away from the coast of lighter surface water leads to a redistribution of mass. The balance between the resulting pressure gradient and the Coriolis force produces a geostrophic current in the equilibrium state. Consequently, on a seasonal basis, one might expect variations in the offshore component of Ekman transport to be well correlated with variations in longshore flow. Indeed, investigators in CUEA have demonstrated this correspondence on shorter time scales (Huyer, et al., 1974).

Surface Currents

The only available direct measurements of ocean surface flow having reasonable spatial and seasonal coverage are reports of drift attributed to ocean currents, compiled from ships' log books. We have made seasonal summaries from the ship drift file of

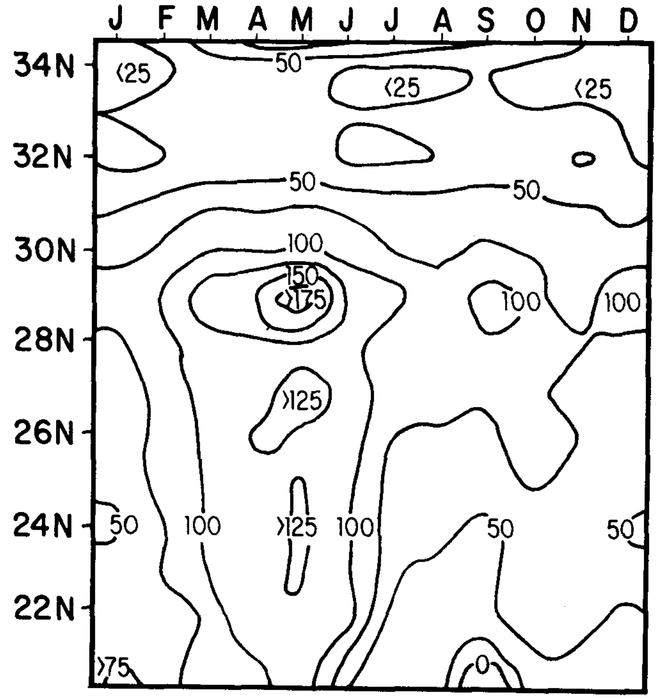

FIGURE 6. Seasonal cycle of offshore Ekman transport. Means of offshore components of Ekman transport were computed by month within the group of selected 1 degree squares near the coast shown in Figure 1. Units are metric tons per second per 100m coastline. Onshore Ekman transport is shaded.

the U.S. Naval Oceanographic Office. These data are much the same as used by Wyrtki (1965). The density of available reports is only about one-tenth that of marine surface observations and is dependent upon the primary coastwise shipping lanes. Significant bias by month and year is apparent; March, May, and November contain approximately two to four times as many observations as any other month, and most of the observations were reported prior to 1940.

Ship drift distributions are inherently noisy and require a large data base to resolve the underlying patterns. To increase the number of observations per averaged value, we have used summaries by 2-degree squares, by month (Figures 7 and 8), and by quarter (Figure 9). The precise interpretation of these measurements remains open to question since wind effects on reporting vessles are indeterminate. However, Stidd (1974) has indicated a closer correspondence of ship drift to ocean current direction than to wind direction. In addition, mean ship drift vectors are in some cases directed oppositely to mean wind vectors. The Southern California Countercurrent is an example.

A significant correlation between the longshore component of surface current (Figure 8) and the offshore component of Ekman transport (Figure 6) is apparent. Specifically, during the period of maximum offshore transport, equatorward surface flow in the California Current is strongest. Indeed, there is a correspondence between the position of

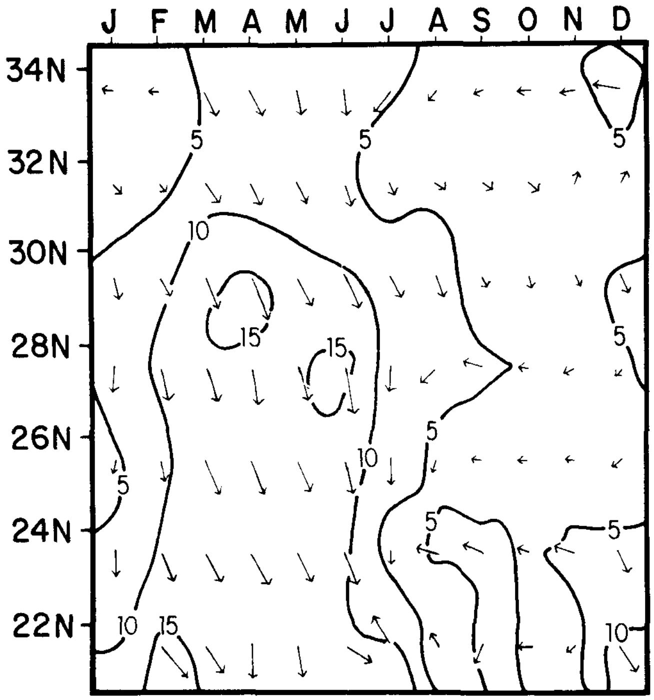

FIGURE 7. Seasonal cycle of ship drift near the coast. Resultant vector were summarized by month from the NAVOCEANO ship drift file, for a group of 2 degree squares along the coast from latitude 20°N to 34°N. Units are cm/sec. Magnitudes are contoured at intervals of 5 cm/sec. Vector symbols are scaled according to the key in Figure 9A.

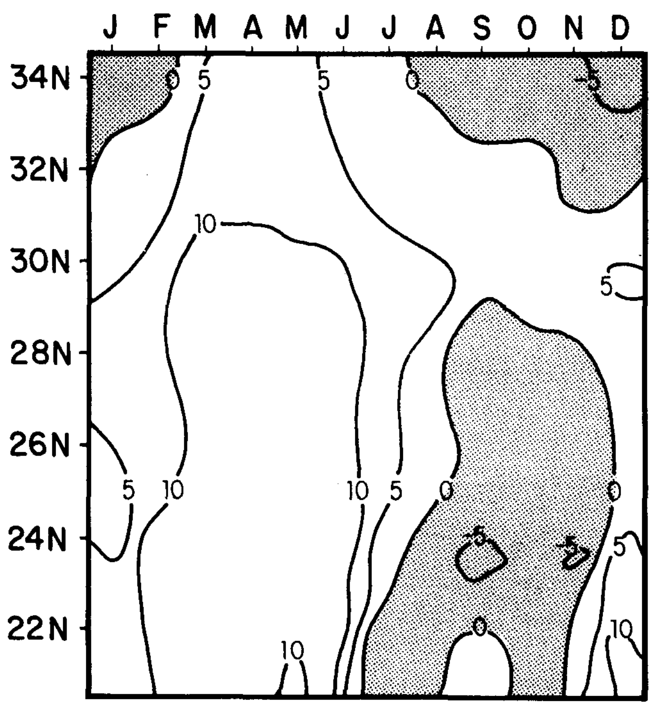

FIGURE 8. Seasonal cycle of longshore ship drift. Means of components parallel to the coast were summarized from the NAVOCEANO ship drift file for a group of 2 degree squares along the coast from latitude 20°N to 34°N. Units are cm/sec. Positive values indicate equatorward drift. Poleward drift is shaded.

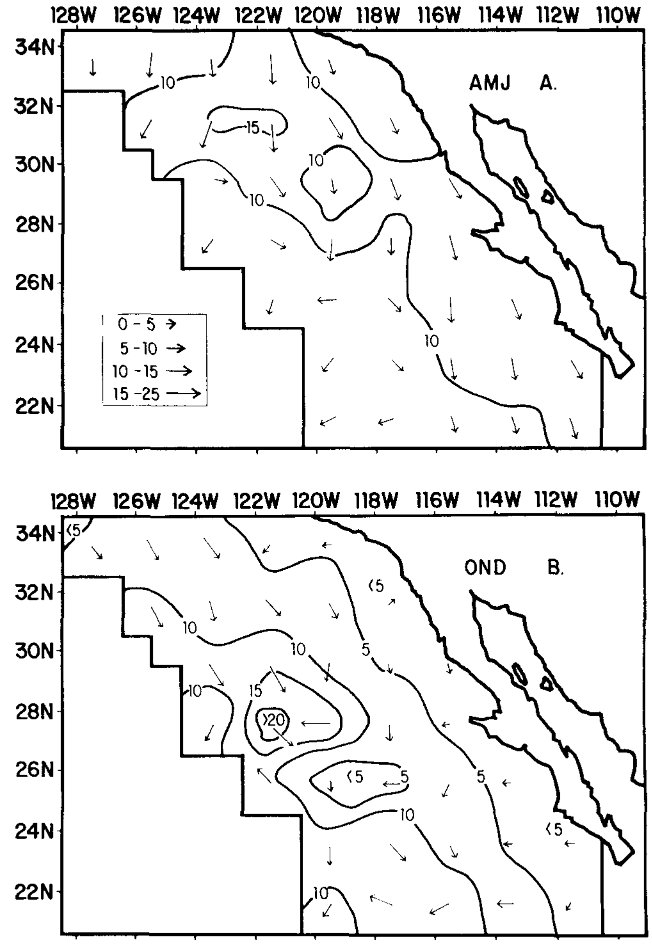

FIGURE 9. Ship drift. Composite field of resultant vectors were summarized by quarter and by 2 degree squares from the NAVOCEANO ship drift file for A. APRIL-MAY-JUNE and B. OCTOBER-NOVEMBER-DECEMBER. Units are cm/sec. Magnitudes are contoured at intervals of 5 cm/sec. Vector symbols are scaled according to the key.

the maximum offshore Ekman transport north of Punta Eugenia (Figure 5) and the position of the strongest longshore surface currents at latitude 29° N in April and May (Figure 7). During the relaxed period of upwelling, from September to December, the surface current changes direction and flows offshore, but has a definite poleward component along the coast. The surface current data indicate cyclonic flow in the Southern California Bight, where offshore Ekman transport is less than 50 metric tons per second per 100 m of coastline throughout the year. These data suggest that the surface countercurrent off Baja California may only form where offshore Ekman transport is weak.

During the spring upwelling season, surface current parallels the coast with only a slight offshore component (Figure 9A) and reaches a maximum strength of about 15cm/sec (Figure 7). During the period of relaxed upwelling, the current changes direction and slows to less than 5 cm/sec (Figure 9B). Flow is primarily offshore, but there is some suggestion of a coastal countercurrent. The lack of coherence in the distributions between 7 and 10 degrees off the coast reflects scarcity of data.

Sea Surface Temperature

Vertical and horizontal advection associated with coastal upwelling alter the patterns of surface isotherms which are approximately zonally distributed off Baja California. The composite surface temperature field for June (Figure 10) shows cold water indicative of upwelling along the coast from Punta Eugenia to Punta Baja. This feature correlates well with the local Ekman transport maximum in the same area. South of latitude 25° N, indications of upwelling in the temperature distribution are slight. In the region off southern California, the warm coastal temperatures may reflect seasonal heating and warm advection in the cyclonic eddy (Reid, Roden, and Wyllie, 1958).

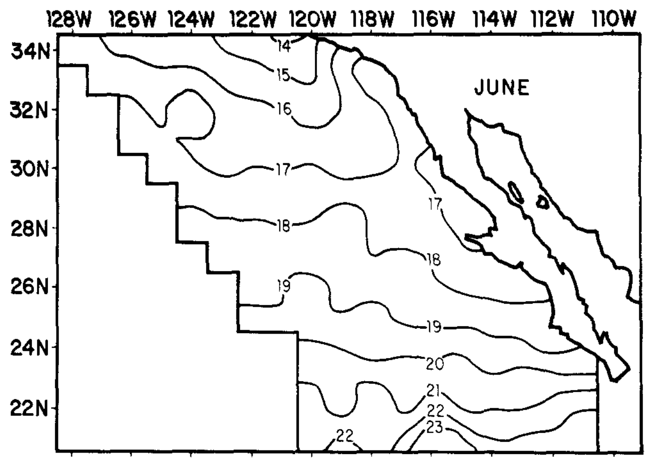

FIGURE 10. Sea surface temperature during June. Mean values of sea surface temperature observations were computed by 1 degree squares for the month of June. Units are degrees Celsius.

The coarse resolution in the 1-degree spatial summaries used in this paper tends to mask fine scale features of the temperature distributions. These particular temperature fields were developed to be compatible in resolution to, and used in conjunction with, our other data fields. More detailed treatments can be found in California Marine Research Committee (1963), Lynn (1967), and Wyllie and Lynn (1971).

The seasonal cycle of the sea surface temperature offshore (Figure 11) shows a normal north-south temperature gradient and a seasonal warming-cooling cycle with a typical range of 2° C to 4° C. Minima occur from February to March and maxima from August to September.

Comparison of the temperature cycle near the coast (Figure 12) with that occurring offshore (Figure 11) shows differences which may be largely

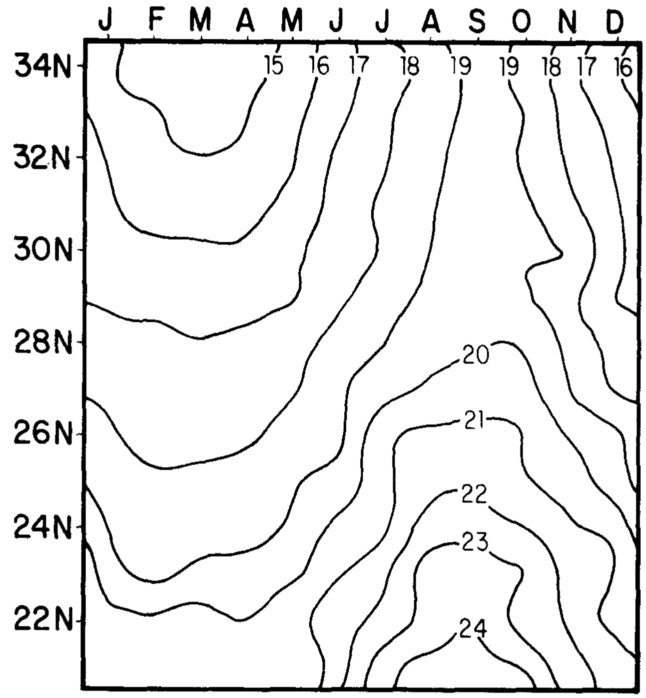

FIGURE 11. Seasonal cycle of sea surface temperature in the offshore region. Mean values of sea surface temperature observations were computed by month for the group of selected 1 degree squares indicated in Figure 1 at the offshore edge of the grid. Units are degrees Celsius.

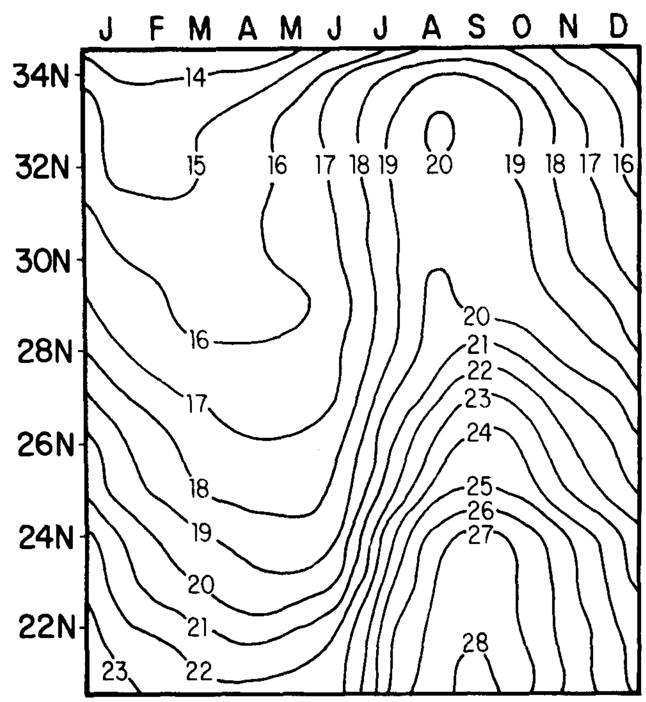

FIGURE 12. Seasonal cycle of sea surface temperature near the coast. Mean values of sea surface temperature observations were computed by month for the group of selected 1 degree squares adjacent to the coast, indicated in Figure 1. Units are degrees Celsius.

attributable to the effect of coastal upwelling, and to differences between horizontal advection in the offshore region and that in the coastal region. There is also the possibility of significant spatial differences in ocean-atmosphere heat exchange. Near the coast the seasonal temperature minimum is delayed relative to that offshore, occurring from March to May in phase with the maximum offshore Ekman transport. A more rapid increase of temperature near the coast during early summer, corresponding to the weakening of the southward surface flow (Figure 7), leads to significantly higher temperatures near the coast during summer than at the same latitude offshore.

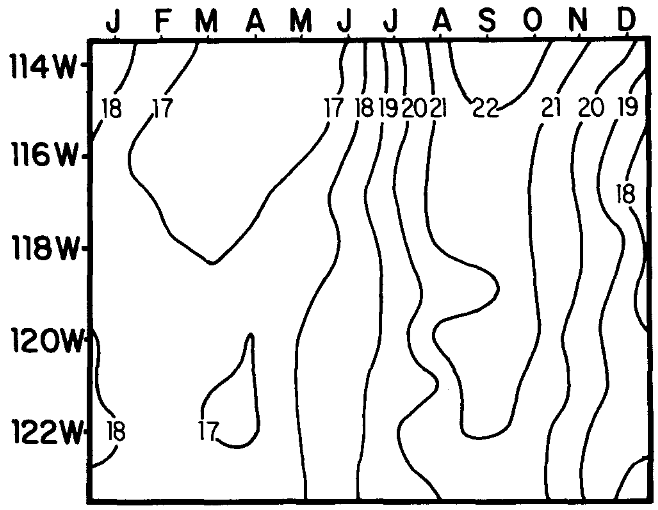

FIGURE 13. Seasonal cycle of sea surface temperature off Punta Eugenia. Mean values of sea surface temperature observations were computed by month for the group of selected 1 degree squares extending westward from the coast south of Punta Eugenia, indicated in Figure 1. Units are degrees Celsius.

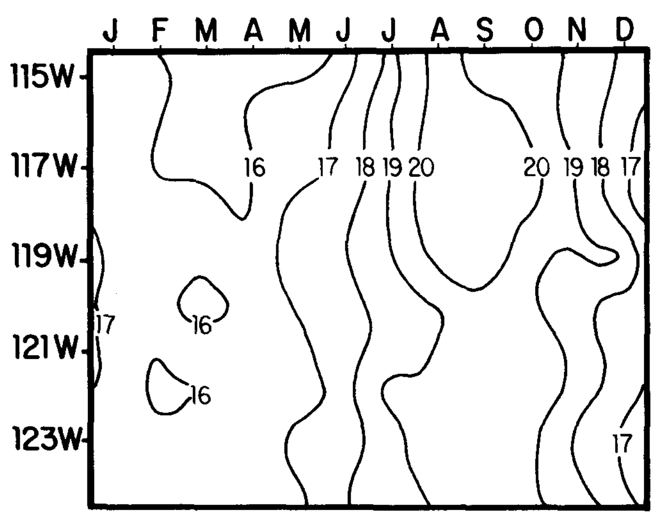

FIGURE 14. Seasonal cycle of sea surface temperature off Punta Baja. Mean values of sea surface temperature observations were computed by month for the group of selected 1 degree squares extending westward from the coast south of Punta Baja, indicated in Figure 1. Units are degrees Celsius.

Time series displays of seasonal sea surface temperatures in lines of squares extending westward from the coast (Figures 13 and 14) show colder water appearing near the coast in March. The gradients extend several hundred kilometers offshore during spring. During early summer, advection and possible spatial variations in ocean-atmosphere heat exchange processes offset the upwelling indicated by a continued, although weakened, offshore Ekman transport (Figure 6), leading to nearly homogeneous temperatures in the offshore direction. By late summer, warmer advection near the coast relative to that occurring offshore appears to dominate. Warm temperatures are found near the coast; gradients extend hundreds of kilometers offshore. During late fall and winter southward flow begins to increase (Figure 8) and the offshore temperature distribution again becomes nearly homogeneous (Figures 13 and 14).

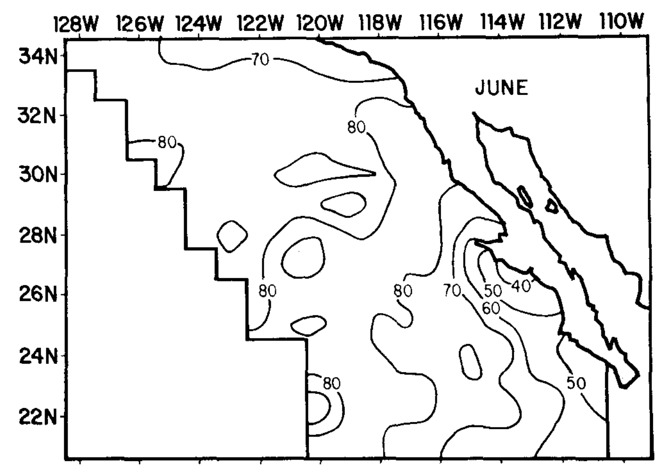

FIGURE 15. Cloud cover during June. Means of reported cloud amounts were computed by 1 degree squares during the month of June. Units are percent of sky obscured.

Cloud Cover

Seasonal and spatial variations in the heat exchange may mask features of upwelling normally evident in distributions of sea surface temperature. In the composite field of total cloud cover for June (Figure 15), Punta Eugenia separates an area of minimum cloud cover along the coast (less than 50%), from an area of maximum cloud cover (greater than 80%). A change in total cloud cover from 40% to 80% could result in a relative decrease of more than 30% in the incident radiation (Seckel and Beaudry, 1973) with corresponding changes in the sea surface temperature.

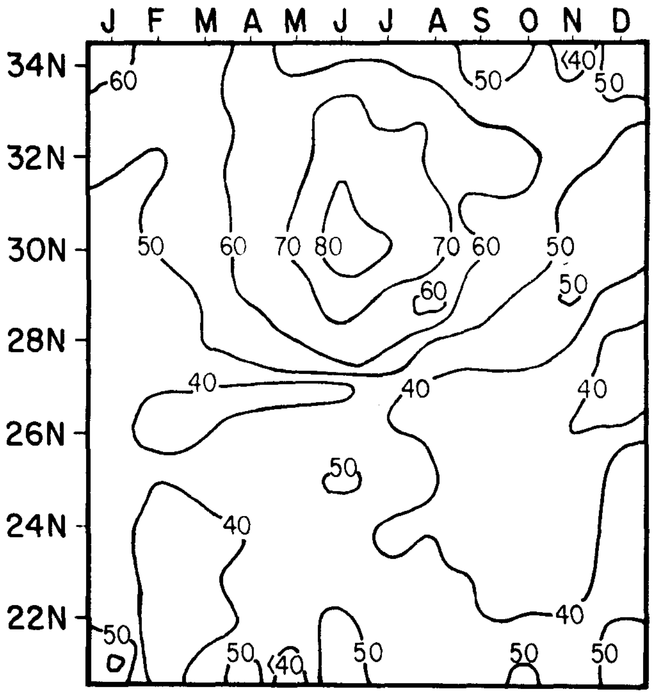

FIGURE 16. Seasonal cycle of cloud cover near the coast. Mean values of reported cloud amounts were computed by month for the group of selected 1 degree squares adjacent to the coast, indicated in Figure 1. Units are percent of sky obscured.

Considering the seasonal variations in cloud cover within the longshore section of coastal squares (Figure 16), maximum cloud cover appears to be associated with the upwelling off Punta Baja, while minimum cloud cover is evident along the entire coast south of Punta Eugenia. When distributions of cloud cover for sections extending westward from the coast are considered (Figures 17 and 18), the section off Punta Eugenia indicates minimum cloud cover at the coast throughout the year, while relative maxima occur at the coast in the Punta Baja section during June and July. The data suggest that differences in the downward flux of radiation associated with these cloud cover distributions could lessen the indications of coastal upwelling in the sea temperature south of Punta Eugenia. To the north, however, the heat flux from the atmosphere during the upwelling season may be insufficient to obscure the effects of cold water upwelled into the surface layer.

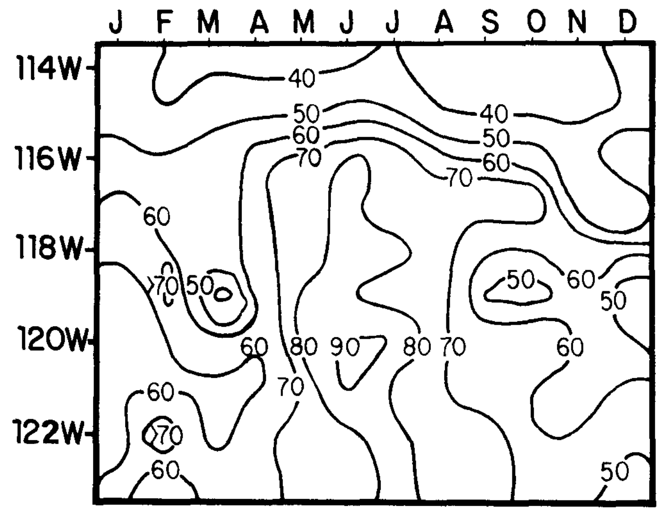

FIGURE 17. Seasonal cycle of cloud cover off Punta Eugenia. Mean values of cloud cover observations were computed by month for the group of selected 1 degree squares extending westward from the coast south of Punta Eugenia, indicated in Figure 1. Units are percent of sky obscured.

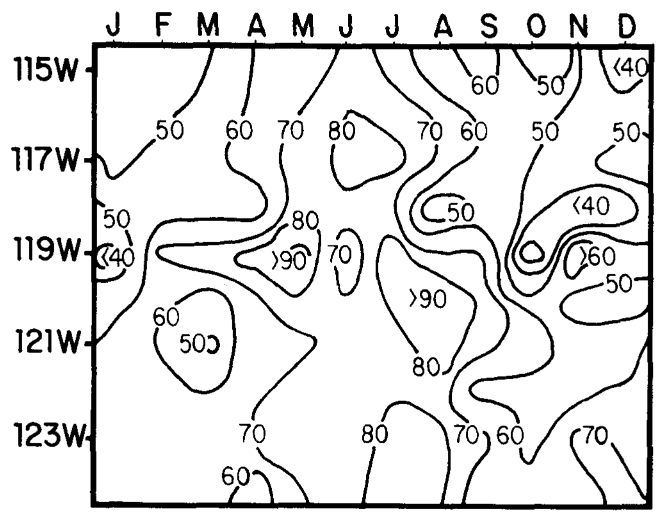

FIGURE 18. Seasonal cycle of cloud cover off Punta Baja. Mean values of cloud cover observations were computed by month for the group of selected 1 degree squares extending westward from the coast south of Punta Baja, indicated in Figure 1. Units are percent of sky obscured.

Wind Stress Curl

Although coastal upwelling occurs only at the ocean boundary, wind-induced upwelling can occur whenever divergence in the surface wind drift is not compensated by other modes of horizontal surface flow. The divergent or convergent nature of the surface Ekman wind drift offshore of the primary coastal upwelling zones is determined by the wind stress curl (Figure 19). If the equatorward wind stress parallel to the coast increases in the offshore direction, a situation characterized by positive curl in the stress field, the offshore component of Ekman transport likewise increases in the offshore direction. The result is continued divergence offshore requiring upwelling to maintain the mass balance. Conversely, if the equatorward longshore wind stress decreases in the offshore direction, the wind stress curl is negative. The result is convergence in the surface wind drift with corresponding frontal formation and downwelling.

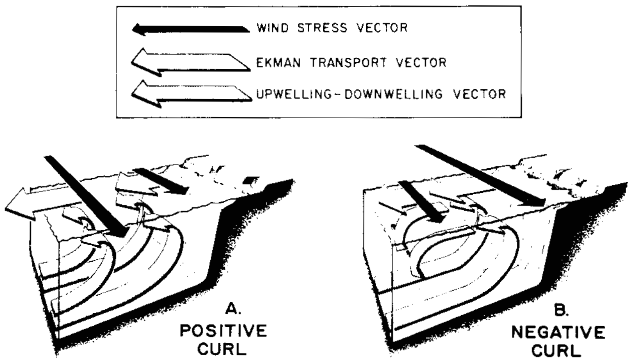

FIGURE 19. A conceptual diagram of the relationship of wind stress curl to divergence and convergence of surface Ekman transport offshore of the primary coastal upwelling zone. An increase in the equatorward wind stress parallel to the coast (positive wind stress curl) produces divergence in surface Ekman transport and continued upwelling offshore. A decrease in the equatorward wind stress parallel to the coast (negative wind stress curl) produces convergence in surface Ekman transport and downwelling offshore.

Actual observations of wind stress curl are not available. Alternatively, we have computed the curl of the mean wind stress fields under the assumption that, since the curl is a linear operator, the resulting distributions may resemble mean fields of actual wind stress curl distributions existing off Baja California. Monthly curl fields corresponding to the mean wind stress distributions (Figure 3) were determined (Figure 20). Negative wind stress curl (Ekman convergence) is characteristic of the offshore region. From Punta Baja to Punta Eugenia the convergent region reaches to the coast. The wind stress distributions thus imply favorable conditions for formation of fronts and convergent patches of recently upwelled water in this area. North of Punta Baja and south of Punta Eugenia areas of positive curl (Ekman divergence) extend from the coast to several hundred kilometers seaward. Within these divergent areas there would tend to be a continued, although much reduced, level of upwelling offshore of the primary coastal upwelling zone.

