AN ABSTRACT OF THE THESIS OF

JOSÉ RAUL CAÑON (Name) for the MASTER OF SCIENCE (Degree)

in OCEANOGRAPHY (Major) presented on 6 December 1972 (Date)

Title: DISTRIBUTION OF ANCHOVETA (ENGRAULIS RINGENS JENYNS) IN NORTHERN CHILE IN RELATION TO SELECTED OCEANOGRAPHIC CONDITIONS

Abstract approved: Redacted for privacy

Dr. James E. McCauley

The present work is an attempt to correlate information collected in the northern part of Chile with the anchoveta distribution and its fluctuation. This information was collected over a three year period (November 1967 to November 1970) by the Instituto de Fomento Pesquero, Chile (IFOP).

The first and second part represent an exhaustive review of the biology of the species and the principal oceanographic features of its habitat. It is based upon several years of research conducted by the Instituto de Fomento Pesquero in Chile, the Instituto del Mar del Peru in Peru, and other institutions. Results of these studies are reported through 1972, providing the necessary background for the discussion presented in later chapters.

In part three the information collected during the three year period by IFOP is presented. Seasonal average maps of temperature, salinity, transparency, fish distribution, volume of zooplankton, eggs and larvae of anchoveta are presented and discussed. Oxygen and temperature sections are also presented in relation to school distribution.

The final part is entirely devoted to a discussion of outstanding features of the interrelationship of the anchoveta to the environment that is found in the region. The effect of temperature appears to be important in the fish distribution and may be responsible for the major concentrations during summer months that result in higher catches by the fishing fleet. Oxygen appears to be of primary importance in the seasonal fluctuations. When upwelling takes place, especially during winter, water with a low oxygen content from the Peru-Chile Undercurrent is brought to the surface forcing the anchoveta to migrate to the west away from the coastal areas. The effect of a highly saline and warm oceanic front may also affect fish distribution. The effect of all these could also affect eggs and larval survival, but the relationships are not clear.

The bibliography at the end of the work is a complete bibliographical review on the subject and will be used for further studies in anchoveta off Peru and Chile.

Distribution of Anchoveta (*Engraulis ringens* Jenyns) in Northern Chile in Relation to Selected Oceanographic Conditions

by

José Raul Cañon

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

June 1973

APPROVED:

Redacted for privacy

Dr. James E. McCauley, Associate Professor of Oceanography, in Charge of Major

Redacted for privacy

Dr. John Byrne, Dean of School of Oceanography

Redacted for privacy

Dean of Graduate School

Date thesis is presented 6 December 1972

Typed by Carla Rathbun for José Raul Cañon

ACKNOWLEDGEMENTS

I would like to thank Dr. Wayne V. Burt for his part in arranging for me to study at Oregon State University although, as a foreigner, I lacked some of the formal qualifications normally required for graduate study here. This thesis is proof that a man can overcome great obstacles and achieve success, given the opportunity and necessary guidance.

I would not have been able to complete this thesis without the continuous professional guidance of my major professor Dr. James E. McCauley. His advice and encouragement during my stay at Oregon State University will be long remembered.

I am indebted also to Mr. David B. Enfield who gave me so much valuable advice and devoted much of his time to discuss and clarify my problems.

The information used in this work was obtained with the help of many of my colleagues in Chile and many fishermen whom I thank, as I do the Instituto de Fomento Pesquero (IFOP) which supported my studies at Oregon State University.

I have learned many valuable things from the people here at Oregon State University, especially from those of the Marine Advisory Program, who gave me the opportunity to share much of their own experience. The theme of this thesis was in part the result of many conversations with Extension people who often discussed the primordial role of Oceanography in the development of fisheries.

At home, my wife Gabriella showed great patience, supported me in my disappointment and enjoyed much of the happiness of my work here. To her and to my country, Chile, I dedicate this modest effort toward the understanding of our most valuable fishery resource: the anchoveta.