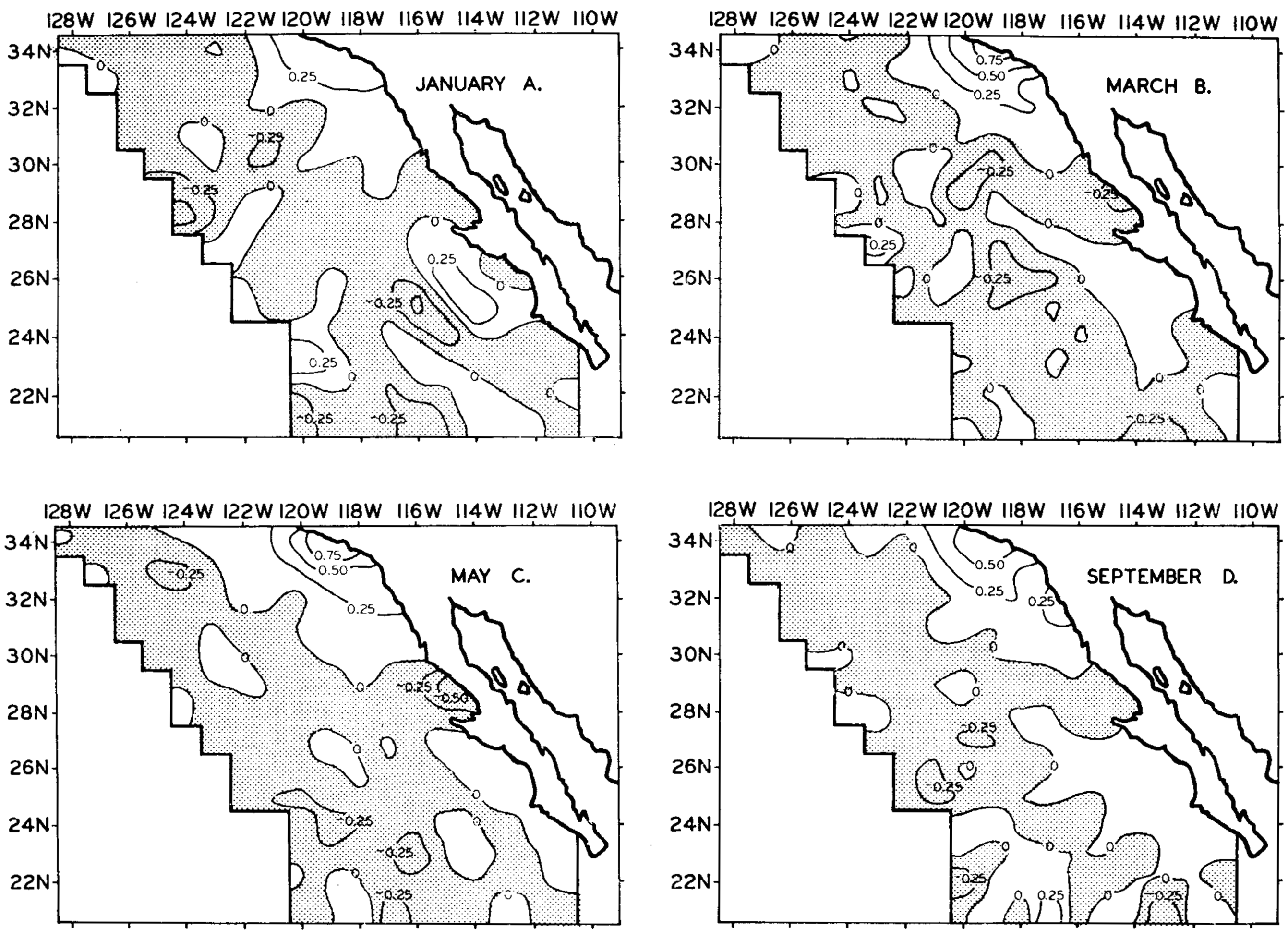

FIGURE 20. Wind stress curl. Monthly composite fields of wind stress curl were computed from the surface wind stress fields shown in Figure 3; A. JANUARY, B. MARCH, C. MAY, and D. SEPTEMBER. Units are dynes/cm²/100km. The coutour interval is 0.25 dynes/cm²/100 km. Negative values are shaded.

Munk (1950) has suggested that the poleward undercurrent observed along the California coast may be a consequence of the local wind stress curl. Pedlosky (1974) has indicated theoretically that a poleward undercurrent would be favored by positive wind stress curl along the coast and a poleward decrease in the surface heating. The surface data presented here cannot describe features of the subsurface flow. However the mean wind stress distributions off the coast appear génerally consistent with a pattern of countercurrent inshore and equatorward flow offshore, except in the region from Punta Eugenia to Punta Baja where the wind stress curl is not positive. During the fall, the relaxation of upwelling induced equatorward surface flow would favor surfacing of a coastal countercurrent. With these considerations in mind it is interesting to note that indications of a poleward component of ship drift during fall (Figure 9B) are lacking in the region from Punta Eugenia to Punta Baja. Rather, the data suggest separate cyclonic gyres in the regions of positive wind stress curl off the Los Angeles Bight and south of Punta Eugenia.

VARIABILITY AND PERSISTENCE

In addition to responding to the seasonal variations, marine biological communities must also respond to a wide spectrum of environmental variations of time scales ranging from many years to small fractions of a year. A central problem in investigating such fluctuations is the formation of consistent time series of pertinent information.

For any particular synoptic sampling the available reports from ships at sea tend to be sparse and unevenly distributed. In such a situation the variability introduced by random errors in measurement or changes in spatial distribution of reports may be as great or greater than the variability in the process itself. If a definite periodicity is known it may be reasonable to composite corresponding portions of different cycles, as was done in the previous section, in order to obtain an adequate data base. This is not possible in the case of fluctuations which are nonperiodic or where, if they do contain periodic components, the periodicities are undefined.

One way to arrive at fairly consistent time series of wind information with which to investigate fluctuations in upwelling is to make use of analyzed products produced by meteorological agencies. In this section we use 6-hourly computations of offshore Ekman transport based on the synoptic surface atmospheric pressure analyses produced by Fleet Numerical Weather Central. These analyses incorporate all available wind reports in the form of equivalent pressure gradients as well as the available pressure data (Holl and Mendenhall, 1972). Conventional reporting periods correspond to 4AM, 10AM, 4PM, and 10PM Pacific Standard time, yielding four synoptic samplings per day.

Bakun (1973) described a procedure for computing offshore Ekman transport from pressure fields using a geostrophic wind computation and a simplified boundary layer approximation. The results of such computations were called *upwelling indices.* A compilation of daily and weekly means of 6 hourly indices at 15 locations off western North America has been published (Bakun, 1975). The time series discussed in this paper are located at five 3 degree grid intersections, from 21°N to 33°N latitude (Figure 1).

This 3 degree resolution is coarse compared to the 1 degree resolution achieved in the previous section. The pressure fields were originally analyzed on a grid of approximately 3 degree mesh length. Thus any information derived on a smaller scale would consist merely of the details of the particular interpolation function used, rather than having any basis in observed data. Underlying this situation is the fact that the number of reports from the area off Baja California during any synoptic period is only of the order of one per 3 degree square and so analysis of pressure on a smaller scale grid would not increase the resolution of data-based information.

The drag coefficient used in equation (1) to compute these indices was 1.3×10^{-3}. This differs from the value 1.6×10^{-3}, based on the work of Denman and Miyake (1973), used in the previous section. Recent progress in the field of ocean-atmosphere boundary processes suggests that 1.3×10^{-3} may be a more appropriate constant value.

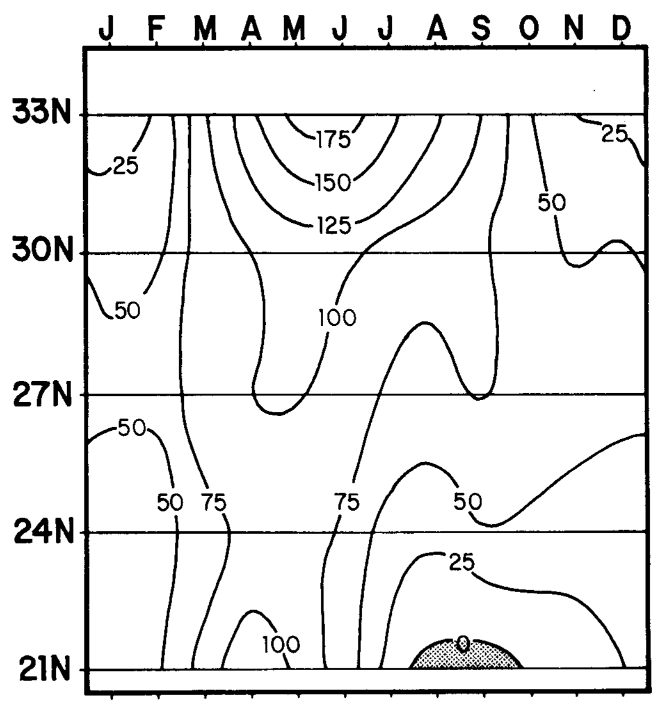

FIGURE 21. Mean values by month and position of 6 hourly coastal upwelling indices for the 7 year period, 1967–73. Locations are indicated by large dots in Figure 1. Units are m³ per second per 100 m of coast. Negative values are shaded.

Actually the drag coefficient appears to vary both with atmospheric stability and with spectral properties of the ocean waves (Davidson, 1974), but the form of the dependencies does not appear well enough established to warrant incorporation of these effects for our purposes. Since the drag coefficient enters linearly into the computations of stress and Ekman transport, the values in the previous section could be adjusted to those of this section by multiplication by the factor $1.3/1.6 = 0.8125$. Because of such uncertainties, these results, although yielding reasonably realistic numerical values, should properly be viewed as being "uncalibrated" in terms of absolute quantitative detail. The uncertainty in magnitudes is more severe in the case of indices computed from analyzed pressure fields.

Comparison of the 7 year (1967–73) mean values of the 6 hourly upwelling indices (Figure 21) to the seasonal cycle of offshore Ekman transport composited on a 1 degree basis from actual ship reports (Figure 6) illustrates the smoothing of gradients and other spatial details on the 3 degree synoptic index format. It also illustrates a severe spatial distortion in absolute magnitudes discussed by Bakun (1973) which results in amplification of the computed indices at 33°N latitude relative to those at points further south. The figures in this paper which display absolute magnitudes of computed upwelling indices are intended to indicate temporal variations, i.e. relationships along the horizontal axis of the figures. Contours are connected between different locations only as a visual aid and to indicate variations in seasonal timing between different locations. Comparisons of absolute magnitudes on the vertical axis can be misleading. In the case of normalized properties such as skewness and kurtosis the problem is less severe.

Properties of Fluctuations

High variance in the 6-hourly computed indices tends generally to correspond in season and location to high mean value (Figure 22). Thus the winter season is characterized by a generally relaxed level of activity and thus a more stable upwelling regime. Two variations from the pattern are noticeable. At 21°N latitude where during late summer the mean goes negative, i.e. downwelling occurs on average, there is a relative maximum in the variance. Thus the low mean absolute values must reflect a near cancellation of contributions to the variance by large positive and negative fluctuations. Off central Baja California where there are double peaks in the mean, the larger occurring in spring and the lesser in late summer, the late summer period exhibits the greater variance.

Skewness of the monthly distributions is generally positive (Figure 23). Thus the strong departures from the mean are most often spikes of even more intense upwelling separated by longer relaxed periods rather than an equal mix of fluctuations above and below the norm. Highly skewed distributions are at 21°N latitude during the spring

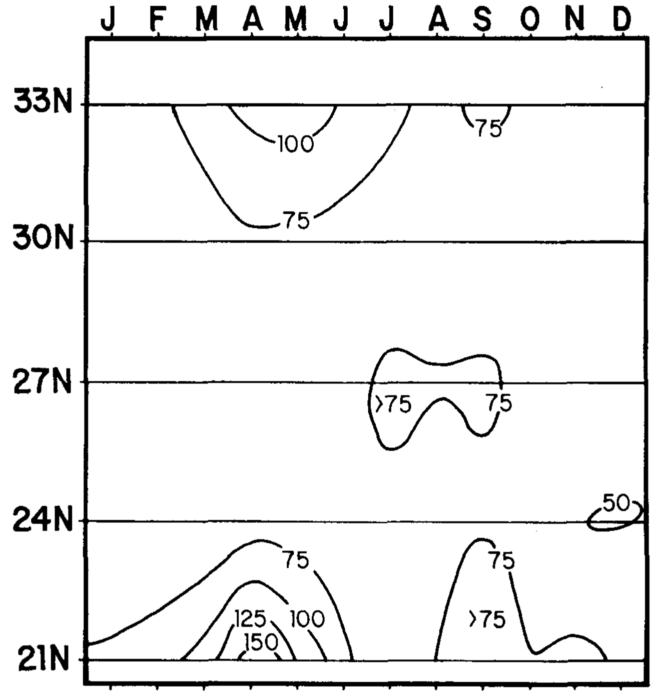

FIGURE 22. Standard deviations of monthly distributions of 6 hourly coastal upwelling indices. Locations are indicated by large dots in Figure 1. Units are m³ per second per 100 m of coast. Period covered is 1967–73.

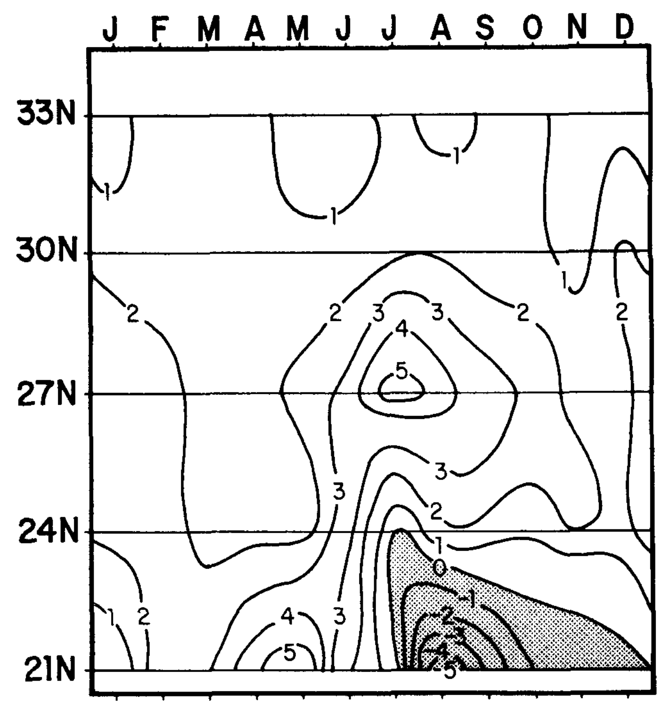

FIGURE 23. Skewness of monthly distributions of 6 hourly coastal upwelling indices. Locations are indicated by large dots in Figure 1. Period covered is 1967–73. Negative values are shaded.

upwelling maximum and off Central Baja California during the relative minimum which separates the spring and late summer maxima. The skewness turns negative during late summer and fall at 21°N. The area of negative skewness extends to 24°N during July and corresponds to a similarly shaped region of low mean monthly values of the indices (Figure 21). This situation appears to be one of fairly consistent low level upwelling interrupted at infrequent intervals by downwelling events of such an intensity as to nearly cancel the upwelling on average. The mean actually goes negative at 21°N during August and September. These downwelling events probably reflect the occurrence of tropical storms.

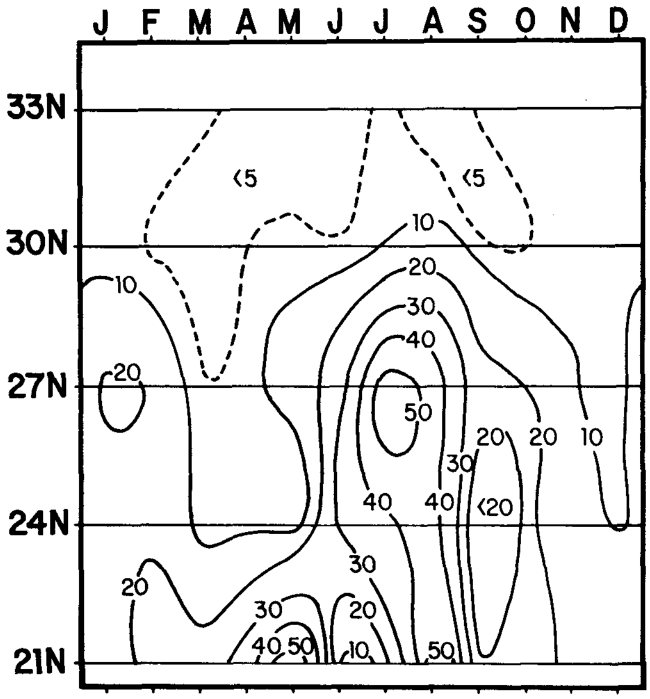

FIGURE 24. Kurtosis of monthly distributions of 6 hourly coastal upwelling indices. Locations are indicated by large dots in Figure 1. Period covered is 1967–73.

Kurtosis of the monthly distributions is greater than 3.0 at all months and locations indicating larger contributions from extreme events than would be the case in a Gaussian process (Figure 24). Off central and southern Baja California during spring and summer the large variance corresponds to large kurtosis, again indicating the importance of rare, very intense events. In the north the spring and fall seasons of maximum variance are characterized by minimum kurtosis, indicating the variance to be dominated by more frequent, less extreme pulsations.

Power spectra (Figure 25) were selected as being representative of a number of similar spectra computed for various segments of the 7 year series of 6 hourly indices. The major features, i.e., the strong diurnal peak and a general increase in energy at low

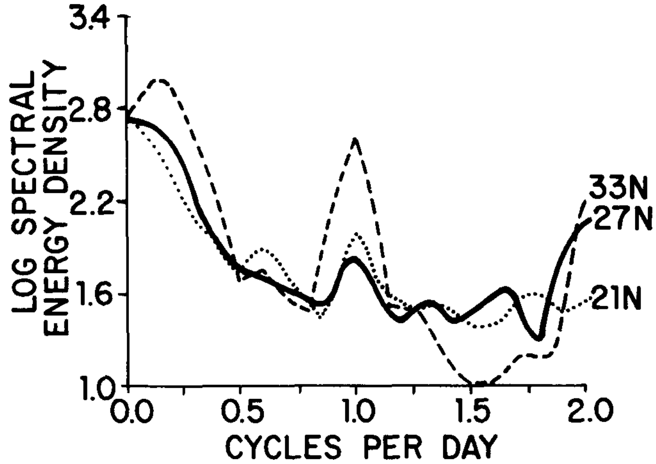

FIGURE 25. Power spectra of 6 hourly coastal upwelling indices. Spectra are plotted for time series at three locations (21°N, 107°W; 27°N, 116°W; 33°N, 119°W) for the period February 27 through July 1, 1972.

frequencies representing seasonal and other long term variations, appear consistently. The indication of a major amount of energy spread over an "event scale" of periods ranging from 2 or 3 days to several weeks is also typical. The spectral peak at the semidurnal frequency reflects the non-sinusoidal shape of the diurnal fluctuation which tends to have a faster rate of change during the morning to afternoon increase than during the evening to morning relaxation.

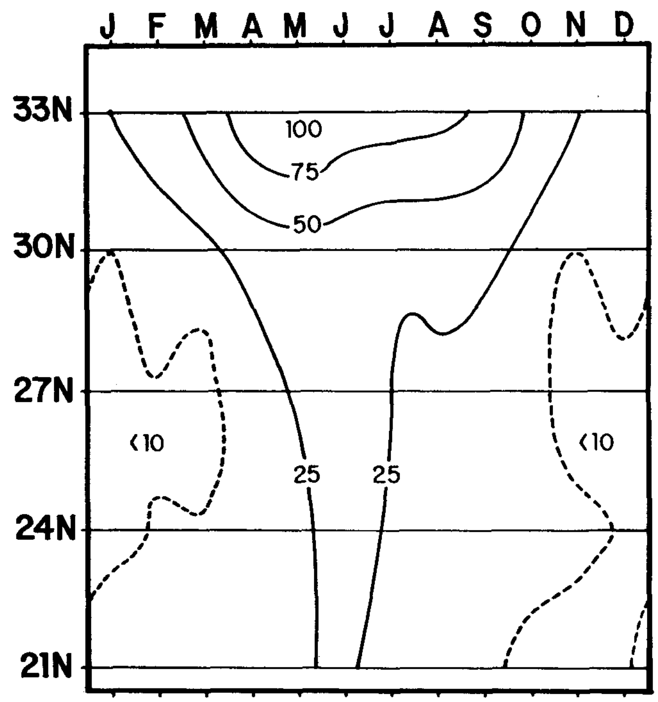

FIGURE 26. Diurnal variation in upwelling indices. Mean differences between upwelling indices computed from the 4 PM Pacific Standard Time synoptic sampling and those computed from the 10 AM sampling 6 hours earlier were computed by month at locations indicated by large dots in Figure 1. These two sampling periods tend to be extremes of the diurnal cycle as resolved by these data. Units are m^3 per second per 100 m of coast. Period covered is 1967–73.

The 10AM and 4PM (Pacific Standard Time) synoptic periods tend to be the extremes of the diurnal cycle as well as it can be resolved with the four samples per day available. The mean difference, the afternoon value minus the morning value, is positive at all months and locations (Figure 26). The amplitude tends to be greatest in the late spring and early summer and least in the winter. At 21°N latitude the minimum is earlier than at the locations further north, occuring during the fall. The diurnal variation is greatest at 33°N and is progressively smaller to the south. How much of this apparent north-south gradient in the diurnal effect may be due to the previously mentioned spatial distortion is presently unclear.

The diurnal effect is very apparent in autocorrelation functions produced from upwelling index time series (Figure 27), where the diurnal rise and fall appears superimposed on a strong decline in autocorrelation which occurs within 1 to 2 days. This rapid decline illustrates the characteristically short time scales of the indicated pulses of upwelling producing wind stress.

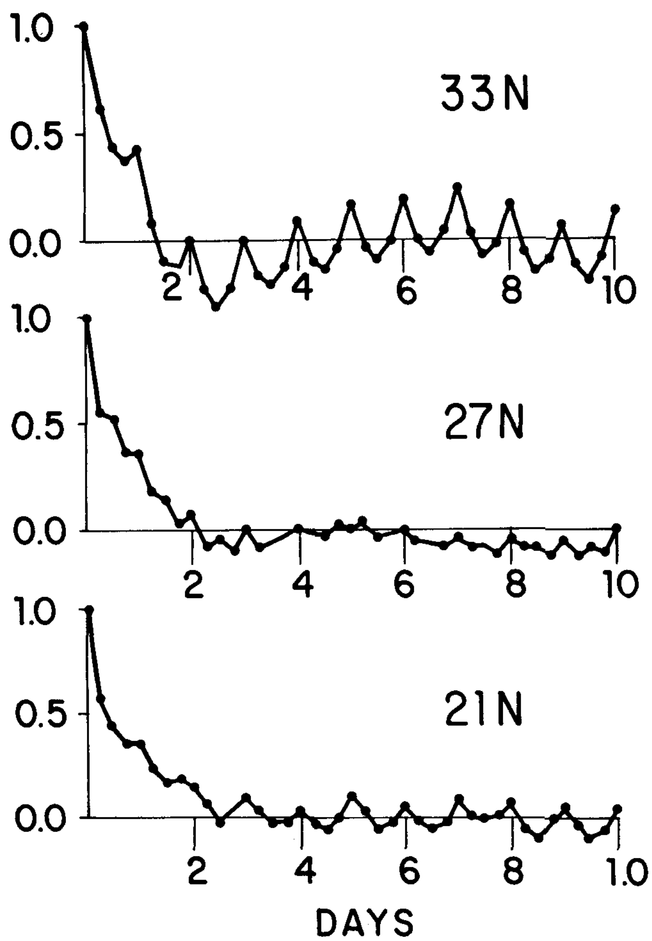

FIGURE 27. Autocorrelation functions for 6 hourly coastal upwelling indices. Functions are plotted for three locations (21°N, 107°W; 27°N, 116°W; 33°N, 119°W) during the period February 27 through July 1, 1972.

Persistence

Characteristic time scales were further examined in terms of persistence of anomalies in the 6 hourly upwelling indices (Figure 28). Since anomalies in these series tend to be much larger than the differences between various types of fits to the annual cycle, mean seasonal values were simply defined by linear interpolation between succeeding months, the midpoints of which were assigned the 7 year composite mean monthly value of the 6 hour upwelling indices. To avoid complicating effects of the diurnal cycle the analysis was done in terms of daily means. An anomaly was defined as the difference between a daily mean value and the value for the particular day from the linearly interpolated mean annual cycle. The percentage of times during the 7 year time series that a daily anomaly had the same sign as the anomaly for the previous day was computed for each month and location (Figure 28A). Situations where the anomaly was so small that it was not significantly either positive or negative were rejected by requiring the previous anomaly to have an absolute value of at least 10 m^3 per second per 100 m of coastline for the particular day to be used in the computation. This process was repeated using the respective anomalies 2, 3, and 5 days earlier in the comparisons (Figure 28B, C, and D).

The daily anomaly has the same sign as the previous day's anomaly about 70 to 80% of the time depending on month and location (Figure 28A). By the second day (Figure 28B) the persistence of sign has dropped below 50%, indicating no tendency for persistence, at some months and locations. After 5 days, the months and locations where the anomaly is below 50% are considerably greater in number than those where it is greater than 60%. Thus any persistence of individual wind stress events on scales greater than 5 days appears to be slight.

In examining these series, however, one notices a certain persistence on longer scales which is evident in groupings of individual events resulting in general levels of average intensity above or below the seasonal norm. To illustrate this a similar analysis was performed on monthly anomalies. In order to have access to a longer data series for such a monthly analysis we have used a series computed from monthly mean pressure fields which extends back to 1946. Bakun (1973) has shown that indices computed in this manner correlate highly with corresponding series of monthly means of 6 hourly indices. In order to have a value 5 months previous to our first data point for comparison, we begin with June, 1946, and then work through the following 28 years ending May, 1974. The resulting distributions (Figure 29) are somewhat more noisy than those produced from the daily series (Figure 28) because there are only 28 data points for each month and location compared to the 200 or more data points per month and location in the 7 year daily series. A level of persistence of

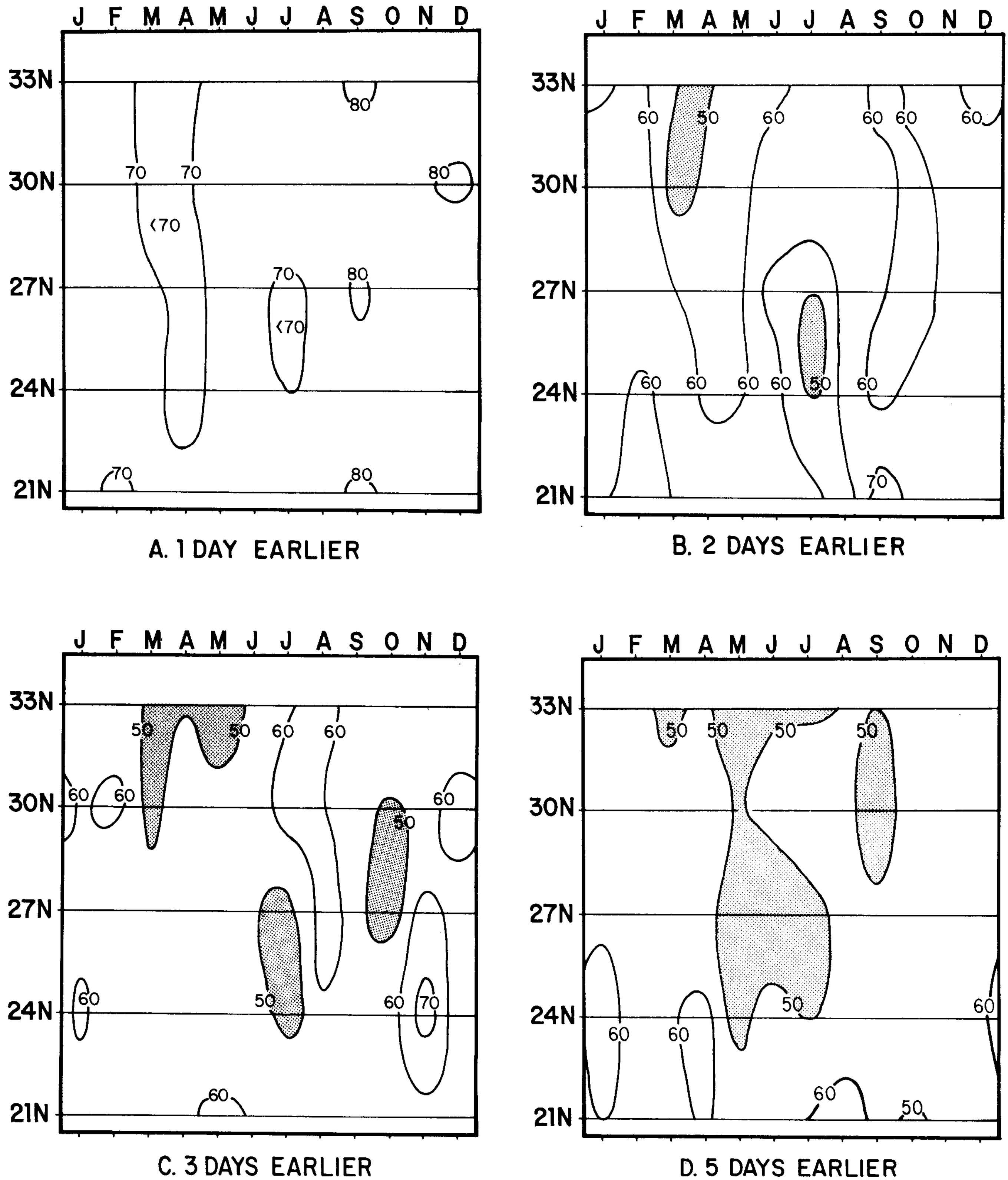

FIGURE 28. Percentage of daily upwelling index anomalies having the same sign as the daily anomaly. A. 1 day earlier, B. 2 days earlier, C. 3 days earlier, D. 5 days earlier. A daily anomaly is defined as the difference between the daily average of 6 hourly coastal upwelling indices and the characteristic value for that day derived from the long term mean annual cycle. Period covered is 1967–73. Shading indicates percentages less than fifty.

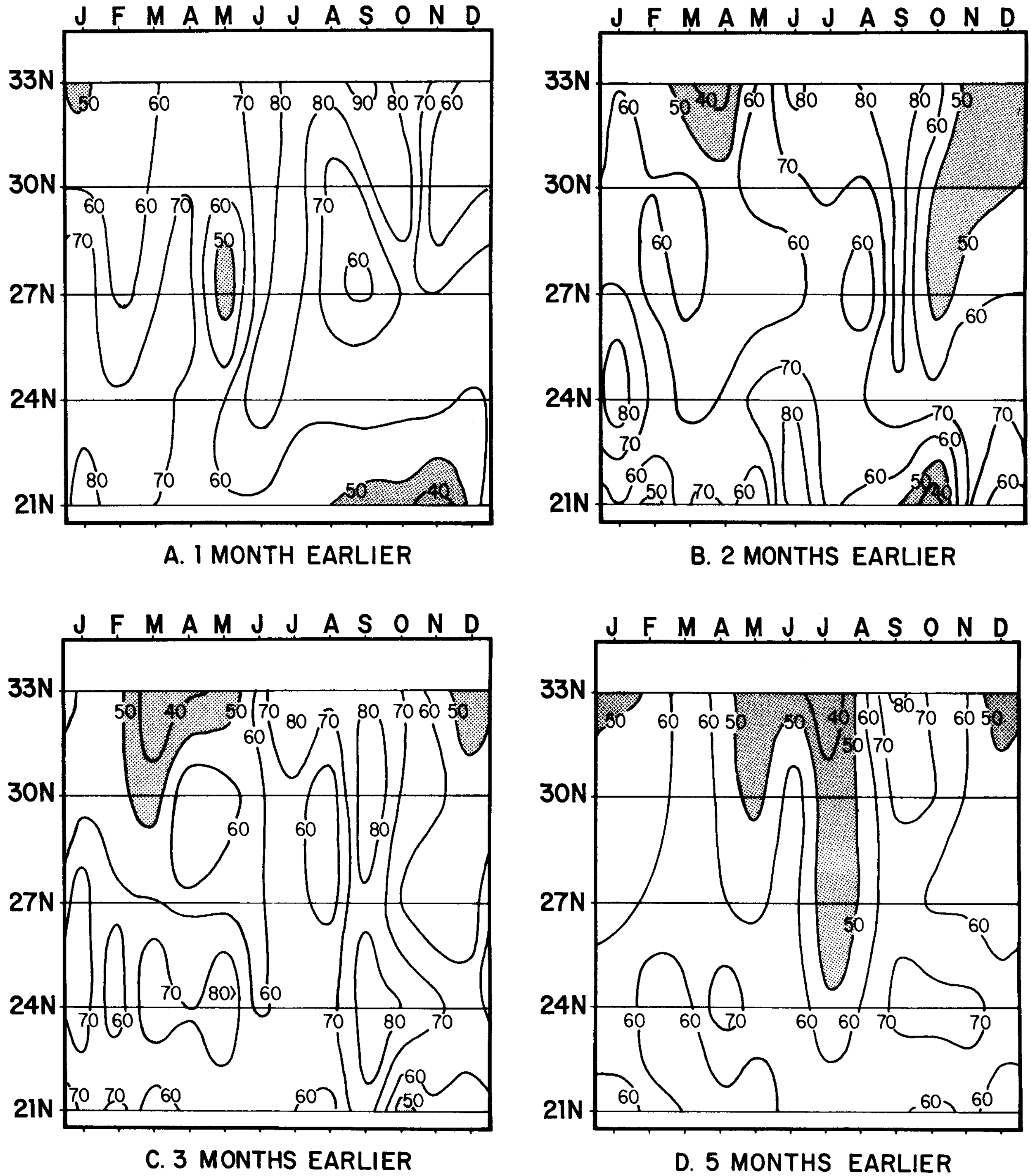

FIGURE 29. Percentage of monthly upwelling index anomalies having the same sign as the monthly anomaly, A. 1 month earlier, B. 2 months earlier, C. 3 months earlier, D. 5 months earlier. A monthly anomaly is defined as the difference between a monthly upwelling index value and a 20 year (1948–1967) mean value for the particular month. Period covered is June, 1946 through May, 1974. Shading indicates percentages less than fifty.

monthly anomalies after 5 months (Figure 29D) roughly equivalent to that for daily anomalies after 5 days (Figure 28D) is indicated.