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PART I. THE BIOLOGY AND ECOLOGY OF THE ANCHOVETA, <u>ENGRAULIS RINGENS</u> JENYNS).

Introduction

The anchoveta, *Engraulis ringens* Jenyns, is by far the most important fishery resource in Peru and Chile, and represents, by itself, more than twenty percent of the total fish catch in the world (F.A.O., 1970). This species is also commonly known in Chile as "anchoa", "sardina bocona" or "chicoria" (De Buen, 1958). In the last decade the anchoveta has become the main economic resource of Peru and a significant source of income to Chile, producing a total income of nearly 400 million dollars annually from fish meal and oil in both countries. However, in spite of numerous investigations, it is still difficult to assess and forecast the anchoveta population. Yearly fluctuations with severe economic implications are common, especially in the Chilean fishery.

The present work summarizes anchoveta studies for both Peru and Chile, describes the fishery, and describes the oceanographic regime in Peruvian and northern Chilean waters. This is followed by an exhaustive analysis of twenty-six months of cruises made in a systematic, cooperative international research program between the Instituto del Mar del Peru (IMARPE) and the Instituto de Fomento Pesquero (IFOP) of Chile, and named Project EUREKA in Peru and Project NORTE in Chile.

Although this study is mainly concerned with findings from the northern part of Chile, it is very difficult to discuss the Chilean and Peruvian stocks of anchoveta separately. Therefore, references to studies in Peru are made throughout the text with special emphasis on studies in the southern part of Peru.

Additional goals of this study are to suggest new policies and priorities in anchoveta resource investigations and to call for international cooperative efforts in areas where further research is needed to effectively manage this valuable resource. Much money and effort can be saved by a comprehensive understanding of anchoveta fisheries and of the biology in both Peru and Chile.

"Engraulidae of the Southeast Pacific"

The genus *Engraulis*, to which the anchoveta belongs, occurs in coastal areas around the temperate zones of the oceans except in the Indian Ocean and the Atlantic coast of North America, where a closely related genus *Anchoa* occurs. The genus extends to latitudes as high as 60°N and 44°S, but is usually restricted to the eastern boundary currents and coastal upwelling regions (Reid, 1967).

Hildebrand (1946) lists one species of *Engraulis*, *Engraulis ringens* Jenyns for Peruvian waters and also three other *Engraulidae*: *Anchoa naso* (Gilbert and Pierson), *Anchoa nasus* (Kner and Steindachner) and *Centengraulis mysticetus* (Gunther). De Buen (1958) lists five species of the genus *Engraulis* for Chilean waters: *Engraulis ringens*, *E. dentex* (not Valenciennes) Guichenot, E. grossidens (not Cuvier) Reed, E. pulchelus Girard, E. encrassicholus (not Linnaeus) Reed, and Lycengraulis grossidens (not Cuvier)Delfin. Engraulis ringens is by far the most dominant species off both Peru and Chile.

Geographical Distribution

Engraulis ringens is restricted to the coastal waters of Peru and Northern and Central Chile. The northernmost range, given by Chirichigno (1965), is off Zorritos, Peru (4°30'S), and the most austral record is at 42°30'S (IFOP, 1970) giving a range of nearly 2,500 miles for north-south distribution with a width generally less than 50 miles. However, the bulk of the population from which most commercial catches are obtained is restricted to waters off the northern and central part of Peru (Figure 1). The population decreases sharply to the north and more gradually to the south. Although most of the catch-effort is in the narrow band from 5 to 25 miles offshore, there are many records of schools as far as 100 miles from the coast. The fact that most of these records are deduced from echo-sounding observations alone leaves the offshore boundary somewhat vague.

Identity of Engraulis ringens Jenyns, 1842

The species was described for the first time from specimens collected off Iquique, Chile, during the voyage of the H.M.S. "Beagle" (Jenyns, 1842). This description is as follows:

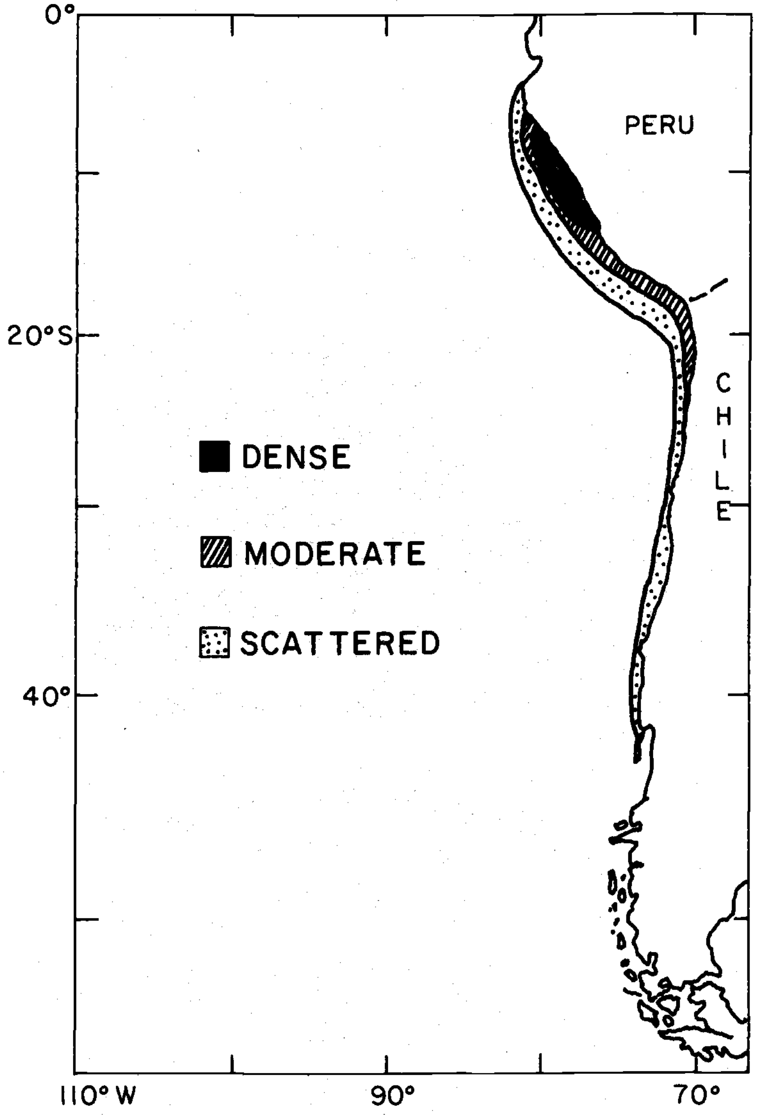


Figure 1. Zoogeographic distribution of anchoveta (*Engraulis ringens* Jenyns) showing areas with commercial concentrations.

Engraulis ringens Jenyns, 1842

(D.15; A.19; C.19 and c.; P.16; V.7)

"FORM: Closely resembling the common Anchovy, but the head decidedly larger and longer, being one fourth of the entire length. Eye larger, but bearing an equal proportion to the size of the head; also rather nearer to the tip of the snout in consequence of this last not being so acute and much reduced. Lower jaw rather narrower, from the greater compression of the head and body. Maxillary, and its fine serratures on the edges for teeth, similar.

The depth of the body is about one-sixth of the entire length. The dorsal commences at the middle point of the length, reckoning this last to the base of the caudal fork, and terminates a little before the commencement of the anal: the first ray is not half the length of the second and third, which equal three-fourths of the depth: the fifth and succeeding rays become gradually shorter than those which precede. The first ray in the anal is likewise very short, and scarcely one third of the next following. The ventrals arise almost directly under the first ray of the dorsal, being scarcely at all in advance; when laid back, they do not reach half way to the anal. Above the pectoral is a long membranaceous scale equalling, or very nearly, the fin itself.