One simple feedback system which may contribute to persistence of levels of upwelling intensity beyond the duration of individual upwelling events is as follows. An upwelling event or combination of events is eventually reflected in cooler water at the sea surface. This increases the temperature gradient in the lower atmosphere between the continent and the ocean, which in turn increases the onshore-offshore atmospheric pressure gradient. The result is greater longshore wind stress which feeds back to the upwelling process, transmitting an underlying level of intensity from one event to another. Whatever the major mechanism may be, these results suggest that general levels of upwelling intensity above or below the seasonal norm have a tendency to be persistent over periods approaching the seasonal time scale.

Spatial Coherence

Finally, an analysis using a spatial lag rather than a temporal lag, can yield some insight into the spatial coherence of upwelling anomalies. The percentage, by month and location, of daily anomalies having the same sign as the corresponding daily anomaly at 27°N latitude was determined (Figure 30). Again, we have required that the anomaly at 27°N be at least 10 m^3/sec/100 m of coast for it to be considered significant. The percentage at 27°N is of course always 100%. The percentage drops off more rapidly to the south than to the north. In fact at 21°N latitude it actually drops below 50% during September indicating the anomaly had a sign opposite to that at 27°N more often than not. In total, the indication is that coherence of upwelling anomalies over regions the size of the coast of Baja California is not necessarily to be expected.

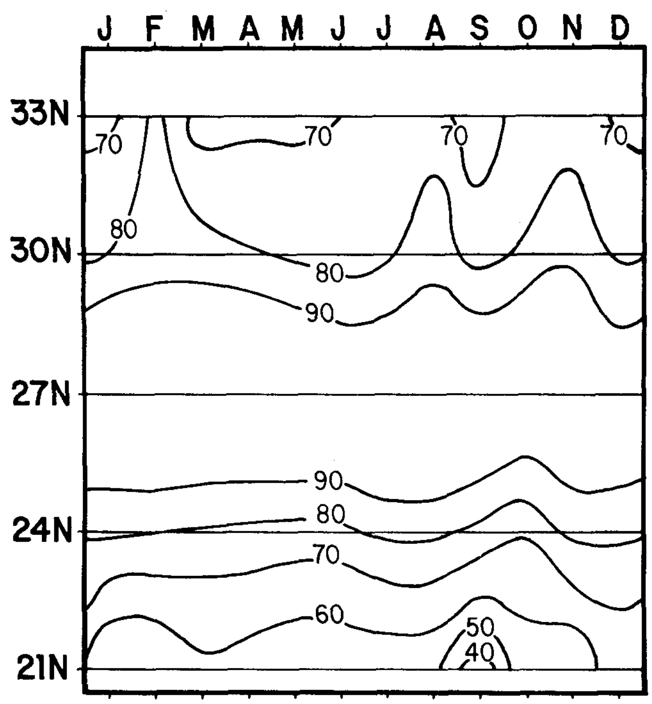

FIGURE 30. Percentage of daily upwelling index anomalies having the same sign as the corresponding daily anomaly at 27°N. Period covered is 1967–73. Shading indicates percentages less than fifty.

UPWELLING OFF BAJA CALIFORNIA DURING RECENT YEARS

We now attempt to characterize the upwelling situation off Baja California since 1972. Bakun (1973) presented coastal upwelling indices based on monthly mean data for the period 1946 through 1971. These are intended to represent the primary coastal divergence mechanism (Figure 2). These series were updated through July 1977 (Table 1) at 5 locations off southern California and northern Mexico (Figure 1). In computing these monthly indices a higher drag coefficient, 0.0026, was employed to roughly compensate for the underestimate of the stress caused by using mean data in the nonlinear calculation involved in equation (1).

In the section on the seasonal cycles we described the effect of the curl of the wind stress in causing convergence or divergence in the surface layer outside of the immediate coastal upwelling zone (Figure 19). This effect is probably important biologically. For example, certain organisms may be favored by a situation where the surface layer continues to diverge, on average, offshore of the coastal upwelling zone. Nutrients would continue to be fed into the surface layer, planktonic grazers swept away, etc. Other organisms may depend on concentration in convergent frontal zones of the organic material produced as a result of the upwelling near the coast. These might be favored by strong coastal upwelling in conjunction with or followed by strong offshore convergence.

In order to have an indicator of this effect, a set of indices of divergence of the Ekman transport field outside of the immediate coastal upwelling region was generated for the same locations and from the same monthly mean pressure fields as were the monthly coastal upwelling indices. The applicable equation is derived by Fofonoff (1963):

$$\nabla \cdot \vec{V}_E = \frac{1}{f}(\nabla \chi \vec{\tau})\cdot\vec{k} - \frac{\beta}{f}\vec{V}_E \cdot \vec{j} \qquad (3)$$

where:

$\nabla \cdot \vec{V}_E$ represents the divergence of Ekman transport

$(\nabla \times \vec{\tau}) \cdot \chi$ represents the vertical component of the curl of the wind stress

f is the Coriolis parameter

β is the meridional derivative of f,

$\vec{V}_E \cdot \vec{j}$ is the meridional component of Ekman transport.

The stress and Ekman transport inputs to equation (3) were computed as for the monthly mean upwelling indices. Numerical values were assigned as vertical velocities required to balance the computed divergences (Table 2).

During the early months of 1972, coastal upwelling appears to have been generally stronger than normal (Figure 31). This was accompanied by anomalous offshore convergence except in the extreme south where anomalous offshore divergence tends to be a persistent feature (Figure 32). Late summer and early fall of 1972 are characterized by lower than normal coastal upwelling index values except during September in the southern portion of the region. The month of December shows stronger than normal upwelling index values along the whole coast. An anomalously divergent situation is indicated offshore during November and December.

TABLE 1

Monthly coastal upwelling indices *

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
					1972							
33N	8	33	168	228	243	283	254	201	144	36	16	24
30N	91	88	186	180	165	168	125	113	90	61	67	85
27N	120	138	199	236	197	162	101	58	94	64	77	81
24N	85	77	161	197	179	156	53	12	84	24	59	45
21N	86	86	128	117	74	97	5	−1	13	1	38	26
					1973							
33N	15	1	182	216	290	282	288	234	167	65	75	24
30N	65	7	178	193	155	178	137	149	121	90	93	97
27N	105	28	173	181	148	138	90	115	138	106	117	97
24N	68	34	155	142	142	107	55	83	122	84	106	72
21N	39	52	163	116	108	83	16	10	27	8	19	33
					1974							
33N	1	43	91	207	372	330	229	245	159	97	26	4
30N	22	104	93	234	284	263	147	167	141	104	74	34
27N	56	105	123	208	208	160	67	116	94	80	60	39
24N	52	78	100	138	147	82	24	50	53	54	43	57
20N	31	60	81	53	125	22	4	1	4	−1	5	37
					1975							
33N	10	45	123	197	282	362	322	251	166	100	55	16
30N	50	62	127	174	187	197	192	194	180	146	134	58
27N	43	84	127	183	165	161	99	115	117	133	99	40
24N	45	85	133	185	130	93	37	46	50	96	56	35
21N	19	47	41	75	100	28	2	−1	−8	6	28	26
					1976							
33N	−1	34	120	198	304	262	277	212	88	50	4	−6
30N	44	64	139	160	231	199	160	145	70	80	54	28
27N	27	51	127	158	215	214	142	170	57	58	28	17
24N	24	50	127	153	191	172	107	86	57	72	34	32
21N	21	33	122	125	119	36	30	4	1	16	18	35
					1977							
33N	9	57	163	207	224	325	285					
30N	38	131	201	169	182	222	181					
27N	10	110	189	206	224	252	135					
24N	23	96	153	194	184	163	79					
21N	83	92	230	192	260	134	70					

* Units are cubic meters per second per 100 m length of coast. Values signify volume transported offshore in the surface Ekman layer.

TABLE 2

Monthly Surface Layer Divergence Indices*

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
					1972							
33N	280	15	242	-195	-328	-465	-689	-155	-218	-31	204	211
30N	97	-326	-434	-627	-651	-801	-687	-458	-408	-154	96	76
27N	-240	-236	-584	-88	-217	-232	-157	-82	-168	42	-1	82
24N	-197	-126	-255	-167	-310	-112	-10	-43	3	-24	-19	5
21N	471	354	380	321	371	303	97	9	138	29	172	87
					1973							
33N	68	-9	267	100	-367	-130	-231	-73	-45	126	119	260
30N	-6	-23	-299	-461	-892	-924	-770	-652	-726	-338	-359	63
27N	-31	-63	-165	-186	-225	-220	-239	-157	-208	-52	-124	90
24N	27	-97	-181	-189	-265	-236	-177	-62	65	22	-23	12
21N	36	152	-43	32	88	163	1	119	133	90	155	195
					1974							
33N	25	375	-103	187	-387	-651	-334	-506	-81	-69	241	310
30N	-22	18	-338	-591	-969	-903	-590	-907	-556	-385	3	151
27N	-67	-49	-118	-136	-207	-135	-45	-112	61	114	116	-65
24N	-8	-81	-121	-103	-203	-131	33	-66	30	-23	-20	-138
21N	141	135	-43	103	25	126	7	-6	88	69	140	274
					1975							
33N	390	30	-9	-65	-387	-1116	-709	-651	-73	129	416	312
33N	189	-204	-332	-503	-909	-1223	-741	-832	-535	-379	46	71
27N	-10	-65	-106	-200	-256	-350	-309	-149	-28	-45	111	15
24N	-111	-127	-160	-91	-166	-163	-163	-88	-64	-94	-37	-40
21N	97	150	135	119	13	20	-13	8	91	131	245	186
					1976							
33N	393	206	376	-64	-201	-277	-350	-570	-30	123	246	230
30N	128	-52	-180	-643	-1097	-1021	-1009	-975	-345	-155	110	111
27N	25	-26	-192	-169	-227	-311	-332	-279	-40	71	142	41
24N	-93	-55	-144	-4	-155	210	-4	41	64	-64	-44	-83
21N	223	215	486	573	553	389	368	128	109	357	413	489
					1977							
33N	230	315	317	-111	-160	-827	-493					
30N	98	-12	-470	-787	-982	-1557	-1155					
27N	72	157	-75	-416	-449	-681	-269					
24N	-137	-5	-217	-409	-218	-131	-27					
21N	668	719	289	382	-312	95	228					

*Values signify vertical velocities at the bottom of the Ekman layer required to balance the indicated divergence or convergence occurring offshore of the primary coastal upwelling zone. Units are millimeters per day, positive upwards.

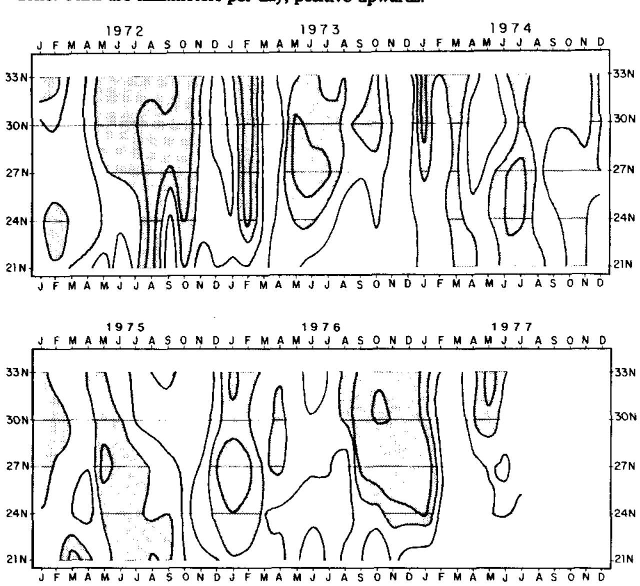

FIGURE 31. Monthly coastal upwelling index values (Table 1) in terms of quartiles of the frequency distribution made up of all values for the given location and calendar month within the 1946–77 time series. Quartiles are delineated by contours. The two quartiles below the median are shaded.

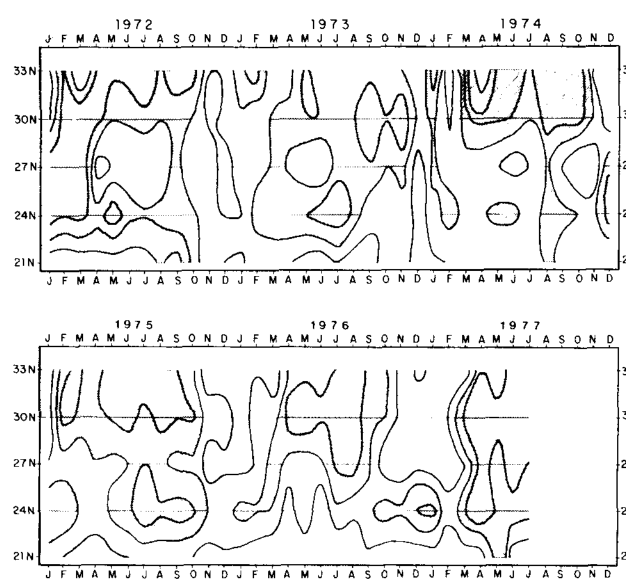

FIGURE 32. Monthly offshore surface layer divergence indices (Table 2) in terms of quartiles of the frequency distribution made up of all values for the given location and calendar month within the 1946–77 time series. Quartiles are delineated by contours. The two quartiles below the median are shaded.

Weak coastal upwelling is indicated off Baja California in February followed by higher than normal intensity during March and April (Figure 31). In the north a low tendency prevailed from May through October coupled with greater than normal offshore convergence. At 21°N latitude the coastal upwelling indices were anomalously high all year, becoming extremely anomalous late in the year. Extreme values appear all along the coast during November and December. The indication of high offshore divergence which is a persistent feature at 21°N during the recent period spreads northward along the whole coast during December (Figure 32).

An alternating pattern off northern Baja California was evident during early 1974 with a low upwelling index anomaly in January, a high anomaly in February, a low in March, and very high values in April and May. Low values appear in the south central region during June and July. The northern area is characterized by anomalous offshore convergence from May through October.

Generally higher than normal coastal upwelling is indicated during March 1975, followed by a period of lower than normal intensity which lasts until May in the north, but continues generally through the summer in the south. The latter portion of 1975 exhibits higher than normal coastal upwelling index values. The offshore region appears to have been anomalously convergent, particularly during summer and early fall (Figure 32).

A period of weak coastal upwelling is indicated during early 1976, followed by stronger than normal upwelling during the summer. The fall and winter are characterized by lower than normal upwelling index values as far south as 24°N latitude. The offshore divergence index values indicate anomalous convergence in the north during spring and summer of 1976, and anomalous divergence during late fall.

During the final revision of this paper, index values were available for the first 7 months of 1977. Coastal upwelling index values are generally above average except during January and during May in the north (Figure 31). Offshore divergence index values are high during January and February, but anomalously low during spring and early summer (Figure 32).

Offshore divergence index values at 21°N tend to be very high in this recent 6 year period relative to the values in earlier years of the time series (Figure 32). Whether this reflects a real longer period variation in the wind pattern is not clear at this time. Changes in the distribution of available data or in the meteorological analysis procedures may be affecting the computed values. In general, care should be exercised in attempting to discern long term trends using this type of index series. Rather, the purpose is to provide a useful indication of relative variations within groups of fairly contemporaneous years.

CONCLUDING REMARKS

In our descriptions of seasonal features, the summaries by 1 degree squares indicated significant spatial variations on scales smaller than the 3 degree resolution we can achieve in synoptic indices. Relating the large scale indices to smaller scale features may require the "engineering approach" suggested by Smith (1968) where one looks at the "outputs," in our case physical or biological data on a smaller scale in those particular instances where it is available from research cruises, shore stations; etc., and the larger scale synoptic "inputs" and attempts to define the "transfer functions." As a first approximation it may be reasonable to assume, for example, that where greater than normal convergence is indicated on the larger scale, smaller scale divergences which exist might weaken and convergences strengthen.

We are continuing to assemble pertinent data including ocean-atmosphere heat exchange components, dynamic topographies from hydrographic data, sea level records, mixed layer depths, temperature series from shore stations, river runoff records, etc. We are looking into possibilities of satellite inputs and are in the process of expanding our wind stress indices to lower latitudes using newly developed "global band" atmospheric products (Lewis and Grayson, 1972).

Our plans for the future include computer modelling of some of the processes controlling the fishery environment. It is sometimes the case in fishery oceanography that rather than having too little detail in our environmental descriptions we have too much, and very little means to integrate it into a total "environmental condition" which will make sense in terms of a total fishery. Modelling, rather than creating any new data, may help to distill the various data available down to a useable number of significant factors, the year to year variations of which could be quantitatively compared. Time series of these factors might be generated from historical data and related to the past history of fishery stocks. Continuous operational updates could than perhaps provide practical environmental inputs for systems approaches to fishery management.

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ESTIMATION OF THE EFFECTS OF ENVIRONMENTAL VARIATIONS ON THE EGGS AND LARVAE OF THE NORTHERN ANCHOVY

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ABSTRACT

Expanded studies of stock and recruitment at the Southwest Fisheries Center have led to additional objectives for laboratory and field work concerning the northern anchovy, *Engraulis mordax.* In addition to monitoring the stock size of the spawning portion of the anchovy population, we have begun to examine the possible causes and rates of larval mortality.

In this paper we show that the sampling effort required to measure changes in larval survival must be much greater than that used to monitor anchovy spawning biomass, i.e., closer intervals of sampling (in time and space) will be needed over relatively broad areas. Although existing sampling techniques are probably adequate to accomplish this, we show that there still remains the need to refine our statistical methods for analyzing larval age groups, data required for assigning larval mortality rates.

Changes in anchovy spawning are compared to seasonal and annual variations in sea water temperature, vertical temperature gradients, upwelling, California Current speed, flushing rate of the Southern California Bight, and secondary production. It appears that the usual habit of the anchovy to spawn in the southern California area in winter, alters radically in some years. The cause for this is not yet known. Quarterly apparent mortality rates are assembled for the years of greatest environmental changes in the southern California regions for anchovy eggs and larvae (to 6.25 mm).

New biological information needed for analyzing the causes of anchovy larval mortality has been assembled. For example, first feeding anchovy larvae require abundant food in a narrow size range and of particular species. *Gymnodinium splendens,* a naked dinoflagellate about 40 μm in diameter, supports growth when it occurs in concentrations of 20 or more cells per ml. Tests with laboratory reared larvae have confirmed the existence of suitable strata of larval food organisms in nearshore waters which are associated with chlorophyll maximum layers at 15–30 m depth. Storms were observed to disperse the food organisms until they were too low in number to support larval growth.

INTRODUCTION

Review of Field and Laboratory Research on California Anchovy, and the CalCOFI Program

In the last two decades (1955–1974) the northern anchovy, *Engraulis mordax,* supplanted the Pacific sardine, *Sardinops caerulea,* in biomass and in the commercial and live bait fisheries off the California coast (Baxter, 1967; Messersmith, 1969; Ahlstrom, 1966). The northern anchovy is now the chief forage fish for most of the large sport and commercial fishes of the California Current and represents a large, underutilized fishery resource, probably exceeding in biomass the former sardine population.

Estimates from a number of sources (see Messersmith, 1969, for a resume; Smith, 1972) agree that the standing stock of the northern anchovy off California and Baja California exceeded 4 million metric tons in the 1960's. This large population is the result of a rapid increase in numbers of anchovies since 1950 to 1951 when the population was estimated to be less than 1 million metric tons (Smith, 1972). This dramatic increase in numbers and biomass of the anchovy took place while the Pacific sardine population declined to a point where fishing was no longer profitable and when the standing stock of sardines was reaching a low point of less than 10,000 metric tons in 1965 (Smith, 1972) from which it had not recovered in the ensuing 8 years.

Loukashkin (1970) has shown that *E. mordax* is chiefly zooplanktivorous; thus, this large biomass of anchovies undoubtedly has had an impact on the food web, in particular on the secondary production and standing stock of zooplankton of the California Current. It also seems likely that the management of fisheries on the northern anchovy will be complicated by radical shifts in the success of year classes contributing to the fishery.

The fundamental objectives of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program in the California Current region have been to measure the changes in biomass of the major pelagic fish populations inhabiting the region and to find explanations for these changes. Recent major reviews of the CalCOFI program including Marr (1960), Murphy (1966), Ahlstrom (1965, 1968), Smith (1972), and Soutar and Isaacs (1974) permit one to conclude that the major changes in the biomass of several populations in this region have been adequately monitored. In addition, it appears that changes in biomass which have been observed cannot yet be explained in terms of fishing effort, competition among species, or environmental variations.

Most changes in biomass of populations studied through monitoring a fishery appear to be due to changes in the success of recruitment to the fishable population. For example, spawning success varied independently of the spawning stock size of the sardine population by 7 times, from 1932 to 1957 (Murphy, 1966, p. 77). There is reason to believe similar changes occurred in spawning success of the anchovy (Soutar and Isaacs, 1974) during the last century.

In a renewed attempt to explain changes in biomass, we intend to examine the food requirements of the anchovy at all stages in its life cycle, to describe the incidence of suitable feeding areas in the ocean, and to discuss how changes in food requirements and feeding might affect recruitment. Where it is applicable, suggestions are made to change present sampling programs in order to provide additional information for evaluating changes in the environment as these might induce changes in the anchovy population, e.g., changes in growth rate, mortality, and fecundity. Because of the existence of considerable information on food requirements at the larval stage, and records of larvae from most of the northern anchovy spawning area since 1951, we have chosen to describe in detail the parameters which seem necessary for estimating the effects of environmental variations on survival and growth of anchovy eggs and larvae. We anticipate this will guide future workers who may need to establish similar criteria for studying biomass fluctuations in other fish populations.

ASSESSMENT OF ANCHOVY EGGS AND LARVAE AND ITS RELATIONSHIP TO THE SPAWNING BIOMASS

The amount of effort required for the efficient assessment of eggs and larvae is different when the objective is to monitor the size of the spawning stock than when the objective is to analyze mortality which occurs during the planktonic phase of a fish's life cycle. The surveys now being conducted in CalCOFI have been designed to monitor the spawning biomass. Estimates of mortality require more precise sampling and the evaluation of some major biases. It is the purpose of the following to define sampling requirements for each of these objectives from the long data record from CalCOFI surveys, and from some intensive investigations of local sampling variability.

Pelagic Pattern

The chief obstacle to effective sampling is the intensity of adult anchovy schooling behavior when spawning. In areas where spawning is taking place, newly spawned eggs at densities of hundreds per square meter may be within a few hundred meters of areas where there are no eggs at all. Dispersal of these eggs from the spawning sites is apparently very slow, with identifiable traces of this pattern persisting for the entire time that the larvae are

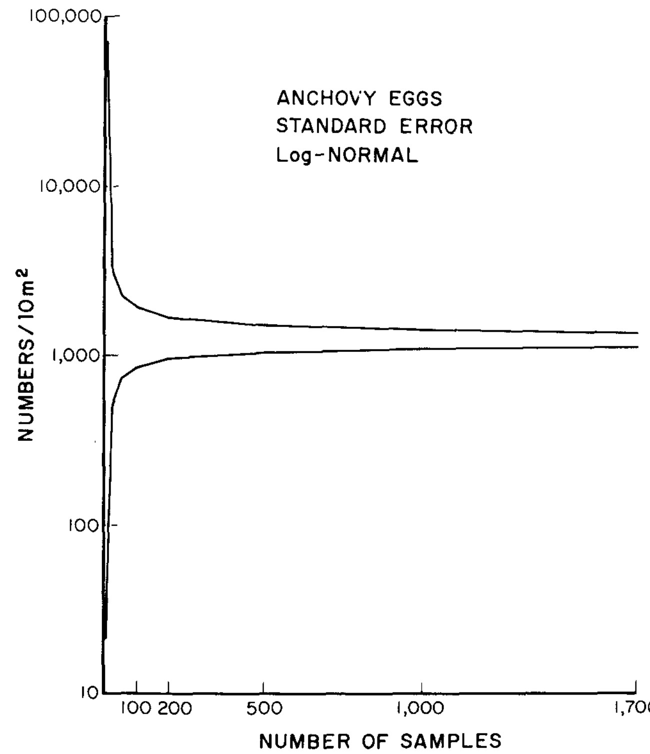

FIGURE 1. The relationship between standard error and number of samples for anchovy eggs using a log-normal transformation. Single sample variability at the origin indicates the intensity of patchiness.

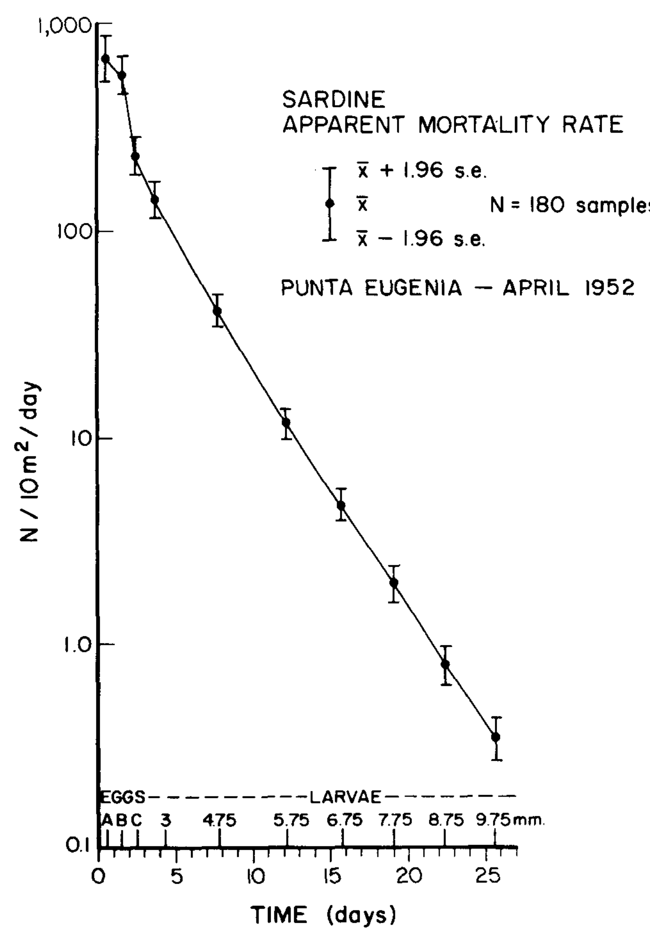

FIGURE 2. Apparent mortality rate of Pacific sardine eggs and larvae, N = 180.

vulnerable to the net. It seems likely that schooling behavior begins before the larvae have been entirely dispersed from the schooling behavior of the adults.

Regardless of the cause of pelagic pattern, the effect on sample precision must be overcome for the purposes of estimating the amount of spawning and determining the fate of the spawn. Precision may be increased by increasing the sampling effort and maintaining a rigorous sampling quality control. This is particularly important in the sampling of log-normal distributions common in the sea. For 10% sample confidence limits, when eggs are sampled, about 500 samples per space-time unit (Figure 1) need to be collected. To obtain a 25% sample confidence limit, which is adequate for determining rapid mortality rates (Figure 2), fewer than 100 samples may suffice (Figure 3). Satisfactory results in monitoring spawning biomass have been obtained in CalCOFI using as few as 30 samples per space-time unit.

For estimation of spawning, the most important bias is due to the loss of eggs and small larvae through the meshes of the plankton net. Lenarz (1952) found that a few paired tows of nets with different meshes are adequate for quantifying this bias. For determining the fate of the spawn, the most important bias is the growing tendency of larvae to avoid the net. No suitable solution is now available for this avoidance problem (Clutter and Anraku, 1968) but bongo nets and other higher speed bridle-free nets can materially increase the number of larger larvae collected.

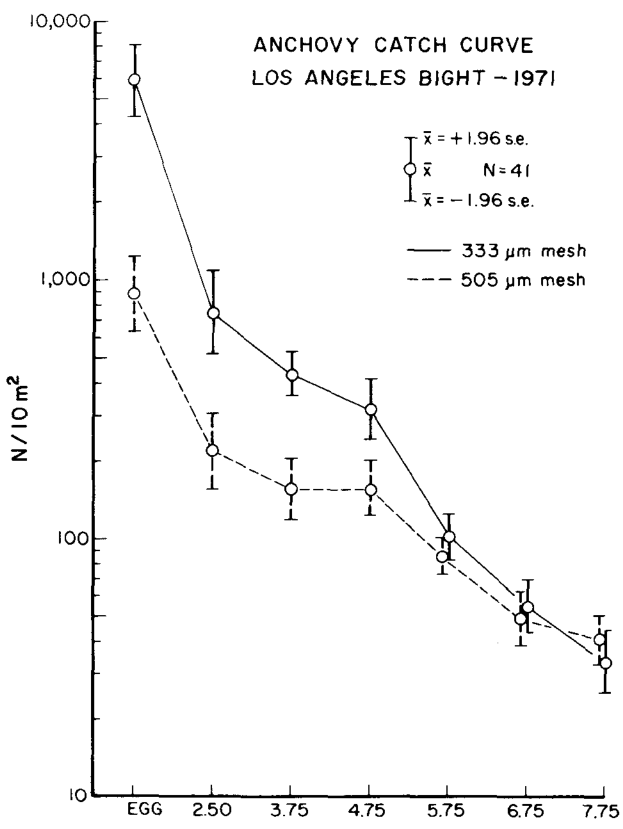

FIGURE 3. An example of the discrimination between the catch of anchovy eggs and larvae using two net meshes, N = 41.