COLOR. Not noticed in the recent state. In spirits, it appears silvery, with the back and upper part of the sides deep dusky blue, the two colours separated by a well defined line." (Jenyns, 1842, p. 136-137)

Subpopulation Studies

The pattern of distribution suggests that the anchoveta is divided into two subpopulations. Brandhorst and Rojas (1965) based subpopulations on differences in the number of vertebrae and were partially supported by Jordán (1965) who studied the Peruvian populations. They found a low mean of 46.73 in the northernmost samples off Chimbote, Peru (9°05'S) and a high mean of 47.26 near Talcahuano, Chile (37°02'S). They separated the Chilean anchoveta into two groups: a northern group, in the zone between Arica and Antofagasta (mean 46.85) and a southern group, in the zone between Coquimbo (29°50'S) and Talcahuano (mean 47.14). In both groups a seasonal cycle in vertebrae number was observed with monthly differences being more pronounced than yearly differences (Brandhorst and Rojas, 1965). This fact was attributed to the different proportion of summer or winter-spring born recruits in the samples taken during different months (Brandhorst, Carreño and Rojas, 1965).

Jordán (1963) studied the number of vertebrae of a large number of specimens collected during 1953 and 1961 in six different localities along the Peruvian coast between Chimbote and Ilo. The mean for all his individuals was 46.75, the largest single one being 47.0. He found no significant differences in number of vertebrae at different latitudes except for the latitude of Chimbote during 1955 where exceptionally low values were found. In the same study Jordán suggested that these lower values could be phenotypical, caused by anomalous high sea temperatures which in certain years are known to occur in this area. However, there appeared to be a slight increase of vertebrae number with increasing latitude. The difference between the arithmetic measurements of the group from Chimbote (Jordán, 1963) and the group of Talcahuano (Brandhorst, Carreño, and Rojas, 1965) is 0.53 which supports the idea of different stocks in the population if we consider only meristic characteristics and assume that the composition of age between both groups of samples was similar or nearly similar.

However one meristic character is not sufficient to define subpopulations even if proper statistical techniques are used, especially in a species like the anchoveta that has two spawning seasons in one year; it (vertebrae count) is also subject to aperiodical changes in oceanic conditions, particularly temperature changes.

Tsukayama (1966) has suggested the possible existence of two groups of anchoveta in Peru on the basis of the average number of gill-rakers. She found a north-south gradient from 87 for the latitude of Chimbote to 83 for the latitude of Mollendo for the average number of gill-rakers in the first arc of the adult anchoveta.

Recently, Rojas de Mendiola (1971) studied the relationship between standard length and the length of the intestines to differentiate between two groups of anchoveta in Peru. Her results show that in northern Peru the intestines are 1.75 times the standard length while in southern Peru and northern Chile this ratio drops to only 0.95. Further study is needed to clarify the status of subpopulations. Tagging experiments should be done in additions to studies of vertebrae counts. Serological studies such as those initiated by Simpson and Simon (1966) should be repeated because preliminary studies were not conclusive.

However for the characteristics considered, anchoveta from northern Chile and southern Peru appear to form a transitional group which separates the group from northern and central Peru from another group in central and southern Chile. The taxonomical level at which this differentiation occurs is a problem that is still unsolved.

Migrations

Migration patterns of the anchoveta are not yet known. However, some evidence of their movements has been derived from recent tagging studies off Peru (Jordán and Malaga, 1972; R. Jordán, personal communication).

The Peruvian tagging program, initiated in April 1970 by IMARPE and continued to the present, has shown that anchoveta stocks intermingle from the latitude of Tambo de Mora and Pisco, Peru, to the latitude of Arica, Chile. Although the tag recoveries suggest a rather rapid migration both north and south of the tagging area, more detailed studies must be made to define patterns of migrations. Recently, tags have been recovered by magnets in the meal lines of processing plants also in Arica, Chile, from fish tagged in Peru. A migration from coastal waters to the open ocean has also been suggested by fishermen whenever anomalously high coastal water temperatures occur. The fishermen report that the migration is most marked whenever the El Niño phenomenon occurs, but this relationship is not supported by concrete evidence.

Subpopulations are important in any kind of migration study because tagging experiments would be conducted quite differently for different population structures. Does the anchoveta population consist of a single intermingled stock, or of two or more genetically different stocks? At least in Chilean waters the latter appears to be the case.

Growth and Age Studies

Studies on the Engraulidae suggest a short life span, with a maximum age of seven years. Growth studies on E. ringens both in Peru and Chile are reviewed below.

Barreda (1953) made a preliminary study of the growth and age of the anchoveta using scales. Jordán (1959) studied the progression of the length mode of anchoveta in the stomach contents of guano birds, and suggested that anchoveta of 7.5 to 8.5 cm long are four or five months old, those 10.0 to 12.0 cm are one year old and those 13 to 14.5 cm are about two years old.

Later studies in Peru, especially that of Saetersdal and Valdivia (1964) found that anchoveta grow to 9 cm in six months, 12 cm in one year, and 13 to 14.5 cm in one and a half years.

Chirinos de Vildoso and Chumán (1968) showed that a fairly good correlation exists between otolith readings and length frequency.

Simpson and Buzeta (1967) used the method of temporal progression of selected modal groups to study anchoveta growth and age in northern Chile. Mean modal lengths at six months were 9.5 cm; at one year, 13.5 cm; and at one and a half years, 15.5 cm. The study showed a seasonal variation in growth that could be related to food availability and sexual cycles. The mean monthly growth increments in the size range of 10 to 15 cm were highest in August and September (0.8 cm) and in the period from November to January (0.9 to 1.0 cm) and lowest (0.4 cm) in the period from May to July. They were unable to use this method to study samples from the central and southern Chilean ports of Valparaiso, Talcahuano and Valdivia owing to a marked overlap in complex polymodal length-frequencies. They suggested that there are good reasons to believe that the growth of the anchoveta south of Coquimbo, Chile, is different from that in northern Chile and Peru, with a maximum size of 21.0 cm compared to 18.5 cm in the north.

Food and Feeding Habits

Although statements that adult anchoveta feed on phytoplankton have been common (Vogt, 1942; Sears, 1954), no definitive study of food habits has yet been made. Oliver-Schneider (1943) suggested that phytoplankton might be a primary food for the anchoveta, but De Buen (1958), using anchoveta collected near Valparaiso, Chile, found zooplankton, especially bits of copepods, decapods larvae and other crustaceans in stomach contents. He suggested that the main food was phytoplankton, which did not appear in great quantity in his samples because it could be more easily assimilate or not available at the time the samples were taken.

Peruvian studies were initiated in 1951 by Rojas de Mendiola (1953) who reported that anchoveta feed primarily on zooplankton but include a major proportion of phytoplankton, especially diatoms. She made further studies during the period 1955-1958. The results of her work show the frequency of occurrence of phytoplankton and zooplankton as a percentage of the identifiable organisms found in stomachs of samples taken at monthly intervals from commercial landings at Chimbote, Peru. Standard lengths varied from 7.8 to 14.5 cm. Her results suggest seasonal feeding patterns in anchoveta. During early spring, when the bloom of phytoplankton occurs, the anchoveta appear to feed almost entirely on phytoplankton, but during late summer and early fall anchoveta feed mostly on zooplankton. In another study Rojas de Mendiola (1969) reported on collections from several ports on the Peruvian coast from Chimbote to Tambo de Mora (9°05'S to 13°30'S). She found that most of the stomachs contained phytoplankton, especially species of _Chaetoceros_ and _Ceratium_. _Thalassiosira subtilis_ was common in the northern zone, but was not present in the southern samples where zooplankton, especially copepods, predominated.