The issue of assigning confidence limits to data derived from counts of eggs and larvae of pelagic fish has rarely been treated satisfactorily (Bagenal, 1955; Harding and Talbot, 1973). Among the pressing problems is evaluating mortality rates between two adjacent age classes when the variance of the number of fish in each age class is changing and the older class has been dispersed over a wider area than the younger class. While analysis of the existence of a difference can be attempted using log-transformed data, estimating the magnitude of the difference must be accomplished using the original arithmetic means. As pointed out by Cassie (1968, p. 109), "means obtained from log-transformed data are, after taking anti-logarithms, geometric means which will be smaller than the corresponding arithmetic means." Observations containing small and uniform proportions of "O" observations are satisfactorily treated in logarithmic transformations by adding a constant to each value, usually "1". However, in larval sampling, there are trends in the proportion of "O" observations. Therefore, the standard practice of adding "1" and taking the logarithm is not applied because it has not been adequately studied under these conditions.

Seasonal and Annual Changes in Spawning, Environmental Parameters, and Apparent Larval Mortality

A sample of existing data has been assembled to illustrate the magnitude and timing of spawning and other seasonal events as well as examples of changes between years. These seasonal and annual changes may be used as guides to design improved surveys and devise analytical techniques for the assessment of larval mortality and some of its causes. The area and time period chosen for these examples is the Southern California Inshore or SCI (Smith, 1972) for the years 1953 through 1960. This area was chosen because it was sampled thoroughly and regularly. The time interval was chosen to span two unusual climatic events; in 1956 the ocean off southern California was colder than average and in 1958 it was warmer than average.

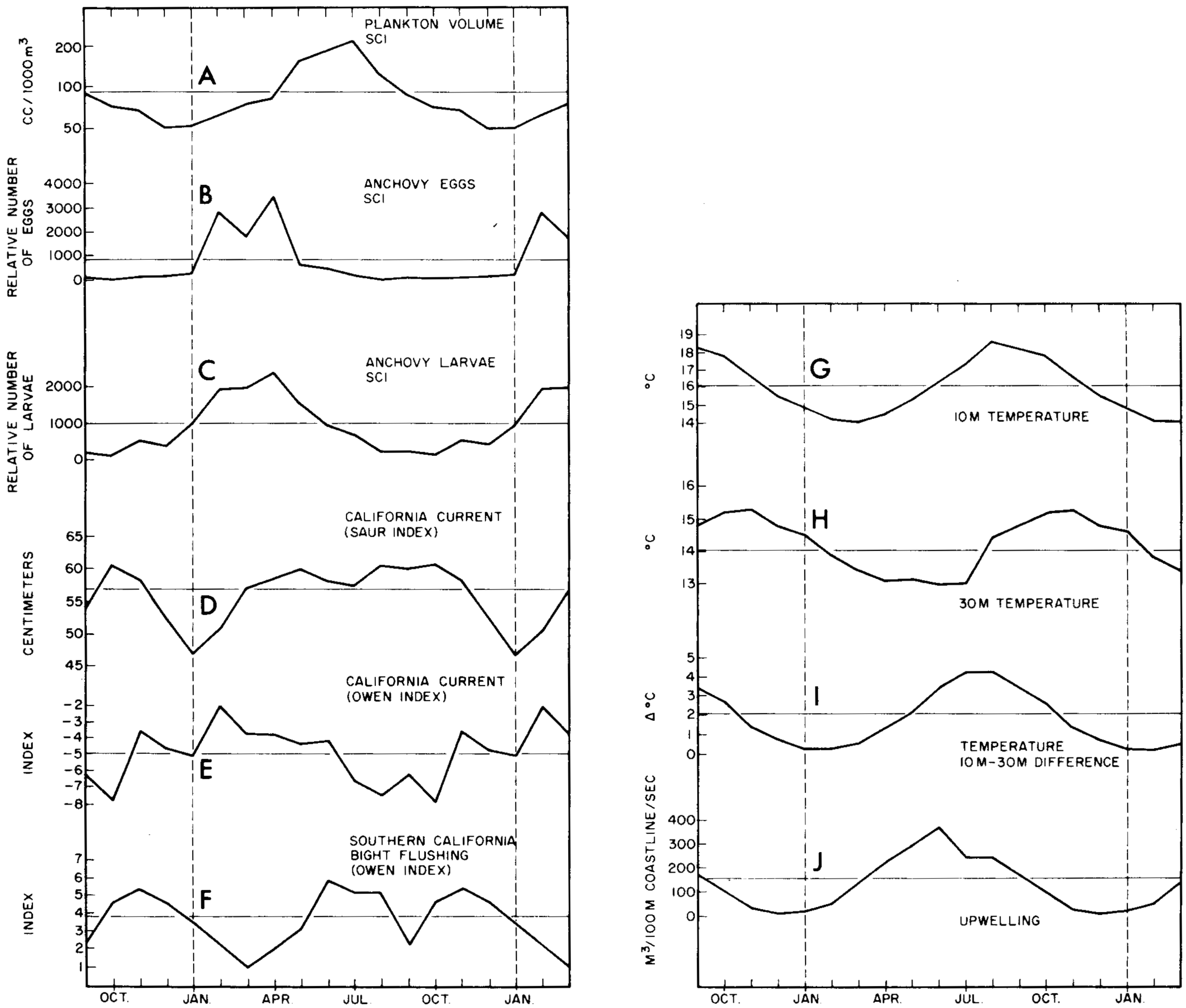

FIGURE 4. Average annual cycles (1953–1960) in the Southern California Inshore region. Six months are repeated for cycle emphasis; a) plankton volume, b) anchovy eggs, c) anchovy larvae, d) the California Current (Saur, 1972), e) the California Current south of Pt. Conception within the CalCOFI grid (Owen, National Marine Fisheries Service, La Jolla, Pers. comm.), f) Southern California Bight Flushing Index (Owen, National Marine Fisheries Service, La Jolla, pers. comm.), g) 10-meter temperatures, h) 30-meter temperatures, i) temperature difference between 10 and 30 meters, j) upwelling (Bakun, 1973).

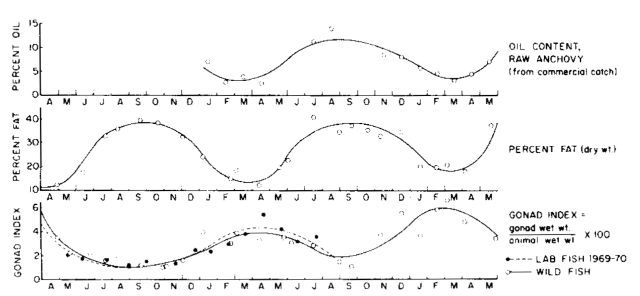

FIGURE 5. Annual northern anchovy fat and gonad cycles for 1965–1967. Oil content is from the commercial catch in California (data provided by Roland Finch, National Marine Fisheries Service, Terminal Island). Laboratory fish were kept in an outdoor pool at the La Jolla Laboratory of the Southwest Fisheries Center under ambient light and temperature conditions.

The seasonal maxima of anchovy spawning in the Southern California Inshore region appear to be in February, March, and April. The minima are in August, September, and October (Figures 4B, C). Maximum spawning coincides with the minimum temperature at 10 m depth. The temperature at 30 m decreases after the spawning maximum and coincides with upwelling (Bakun, 1973) which reaches a peak in June. Anchovy spawning also coincides with the maximum rate of increase in the 1953 to 1960 upwelling index. The lowest zooplankton standing stock is coincidental with the upwelling minimum in December although the zooplankton peak in July appears 1 month after the upwelling maximum. The fastest rate of increase in fat content of anchovy adults coincides with the zooplankton maximum (Figures 4A and 5). Average conditions for California Current strength by sea level difference approximations (Saur, 1972) and by geostrophic calculations (Owen, National Marine Fisheries Service, La Jolla, pers. comm.) do not agree closely (Figures 4D, E). Exchange of water between the rather permanent eddy in the Southern California Inshore region and the California Current (Owen's Southern California Bight Flushing Index, Figure 4F) appears to be at a minimum during the height of anchovy spawning. This indicates that water and spawned eggs and larvae are moving out of the Southern California Inshore region at a relatively slow rate. An 8 year average of each environmental and biological variable was calculated (Figures 4A–J and 5).

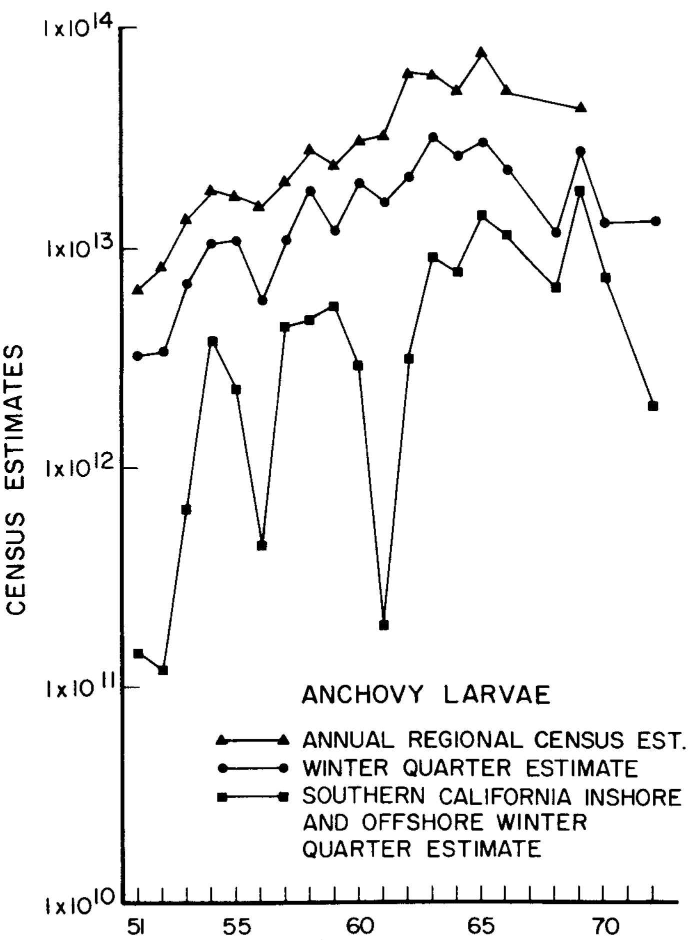

FIGURE 6. Time series of regional census estimates of anchovy larvae (Smith, 1972).

Five additional time series have been selected to illustrate the magnitude and extent of coincidence of annual variations in spawning and other routinely measured environmental data. Three curves represent the abundance of anchovy larvae (Figure 6). The increase in estimates of the abundance of larvae appears to be rather gradual in the annual census estimate for all anchovy larvae in the entire California Current sampling grid in all seasons. There is an increase in the total abundance of larvae in the winter quarter generally parallel to the annual estimates. The abundance of anchovy larvae in the winter quarter in both the Southern California Inshore and Offshore regions indicate this is a major spawning area for anchovy (Figure 6). The considerable changes in the fraction of the total larval population in these combined regions in this season suggest that studies of survival will need to be conducted over an even bigger area than the 35,000 square nautical miles represented.

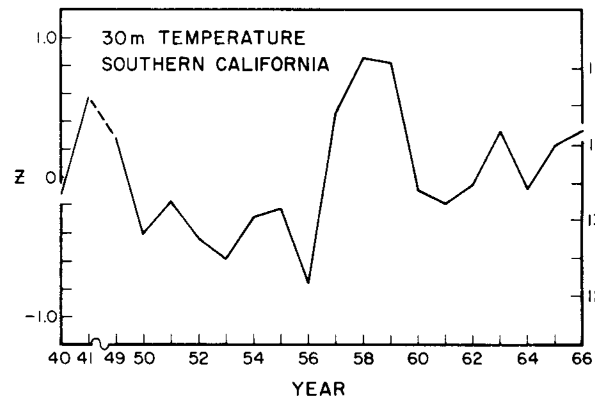

FIGURE 7. Thirty (30) meter annual average temperature for the Southern California Inshore zone, Z is the normalized standard deviation of the variable.

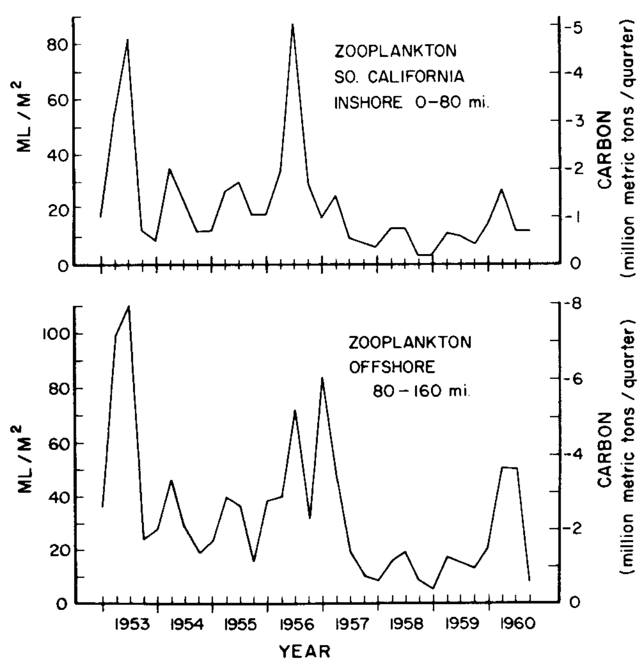

FIGURE 8. Zooplankton volumes, 1953–1960 for Southern California Inshore and Offshore regions. Carbon equivalents were obtained by multiplying wet volume figures by 0.056 (Cushing, 1971).

The time series of temperature at 30 m depth illustrates major climatic shifts in the Southern California Inshore region (Figure 7). Yet there does not appear to be any obvious direct control exerted by temperature over spawning. Lastly, two curves illustrate Southern California Inshore and Offshore zooplankton standing crop as well as estimates of secondary production by the "Cushing" method (1971) over the same reference period (Figure 8). Estimates of zooplankton production do not offer obvious explanations for major shifts in the amount or location of spawing. We conclude from these time series that over gross areas, changes in temperature and zooplankton production do not offer promising leads for finding cause and effect mechanisms which determine survival of larvae and recruitment to the parent stock.

Mortality rates for larvae in the sea are of special interest because these are needed to measure the effects of environmental variations on recruitment. These rates are difficult to derive because there have been few attempts to assign ages to the various size categories of larvae in our samples (Ahlstrom, 1954). Hatching time, however, is a function of temperature and as a first approximation, the ratio of hatching time at ambient temperature to that at 15°C has been used to adjust each egg and larval count. The regional census estimates of the eggs and various sizes of anchovy larvae have been assembled from the adjusted data. The numbers of eggs and larvae also have been corrected for an escapement bias described by Lenarz (1972). Quarterly estimates of egg and larval abundance in the Southern California Inshore region have been made (Table 1). The parameters of the least squares fit made to the simple exponential equation:

$$N_t = N_o e^{-zt}$$

where:

N_t = is an estimate of the number of eggs or larvae at time "t" in days

N_o = is the ln N at time zero, and

z = is the instantaneous rate of apparent mortality.

TABLE 1

Larval anchovy mortality rate by quarter (QTR) for each year (YR), 1953 to 1960.*

YR-QTR	Eggs	2.50 mm larvae	3.75 mm larvae	4.75 mm larvae	5.75 mm larvae	r_1	r_2	z_1	$(N_0)_1$	z_2	$(N_0)_2$
	1.5 days old	3.8 days old	5.6 days old	7.5 days old	9.8 days old						
53–1	1328	536	195	80	65	–.949	–.975	.3538	7.3889	0.3870	7.6431
2	355	201	83	47	15	–.996	–.993	.4188	6.8694	.3824	6.5866
3	493	1951	406	431	191	–.904	–.619	.3407	8.4987	.1623	7.1354
4	787	3197	1426	661	279	–.999	–.622	.4034	9.5563	.1755	7.8147
54–1	2482	3718	1725	964	462	–.997	–.902	.3408	9.4441	.2294	8.5927
2	2560	1494	256	133	61	–.957	–.976	.5046	8.8311	.4820	8.6584
3	3420	1585	434	264	129	–.969	–.985	.3964	8.6142	.4081	8.7040
4	475	500	193	84	39	–.994	–.962	.4216	7.7061	.3307	7.0116
55–1	3679	1707	1251	649	330	–.994	–.997	.2808	8.5859	.2854	8.6208
2	1879	1079	671	321	170	–.997	–.997	.3140	8.1948	.2954	8.0534
3	312	2461	597	307	170	–.961	–.486	.4273	9.1169	.1545	7.0320
4	187	86	137	36	21	–.866	–.913	.2829	5.8879	.2596	5.7106
56–1	1627	102	154	31	19	–.882	–.927	.3355	6.2490	.5001	7.5068
2	4631	2321	828	318	166	–.987	–.992	.4392	9.2664	.4225	9.1390
3	597	188	162	204	148	–.467	–.773	.0261	5.3340	.1356	6.1709
4	598	130	70	62	27	–.973	–.957	.2433	5.7584	.3432	6.5214
57–1	34741	3147	1989	1220	338	–.979	–.960	.3643	9.5757	.5067	10.6639
2	25402	5608	2050	1108	592	–.983	–.979	.3644	9.8443	.4488	10.4889
3	685	1721	382	200	137	–.934	–.824	.4030	8.5926	.2574	7.4798
4	1001	58	98	100	47	–.271	–.743	.0397	4.5401	.2821	6.3925
58–1	9668	3746	2044	760	376	–.995	–.997	.3933	9.7277	.3972	9.7573
2	3540	3627	1329	827	495	–.971	–.960	.3183	9.2015	.2632	8.7803
3	84	396	189	156	80	–.978	–.231	.2489	6.8242	.0472	5.2831
4	793	255	25	11	10	–.874	–.941	.5098	6.7669	.5771	7.2808
59–1	2227	1345	1103	207	93	–.967	–.959	.4856	9.2588	.4035	8.6317
2	3269	1581	1058	702	434	-1.000	–.995	.2143	8.1694	.2387	8.3558
3	41	372	87	41	21	–.968	–.487	.4621	7.3690	.1663	5.1092
4	196	398	97	19	8	–.984	–.906	.6609	8.3060	.4576	6.7524
60–1	1957	2411	948	390	186	–.993	–.945	.4259	9.3003	.3178	8.4747
2	6846	1172	757	532	293	–.998	–.945	.2262	7.9225	.3508	8.8747
3	127	247	75	76	37	–.923	–.804	.2811	6.3177	.1761	5.5153
4	53	48	6	5	1	–.955	–.956	.5867	5.7329	.4986	5.0596
n	32	32	32	32	32						
$\bar{x}$	3626	1481	651	342	170	–.995	–.997	.3550	8.5562	.3722	8.6876
s	7351	1416	653	346	165						

* Low values of z_1 and z_2 indicate high survival or low mortality; high values, the opposite. The intercept, N_0, is an *index* of the size of the spawning population, proportional to the logarithm of the amount of spawning which took place in each quarter. No extrapolation nor prediction should be conducted from these slopes and intercepts without refitting curves with non-linear least squares; for example, the Marquardt algorithm or equivalent.

r_1, z_1 and $(N_0)_1$ = without eggs.

r_2, z_2 and $(N_0)_2$ = with eggs.

Sample values for eggs and larval lengths through 6.25 mm and the age of each stage are listed (Table 1). Parameter estimates r_1, z_1, and $(N_0)_1$ exclude the egg sample variable whereas r_2, z_2, and $(N_0)_2$ include the variable. One may see from the correlation coefficient, r, that the simple exponential model more effectively describes the sample data at the height of spawning in winter and spring quarters than in the summer and fall quarters. The sample variation is better described when the egg census estimate data are omitted. From the tabular summary, it is evident that the number of eggs from sample to sample varied proportionately more than did the larvae.

BASE REQUIREMENTS FOR FEEDING, GROWTH, AND SURVIVAL OF ANCHOVY LARVAE

Numbers of research papers have appeared from the Southwest Fisheries Center, La Jolla, California, which developed criteria for growth and survival of anchovy larvae (Hunter, 1972; Hunter and Thomas, 1974; Kramer and Zweifel, 1970; Lasker, 1964; Lasker et al., 1970; Lasker, 1975; O'Connell and Raymond, 1970; Theilacker and Lasker, 1974; Theilacker and McMaster, 1971; Thomas, Dodson and Linden, 1973).

Feeding of larvae in relation to biological and physical environmental conditions has been the main area of investigation in order to examine the hypothesis that variations in year class strength are probably due to differential mortality of larvae when they first begin to feed; i.e., that a lack of food at the time of first-feeding may be the main cause of huge mortalities and result in small year classes (Hjort, 1914).

The northern anchovy has been and can be continually matured sexually and spawned in captivity at the Southwest Fisheries Center (Leong, 1971) which provides investigators with ample eggs and larvae for experimental work. Some of the studies referenced above have been done with laboratory produced larvae. These investigations have shown us that the following criteria need to be met for reasonable success in laboratory survival and growth of *Engraulis mordax* larvae. Another discussion of these criteria may be found in Lasker (1975).

The size of the food particle at first-feeding must neither be too small nor too large. Berner (1959) examined stomach contents of northern anchovy larvae from field collections and found that particles of food in the intestines of first-feeding larvae ranged from 24 to 186 μm long. However, over 70% of the food was between 60 and 80 μm long. This seems to be controlled by the mouth gape of the larva as borne out by laboratory feeding studies. Algal cells between 10 and 20 μm in diameter are not eaten by first-feeding anchovy larvae while particles of 40 μm and larger are eaten without difficulty. Organisms the size of the rotifer *Brachionus plicatilis,* which range from 99 to 281 μm long and 66 to 182 μm wide can be taken by a small proportion of first-feeding anchovy larvae (Theilacker and McMaster, 1971; Hunger, 1972).

The number of food particles per unit volume in the first-feeding anchovy's environment must be above a minimum concentration. O'Connell and Raymond (1970) showed that a minimum density of micronauplii (about 1/ml) was needed for anchovy larvae to survive in laboratory experiments. Hunter (1972) has shown that there is a minimum density of algal cells that must be present if an anchovy larva is to obtain enough nutrients for metabolism, but his calculation is about 10X lower than the minimum number of cells we find to be necessary (i.e., about 20 to 40 cells/ml) for metabolism, growth, and to account for capture inefficiency in the laboratory.

Not all food organisms capable of being eaten by anchovy larvae support growth and survival. In the laboratory only one phytoplankter, *Gymnodinium splendens,* of a number tested, suppported growth of first-feeding anchovy larvae. However, larvae fed a variety of foods, such as found in wild plankton, invariably grow faster and survive better than those fed single species of organisms in the laboratory, but only when the plankton was concentrated to increase the density of the food organisms per unit volume (Kramer and Zweifel, 1970). Hunter (1972), who analyzed Arthur's (1956) data, pointed out that phytoplankton comprises at least 32% of the diet of first-feeding anchovy larvae. We know from rearing experiments that some nauplii (e.g. from the harpacticoid copepod *Tisbe furcata;* Hunter, National Marine Fisheries Service, La Jolla, unpublished) support good growth in first-feeding larvae, while other invertebrate larvae do not (Lasker et al., 1970).

The frequency of feeding strikes, and thus the success in capturing food is greater with high densities of food organisms. Hunter (1972) showed that feeding success at first-feeding for anchovy larvae is only about 10% of the feeding strikes made. Recently, Hunter and Thomas (1974) studied the feeding behavior of anchovy larvae in patches of *Gymondinium splendens* and found that the larvae fed more frequently inside the patch than outside. This differential feeding was related to the density of the food organisms in the larva's area.

Recent Observations at Sea

Lasker (1975) used first-feeding anchovy larvae produced by laboratory spawned fish to detect concentrations of larval fish food *in situ* along the California coast. First-feeding larval anchovies, whose development was controlled by temperature manipulation aboard ship, were placed in samples of Southern California Bight water taken from the surface and from chlorophyll maximum layers, usually 15 to 30 m below the surface. Feeding by larvae in water from the surface was minimal in all experiments but extensive feeding occurred in water from the chlorophyll maximum layers when these contained phytoplankters having minimum diameters of approximately 40 μm and which occurred in densities of 20 to 400 particles/ml. In March and April 1974, the chlorophyll maximum layer along the California coast from Malibu to San Onofre (a distance of about 100 km) consisted chiefly of a bloom of the naked dinoflagellate *Gymnodinium splendens,* a food organism known to support growth in anchovy larvae. Copepod nauplii and nonliving particles were never in high enough concentration or of the proper size to be eaten by the larvae. A storm which caused extensive mixing of the top 20 m of water obliterated the chlorophyll maximum layer and effectively destroyed this feeding ground for larval anchovy.

ADULT PHYSIOLOGY

Lenarz and Hunter (National Marine Fisheries Service, La Jolla, pers. comm.) have demonstrated that there is a distinct seasonal trend in anchovy egg size and that the size of larvae at 3 days of age is related to the original egg size. Whether smaller larvae are at a disadvantage in the sea is not known but knowledge of when adults spawn is probably essential information in later studies of recruitment.

We know also from MacCall (California Department of Fish and Game, La Jolla, pers. comm.) that the apparent mortality rate of adults from the southern subpopulation (see below) is higher than that of the central subpopulation. These examples have prompted us to examine some pertinent features of cyclic phenomena in the physiology of the adult northern anchovy.

Subpopulations

Unpublished work by Vrooman and Paloma (MS)[1] gives good immunological evidence for the existence of three distinct subpopulations of the northern anchovy off the west coast of the United States and Baja California, Mexico. Presumably, these reproductively separate races do not interbreed. One population is centered chiefly off lower Baja California, another, the so-called central subpopulation which contains the major portion of the stock, ranges from northern Sebastian Vizcaino Bay, Baja California, to San Francisco, California, while a northern subpopulation extends from San Francisco to at least Newport, Oregon. A considerable amount of information is available on the year class strength and biomass of the central California subpopulation (Vrooman and Smith, 1971; Smith, 1972; Soutar and Isaacs, 1974).

Lasker (1970) showed that there is a reciprocal relationship between the amount of fat in the body of the Pacific sardine, *Sardinops sagax caerulea,* and the maturation of the gonad, as measured by the gonad index (i.e. wet weight of the gonad divided by the wet weight of the fish X100). Shul'man (1960) in his review on lipids in fish stated that this is to be expected in most temperate fish. The same kind of relationship exists in the northern anchovy (Figure 5). Note that oil extracted from the commercial catch also reflects this cyclic phenomenon. We have also plotted mean gonad indices from anchovies kept in an outdoor tank at the La Jolla Laboratory. All of the fish came from the central subpopulation. Lipid deposition reaches a maximum in the anchovy during the summer, and a minimum during the peak of the spawning season (February, March, and April).

[1] Vrooman, Andrew M. and Pedro A. Paloma. MS. Subpopulations of northern anchovy *Engraulis mordax* Girard.

Laboratory experiments (Leong, 1971) have shown that northern anchovy gonad maturation can be induced by exaggerating winter light conditions. For example, 4 hours of light and 20 hours of darkness insures maintenance of high gonad indices (i.e. GI = 5% or higher) for as long as this light regime is maintained. Thus, this winter-early spring spawning fish's reproductive activity seems keyed to the seasonal light regime.

LARVAL ANCHOVY SURVIVAL

Recent work by Lasker (1975) has shown a correlation between the vertical stratification of suitablysized phytoplankters and the appearance of first-feeding anchovy larvae. The importance of the extent of these phytoplankton stratified patches, both horizontally and vertically, cannot be overestimated. We believe that virtually all survival of first-feeding anchovy larvae is linked to these favorable areas.

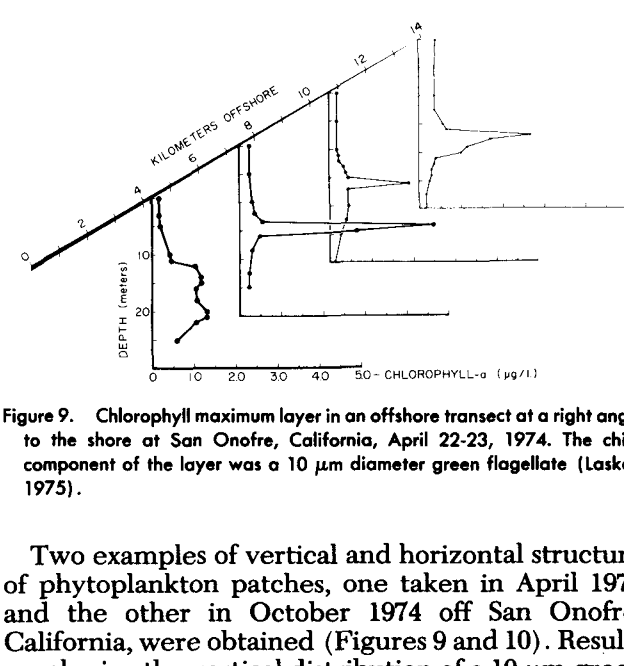

Figure 9. Chlorophyll maximum layer in an offshore transect at a right angle to the shore at San Onofre, California, April 22-23, 1974. The chief component of the layer was a 10 μm diameter green flagellate (Lasker, 1975).

Two examples of vertical and horizontal structure of phytoplankton patches, one taken in April 1974 and the other in October 1974 off San Onofre, California, were obtained (Figures 9 and 10). Results emphasize the vertical distribution of a 10 μm green flagellate (Figure 9) and the horizontal, vertical, and size distribution of a patch characterized by a 30 to

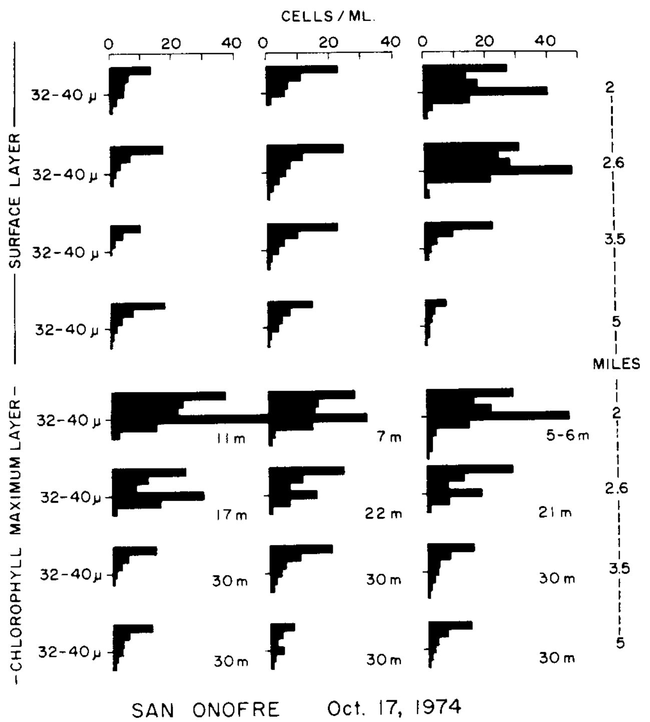

Figure 10. Particle size distribution from 12 adjacent stations off San Onofre, California, October 17, 1974. Five size groups are shown in histograms for each station; these are, top 16–20 μm, followed by 20–25 μm, 25–32 μm, 32–40 μm, 40–50 μm, and 50–64 μm.

40 μm dinoflagellate, *Gonyaulax polyedra* (Figure 10).