Later on (1971) the same author, in a study of stomach contents of anchoveta caught at the same time but in four different areas off Peru, found that a latitudinal variation in feeding habits was present. In northern Peru, the stomach content was predominantly phytoplankton, while zooplankton predominated in southern Peru and in northern Chile. Neither of them predominated in central Peru (off Callao). Her conclusions are supported by variations in the intestine-standard length ratio with latitude. The greater ratio in the northern area may indicate the possible existence of variations in feeding habits with latitude.

All these facts suggest a correlation between latitude and feeding preference of anchoveta, but the fact that the average size of specimens from the north are larger than from the south could distort the results.

Although only relatively small numbers of anchoveta were analyzed in these studies, and little attention made to size differences, studies on other Engraulidae show that their feeding habits vary with age. Engraulis japonica feeds on zooplankton in its early stages, but phytoplankton in its adult stage (Kubo, 1961; Yamashita, 1957). The Argentinian anchovy E. anchoita (Hubbs and Marini) feeds first on zooplankton (Chiechomski, 1967; Angelescu and Fuster de Plaza, 1962). This variation may also occur in the Chilean and Peruvian anchoveta. Further studies in feeding habits must take into consideration not only latitudinal distribution and seasonal variations, but also year class and age of the anchoveta.

Phytoplankton and zooplankton sampling at the time of the collection of the samples would give an idea of the availability of different types of food in areas under study. Laboratory studies must also be conducted. Feeding habits may be dictated by the kind and abundance of food available. Evidence to support this hypothesis has been reported by IFOP in the northern part of Chile, but further studies are needed.

Studies of feeding time are also important but those that have been made are inconclusive. According to Rojas de Mendiola (1967, 1965) the anchoveta feed at least twice in 24 hours, once in the morning and once in the afternoon. It is mainly fished at these times and the relative stage of digestion of the food organism may have influenced her conclusions. In the northern part of Chile no studies are available, but here also most of the catches are made early in the morning, near sunrise, which may be the time when anchoveta are more actively feeding. Until samples have been collected from all times of the day and night conclusions about feeding times must remain tentative.

Predators

All Engraulidae are subject to predation by other fishes, invertebrates, and birds, as well as by man. The anchoveta is preyed upon to such extent by birds that its fluctuations also affect the guano industry.

Jordán (1967) studied the predation of guano birds on the anchoveta, and listed tha main species of birds that feed on anchoveta. These are in order of importance: *Phalacrocorax bougainvillii* Lesson (cormorant); *Sula variegata* Schud (gannet); *Pelecanus occidentalis thagus* Molina (pelican); *Spheniscus humboldti* Meyer (penguin); *Puffinus griseus* Gmelin (sooty shear-water); *Sula nebouxi* Milne-Edwards (blue-footed booby); *Phalacrocorax gaimardi* Lesson (red-footed shag); *P. brasilianus* Humboldt (bigua cormorant); and *Larosterna inca* Lesson (Inca tern). Of these Jordán stated that the main consumers are the first three and that these species constitute more than 90% of the guano producing bird population in Peru.

Aerial observations in the north of Chile where total bird populations are generally less reveal that these three species prey upon anchoveta, but make up a smaller percentage of the total sea bird population than indicated by Jordán (Brandhorst and Cañón, 1968).

It was estimated by Jordán (1959) that a guano bird consumes an average of 4 pounds of anchoveta per day. Thus in 1963 an estimated 16 million birds consumed 7,000 tons of anchoveta daily or 2.5 million tons annually. However the number of birds is subject to great fluctuations because of the anomalous oceanographic conditions present at times and related to the El Niño phenomenon. The El Niño was present off Peru two times during the last 15 years, in 1958 and 1965, with catastrophic consequences for the bird population. Jordán (1966) estimated that over 28 million birds were present in 1955 but after the 1958 El Niño this population was reduced to 6 million. In 1963 the population of birds had increased to an estimated 18 million. In 1965 another oceanographic anomaly reduced the availability of food for the birds and the number dropped to an estimated 5 million. The bird population has remained at about that level in recent years mainly because of the increase in the harvest of anchoveta by man. Another occurrence of El Niño could cause an almost total disappearance of the birds with unpredictable ecological repercussions.

Besides birds and man, anchoveta is preyed upon by large fish such as the Chilean hake (Trachurus murphy Nichols), bonito (Sarda chilensis Cuvier and Valenciennes), tunas (Neothunnus macropterus Schlegel and Katsuwonus pelamis Linnaeus), squid (Dosidicus gigas D'Orbigny) and by marine mammals. But the influence that these have on the anchoveta population has not been studied.

Systematically or Ecologically Related Species

Because of the difficulty of separating species, other species often are included with the anchoveta. Catch statistics from both Peru and Chile may be reported as anchoveta, when, in fact, they may contain a small proportion of other species. At times these other species are extremely abundant, and constitute a high percentage of the total catch. Among these "contaminants" we have the common sardine (*Clupea bentinki* Norman); the Spanish sardine (*Sardinops sagax sagax* Jenyns); the Peruvian sardine (*Sardinops sagax musica*); the machuelo (*Brevoortia chilcae* Hildebrand); the caballa (*Pneumatophorus peruanus* Jordán and Hubbs); the bacaladillo (*Normanichthys crockery*) and juveniles of hake (*Trachurus murphy*) and bonito (*Sarda chilensis*). Little is known about the relation of these species to the anchoveta at the present time.

Reproduction and Sex Ratio

The anchoveta is heterosexual without secondary external characteristics; cases of hermaphroditism are not known. Jordán(1959), Einarsson, Flores and Miñano (1966), Miñano (1968) and Simpson and Gil (1967) have examined the sex ratios of the anchoveta at various locations off Peru and Chile. In general there are more females (more than 50 and less than 60%) than males, but males may predominate in populations of medium size (118-142 mm). This ratio may be representative of the population or it may be related to differential avoidance of the net, decrease in swimming ability of the heavier females, or some other behavioral pattern.

Maturity

The sexual maturity of the anchoveta has been studied by Einarsson, Flores and Miñano (1966). It has been determined by macroscopic examination of the gonads by Chirinos and Alegre (1969); Simpson and Gil (1967), and Miñano (1968).

In general, males reach sexual maturity before females. Off Peru a few males reach sexual maturity at 115 mm and females at 120 mm (Miñano, 1968). At 140 mm 50% of the individuals of both sexes are mature.

In Chile Simpson and Gil (1967) showed that, at least for the data from Iquique, maturation begins at a length of 110 mm and is largely completed at a mean length of 135 to 140 mm. The length at which 50% began spawning was 125 mm for the summer-autumn spawners and about 115 mm for the winter spawners.

Fecundity

Although little attention has been placed on the fecundity of the anchoveta, according to Miñano (1968) large females from 120 to 170 mm in length spawn an estimated 9,000 to 21,000 eggs. Individuals females may spawn from 6,500 to 35,500 eggs. There is no indication whether individual anchoveta spawn one or two times in a year but it is apparent that one major spawn takes place per female.

The weight of the gonads increases slowly with body length to a length of 120 mm, then increases faster as the fish mature. During March-June a drop in gonad weight results from spawning (Miñano, 1968).

Spawning Seasons

Anchoveta spawn over a wide region between a latitude of 6°S and 40°S, from the coast to the open ocean. However, the spawning activities are concentrated a few miles off the coast. Most of the spawning takes place over the continental shelf, in shallow waters.

The spawning season lasts throughout the year off both Peru and Chile.

In studies of gonad stages in samples of mature fish netted near Chimbote and Callao, Peru (Chirinos de Vildoso and Alegre de Haro, 1969), spawning occurs during at least eight or nine months, from July to March, but eggs are sometimes found in other months as well. Spawning starts in mid-July or early August and reaches maximum intensity during September or October (austral spring).