Quantitative studies of the food requirements of larvae and the feeding capability of predators on larvae (Hunter, 1972; Lillelund and Lasker, 1971; Theilacker and Lasker, 1974) indicate that average conditions in the sea are insufficient in food supply and sufficient predatory capability exists to consume the entire spawn. We have seen above that spatial patterns in the vertical and horizontal planes results in nursery patches for first-feeding anchovy larvae. Cursory examination of the patchy distribution of predatory organisms such as euphausiids and chaetognaths indicates that most of the predatory capability is concentrated in a relatively small proportion of the ocean, thus the spaces between patches of predators serve as a refuge for the survival of sufficient numbers of larvae for maintenance of population. The major criteria for survival of larvae appears to be related to coincidence rather than abundance alone; that is, a patch of larvae will survive if it coincides with an adequate patch of food organisms and also if it does not coincide with a patch of predators adequate to destroy the larval patch. These conditions also lead one to infer that the major influences on larval survival depend not on adequate production alone, but a stable oceanographic environment which will permit and maintain a discrete pattern of distribution of larval food, larvae, and the predators on larvae.

ACKNOWLEDGMENTS

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BEHAVIOR AND SURVIVAL OF NORTHERN ANCHOVY *ENGRAULIS MORDAX* LARVAE

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ABSTRACT

The object of this review was to provide an understanding of the behavioral factors that determine whether or not larvae of the northern anchovy, *Engraulis mordax* Girard, will starve. The swimming and feeding behavior of anchovy larvae is described and related to temperature, developmental stage, characteristics of the food and food distribution and to other variables. The principal sources of this information were published and unpublished observations of larvae cultured in the laboratory.

INTRODUCTION

Predation and starvation are considered by most specialists to be the dominant factors influencing survival of larval fishes. In the Southwest Fisheries Center (SWFC) of the National Marine Fisheries Service (NMFS), we have concentrated on the problem of starvation although some studies have been made on predation (Lillelund and Lasker, 1971; Theilacker and Lasker, 1974). The object of this review is to provide an understanding of the behavioral factors that determine whether or not an anchovy larva will starve. The swimming and feeding behavior of anchovy larvae is described and related to temperature, developmental stage, characteristics of the food and food distribution, and to other variables. The principal source of this information is observations of larvae cultured in the laboratory. Experimental design will not be given where information is already published, but a brief description will be given for new data. For information on laboratory culture of northern anchovy, the reader should consult Lasker, Feder, and Theilacker (1970), Theilacker and McMaster (1971), and Hunter (1976).

EGGS AND YOLK-SAC LARVAE

In southern California the major spawnings of anchovy occur in February and March but some spawning continues throughout the year (Lasker and Smith, 1977). During the height of the spawning season, temperatures in the upper 10 m vary from about 13° to 16° C.

Eggs are transparent oblate spheroids about 1.34 mm long and 0.66 mm wide, and are neutrally buoyant. Larvae hatch in 89.8 hrs at 13° C and at 59.8 hrs at 16° C (Zweifel and Lasker, 1976). The larvae at hatching averages 2.86 ± 0.028 mm standard length and weigh 0.0246 ± 0.0014 mg dry weight, of which 53% is yolk. At hatching larvae are nearly transparent, have no functional eye or jaw but olfactory and lateral line organs are developed (C. O'Connell, National Marine Fisheries Service, La Jolla, pers. comm.). After hatching, larvae are inactive; over 90% of the time they float motionless in the water usually with head directed downward. About once a minute they execute a burst of intense swimming, lasting about 1 to 2 sec. These bursts of activity may have a respiratory function as they occur regularly and increase in frequency when oxygen concentrations are below saturation (Hunter, 1972). The larvae have no functional gill filaments at this time so movement could serve to increase the transport of gases across the integument.

Owing to their inactivity, small size, and lack of a functional visual system, it appears anchovies in the yolk sac stage must be extremely vulnerable to predation. Indeed, Lillelund and Lasker (1971) showed that the copepod *Labidocera trispinosa* were 60% successful in capturing 1 day old yolk-sac larvae whereas success decreased to 11% for larvae that had begun to feed (4 days old). These authors also point out that success of capture seems to be correlated with the degree of activity of the larvae.

Development of a functional visual system and jaw, and nearly complete absorption of yolk coincides with the onset of feeding and a major increase in locomotor activity. Typically, larvae average about 4.0 mm standard length (SL) at this time but means vary from 3.8 to 4.4 mm depending on average egg size. The mean size of anchovy eggs varies seasonally, with larger eggs being more common in the winter (February and March) and small eggs occurring more frequently during the summer months (Lenarz and Hunter, MS). This seasonal variation would be expected to produce a seasonal trend in average larval size at first feeding. A larger size at first feeding would probably be of greater adaptive advantage in the winter months when cold temperatures produce slower growth rates than in the summer when it is more rapid.

SWIMMING BEHAVIOR OF POST YOLK-SAC LARVAE

Knowledge of swimming abilities of larval fish is essential for an understanding of survival. For example, the cruising speed of a larva will determine the frequency it will encounter prey, and determines in part whether or not a larva will remain in areas where prey are concentrated; also swimming accounts for most of the larva's energy expenditure. Burst speed capabilities determine in part the ability of a larva to avoid predation and plankton nets.

From the onset of feeding through adulthood, anchovy swimming consists of two types: continuously propagated caudally directed waves typical of most fishes that swim by caudal propulsion, and a series of bursts of motion consisting of a single tail beat followed by a rest or a glide. The beat and glide mode of swimming or intermittent swimming is used for cruising, whereas the other mode, continuous swimming, is used for high speed bursts. Nearly all swimming is intermittent in adult anchovy and in larvae after feeding begins. Continuous swimming in larvae is used for occasional bursts lasting usually less than a second and with a frequency of about 12 bursts/hour, less than 1% of the time devoted to swimming (Hunter, 1972).

Vlymen (1974) developed a model for energy expenditure of larval anchovy during intermittent swimming from theoretical considerations and analysis of cine photographs. He found that larvae of 14 mm standard length expended 5×10^{-3}cal/hr, and had a metabolic efficiency of 25%. This efficiency was high when compared to values obtained for larger fish and led Vlymen to speculate that this may have given anchovy larvae a competitive advantage over the Pacific sardine, *Sardinops caerulea.* It should be mentioned parenthetically, that although intermittent swimming may be more efficient, it is slow, and consequently the volume of water that can be searched for prey is less than that of a fish that swims in the continuous mode.

Swimming speeds of larval anchovy have been measured in various ways: plotting positions from cine photographs; counting tail beat frequencies; and visual approximation of larval position against a grid. For a temperature of 17° to 18° C the mean swimming speed of a 5 mm larval anchovy was 3.0 mm/sec using the photographic technique, 4.1 mm/sec using counts of tail beat frequency (Hunter, 1972); and 4.5 mm/sec when a grid was used (Hunter, unpublished data). These data set a range of cruising speeds of 0.6 to 0.9 body lengths/sec for anchovy larvae at 17° to 18°C. Maximum bursts of speed, on the other hand, appeared to be about 15 body lengths/sec but swimming in this case is continuous rather than intermittent and can be sustained for only brief periods (Hunter, 1972).

Although it is clear that larval size is a significant determinant of speed, the methods used to measure speeds of larvae, however, are not sufficiently accurate to establish the correct length coefficient. To do this larvae must be subject to known water speeds. Consequently, to adjust for size, the convention of dividing speed by length has been followed (Bainbridge, 1958), but it should be recognized that the true coefficient is probably less than unity (Brett, 1965). In addition to size, cruising speeds are influenced by many other variables, thus the above averages can be considered only to be general estimates.

Temperature, age, food distribution, feeding activity, and condition of the larva all influence swimming speed. Speed declines in starving larvae until they remain almost motionless, floating head down in the water. Food distribution may have several effects on swimming speed. In dense patches of food (*Gymnodinium splendens*) speed declines by about 60%. On the other hand, at any given density the larvae that are feeding at the highest rate are generally the ones that are swimming the fastest (Hunter and Thomas, 1974). This latter effect might be caused by the physical state of the larvae. For example, within a given food density the healthy and presumably better fed larvae are the most active and feed most often.

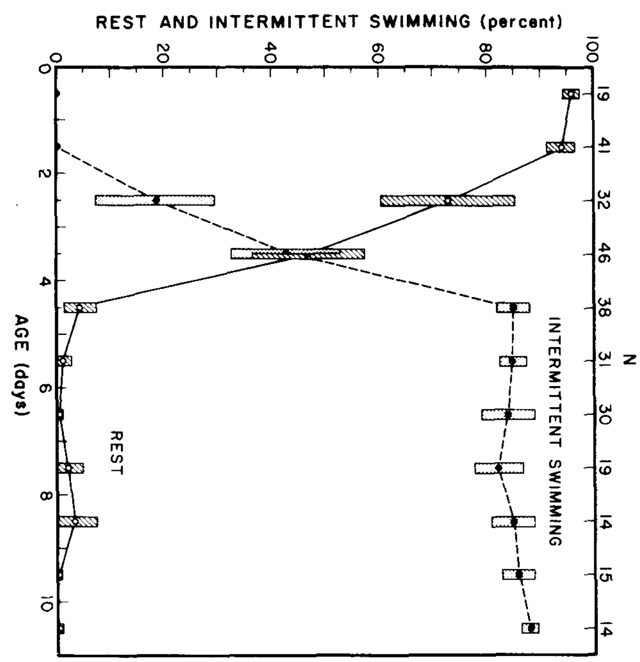

FIGURE 1. The proportion of time spent in rest and intermittent swimming by anchovy larvae during the first 10 days of larval life at 17° to 18° C (from Hunter, 1972). Points are the mean percent ± 2 X SE; the number of observations (N) is given at top of graph.

Temperature affects rate of development which, in turn, affects the age at which the transition occurs between occasional bursts of swimming typical of yolk-sac larvae to the almost continuous intermittent swimming typical of larval and adult anchovy. This transition is shown for the temperature range of 17° to 18° C, and indicates that by age 5 days the proportion of time spent in intermittent swimming becomes nearly constant (Figure 1). More recent data show how temperature determines the time at which this transition is made. The very low swimming speeds at 13° C (Figure 2) indicate that the transition did not begin at age 4 days, whereas the transition had started in larvae in 14° C water, and was almost complete in 4 day larvae in 17.5° C water. By age 6 days, larvae at all temperatures have completed the transition. The data indicate a direct temperature effect on swimming behavior as well. At ages 8 to 12 days larvae reared at temperatures less than 16° C appear to swim at a slower speed than those above 16°C.

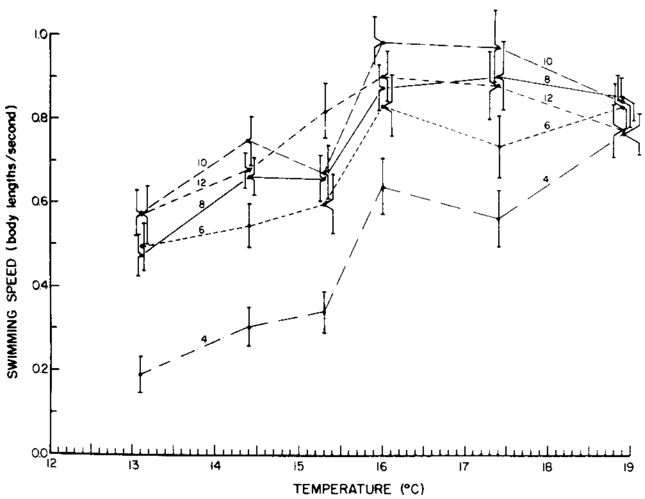

FIGURE 2. Swimming speed in body length/sec for anchovy larvae reared at five different temperatures. Speed was measured at ages 4, 6, 8, and 12 days by visual approximation of larvae against a grid; points are means ± 2 X SE (bars); numbers are age in days. All larvae were reared on *Gymnodinium splendens.*

In summary, size, temperature, food distribution, and starvation all influence cruising speeds. It is the complex interaction of these variables that determine whether or not a larva will find food and survive. Cooler temperatures cause a reduction in activity and therefore, in metabolic demand; on the other hand, cold temperatures result in slower growth and greater exposure to predation during the larval phase.

ENERGY SPARING MECHANISMS

Mechanisms that reduce activity and thereby conserve energy are probably important in the survival of larval fishes. Two possible mechanisms have been mentioned previously in this report: the reduction in activity associated with high food density; and the reduction in activity associated with colder water temperatures.

Another possible energy-sparing mechanism was proposed by Uotani (1973) for a Japanese anchovy and sardine, presumably *Engraulis japonica* and *Sardinops melanosticta.* Uotani found that net captured larvae of both species had expanded gas bladders at night and deflated ones in the day. He proposed that inflation at night was an energy sparing mechanism. He also suggested it might be effective in reduction of predation at night.

This behavior was examined for the northern anchovy, *Engraulis mordax,* in the laboratory by measuring the width of the gas bladder at night and during the day[1]. Larvae were maintained under a 12 hr light-12 hr dark cycle without a dawn or dusk transition in illumination. The width of the gas bladder of larvae collected in the dark and in the light was measured for nine, 0.5 mm length classes for larvae 8.5 to 15.4 mm SL and statistical comparisons were made between dark and light samples for each length class using the Mann-Whitney U test (Siegel, 1956). Larvae 8.5 to 9.4 mm showed no difference in gas bladder width in the dark from the light (P = 0.78) while larvae 9.5 to 10.4 mm differed at P = 0.035, and the remaining seven length classes differed at P 0.001. Thus, the threshold larval length for filling the bladder at night occurred between 9.5 and 10.4 mm corresponding to the intersections of the regression lines for bladder width on length for larvae in the dark and light (Figure 3). In this comparison, only data from larvae collected in the middle of the day were used because a transitional period of 2 to 4 hours occurs in the morning after the onset of the light (Figure 4). The change in light intensity would be expected to be much slower for larvae in the sea than in this laboratory experiment and thus deflation of the bladder is probably not a critical problem. In the dark, larvae with inflated bladders were suspended motionless, head downward, until disturbed by the light used to see them. The bladders were frequently so distended at night that they constricted the gut, a feature noted by Uotani (1973) in field caught larvae. The most tenable explanation of diel change in bladder size is that it permits the larva to adjust to neutral buoyancy at night and thus to conserve energy. It might also be useful if it enabled the larva to remain at about the same vertical position in the water column at night.

[1] This work has been described in detail by Hunter and Sanchez (1976) after this paper was submitted for publication.

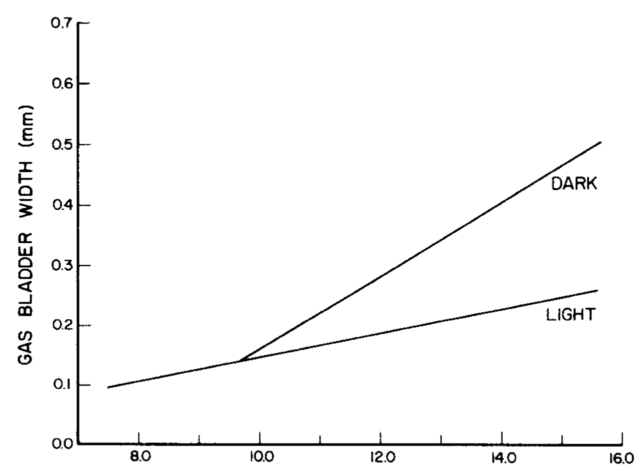

FIGURE 3. Regression of width of gas bladder in the dark (Y) on larval length (X) is Y = 0.613 X −0.453 and standard error of the estimate, s_{yx} = 0.0785; the regression of width of gas bladder in light on larval length is Y = 0.203 X −0.0556 and s_{yx} = 0.038.

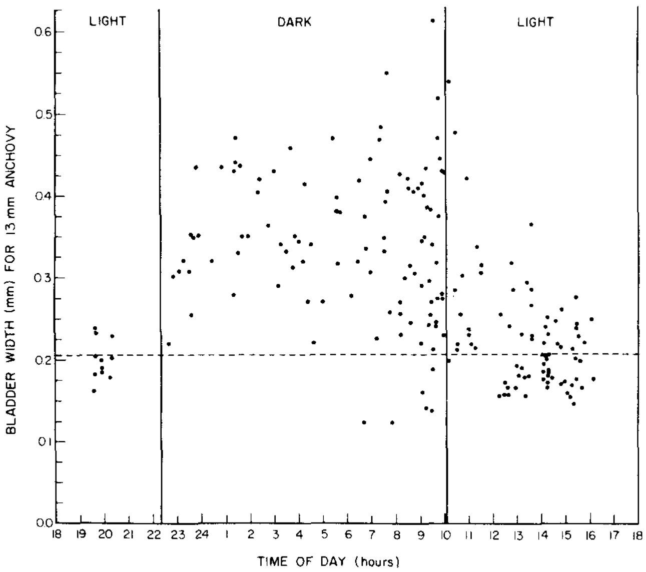

FIGURE 4. Diel change in width of gas bladder for anchovy larvae 13 mm SL. Larvae in sample ranged in length from 12.0 to 15.4 mm SL. Gas bladder width was adjusted to a common length, 13 mm, by using regression equations given in Figure 3.

FEEDING BEHAVIOR

Studies of the feeding behavior of larval anchovy provide insight into the conditions at sea that would favor starvation or growth. A complex of interacting variables determine if a larva will respond to a prey and whether or not it will find enough food to survive. Starvation, temperature, stage of development, time of day, larval size, prey size, feeding success, swimming speed, sighting range for prey, prey visibility, prey avoidance behavior, prey distribution and density may affect the amount of food ingested directly, and may affect it indirectly through interactions with other variables. Some information exists on the direct effects of some of these variables but little information exists on possible interactions.

Description of Feeding Behavior

On the average, larval anchovy first react to a prey when it is about 0.4 body length from the head of the larva. Upon sighting a prey the larva forms an S-shaped posture and advances toward the prey by sculling the pectoral fins and undulating the finfold, while maintaining the S-posture. When the prey is about 0.07 body length from its snout, the larva opens its mouth and straightens its body. This causes the body to drive forward, and the prey is ingested. The prey is maintained in the center of the binocular field while the fish is in the S-posture by slight adjustments in the position of the head and body. The entire act requires 1 to 2 seconds.

Time of Day and Satiation

Larval anchovy feed during the day and not at night, at least during the first half of larval life. Rods are not present in the retina in noticeable numbers (C. O'Connell, National Marine Fisheries Service, pers. comm.) until 20 days of age (11 mm SL). That larval anchovy feed only during the day is supported by my laboratory observations and also by field data described by Arthur (1956) who examined the stomach contents of sea-caught larvae 3 to 12 mm in length. In addition, stomach content analysis of adult anchovy also indicate that adults feed primarily during the day (Loukashkin, 1970).

In the laboratory, larval anchovy do not cease feeding once the gut is filled. Larvae with filled guts, sometimes with a fecal pellet protruding from the anus, can be seen feeding throughout the day. Thus satiation probably does not occur during the early portion of larval life, but it may occur after the larva reaches 18 to 20 mm and schooling begins. Satiation does occur in adult anchovy (Leong and O'Connell, 1969).

Starvation

Feeding declines with starvation until a point is reached where larvae are unable to feed sufficiently to maintain life although they may live a number of days after they reach this point. First feeding larvae reach this point 2.5 days after yolk absorption (Lasker, et al, 1970). At metamorphosis, on the other hand, anchovy are able to withstand starvation for over 2 weeks and survive when given food (Hunter, 1976). Thus, there exists a dramatic change in the ability to withstand starvation over the larval period ranging from 2.5 days for first feeding larvae to 2 weeks for newly metamorphosed anchovy (35 mm SL).

Temperature

The effect of temperature on feeding behavior in anchovy 4 to 12 days old was recently examined. For this survey I selected data on feeding behavior from rearing experiments conducted at a variety of temperatures in which the lengths of the larvae were about the same. Owing to different growth rates at different temperatures the ages of larvae are different but all were grown at high food densities in excess of 200 *Gymnodinium splendens* cells per ml. Only larvae greater than 4.5 mm or larger are considered because the stage of development influences feeding rate for smaller larvae and developmental stage is also a function of temperature. Feeding activity was measured by counting the number of feeding strikes executed by a larva in 5 minutes. Observations were made on 3 to 4 groups of larvae at each temperature and usually 15 observations per group per day. The data show that for larvae of similar length, and thus similar weight, feeding rates are higher for higher temperatures (Table 1). Thus the effect of temperature on feeding coincides with that on activity, indicating increased metabolic demand at higher temperatures. The feeding rates observed are, in general, quite high at all temperatures. This is because the larvae were feeding on a prey, *Gymnodinium splendens,* that is less than optimal in size, a point I shall return to in more detail later.

TABLE 1
Average Feeding Strikes per Minute and Mean Length of Anchovy Larvae Reared on *Gymnodinium splendens* at Various Temperatures.

Temp. °C	Age (days)	Length mm ± 2 × SE*	Feeding strikes/min ± 2 × SE*	Age (days)	Length mm ± 2 × SE*	Feeding strikes/min ± 2 × SE*
13.1	12	4.7 ± 0.1	3.1 ± 0.6	—	—	—
14.4	10	4.6 ± 0.1	4.3 ± 0.8	12	5.0 ± 0.1	4.7 ± 0.6
15.3	10	4.6 ± 0.1	3.3 ± 0.6	12	5.0 ± 0.1	4.1 ± 0.7
16.0	8	4.8 ± 0.1	4.1 ± 0.8	10	5.0 ± 0.1	4.3 ± 0.9
17.4	6	4.5 ± 0.1	4.8 ± 1.0	8	5.0 ± 0.1	5.9 ± 0.9
18.9	6	4.8 ± 0.1	7.0 ± 1.0	8	4.9 ± 0.2	7.7 ± 1.3

* SE = Standard error.

Density and Distribution of Food

Larval anchovy feed less often at lower food densities than at higher ones. Food density, however, also alters the structure of the search pattern for food. Larvae that enter a dense patch of *Gymnodinium* reduce speed, and alter the directional characteristics of their search pattern. In a dense patch they swim directly ahead less frequently and make more 180° turns than they do when the density is lower. The result of these changes in search pattern is a reduction in the area covered while searching for food if the food is highly concentrated and an increase in area covered when it is not. In other words, larvae respond kinetically to a food distribution which results in the larvae remaining in areas where food is more dense (Hunter and Thomas, 1974).

Feeding Success

At the time of first feeding, larvae are much less successful in capturing prey than they are later in life. This pattern has been observed in herring and other larval fishes (Rosenthal and Hempel, 1970). Larval anchovy capture about 10% of the food at which they strike at the time of first feeding but this value increases to about 90% when they are 20 days old (Hunter, 1972). This observation suggests that larvae are more vulnerable to starvation at the time of first feeding than later in development.

Characteristics of Prey

The characteristics of the prey such as size, nutritional value, digestibility, visibility, avoidance behavior, and the presence of protective devices such as spines must be important elements in the survival of larval fishes. The importance of most of these characteristics to marine fish larvae have not been evaluated. There is some evidence that digestibility may be important. For example, *Artemia salina* nauplii are ingested by herring and anchovy larvae but they fail to digest them completely and grow slowly or die when fed an exclusive diet of *Artemia* (Rosenthal, 1969; Hunter, 1976). Once a larval anchovy develops a differentiated gut, however, they are able to grow and survive on *Artemia* nauplii. In addition, evidence exists that first feeding anchovy larvae do not survive or grow slowly when fed some species of thecate algae whereas they are able to survive when fed unarmored dinoflagellates such as *Gymnodinium splendens* (Lasker et al., 1970). Thus, the straight tube gut, characteristic of young larval clupeoid fishes, may restrict these fishes to food that may be easily digested. Such potentially indigestible items as copepod eggs and diatoms which are found in guts of anchovy larvıe (Arthur, 1956) may contribute little to growth or survival.

Prey size is the only other characteristic for which some evidence exists on the importance to larval survival. Culture techniques for all larval fishes require that prey size be increased as a larva grows. Most studies of foods ingested by larvae indicate that prey size increases with larval length. This has been shown for larval anchovy by Berner (1959) and Arthur (1956).

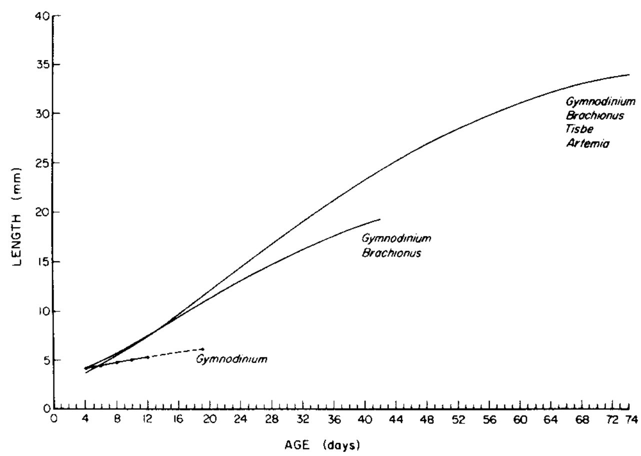

FIGURE 5. Growth of anchovy larvae fed different foods at 16° C. Foods used in rearing are given at end of each curve. Top, Laird-Gompertz growth curve for anchovy through metamorphosis and fed a graduated series of foods; middle, Laird-Gompertz growth curve for larvae fed only smaller foods (*Gymnodinium; Brachionus*); bottom, the curve connects mean lengths for ages 4 to 20 days for larvae fed only *Gymnodinium.* Densities for the same food are comparable in all experiments. Data and parameters for the first two curves are given by Hunter, (1976); data for the last curve are unpublished (n = 120 larval lengths per point; results are from eight rearing experiments; the last point, age 19 days, is from Lasker et al. (1970)).

The importance of increasing prey size with growth is illustrated by comparing growth rates of larval anchovy fed different foods (Figure 5). When larvae are fed *Gymnodinium* alone, growth becomes asymptotic at about 6 mm, whereas, when *Gymnodinium* and the rotifer *Brachionus plicatilis* are used, growth becomes asymptotic at about 20 mm and few larvae survive. A heavy mortality occurs in larvae fed only *Brachionus* and *Gymnodinium;* survival drops from 46% at age 26 days to 6% at age 42 days. On the other hand, if larvae are given, in addition to these foods, copepodites and adults of *Tisbe* sp., and *Artemia* nauplii when the gut becomes differentiated, larvae can be grown through metamorphosis with a reasonable survival, 12.5% at age 74 days (Hunter, 1976). The most tenable explanation for this result is that it becomes physically impossible for larvae to ingest sufficient numbers of prey when the prey are below a certain size. To illustrate this point, I calculated the number of *Brachionus, Gymnodinium,* and *Artemia* needed for larvae of different sizes (Table 2). The calculation is based on oxygen consumption data of Lasker (unpublished data), and the caloric value for the different foods and does not include adjustments for success in feeding or digestive efficiency which would increase the numbers needed.

TABLE 2

Numbers of *Gymnodinium splendens*, *Brachionus pilicatilis* and *Artemia salina Nauplii needed per day to meet metabolic requirements of anchovy of various sizes.*

Larval length mm	Dry weight mg	Numbers needed per day *		
		Gymnodinium	*Brachionus*	*Artemia*
4	0.021	230	14	—
6	0.064	690	43	4
10	0.314	3,400	210	18
20	4.164	45,000	2,800	230

* Calculated from: A respiratory requirement of 0.54 cal/mg dry weight larval anchovy/day and the caloric value per organism of

Gymnodinium = 0.00005 cal
Brachionus = 0.0008 cal
Artemia = 0.0096 cal

These calculations indicate that extremely high rates of ingestion must be maintained just to meet metabolic needs when the prey is small relative to the larva. Feeding activity would be considerably higher than the required ingestion rate since feeding success and digestive efficiency is not 100%, and many feeding acts are not completed. Other works suggest that a prey too small to support growth alone still may be beneficial as a supplement to the diet as long as larger organisms are also available (Hunter, 1976).

From the above considerations it seems obvious that it would be adaptive for an anchovy larvae to select as large a prey as possible. Shirota (1970) correlated the gape of the mouth of various larvae to the width of typical foods and found reasonable correspondence between 50 to 75% of gape and the width of typical prey organisms. Ambiguity exists, however, on the critical dimension of prey. For example, Arthur (1956) used the maximum prey width when studying the food of anchovy larvae, whereas Berner (1959) used the maximum dimension. This is not a trivial point since copepods, the principal food of larval fishes, are oblong. Thus, to determine whether or not a copepod or a particular stage of copepod can be ingested one needs to know the critical dimension. To solve this problem and determine the relationship between feeding success and mouth size, the mouth size of larval anchovy was measured and compared to the feeding success of larvae fed freshly hatched *Artemia.* Anchovy larvae of various sizes were allowed to feed on *Artemia* nauplii (density 10 *Artemia* /ml), and their stomachs were examined 4 hours later. The larvae had no previous experience feeding on *Artemia.*

The mean size of the *Artemia* selected (0.236 mm wide x 0.433 mm long) was less than the mean size of the *Artemia* in the tank (0.260 x 0.525 mm). When the mouth width was equal to or less than the width of *Artemia* selected, no prey were taken, whereas, when the mouth was slightly larger than the width of *Artemia,* 25% of the larvae captured one or more *Artemia* (Figure 6). When the mouth size was 1.5 times the width of the prey (larval length 8.1 to 8.5 mm), all larvae ingested one or more *Artemia* in the 4 hour feeding period and the mean number eaten, 19 ($N = 7$), exceeded the numbers required to meet metabolic needs for an entire day. These results also indicate that all prey were ingested end on since the length of the *Artemia* exceeded the width of the mouth in all cases.

Thus, a reasonably close correspondence existed between the maximum width of prey that was ingested by larval anchovy and the width of the mouth. On the other hand, for ingestion of prey to be independent of mouth width, the width of the mouth must exceed that of the prey by about 1.5 times.

Estimates of Food Densities

Two approaches have been used to estimate the density of food needed for survival of larval anchovy. Survival can be determined for larvae reared in the laboratory at various food densities or alternately the required density can be calculated from a searching model based on estimates of daily ration and the volume of water searched by a larva per day.

O'Connell and Raymond (1970) using the first approach, determined that first feeding anchovy larvae need at least one copepod nauplius per ml to survive and four or more per ml to insure good survival (about 50% survival after 12 days at 17° C). Lasker (1975), in a series of density experiments, found that anchovy larvae need 20 to 40 *Gymnodinium splendens* cells/ml to fill their guts in 8 hours, and Lasker et al. (1970) found that 100 to 200 cells/ml were required to insure growth for the first week.

The searching model approach was employed by Hunter (1972) to estimate the food density requirements of anchovy larvae. The model is similar to models of Cushing and Harris (1973), Blaxter

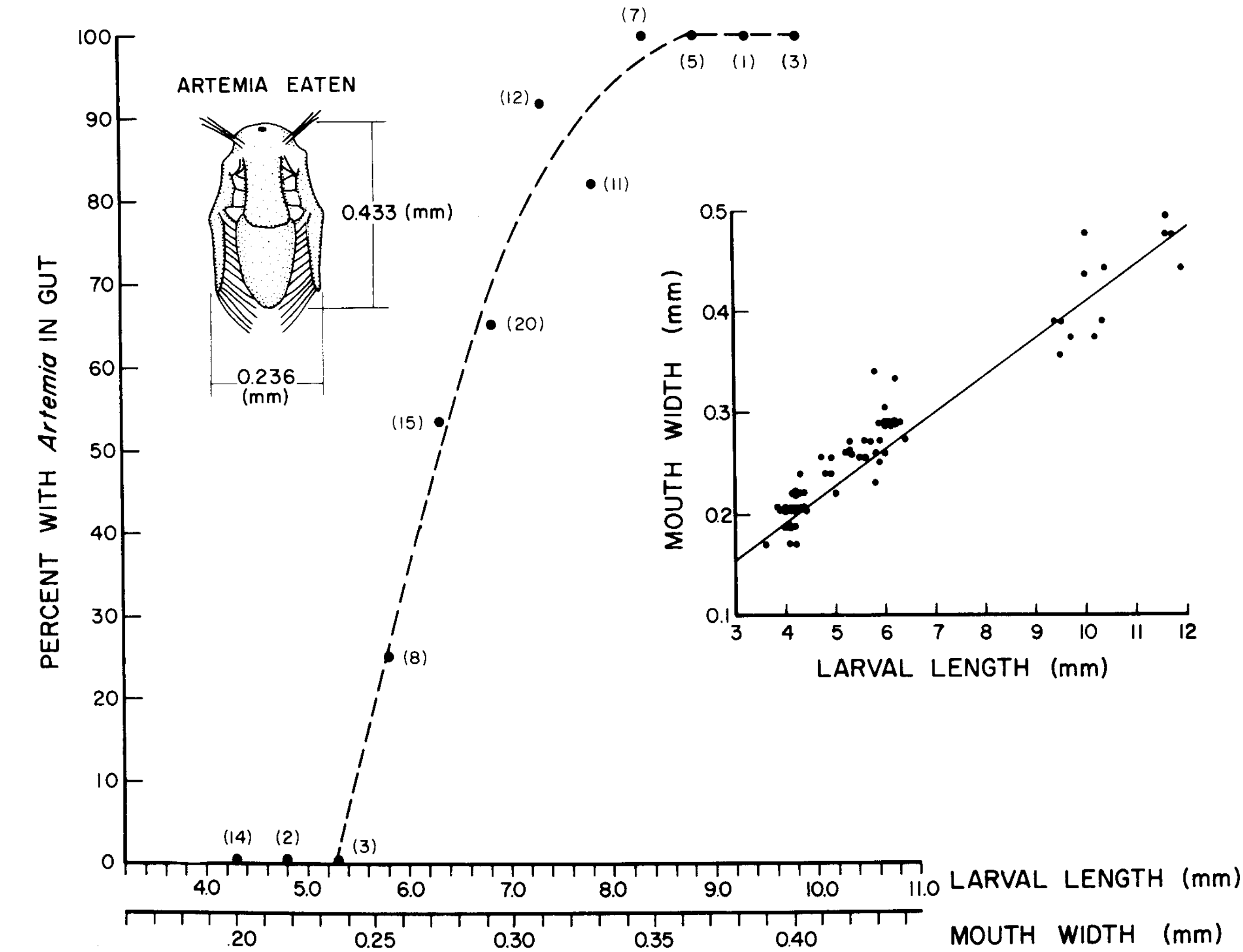

FIGURE 6. Percent of anchovy larvae with one or more *Artemia* nauplii in stomachs after 4 hours of feeding. Percentages calculated for 0.5 cm length classes and plotted at the midpoint of each class; number of larvae per class is given in parentheses. In the upper left corner the mean dimensions of the nauplii ingested are given, drawn to show the position of appendages when measured. Upper right, regression of mouth width (Y) on larval length (X) where Y = 0.0431 + 0.0366X and s_{yx} = 0.0585; this regression was used to construct mouth width scale at the bottom of the figure.

(1969), and Rosenthal and Hempel (1970). It is an estimate of daily ration, adjusted for feeding success, divided by the volume of water searched by a larva per day. The volume searched per day is the product of cruising speed (assumed here to be 0.29 cm/sec for a 4 mm larva) and the cross sectional area of the reactive perceptive field for prey (the attack range of Cushing and Harris, 1970). When the 95% limits of the perceptive field for prey are used (0.36 body length to the sides, and 0.40 body length above and below the swimming plane), the volume searched in 10 hours is 622 ml (Hunter, 1972). On the other hand, if the mean distance at which prey are sighted (0.185 body length) is used the volume searched per day is only 148 ml (data recalculated from Hunter, 1972). The ration is calculated from metabolic requirements for a 4 mm larva (Table 2), but is increased to account for digestive efficiency assumed here to be 80% (Lasker, 1965) and for feeding success which is 11% for first feeding larvae (Hunter, 1972). The ration adjusted in direct proportion to these percentages is 2,614 cells of *Gymnodinium*. Division of this ration by the two volume estimates gives 4 cells/ml when the 95% limits are used and 18 cells/ml when the average distance to prey is used. Despite the relatively large ration, the estimated densities are still below the densities of *Gymnodinium* required in laboratory tanks for larvae to survive.

The large difference between the estimate in which the mean perceptive field was used and the one in which the 95% limits was used, demonstrates the extreme sensitivity of the model to assumptions regarding the size of the perceptive field. Probably one of the more serious problems in models of this type is the tacit assumption that a larva reacts to and attempts to capture every prey that enters its perceptive field. In the laboratory, larvae frequently pass without responding to many *Gymnodinium* cells which appear to be in their perceptive field. It is likely that a larva reacts only to one prey at a time; thus, the division of the ration by the volume searched produces an unrealistically low food density requirement. The proportional increase in prey density to account for the prey attacked but not captured is probably also a source of error. In addition, search patterns of larval fish may have considerable redundancy (Hunter and Thomas, 1974). Clearly, more realistic models are required.

In summary, laboratory density experiments yield higher food density requirements for survival of anchovy larvae than simple searching models. The laboratory density experiments have the advantage that they measure density directly but they suffer from the possible existence of larval density dependent interactions, and a small tank volume which may limit the searching capacity of the larva. The searching model is not affected by these variables but is affected by errors in the parameters, and in the assumptions required by the model.

CONCLUSIONS

The average density of food in the sea is too low to support larval anchovy, regardless of whether one used laboratory density experiments or searching models. Lasker (1975) has recently shown that patches of dinoflagellates known to be nutritious to anchovy larvae exist in the sea in sufficient concentrations to support larval life during the first feeding stage. Laboratory studies reported here indicate that larvae have the ability to remain in patches of food once they find them. On the other hand, such patches may be ephemeral features, and even if they persisted for a reasonable period larvae would have to find other patches of larger prey to exist. Whether or not a larva will find a concentration of food organisms of the appropriate size and whether or not it will be able to survive until it finds another, involves a complex set of interacting variables including all of those described in this review. At present it is impossible to predict the outcome of such a series of interacting variables. Evaluation of this will require development of more complex models of larval feeding behavior and energetics than presently are available. I believe our understanding of the ecology of larval anchovy is at the point where such models could be constructed on a more realistic basis than has been possible in the past, and these models would expand our understanding of larval fish ecology.

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THE FISHERY FOR NORTHERN ANCHOVY, *ENGRAULIS MORDAX*, OFF CALIFORNIA AND BAJA CALIFORNIA IN 1975

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ABSTRACT

Anchovy landings during 1975 totaled 200,663 metric tons (221,201 tons) of which 143,786 mt (158,505 tons) were caught by the U.S. and 56,877 mt (62,695 tons) by Mexico. Age data from both countries were dominated by the 1972 year class. Anchovy mean lengths ranged from 116.8 mm standard length (Baja California) to 137.7 mm standard length (central California). Female to male ratios ranged from 1.6 to 1 (southern California) to 2.8 to 1 (Baja California).

EXTRACTO

El desembarque de anchoveta en el ano 1975 fue de un total de 200,663 tonelados metuco (221,201 tonelados) de las cuales 143,786 mt (158,505 tons) fueron capturadas por los Estados Unidos y 56,877 mt (62,695 tons) por Mexico.

Los datos de la edad fueron denominodos por ambos paises en la classe ano 1972.

El longitud promedio de la anchoveta es de 116.8 mm longitud patron (Baja California) hasta 137.77 mm longitud patron (Centrol California).

Hembras y machos son de una proporcion de 1.6: 1 (Sur California) hasta 2.8: 1 (Baja California).

INTRODUCTION

The northern anchovy resources off the coast of California and Baja California support a fishery conducted by fishermen of both the United States and Mexico. The major portion of the catch is made from the same stock which occurs from about San Quintin, Baja California, to north of San Francisco, California. Major ports of landing are Ensenada, Los Angeles, Oxnard and Monterey (Figure 1).

Since both countries primarily are fishing the same stocks, the Instituto Nacional de Pesca and the California Department of Fish and Game have entered into an informal cooperative program designed to monitor the anchovy fishery of each country. This program includes using comparable sampling techniques, processing samples in the same way, gathering similar logbook information, and holding bi-monthly meetings to calibrate aging techniques and exchange data.

Besides the Instituto Nacional de Pesca/California Department of Fish and Game fishery monitoring program, cooperative research programs concerning anchovies have been established between California Cooperative Oceanic Fisheries Investigations (CalCOFI) Agencies and the Instituto Nacional de Pesca. In addition to the California Department of Fish and Game, these agencies include the National Marine Fisheries Service, Scripps Institution of Oceanography, and California Academy of Sciences. These programs have focused on stock assessment, physical oceanography, and data management, and have included joint participation in cruises, calibration of acoustic equipment, egg and larvae surveys, publications, and the training of Mexican personnel.

This publication is an attempt to document the anchovy fishery in both Baja California and California for 1975.

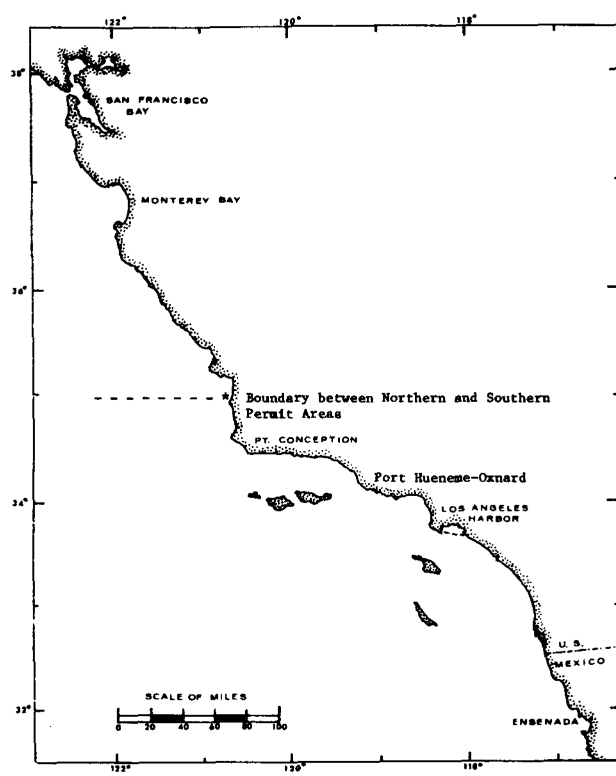

FIGURE 1. California anchovy fishing areas.

ANCHOVY BIOLOGY

Northern anchovies occur from Cape San Lucas, Baja California, to the Queen Charlotte Islands, British Columbia. They are pelagic schooling fishes generally found in coastal waters between 14.6°C and 20.0°C. CalCOFI surveys indicate anchovies are most abundant from Magdalena Bay, Baja California, to San Francisco, California. Eggs and larvae have been found from Cape San Lucas to Cape Mendocino, California, and as far as 300 miles offshore; however, most occur within 100 miles of shore.

Some anchovies reach sexual maturity at the end of their first year of life when 10.2 cm to 11.4 cm total length long. Studies of the commercial catch indicate all are mature at the end of 2 years and are 12.7 cm to 14 cm (TL) long. Female anchovies, 11.4 cm to 16 cm to total length, contain 4,025 to 21,297 eggs in an advanced stage of development.

Although spawning occurs in every month of the year, it usually peaks during late winter and early spring with another minor peak in early fall. The eggs are ovoid, clear, and translucent, and require 2 to 4 days to hatch, depending on temperature.

The northern anchovy is relatively short lived, rarely exceeding 4 years of age and 17.8 cm in total length, although individuals 7 years old and 22.9 cm (TL) long have been recorded. They apparently are indiscriminate filter feeders excepting phytoplankton and zooplankton. In addition, they will feed on small fish. Anchovies along with squid, euphasids, pelagic red crabs, and lanternfishes are preyed upon heavily by most predator species in waters off Baja California and California. In southern California waters the average annual mortality rate is 66.5% (McCall, 1973).

Meristic measurements done in the 1940's (McHugh, 1951), blood genetics work (Vrooman and Smith, 1971), and an otolith variation study (Spratt, 1972) all indicate there are three distinct groups of anchovies off Baja California and California (Figure 2). The limits of these populations are not clearly defined at this time and appear to shift seasonally. The southern population probably extends from Cape San Lucas to approximately Punta Baja, Baja California; the central from the Punta Baja area to north of San Francisco, California; and the northern stocks occur north of this area. There is a certain amount of overlapping between the populations.

Anchovy movement within a population group is an important factor. A tagging study initiated in 1966 and concluded in 1969, has provided considerable information concerning movements of anchovies in waters off California and northern Baja California. During the course of this study, a total of 418,762 anchovies was tagged and 1,600 tags were recovered (Figure 3).

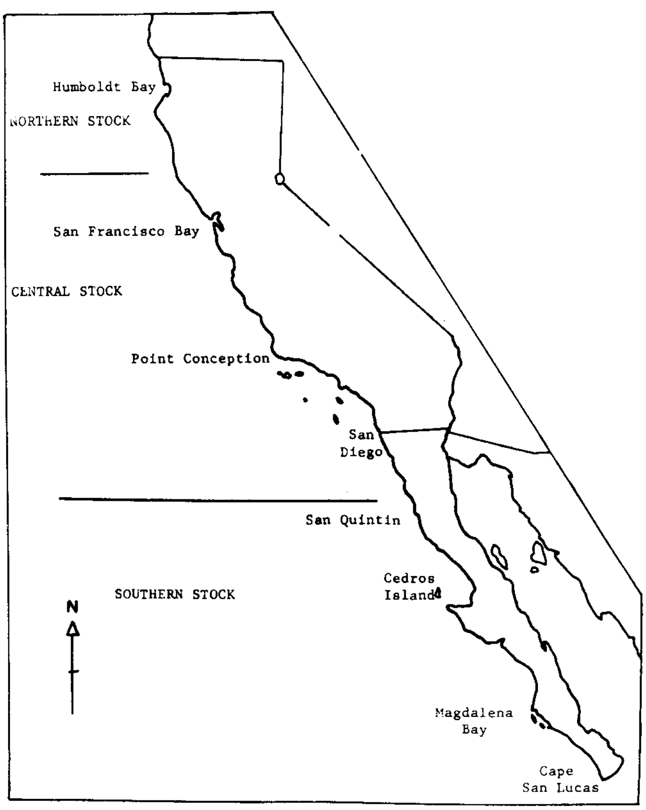

FIGURE 2. Distribution of anchovy subpopulations.

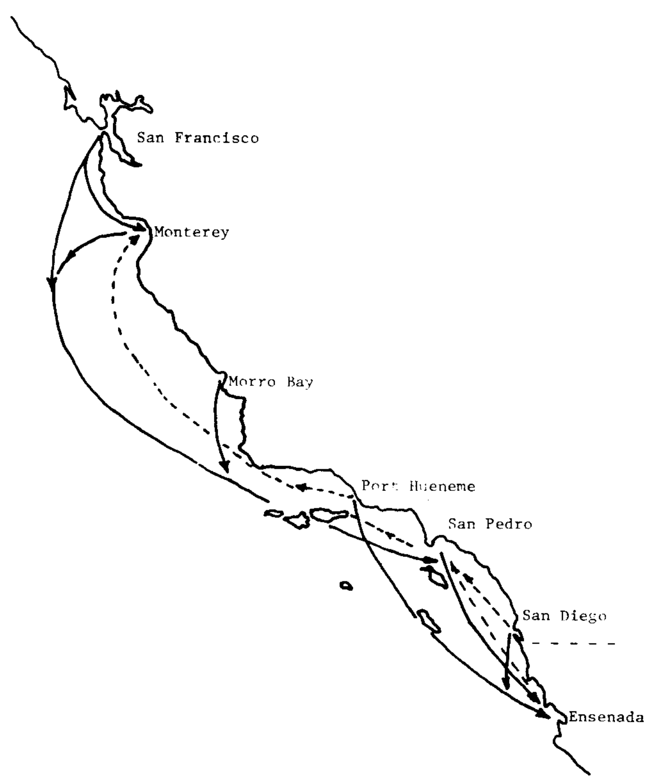

FIGURE 3. Anchovy tagging migration.

Tag recoveries demonstrated coastwide movements in both southerly or northerly directions. Fish tagged in San Francisco Bay were captured in Monterey Bay and off southern California; fish tagged in Monterey Bay were taken off southern California as were fish tagged in Morro Bay; and fish tagged at Port Hueneme, off Santa Catalina Island, in the Los Angeles-Long Beach Harbor, off San Clemente Island, and at San Diego were captured by the fleet operating out of Ensenada, Baja California. Conversely, fish tagged at Ensenada were captured in the southern California fishery. Fish tagged at San Diego, off San Clemente Island, off Santa Catalina Island, and at Port Hueneme were captured in Monterey Bay. Numerous recoveries were made of fish tagged in San Diego and captured on the southern California fishing grounds.

An offshore to inshore movement was documented when five fish tagged off San Clemente and Santa Catalina Islands were captured in the Los Angeles Harbor.

Inshore to offshore movements were demonstrated by fish tagged in Los Angeles-Long Beach Harbors being caught in offshore southern California fishing grounds and by the Ensenada fleet off Baja California.

Tag returns have shown that anchovies move quite widely within the area covered by the study, and that there is interchange of fish between central California, southern California, and northern Baja California fishing grounds.

The dominant and prevailing schooling behaviors of anchovies generally render them invulnerable to capture using present commercial fishing techniques. Only a small portion of the population is vulnerable at any particular time, even in periods of relatively high availability. There are periods of time lasting up to several months when virtually the entire population cannot be fished effectively (Mais, 1974).

By far the most prevalent and common schooling behavior of anchovies off northern Baja California and southern California is the formation of small, very low density near-surface schools during daylight hours.

A schooling behavior favorable for commercial harvest occurs from fall through winter. Large schools occur during daylight hours over the deep water basin and channels adjacent to the coast. School densities are relatively light but more dense than those mentioned above. At sundown these schools disperse into a course scattering layer until around midnight when distinct schools begin to form. The schools are usually the largest and densest slightly before dawn. This behavior has been recorded as occurring in August off Baja California and occasionally with juvenile fish in June off southern California.

THE CALIFORNIA FISHERY

An anchovy fishery has been conducted by California fishermen since 1916 although landings were of minor importance with significant landings occurring in 1947 and 1953 (Frey, 1971). In November of 1965, permission was granted for an anchovy fishery for reduction resulting in a gradual increase in landings, reaching a record high of 143,786 metric tons (158,505 tons) in 1975 (Table 1). This considerable rise was due to both increased demands of fish meal products and rising fish prices.

The present fishery is conducted in two geographical areas: Monterey Bay and southern California (Figure 1). The Monterey fleet, numbering 12 vessels, consists of seven lampara and five purse seine boats (Table 2). Average length of a boat is 13 m (42.6 ft) with a mean catch capacity of

TABLE 1

California Anchovy Landings From 1965 to 1975 *

Year	Landings *
1965	2,600
1966	28,250
1967	31,574
1968	14,096
1969	61,361
1970	87,310
1971	40,690
1972	62,687
1973	120,325
1974	74,920
1975	143,786
Total	667,599 *
Short tons	735,894

* Metric tons.

TABLE 2

California Anchovy Fleet for 1975

	Location		
	Monterey	Port Hueneme	San Pedro
Total number of boats	12	2	42
Average length (in meters)	13	24	19
Range	6–22	20–28	11–28
Average holding capacity (metric tons)	21	131	76
Range	5–29	81–181	23–181
Combined fleet capacity (metric tons)	200	262	2,540
Number of boats by month			
January	3	2	35
February	6	2	27
March	4	2	30
April	–	2	27
May	–	2	26
June	–	–	3
July	–	–	2
August	4	–	2
September	7	2	34
October	5	2	35
November	4	2	31
December	2	2	30

21 mt (23 tons). Maximum fleet capacity totaled 200 mt (220 tons) per day. Southern California maintains two fleets; the major one based at San Pedro, totals 42 boats consisting of 3 lampara and 39 purse seine vessels. Average boat length is 19 m (62 ft) and mean holding capacity of 76 mt (84 tons). Combined fleet capacity is 2540 mt (2800 tons) per day (Table 2). The minor Port Hueneme fleet totals no more than two boats with a mean length of 24 m (79 ft) and a 131 mt (144 tons) catch capacity. Daily maximum fleet capacity totaled 262 mt (289 tons). The majority of the boats are equipped with sonar and acoustic instruments and are aided by spotter planes in locating schools.

Fishing takes place during both day and night hours with daytime fishing occurring in spring while fall months are characterized by night and early morning fishing. The San Pedro fleet usually leaves port after midnight and returns within 12 hours if fish are located nearby in the San Pedro Channel. Trips as long as 2 days are common when fishing occurs in the Santa Barbara Channel, a distance of approximately 90 nautical miles. Monterey boats travel relatively short distances due to lack of shelter from severe weather conditions and smaller boat sizes.

Fleet size increases or decreases with fishing interests in other species. The number of boats remained constant throughout the year except during the summer, when reduction fishing was allowed only in central California (Table 2). The stable number of boats fishing for anchovy was the result of unavailability of other species such as jack mackerel, *Trachurus symmetricus,* and Pacific bonito, *Sarda chiliensis.*

Four processing plants are situated in the southern area with a capacity of processing 1677 mt (1850 tons) per day. Monterey area has two reduction facilities with a daily processing capacity of 200 mt (220 tons).

Anchovy price stabilized to $30 per short ton with periodic fluctuations between $29 to $31 per ton. Price was dependent upon several economic factors including the supply of Peruvian fish meal and domestic soybean meal.

Regulations

The following regulations have been established during the previous 10 years and apply generally to the California reduction fishery which accounts for 99% of all landings.

The California reduction fishery consists of two areas; the northern zone, an area north of Point Buchon and the southern zone, the area south of Point Buchon (Figure 1).

The fishery is regulated by a season which opens August 1 in the northern zone and September 15 in the southern zone. All reduction fishing ceases in both areas on May 15 or when the quota is attained. Quotas are determined prior to each season. Quotas for the 1974–75 season were 13,608 mt (15,000 tons) north of Point Buchon and 104,326 mt (115,000 tons) south of this point. The 1975–76 season's quotas were 13,608 mt (15,000 tons) for the north and 136,078 mt (150,000 tons) for the south.

Fishing for reduction purposes in the southern area has been assigned to all waters beyond 3 nautical miles of the coastline in addition to local restrictions of 4 to 6 miles in certain areas. Santa Monica Bay and the east side of Santa Catalina Island are restricted areas.

California has established a minimum size of 127 mm total length (TL) or approximately 108 mm standard length (SL), with an undersize allowance of 15% by weight. All vessels are required to have identification numbers on their sides. The fishermen also are required to maintain and return daily records of fishing activities in forms provided by the Department of Fish and Game. All reduction permits and fishing can be suspended on 48 hours notice by the California Fish and Game Commission when approaching the quota.

Commercial Catch

Landings

The final 1975 landings from all sources in California totaled 143,786 mt (158,505 tons). Of this total, 80% was landed at Los Angeles Harbor, 16% at Port Hueneme and 4% at Monterey–San Francisco area (Table 3). The reduction fishery accounted for 99% of the commercial take of anchovies, with the remaining 1% caught for frozen bait and human consumption.

TABLE 3

California Anchovy Landings for 1975 *

Months	Monterey-San Francisco	Port Hueneme	Los Angeles Harbor	Total
January	1,332	2,667	12,918	16,917
February	811	1,543	6,414	8,768
March	180	438	3,928	4,546
April	71	919	16,134	17,124
May	142	1,095	14,148	15,385
June	34	26	41	101
July	68	27	51	146
August	653	11	70	734
September	1,126	1,863	12,030	15,019
October	1,506	5,450	16,630	23,586
November	550	4,314	13,632	18,496
December	378	4,720	17,866	22,964
Total	6,851	23,073	113,862	143,786
%	4.8	16.0	79.2	100.0%

* Metric tons.

Fishing in southern California has been traditionally excellent during spring and fall months as indicated by large landings during those months (Table 3). December yielded the largest total with 22,586 mt (24,896 tons). Monthly productions for February and March were considerably less with 7,957 mt (8,771 tons) and 4,366 mt (4,813 tons) respectively, coinciding with the onset of spawning.

TABLE 4

Southern California Reduction Landings by Block Origin and Area—1975 *

Area	Block #	January	February	March	April	May	September	October	November	December	Total %
Santa Barbara	653–670	2,221	1,179	377	839	827	1,329	5,143	11,730	4,947	28,592
%		14.3	14.9	8.8	4.9	5.6	9.6	23.5	65.1	22.1	21.0
Port Hueneme	682–688	439	365	27	0	90	191	1,111	1,964	2,943	7,130
%		2.8	4.6	0.6	0	0.6	1.4	5.1	10.9	13.1	5.2
Point Dume	701–707	409	26	876	0	316	597	891	729	5,144	8,988
%		2.7	0.3	20.6	0	2.1	4.3	4.1	4.0	22.8	6.6
San Pedro Channel	719–743	11,270	6,152	1,635	11,108	10,352	11,293	11,108	3,517	8,677	75,112
%		72.6	77.7	38.4	65.1	68.4	81.8	50.6	19.6	38.3	55.2
Catalina Island	758–762 805–807	1,100	195	1,295	4,700	2,876	412	3,665	57	851	15,149
%		7.6	2.4	30.4	27.3	19.1	2.9	16.7	0.03	3.7	11.1
Oceanside	757,802–848	79		52	407	648					1,186
%		0.5		1.1	2.4	4.3					0.9
Total		15,516	7,917	4,262	17,054	15,038	13,822	21,918	17,997	22,535	136,157
%		11.4	5.8	3.1	12.5	11.1	10.2	16.1	13.2	16.6	

* Metric tons.

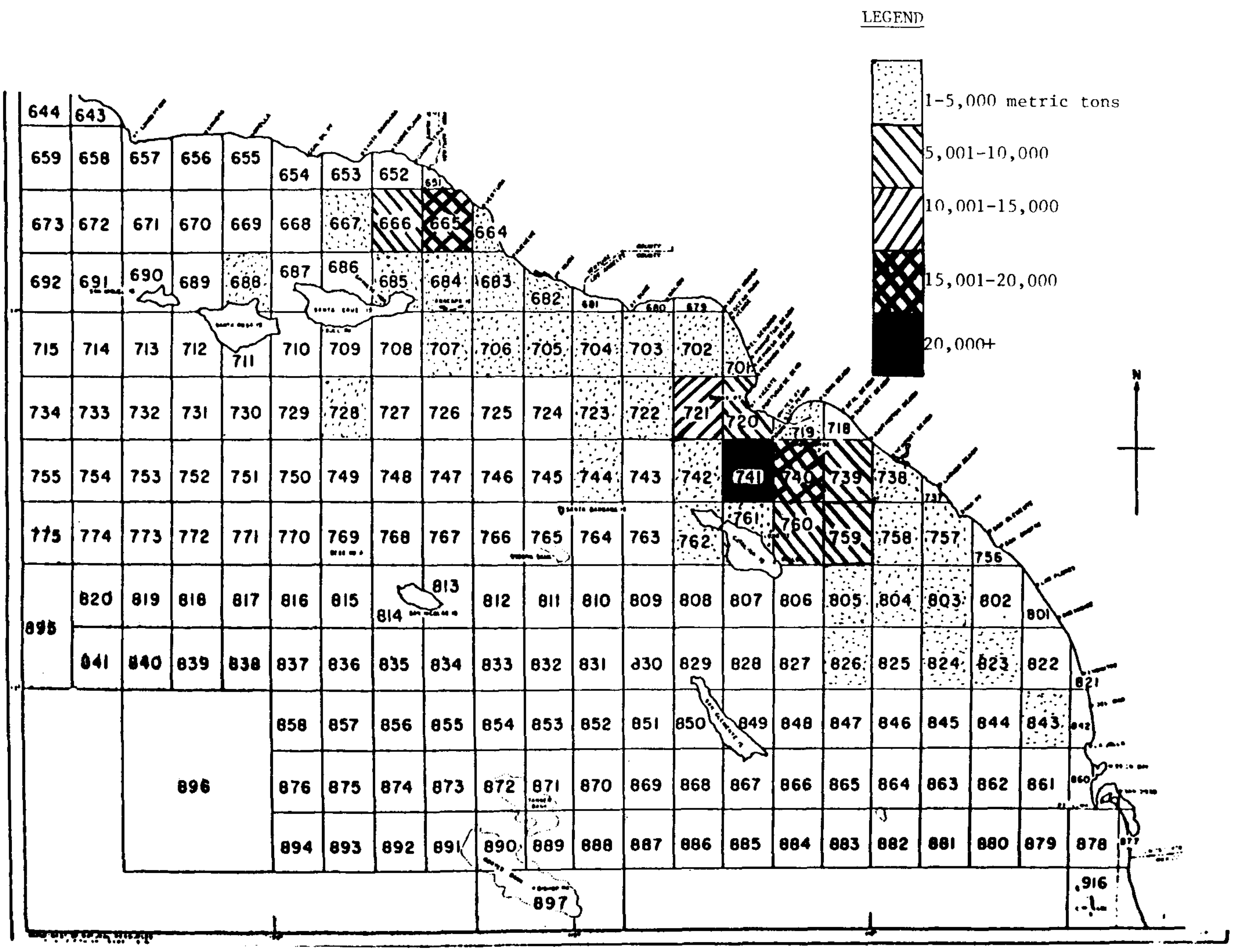

FIGURE 4. Anchovy landings by block area for southern California.

Central California landings occurred mainly during the fall with October (Table 3) accounting for 1,506 mt (1,660 tons). This region encountered severe weather conditions during winter and spring months, reducing fishing effort.

Area of Catch

The majority of the southern California landings occurred in the San Pedro Channel, which accounted for 55% of the catch, while the second most productive area was the Santa Barbara area amounting to 21% (Table 4; Figure 4). Santa Catalina Island area contributed 11% while Port Hueneme, Point Dume and Oceanside totaled the remaining 13%.

Central California's catches were mainly centered in Monterey Bay with major concentrations off Moss Landing (Figure 5; Table 5). Since the fishing activities were highly concentrated in few areas, any noticeable monthly trends in areas of catch were not apparent.

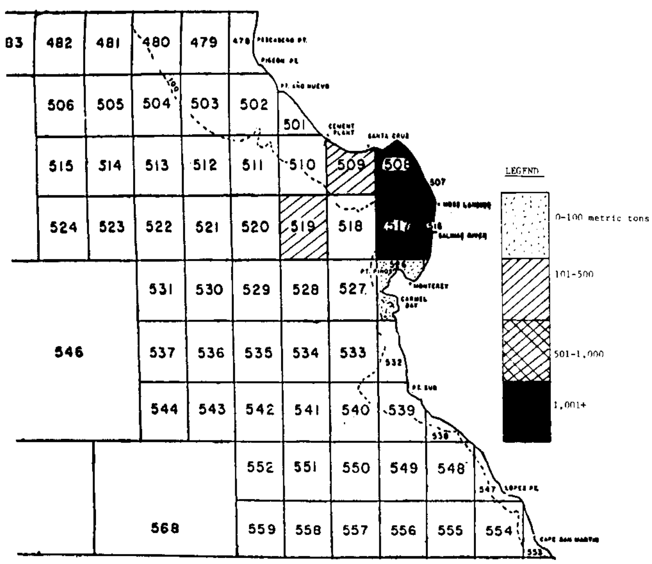

FIGURE 5. Anchovy landings by block area for central California.

FISHERY MONITORING

Sampling Plan

The anchovy sampling program for San Pedro is accomplished by using a stratified random sampling plan. A stratum consists of 5,000 short tons of anchovies and within a stratum, 30 samples are selected from 30 random numbers representing the cumulative tonnage. From the boat load, a sample cluster of 500 grams (1.1 lbs.) is collected; however, only 250 grams (0.55 lb) are processed as a sample (Witeck, 1975). Data concerning age, length, weight, sex and sexual maturity are recorded for analysis.

The central California sampling plan consists of one sample from a purse seiner and one from a lampara boat per day. The samples of 250 grams (0.55 lb) are processed in the same manner as in southern California.

Age Composition

Age and length data were collected from commercial samples totaling 8,950 fish from southern California and 254 individuals from central California (Sunada 1977; 1978). All age determinations were made using otoliths rather than scales. Methods and techniques used in aging were described by Collins and Spratt (1969).

The southern California catch was dominated throughout the year by 1973 and 1972 cohorts comprising 33.1% and 34.4% by number respectively (Table 6). Other year classes; 1971 and 1970, contributed significantly with 15.9% and 5.7% respectively. The fish of the year (1975 year class) did not appear until fall when they became vulnerable to the gear and contributed less than 1%. The 1974 year class contributed 9.4% of the catch.

Central California samples indicated the 1971 and 1970 year classes dominated the catch, with 31.1% and 26.3% respectively, followed by the 1972 year

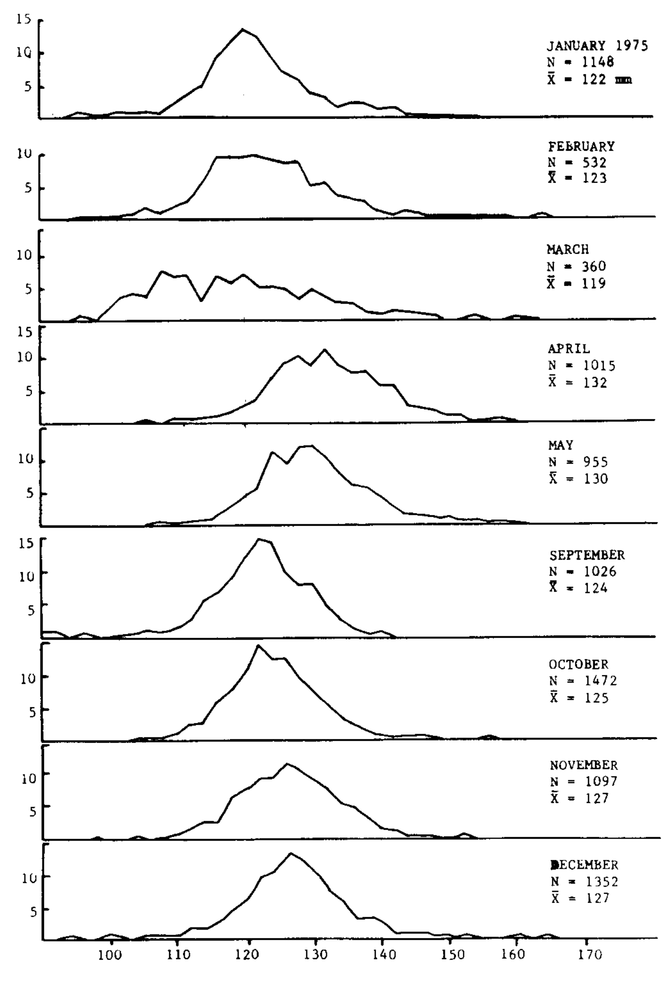

FIGURE 6. Length Distribution of Anchovies Landed at Terminal Island during 1975.

TABLE 5

Anchovy Reduction Landings for Central California—1975 *

Block #	January	February	March	August	September	October	November	December	Total
508				460	379	530			1,369
%				87.8	37.6	35.9			22.9
509						54	54		108
%						3.7	10.8		1.7
516					197	715	411	369	1,692
%					19.5	48.5	82.2	100	27.2
517	1,331	811	180	64	367	27	35		2,815
%	100	100	100	12.2	36.4	1.8	.7		45.4
519						150			150
%						10.2			2.4
526					66				66
%					6.5				1.0
Total	1,331	811	180	524	1,008	1,475	500	369	6,200
%	21.5	13.1	2.9	8.4	16.3	23.8	8.1	5.9	

* Metric Tons.

TABLE 6

Anchovy Age Composition by Year Class for Southern California

Year class	1975	1974	1973	1972	1971	1970	1969	1968	Total
January									
Numbers		51	223	518	258	86	12		1,148
%		4.4	19.4	45.1	22.5	7.5	1.0		
February									
Numbers		41	135	188	123	39	6		532
%		7.7	25.4	35.3	23.1	7.3	1.1		
March									
Numbers		128	98	42	47	39	5	1	360
%		35.6	27.2	11.7	13.1	10.8	1.4	–	
April									
Numbers		23	146	297	329	185	33	2	1,015
%		2.3	14.4	29.3	32.4	18.2	3.2	–	
May									
Numbers		30	188	359	266	93	16	3	955
%		3.1	16.7	37.6	27.8	9.7	1.7	–	
June		–	–	–	–	–	–	–	–
July		–	–	–	–	–	–	–	–
August		–	–	–	–	–	–	–	–
September									
Numbers	8	157	508	297	48	7	1		1,026
%	0.7	15.7	49.5	28.9	4.6	0.6	–		
October									
Numbers	5	205	685	459	99	18			1,471
%	0.3	13.9	46.5	31.1	6.7	1.2			
November									
Numbers	3	86	436	442	111	18			1,096
%	0.2	7.8	39.7	40.2	10.1	1.6			
December									
Numbers	24	123	544	482	147	24	3		1,347
%	1.7	9.0	40.2	36.0	10.8	1.7	–		
Total									
Numbers	40	844	2,963	3,084	1,428	509	76	6	8,950
%	0.4	9.4	33.1	34.4	15.9	5.7	0.8	0.1	

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TABLE 7
Anchovy Age Composition by Year Class for Central California

Year Class	1975	1974	1973	1972	1971	1970	1969	Total
January								
Number	-	1	5	9	25	17	5	62
%		1.6	8.1	27.4	40.3	27.4	8.1	-
February	-	-	-	-	-	-	-	-
March								
Number	-	-	2	3	7	6	2	20
%			10.0	15.0	35.0	30.0	10.0	
April	-	-	-	-	-	-	-	-
May	-	-	-	-	-	-	-	-
June	-	-	-	-	-	-	-	-
July	-	-	-	-	-	-	-	-
August								
Number	-	-	4	8	11	9	-	32
%			12.5	25.0	34.4	28.1		
September								
Number	-	-	8	17	20	24	4	73
%			10.9	23.3	27.4	32.9	5.5	
October								
Number	8	1	7	12	11	8	2	49
%	16.3	2.0	14.3	24.5	22.4	16.3	4.1	
November								
Number	1	1	3	4	5	3	1	18
%	5.6	5.6	16.7	22.2	27.8	16.7	5.6	
December	-	-	-	-	-	-	-	-
Total	9	3	29	53	79	67	14	254
%	3.5	1.1	11.4	20.8	31.1	26.3	5.5	

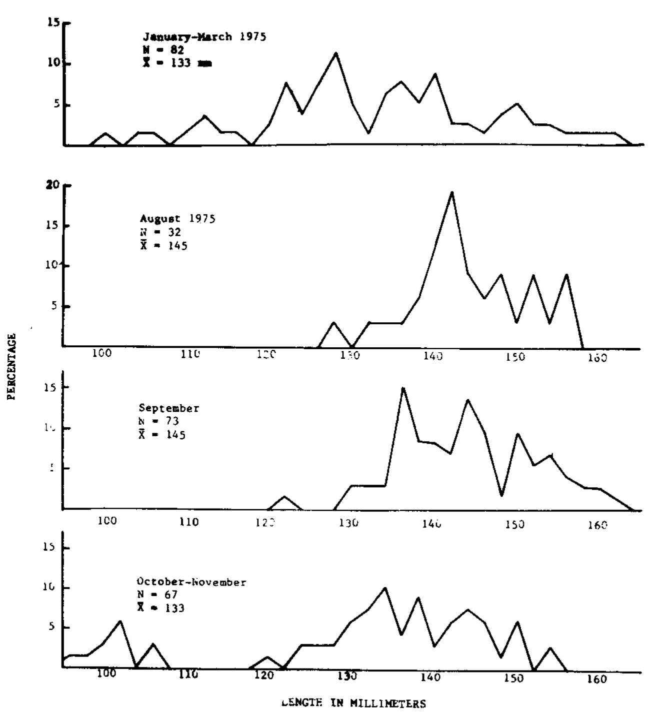

FIGURE 7. Length Distribution of Anchovies Landed at MOss Landing during 1975.

class which contributed 20.8% (Table 7). In contrast to the southern area, the 1973 year class comprised only 11.4%, while the 1974 year class was a mere 1.2% of the total. The 1975 year class fish were more numerous with 3.5%

Length Composition

Anchovies from southern California ranged from 88 to 170 mm standard length (103 mm to 200 mm total length) with an average length of 125.8 mm SL or 148 mm TL. Monthly length distributions revealed a single mode throughout most of the year with exceptions in February, and March (Figure 6). The wide distribution in February and March was the result of the presence of the 1973 and 1974 year class fish. After March, the 1972 and 1971 year class fish regained their prominence in the catch as indicated by the single mode and by the age composition (Figure 6, Table 6).

Length composition for September exhibited a major peak at 124 mm SL and a minor one at 130 mm SL, which represented the 1973 year class and the 1972 year class respectively. The remaining months revealed a single mode near 127 mm SL (Figure 6). Young-of-the-year fish (1975 year class) were observed in minor numbers during December when small fish were noted (Figure 6).

Central California fish ranged from 92 mm to 173 mm SL (108 mm to 203 mm TL) with a mean length of 137.7 mm SL (162 mm TL). Modes were less distinct due to small sample sizes, although a pronounced peak occurred in August (Figure 7). Monthly mean lengths were generally larger than San Pedro samples, due to the presence of older fish in the catch. Small fish did appear early and late in the year, representing the 1974 and 1975 year classes (Figure 7).

Sex Composition and Maturity

The sexual maturation index is based on methods devised by Hjort (1914), using seven stages, with Stage 1 being immature, progressing in development with each stage, culminating with Stage 6 as spawning condition. Stage 7 is considered the spent condition.

Sex composition of the San Pedro catch remained fairly constant throughout the year, with 38.4% being males and 61.6% females, although February samples displayed a near 1:1 ratio (Table 8).

TABLE 8
Anchovy Sex Ratios for Southern California

Month	Male		Female	
	Number	%	Numbers	%
January	440	38.4	704	61.6
February	255	48.0	276	52.0
March	139	40.4	205	59.6
April	384	37.9	628	62.1
May	345	36.5	600	63.5
September	298	36.1	611	67.9
October	578	40.2	858	59.8
November	409	39.4	628	60.6
December	473	36.8	812	63.2
Total	3,321	38.4	5,322	61.6

Ratio 1.60 Females : 1 Male

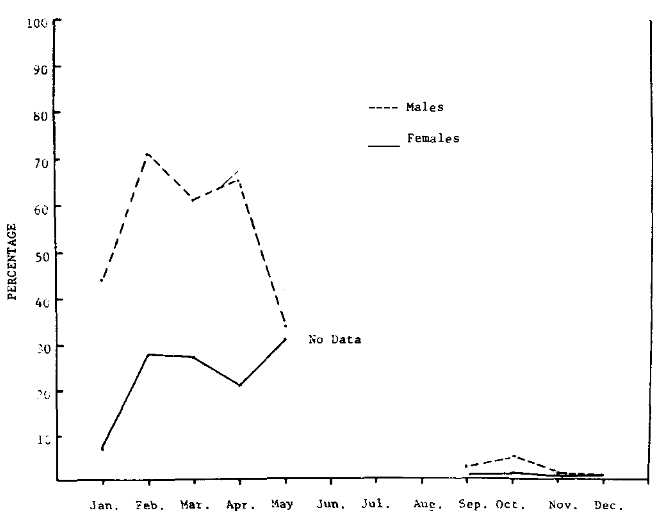

FIGURE 8. Percent Occurrence of Mature and Near-mature Stages (4–6) in southern California anchovies.

Sexual development of anchovies occurred throughout the year, reaching mature and near-mature conditions (Stages 4–6) in February, March, and May (Figure 8). Males appeared to mature earlier than females.

TABLE 9
Anchovy Sex Ratio for Central California

Month	Male		Female	
	Numbers	%	Numbers	%
January	29	48.3	31	51.7
February	–	–	–	–
March	7	35.0	13	65.0
April	–	–	–	–
May	–	–	–	–
June	–	–	–	–
July	–	–	–	–
August	8	25.8	23	74.2
September	20	27.4	53	72.6
October	15	32.6	31	67.4
November	8	44.4	10	55.6
December	–	–	–	–
Total	87	35.1	161	64.9

Ratio 1.85 Females : 1 Male

Central California anchovy sex composition was similar to that of southern California with 35.08% male and 64.92% females (Table 9). The sex ratio reached a near 1:1 ratio during January (Table 9). Since adequate samples were not obtained during peak spawning time, maturity development could not be determined.

RESEARCH CRUISES

The California Department of Fish and Game has annually conducted pelagic fish survey cruises since 1950, as a part of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) program. During 1975, eight cruises were conducted by the ALASKA by the Assessment of Commercial Fisheries Resources Project. Of eight cruises, five were acoustic surveys to determine the distribution and abundance of the northern anchovy. Other efforts included the gathering of limited oceanographic data relating to fish distribution; determining the abundance of Pacific mackerel and sardine; and conducting surveys with respect to other pelagic fish and invertebrate species (Mais, 1976).

FISHERY OF BAJA CALIFORNIA

The harvesting of anchovies for canning and human consumption was initiated in Ensenada in 1950 as a consequence of the first signs of sardine scarcity in the coastal waters next to this port (Flores, 1970). However, it wasn't until 1964 that the local packers decided to utilize the species on an industrial scale, installing two plants with special equipment for the cutting and canning of anchovies that year. According to Flores (1970), in 1965 and 1966 four more packers diversified their activities by including anchovies in their installations with the corresponding increase in the landings. In 1975, nine Ensenada plants processed this species for the purpose of fish meal and canning.

The Fishery

Generally the fishing operations are carried out in the vicinity of Ensenada, although the boats travel greater distances when anchovies are scarce, some traveling as far north as the Coronado Islands, some 45 nautical miles from port (Figure 9), and to the south they ventured to Punta Colnett, a locality situated approximately 55 nautical miles from Ensenada. The boats operate at a maximum distance of 3 miles from the coast.

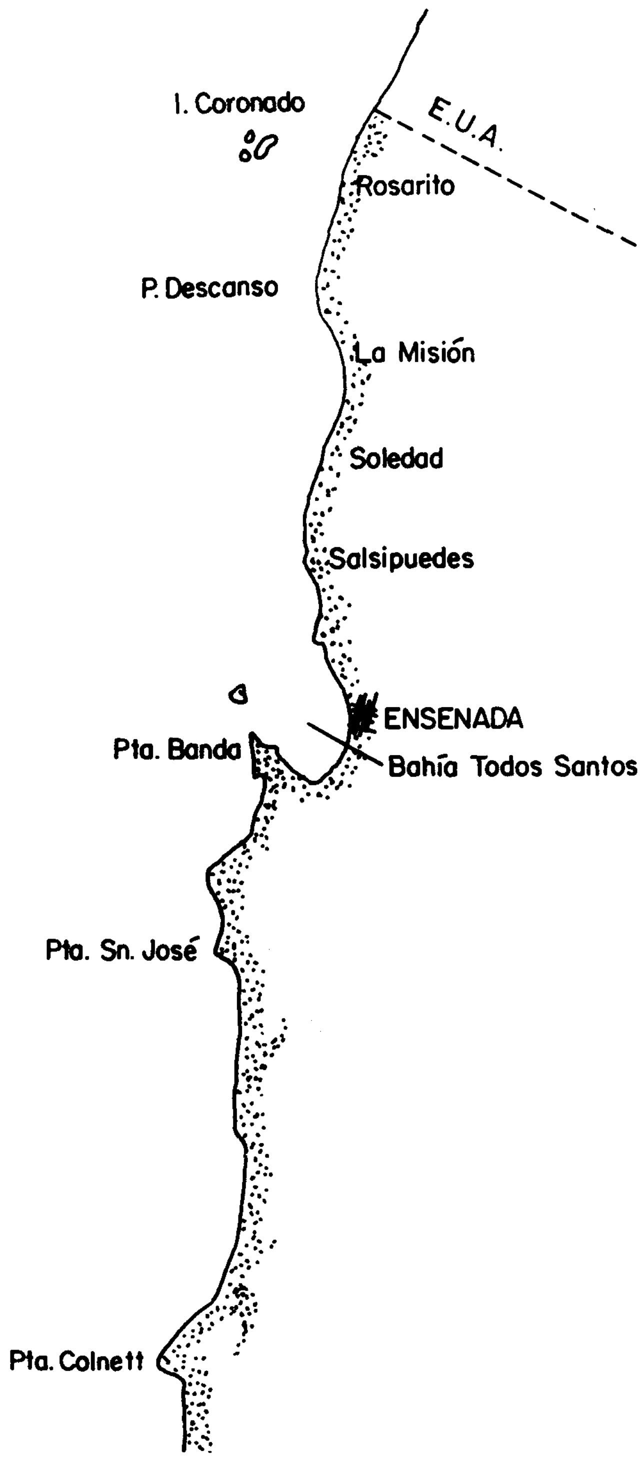

FIGURE 9. Anchovy fishing grounds off Baja California.

In 1975 33 boats were involved with anchovy fishing; the number of boats per month varied from five (December) to 26 (July). After October or November, the majority of the boats moved to the Gulf of California where they fished for Monterey sardines, *Sardinops sagax,* and crinuda sardines, *Opisthonema libertate.*

The gross tonnage of the vessels varied from 19 to 499 metric tons (21 to 550 tons) with an average of 111.3 mt (122.7 tons); the ship length fluctuated from 8 to 53 m (21.2); the breadth was from 4 to 12 m (5.9), and the age of the vessels varied from 2 to 61 years (26.1). Only one boat fished with a lampara net (Castellanos, 1975); the rest used round haul nets made of nylon; the nets measured lengthwise from 252 to 600 m, with an average of 381.8 m.

In general, the boats left the port in the early hours of the day and returned the same day; this occurred mostly from June to August when practically the whole fleet worked in the waters off Ensenada; the trips were very short in the winter when smaller boats continued to fish anchovies, while the rest of the fleet moved to the Gulf of California. During the preceding months the proportion of the trips with a 2 day duration increased while some boat operators traveling to Cabo Colnett took 3 days to return to port.

The capture of anchovies occurred frequently at night, because the location of the fish was almost always visual and easy to distinguish during hours of darkness. All of the boats had an echo sounder and four had sonar. Five of the boats in 1975 fished in combination with light airplanes for locating anchovy schools.

The official system of fishery statistics collected information about landings but not of where the catches were made. Information about catch locations was obtained from logs which were distributed to the skippers, but since this information is voluntary, not all skippers provided it, at least not on a constant basis. The completed information from the logs analyzed in 1975 provided us with an idea of the movements of the fleet during the year in the principal fishing zones.

The proximate zone near Ensenada (including Bahia de Todos Santos, Punta Banda, La Bufadora, Canal de Punta Banda and the area surrounding the Isla Todos Santos) constituted the principal fishing area from January to July and then in September and December. The second important zone was to the north of Ensenada, between Salsipuedes and La Mision, with the exception of September, when the secondary fishing grounds were Punta Colnett and the area between Rosarita and the Coronado Islands.

In August and November the area between Salsipuedes and La Mision was fished with more intensity, while in October the boats with the greatest range operated mostly off Cabo Colnett.

In 1975 the boats caught anchovies on 1373 trips; the numbers of trips per month fluctuated from 6 (December) to 314 (June). The number of trips by month are as follows: January, 151 trips; February, 45; March, 46; April, 47; May, 116; June, 314; July, 309; August, 158; September, 126; October, 36; November, 19; and December, 6.

The minimum and maximum catch attained by a boat in a fishing day was 1.1 mt (1.2 tons) in May and 259.8 mt (286 tons) in June respectively. It was observed that the average monthly catch per trip was most reduced in February and March, and reaching the maximum between June and September.

Anchovy landings at Ensenada constitute the majority of anchovies landed in Mexico and have been increasing in recent years reaching 56,877 mt (62,695 tons) in 1975 (Table 10). Minor landings have been recorded occasionally in other Baja California localities such as Cedros Island, Bahia Tortugas, the Coronados Islands, and San Quintin.

TABLE 10

Anchovy Landings at Ensenada, Baja California, From 1962 to 1975 *

Year	Landings *
1962	669
1963	944
1964	4,599
1965	9,171
1966	13,243
1967	20,104
1968	14,267
1969	3,871
1970	27,977
1971	20,079
1972	30,047
1973	15,424
1974	44,987
1975	56,877

* Metric tons.

With respect to 1975, the greatest production was in June and July (Table 11) with a monthly average of 4,739.7 mt (5,224 tons). Fishing was permitted during the entire year.

Other species fished besides anchovies were, in order of importance, jurel, *Seriola dorsalis;* charrito, *Trachurus symmetricus;* bonito, *Sarda chiliensis;* and mackerel, *Scomber japonicus.*

Nine plants processed anchovies during 1975; three of them were dedicated exclusively to the production of fish meal, four to canning, and the rest combined both products. According to official statistics of the Subsecretary of Fishery (now the Department of Fishery) 93.1% of anchovies captured in 1975 was reduced to fish meal, and the rest canned for human consumption. Both products were designated for the national market, with the fish meal used for protein supplements and as food for poultry and pigs (Jimenez and Esparza, 1976).

TABLE 11

Anchovy Landings at Ensenada During 1975 *

Months	Fish Meal	Canning	Total *
January	5,179	209	5,388
February	631	114	745
March	722	42	764
April	1,207	85	1,292
May	4,358	158	4,516
June	14,578	805	15,383
July	13,535	1,091	14,626
August	5,389	718	6,107
September	4,373	559	4,932
October	2,471	19	2,490
November	396	89	485
December	145	4	149
Total *	52,984	3,893	56,877
Short tons	58,404	4,291	62,695

* Metric tons.

The price per metric ton of anchovies for reduction fluctuated from $450 to $475 (U.S. $36 to $38) and from $625 to $650 (U.S. $50 to $52) for canning.

Regulations

In Baja California the anchovy fishery has no regulations with respect to closed seasons, minimum size, etc., there is only a condition of the Local Fishing Office which prohibits the operation of boats with a hold capacity of more than 100 mt (110 tons) in the Bahia de Todos Santos.

Fishery Monitoring

The first investigations regarding commercial fishing of anchovies off Baja California were carried out in 1965 and 1966 by personnel of the Station of Biology Fishery of the National Institute of Biological Fishery Investigation. The results obtained concerning the fishery were printed as a Professional Thesis (Flores, 1970) with a limited distribution.

In 1974, within the Fishery Exploration Program of the National Institute of Fishery, the Section of Sardines and Anchovies was created, which conducted studies of *Engraulis mordax* based on samples from the commercial landings. In October 1974 the Anchovy Program was established, and investigations regarding this species were enlarged considerably, increasing the duties of the research vessels ANTONIO ALZATE and ALEJANDRO DE HUMBOLDT. Besides the biological aspect, studies of food technology and methods of fishing were included, as well as management considerations.

Sampling Plan

The fishing zone of the anchovy fleet was divided into 10 mile squares, considered subzones. At the Ensenada landing dock, a daily sample of anchovies was obtained which weighed 1 kilo from each of the subzones in which the boats worked.

At the dock the following data were recorded: date and locality of fishing, boat name and total catch of anchovy. From the 1 k sample, 250 gms were taken upon which biological studies were carried out. The following data were recorded for each individual anchovy: standard length, sex and sexual maturity, gonadal length and weight, eviscerated and whole weight of the specimen, fat contents, and stomach contents; otoliths were taken to determine the age, as were female gonads in the advanced stage of maturity for determining fecundity. The criteria utilized to determine the stage of sexual maturity, stomach content, and fatty content were described by Sokolov and Wong (1974). Length measurements only were taken for the remaining 750 gms of the anchovy sample.

As previously indicated, logs were distributed to the skippers of the commercial boats for the purpose of determining fleet movements, zones of major production, accompanying species, etc. Monthly processing plants submit a record of daily catches.

Age Composition

The ages of the fish were from 0 to 5 years old. While 1972 year class fish dominated the catch with 42.6% by number, the 1971 and 1973 year classes constituted 15.8% and 24.9% respectively (Table 12).

TABLE 12
Anchovy Age Composition by Year Class for Baja California

Year Class	1975	1974	1973	1972	1971	1970	1969	Total
January								
Numbers	-	18	28	129	44	7	-	226
%		7.9	12.3	57.0	19.4	3.0		
February								
Numbers	-	7	6	9	1	-	-	23
%		30.4	26.0	39.1	4.3			
March								
Numbers	5	38	56	15	7	2	-	123
%	4.0	30.8	45.5	12.1	5.6	1.6		
April								
Numbers	-	6	14	16	15	1	-	52
%		11.5	26.9	30.7	28.8	1.9		
May								
Numbers	-	1	12	23	28	6	1	71
%		1.4	16.9	32.3	39.4	8.4	1.4	
June								
Numbers	1	4	49	94	16	1		165
%	0.6	2.4	29.6	56.9	9.6	0.6		
July								
Numbers	1	9	53	84	31	6		184
%	0.5	4.8	28.8	45.6	16.8	3.2		
August								
Numbers	3	7	18	30	7			65
%	4.6	10.7	27.6	46.1	10.7			
September								
Numbers	26	16	26	50	19	1		138
%	18.8	11.5	18.8	36.2	13.7	0.7		
October								
Numbers	-	2	3	4	2	1		12
%		16.6	25.0	33.3	16.6	8.3		
November								
Number	2	6	6	9	2	1		26
%	7.6	23.0	23.0	34.6	7.6	3.8		
December								
Numbers	-	-	-	-	-	-	-	-
%								
Total								
Numbers	38	114	271	463	172	26	1	1,085
%	3.5	10.5	24.9	42.6	15.8	2.3	0.9	

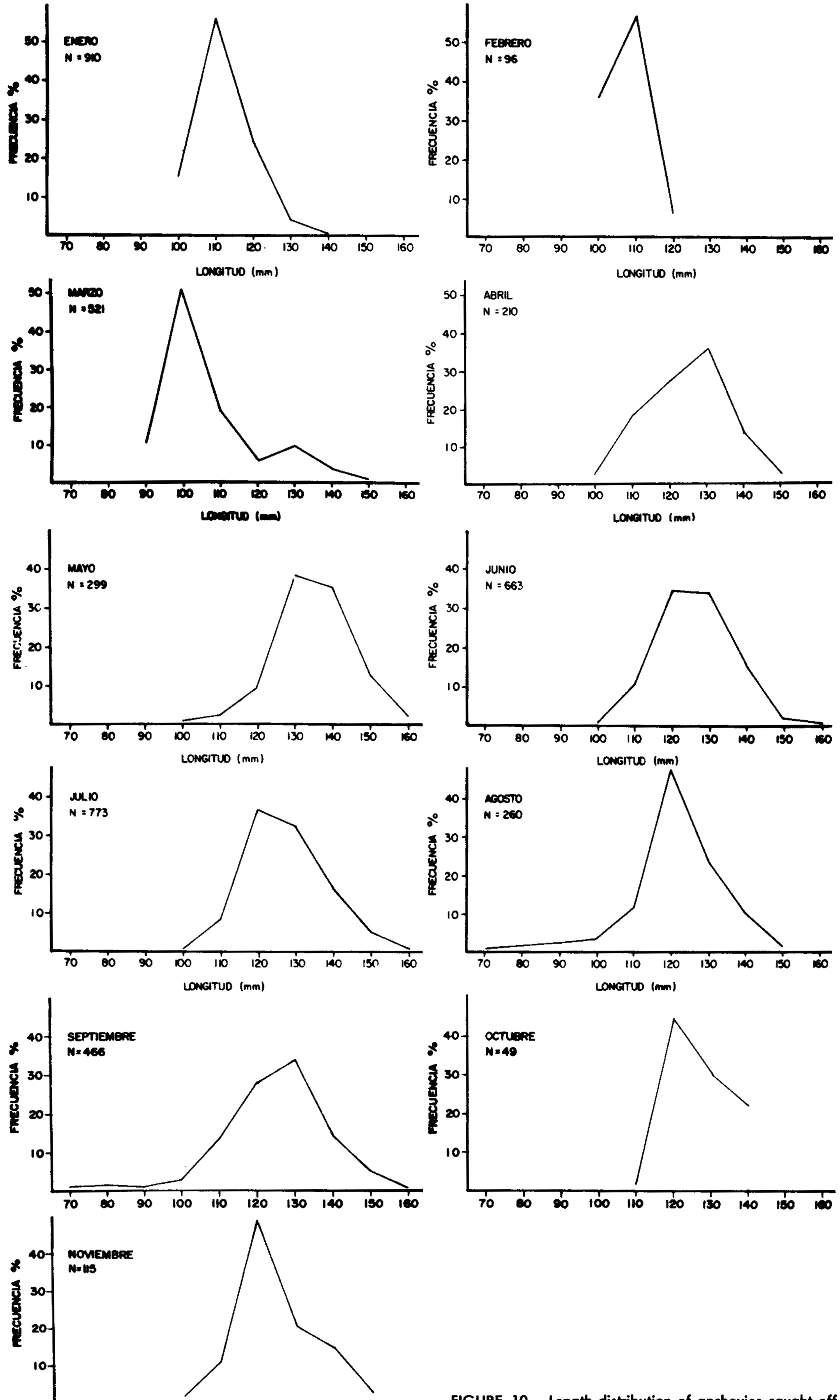

FIGURE 10. Length distribution of anchovies caught off Baja California.

Size Composition

The size range of all samples studies was from 62 to 158 mm SL; or 72 mm to 185 mm TL; the average length of the fish was 116.7 mm SL or 135 mm TL. The sizes which dominated the samples were from 11 to 13 cm SL. Individuals less than 100 mm SL occurred every month except for October, appearing with a greater abundance from January to March, principally in the latter month. These fishes represented 11.4% of the total of individuals measured (Figure 10).

Sex Composition

Sex composition of the samples was 73.7% female and 26.3% males; every month (Table 13) females appeared in greater abundance, changing the proportion of 56.6% in April to 100% in October.

TABLE 13
Anchovy Sex Ratios From Ensenada

Month	Males		Females	
	Number	%	Number	%
January	73	32.3	153	67.7
Feburary	9	39.1	14	60.8
March	45	36.5	78	63.4
April	23	43.4	30	56.6
May	16	22.8	54	77.1
June	43	25.9	123	74.1
July	18	9.7	167	90.2
August	24	39.3	37	60.6
September	18	16.9	88	83.0
October	–	–	12	100.0
November	7	28.0	18	72.0
December	–	–	–	–
Total	276	26.3	774	73.7
Ratio	2.8 Females: 1 Male			

Individuals in the reproduction stages occurred from January to September with a maximum in March (Figure 11). Silva and Villamar (1976) indicated that the species has two peak reproductive periods of diverse intensity during the year.

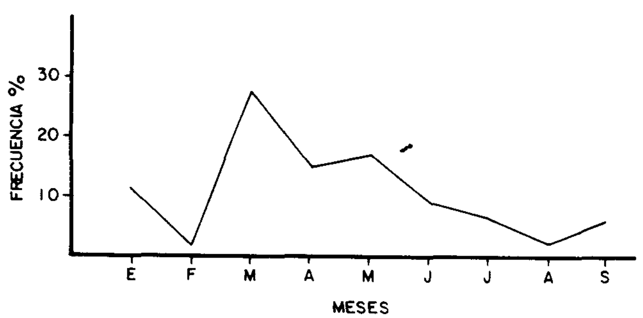

FIGURE 11. Percent occurrence of mature and near-mature stages in Baja California anchovies.

RESEARCH CRUISES

Besides the study of commercial catches, during 1975 the research vessels ANTONIO ALZATE and ALEJANDRO DE HUMBOLDT conducted 10 cruises during different seasons of the year and covering the western coast of Baja California. These cruises consisted of conducting acoustic surveys in order to determine the distribution and abundance of anchovies; taking samples for biological studies of anchovies as well as other principal species and such as squid, hake, and pelagic red crab; collecting ichthyoplankton, to become acquainted with the distribution and abundance of eggs and larvae of anchovies to estimate the reproductive biomass; and recording various metereological and hydrographic parameters.

REVIEW OF U.S.-MEXICAN FISHERIES

The Fisheries

Mexico and the United States have fished a common stock of anchovies for many years. An anchovy fishery has been conducted by California fishermen since at least 1916 and landings reached a record high of 143,786 mt (158,505 tons) in 1975.

Mexico has allowed an anchovy fishery since 1950 although landings were not significant until 1964 when two plants were built in Ensenada for canning. By 1975, nine plants were processing anchovies for fishmeal and canning. In that year, Mexican fishermen harvested 56,877 mt (62,695 tons) of anchovies.

The combined anchovy take by the two countries has increased substantially since 1970, reaching a record high of over 200,000 mt (221,191 tons) in 1975 (Table 14). From 1965 through 1975, 923,646 mt (1,018,135 tons) were harvested, with an annual mean take of nearly 84,000 mt (92,300 tons). The U.S. take amounted to nearly 72% of the total landings during the 11 year period; Mexico's share was 28% (Table 14).

TABLE 14
Anchovy Landings From U.S. and Mexico During 1965 Through 1975*

Year	U.S.	%	Mexico	%	Total
1965	2,600	22.1	9,171	77.9	11,771
1966	28,250	68.1	13,243	31.9	41,493
1967	31,574	61.1	20,104	38.9	51,678
1968	14,096	49.7	14,267	50.3	28,363
1969	61,361	94.1	3,871	5.9	65,232
1970	87,310	75.7	27,977	24.3	115,287
1971	40,690	67.0	20,079	33.0	60,769
1972	62,687	67.6	30,047	32.4	92,734
1973	120,325	88.6	15,424	11.4	135,749
1974	74,920	62.5	44,987	37.5	119,907
1975	143,786	71.6	56,877	28.4	200,663
Total	667,599		256,047		923,646
%		72.3		27.7	100.0%
Short Tons	735,894		282,241		1,018,135

* Metric tons.

Fishing occurred in three distinct areas: near Ensenada, Baja California, in the southern California Bight; and in Monterey Bay. Within these areas, 56 American and 33 Mexican boats were involved in anchovy fishing during 1975. The average size of the Mexican boat was slightly larger and heavier than its American counterpart (Table 15). Most vessels from both countries were equipped with sonar and frequently assisted by spotter planes. Major fishing grounds were located from 20 to 100 miles from port. Extreme fishing areas for American fishermen ranged from Point Conception to Oceanside whereas Mexican fishermen traveled as far as Coronado Islands and Punta Colnett (Figure 9). Fishing was conducted mainly at night by both groups of fishermen during summer and fall months, although spring fishing occurred predominately during the day.

TABLE 15

U.S. and Mexican Fishing Vessel Information

	U.S.	Mexico
Total Number of Boats	56	33
Mean Vessel Size (Meters)	19.0	21.2
Range	6–28	8–53
Mean Vessel Weight (Metric Tons)	76.0	111.3
Range	5–181	19–499

The degree of involvement or effort with this fishery varies according to fish availability and presence of more desirable species. In Ensenada the majority of the fleet departs during the fall for the Gulf of California sardine fishery. Likewise, U.S. boats fish other desirable species when available, such as jack mackerel, bluefin tuna, and bonito. This diversity in effort has some effect upon anchovy landings in certain years.

Regulations

The following regulations have been established during the past 10 years and apply generally to the California reduction fishery.

The California reduction fishery season opens on August 1 for the region north of Point Buchon, and September 15 for the area south of this point. All reduction fishing ceases in both areas on May 15 or when the quota is attained. Quotas are determined prior to each season and increases can be made. Quotas for the 1974–75 season were 13,608 mt (15,000 tons) for the northern area (north of Point Buchon) and 104,326 mt (115,000 tons) south of this point. The 1975–76 season's quotas were 13,608 mt (15,000 tons) for the month and 136,078 mt (150,000 tons) in the south.

Fishing for reduction purposes has been assigned to all water beyond 3 miles of the coastline in addition to local restrictions of 4 to 6 miles in certain areas. Santa Monica Bay and the eastside of Santa Catalina Island are restricted areas.

California has established a minimum size of 127 mm total length (TL) or approximately 108 mm standard length (SL), with an undersize allowance of 15% by weight.

All vessels are required to have identification numbers on their sides. Fishermen also are required to maintain and return daily records of fishing activities on forms provided by the Department of Fish and Game. All reduction permits and fishing can be suspended on 48 hours notice by the California Fish and Game Commission when approaching the quota.

The Mexican fishery is not restricted by quota, season, or minimum size limits. The only regulation concerns the restriction of fishing in Todos Santos Bay by vessels larger than 100 mt (110 tons).

Catch by Month and Area

The combined American and Mexican take of anchovies during 1975 totaled 200,663 mt (221,201 tons) of which 143,786 mt (158,505 tons) were caught by the U.S. Monthly landings fluctuated considerably, with the major share of California's take occurring during the fall and spring months, whereas Mexico's fishermen were most successful during the summer (Table 16). The noticeable decline in California's landings during the summer was due to the closure of the reduction fishery which accounted for 99% of the anchovy harvest. Both countries had low landings in March which may have been the effects of spawning, a period when the fish were less vulnerable to fishing.

TABLE 16

Anchovy Landings for 1975 *

Month	California	Mexico	Total
January	16,917	5,388	22,305
February	8,768	745	9,513
March	4,546	764	5,310
April	17,124	1,292	18,416
May	15,385	4,516	19,901
June	101	15,383	15,484
July	146	14,626	14,772
August	734	6,107	6,841
September	15,019	4,932	19,951
October	23,586	2,490	26,076
November	18,496	485	18,981
December	22,964	149	23,113
Total	143,786	56,877	200,663
Short tons	158,505	62,696	221,201
Percent	71.7	28.3	100.0%

* Metric tons.

Primary Mexican fishing grounds were located near Ensenada during January to July and later in December, while secondary areas were located north of Ensenada, between Salsipuedes and La Mision, which were heavily fished in August and November. Coronados Islands near the U.S.-Mexican border and Punta Colnett in the south were major fishing areas in September while fishing operations in October occurred only near Punta Colnett.

Southern California boats ranged from the Santa

Barbara Channel to the City of Oceanside, although the primary fishing areas during January to May were the San Pedro Channel and near Santa Catalina Island. The San Pedro Channel also was the primary fishing grounds in September and October. This region accounted for 55% of the total annual catch. The Santa Barbara region with 21% of the annual take was the second most productive area. Central California's fishery was limited to Monterey Bay with the region's total accounting for 4% of U.S. anchovy landings.

Fishery Monitoring

Methods and Materials

Sampling methods for the two countries were not standardized due to the varied differences in the two fisheries, although the results were comparable. The American method was the same as since the beginning of reduction fishery in 1968 (Collins, 1971). Mexico's sampling plan utilized the same 250 gram sample weight size although an additional 750 grams were taken for length measurements. The 250 gram sample was processed in the same manner as the American method.

Age determination was accomplished by the use of otoliths by both countries along criteria developed by Collins and Spratt (1969).

Results

Age Composition

Age data from southern California and Baja California indicated the annual catches were dominated by fish of the 1972 year class (34.4% southern California and 42.6% Baja California) followed by the 1973 year class (33.1% and 24.9% respectively) (Figure 12). The 1971 year class was present in near identical proportions (16% in southern California and 15.8% in Baja California) although the 1970 year class occurred in (5.7%) greater numbers from San Pedro samples in contrast to 2.3% of Ensenada landings. Proportions of the 1974 year class were similar between southern California (9.4%) and Ensenada (10.5%) samples while the 1975 year class contributed little to both fisheries, amounting to 0.5% for southern California's landings and 3.5% of Mexico's total.

Central California's age structure consisted of older fish, mainly the 1971 year class (31.7%) and the 1970 year class (26.4%). In contrast to San Pedro and Ensenada samples, this area contained only 11.4% from the 1973 year class and 20.8% 1972 year class (Figure 12).

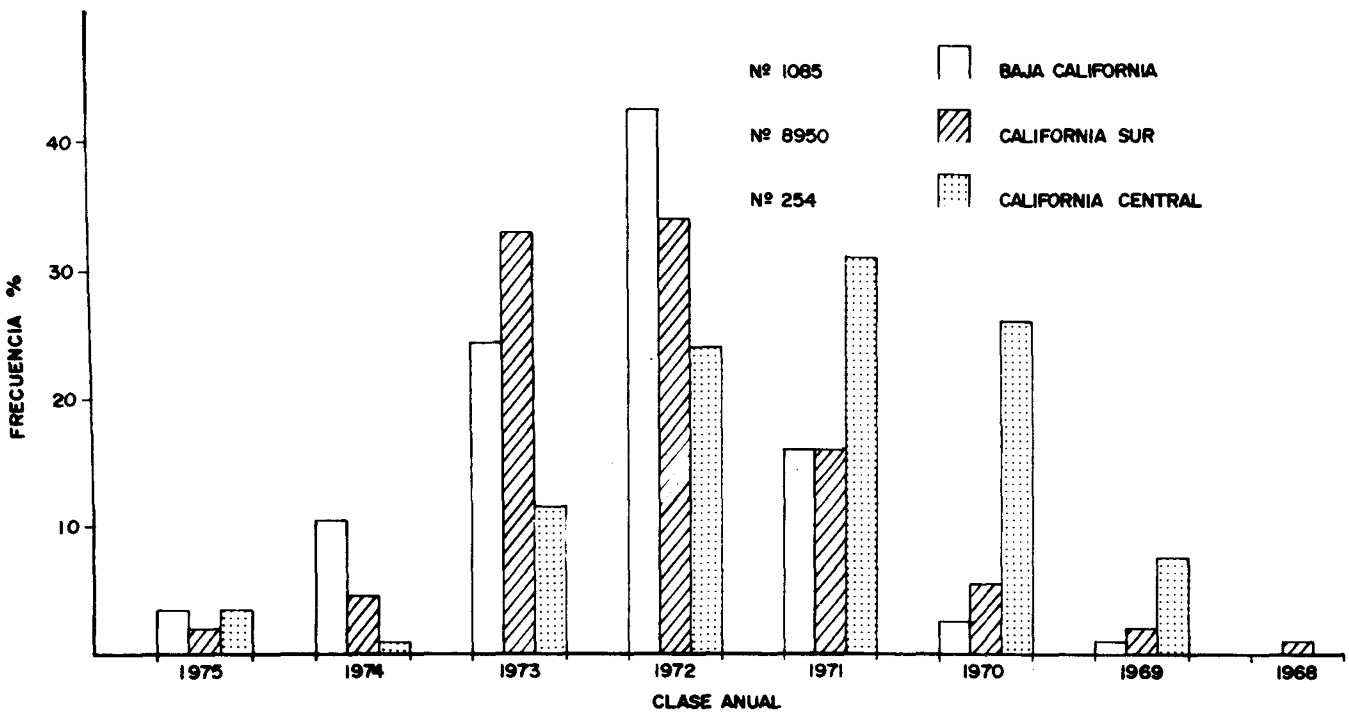

FIGURE 12. Age composition of anchovies caught off California and Baja California.

Monthly age compositions derived from Californian and Mexican samples compared quite similarly in most months, although August's data differed greatly due to California's samples originating from central California (Figure 13). Samples from this region contain a greater percentage of older fish as was previously stated. In both countries, recruitment of the 1974 year class appeared in late winter, although that year class did not constitute a significant portion of the catch (Figure 13).

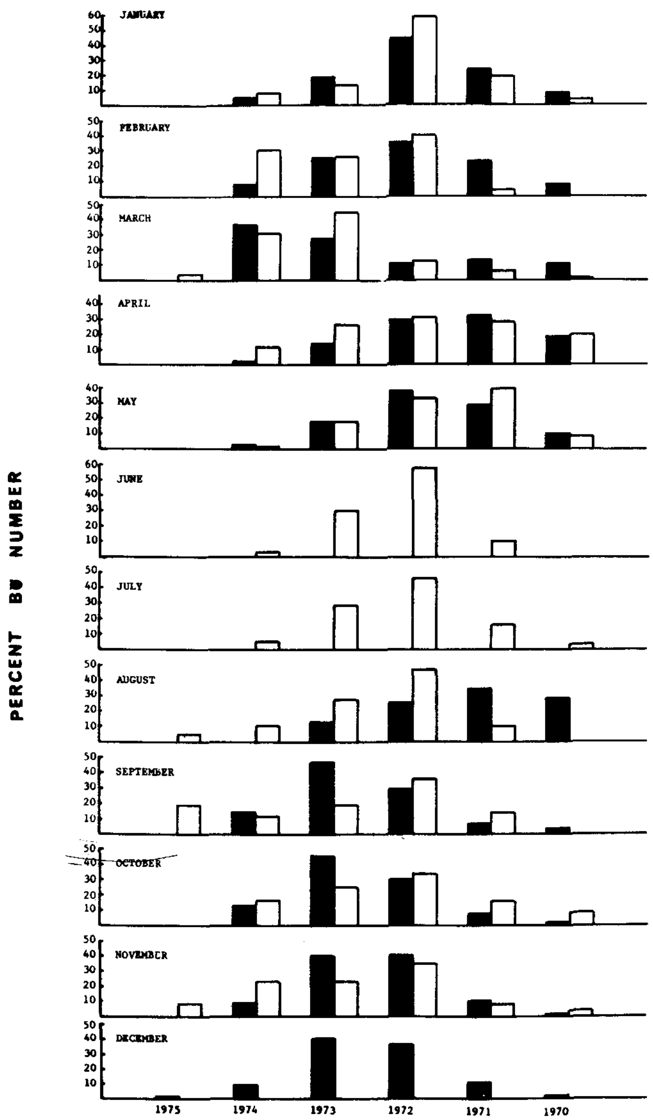

FIGURE 13. Monthly anchovy age composition by year class: solid bars California, open bars Baja California.

In September, the 1975 year class appeared in nearly 19% of the Mexican samples while comprising a mere 0.7% of the Californian samples. The lack of size regulations in Mexico could account for this high percentage of the 1975 year class since these fish (smaller than 100 mm) would not be vulnerable to the U.S. fishery due to the size restriction.

Length Composition

Fish ranged from 65 mm SL in Baja California to 173 mm SL in central California (Figure 14). The average fish lengths differed greatly from Baja California with 117 mm SL, southern California with 126 mm SL and central California 138 mm SL. The length distribution from these areas exhibited discernable modes with considerable overlap, although the Mexican catch contained a considerable number of fish smaller than 110 mm SL (Figure 14).

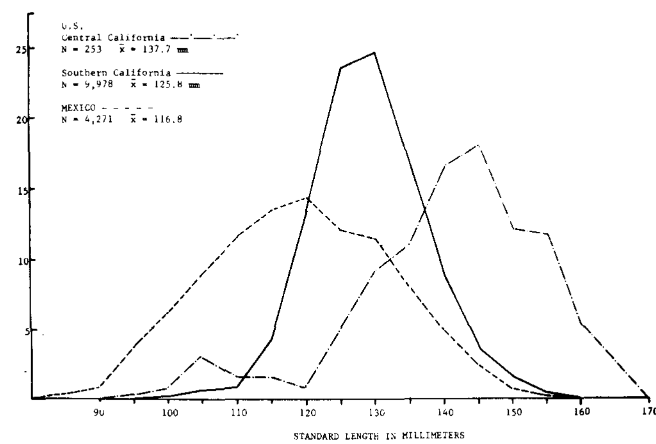

FIGURE 14. Annual length frequency distributions of anchovies taken off California and Baja California.

Length frequencies from Ensenada and California samples demonstrated a difference from one another during the winter; the former samples contained small fish (Figure 15). Size compositions from both areas became nearly identical during May and this correlated closely with the age data.

The absence of a reduction fishery in California during June and July precluded any length comparisons between the two fisheries for these months. In August, the lengths of central California specimens were considerably greater than those of Ensenada specimens (Figure 15).

A divergence between the Ensenada and California length frequencies was observed during fall, being most noticeable in November (Figure 15). During that month, San Pedro based fishermen fished extensively in the Santa Barbara region, which accounted for 65% of the month's total. Mexican fishing activities during the fall occurred at the extreme north and south ends of the fishery, the Coronado Islands and Punta Colnett areas respectively.

Sex Composition and Maturity

Sex ratios were nearly constant throughout most of the year for all areas, with females outnumbering the males as great as 2.8 to 1 (Table 17). Ensenada samples had the greatest female-male proportion of 2.8 to 1, while southern California exhibited a 1.6 to 1 ratio and central California with a ratio of 1.8 to 1 (Table 17). The ratios approached a near 1:1 value first in central California during January followed by southern California in February while Ensenada data showed a 1.3:1 ratio in April (Table 17).

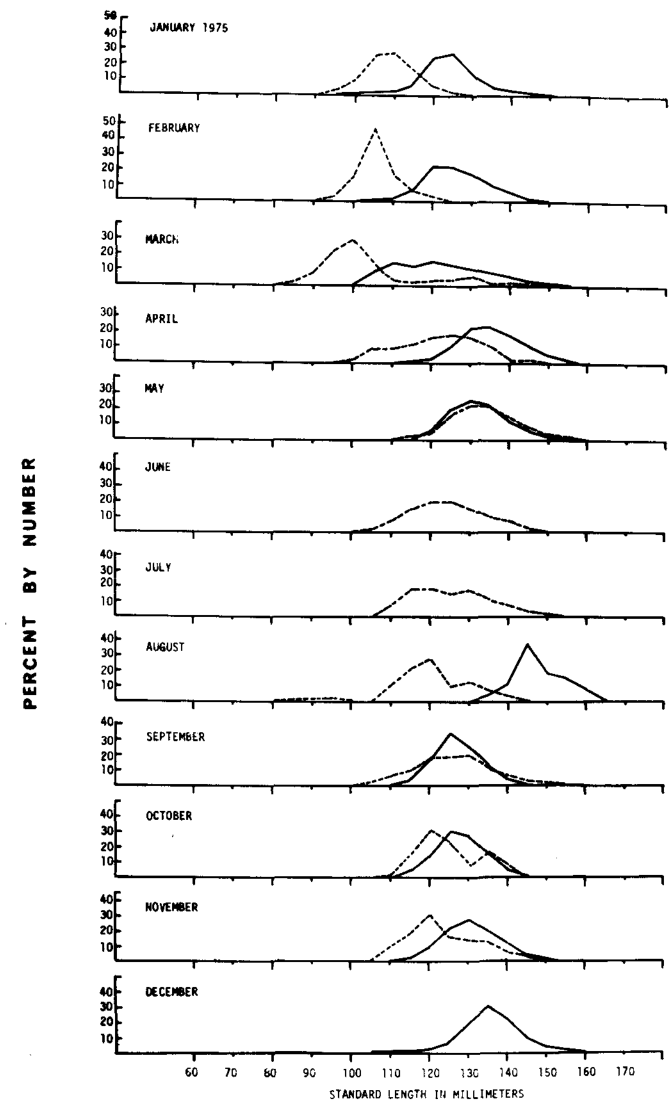

FIGURE 15. Length frequency distributions of anchovies by month; Baja California — — —, California —.

TABLE 17
Anchovy Sex Ratios for U.S. and Mexico, Percentage by Numbers

Month	Central California		Southern California		Mexico	
	Male	Female	Male	Female	Male	Female
January	48.3	51.7	38.4	61.6	32.3	67.7
February	–	–	48.0	52.0	39.1	60.8
March	35.0	65.0	40.4	59.6	36.5	63.4
April	–	–	37.9	62.1	43.4	56.6
May	–	–	36.5	63.5	22.8	77.1
June	–	–	–	–	25.9	74.1
July	–	–	–	–	9.7	90.2
August	25.8	74.2	–	–	39.3	60.6
September	27.4	72.6	36.1	67.9	16.9	83.0
October	32.6	67.4	40.2	59.8	0	100.0
November	44.4	55.6	39.4	60.6	28.0	72.0
December	–	–	36.8	63.2	–	–
Total	35.1	64.9	38.4	61.6	26.3	73.7
Sex ratio	1.85 F:1M		1.60 F:1M		2.80 F:1M	

Sexual development of southern California and Baja California anchovies was observed throughout the year, reaching mature and near mature stages during February through May (Figure 16). Maturity development could not be determined from central California due to small sample sizes. Maturity development of Mexican fish declined in the summer months with a minor increase in September. California's data indicated the spawning peaked during the period of February through May, with a minor spawning peak in September (Figure 16).

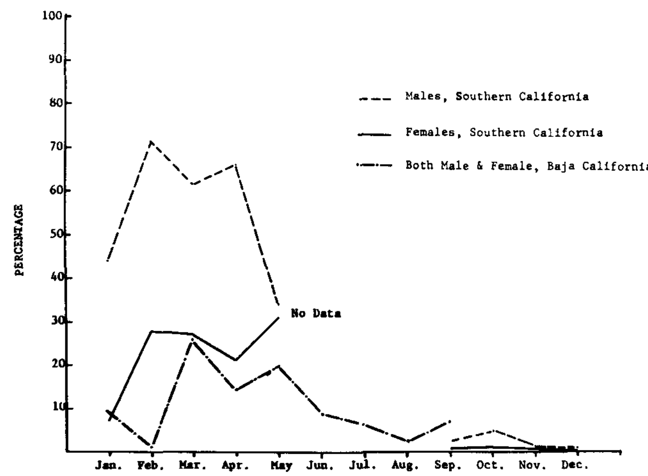

FIGURE 16. Percent occurrence of mature and near-mature stages (4–6) in southern California and Baja California anchovies.

Both Mexican and American data indicate a presence of two spawning peaks, which confirmed the findings of Silva and Villamar (1976) who determined two distinct reproductive periods.

RESEARCH CRUISES

During 1975, eight sea survey cruises were conducted by the California Department of Fish and Game, and 10 cruises by the staff of the Instituto Nacional de Pesca (INP). The objectives for both agencies were the gathering of limited oceanographic data relating to fish distribution; to determine by acoustic methods, the distribution and abundance of the northern anchovy; and to survey other pelagic fish and invertebrate species.

CONCLUSION

The anchovy fishery has recently become a significant fishery, especially since 1970. During 1975, the California Department of Fish and Game and Mexico's Instituto Nacional de Pesca (INP) have collaborated in a joint CalCOFI study concerning the anchovy resource. Results from this study provided important insights into this fishery.

Annual landings of both countries have been increasing since 1970 in response to an increased demand and rising prices of fishmeal. The major fishing effort of California fishermen occurred mainly during fall and spring months while Ensenada based fishermen fished mainly during the summer. In both fisheries, anchovy fishing was influenced by the absence or presence of other species.

Age composition from both American and Mexican samples were similar, while the size frequencies displayed differences during winter and fall months. Sex ratios of the samples revealed a higher proportion of females among the Mexican samples.

Results indicate the Mexican fishery harvested anchovies from both the southern and central subpopulations. While the exact proportions cannot be ascertained without further study, the major portion was from the central stocks.

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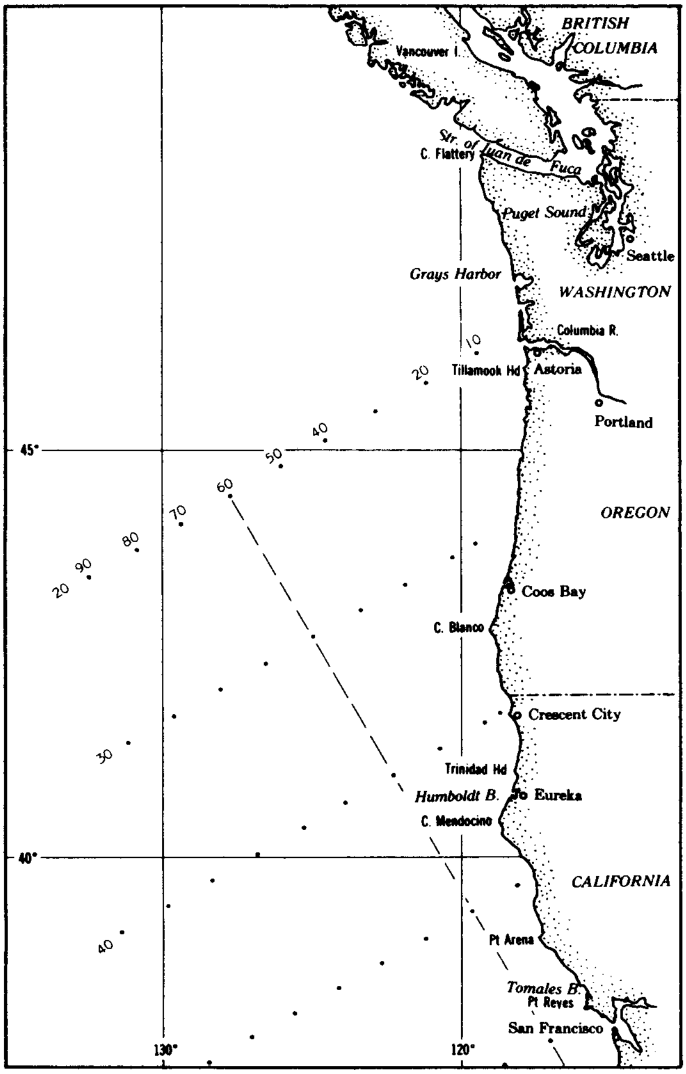

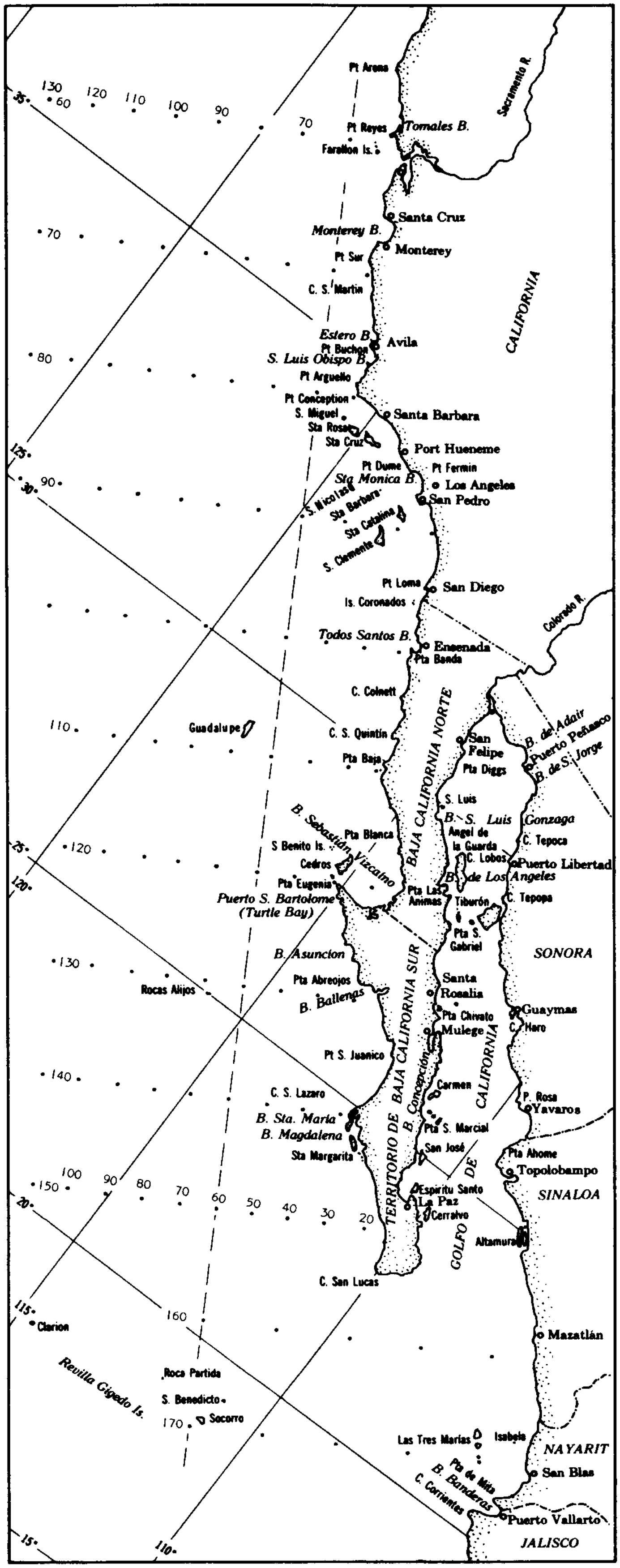

These maps are designed to show essential details of the area most intensively studied by the California Cooperative Oceanic Fisheries Investigations. This is approximately the same area as is shown in color on the front cover. Geographical place names are those most commonly used in the various publications emerging from the research. The cardinal station lines extending southwestward from the coast are shown. They are 120 miles apart. Additional lines are utilized as needed and can be as closely spaced as 12 miles apart and still have individual numbers. The stations along the lines are numbered with respect to the station 60 line, the numbers increasing to the west and decreasing to the east. Most of them are 40 miles apart, and are numbered in groups of 10. This permits adding stations as close as 4 miles apart as needed. An example of the usual identificaiton is 120.65. This station is on line 120, 20 nautical miles southwest of station 60.

The projection of the front cover is Lambert's Azimuthal Equal Area Projection. The detail maps are a Mercator projection. Art work by George Mattson, National Marine Fisheries Service.

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