Beginning in December and January a second less intense spawning season takes place that continues through March.

In another study from 1961 to 1968 the same authors found that sexual activity extends from August to March with peaks of activity in September and February. The September peak is the more significant of the two. These results are in agreement with studies of eggs and larvae of anchoveta in collections off Callao and Chimbote (Einarsson, Flores and Miñano, 1966) who found a similar pattern to that inferred by the gonad study. The peak of sexual maturity in summer is almost equal to that of winter, but the predominance of small anchoveta during the summer makes verification difficult. According to Miñano (1968) the older anchoveta spawn for longer periods and more intensively than the younger females due to the greater number of eggs per female.

Studies of samples from southern Peru (Chirinos and Alegre, 1969) and northern Chile (Simpson and Gil, 1967) show some slight differences from the northern Peru pattern. The spawning season starts in June or July with a peak during August. A second peak occurs in November-December. The northern part of Peru, between 6° and 10°S appears to be by far the largest spawning area (Einarsson and Rojas de Mendiola, 1968).

Plankton collections along the Chilean coast from 1964 to 1968 contained eggs of anchoveta all year round for the coastal waters between Arica and Caldera. Two main peaks of abundance occurred, one in winter with the maximum intensity during August and the other in summer with the maximum in January. Almost 90% of the eggs and larvae were collected in these two periods (IFOP Final Report, 1970). The eggs in the principal spawning season are usually found in specific locations which suggest the existence of "spawning centers". Three such locations have been identified off the northern coast of Chile: near Arica, Rio Loa, and south of Taltal.

Eggs have been collected as far from shore as 100 miles off Arica, while larval catches are restricted to 40 miles offshore. Apparently surface currents carry eggs and larvae during developmental stages. Spawning appears to take place in the upper 20 to 50 m. Farther south, off Valparaiso Fischer (1965) has determined that the spawning season increases from May until July, decreases in August and becomes almost zero during November to January. Eggs were found in October and February through April but the information was obtained from only a few samples and must be considered as preliminary.

Development

Egg and larvae stages were studied by Barreda (1950) off Peru and Fischer (1958) off Chile. The latter described the steps of development of anchoveta up to the prelarval stage with average lengths of 5.4 mm in samples collected off Valparaiso, Chile.

The eggs are the typical ovoid shape of all engraulids, lack an oily drop, and have a completely smooth capsule. The yolk is separated into numerous alveoli. The longitudinal axis is 1.22-1.49 mm mostly in the range between 1.32 and 1.41 mm and transversal axis is 0.54-0.68 mm (Fischer, 1958).

A large number of eggs sorted from plankton samples collected in Peru (Einarsson and Rojas de Mendiola, 1968) have the same characteristics of those described above by Fischer (1958). On the average the longitudinal axis is 1.42 mm and ranges from 1.19-1.60 mm. The transversal axis is 0.71 mm and ranges from 0.57 mm to 0.86 mm.

There are no significant differences between eggs found off Chile and Peru.

Fischer (1958) recognized five phases in the development of the eggs while Einarsson and Rojas de Mendiola (1966) recognized only three.

Rojas de Mendiola (1967) has suggested that, because the first phase is most abundant in nocturnal plankton hauls, spawning occurs mainly at night, but this has not been confirmed.

The larvae of E. ringens are 1.72-2.25 mm long at hatching, and differ from other engraulid larvae in their peculiar pigmentation, short anal fin, with 18-20 rays in larvae from 10 to 17 mm, and dorsal fin with 14-16 rays. Vertebrae numbers are 45 to 47, similar to adult specimens.

Postlarval and juvenile stages have received little attention. By this age the young fish have gained enough swimming ability to avoid the Hensen net and as the faster Isaacs-Kidd net has only recently been introduced in the area, collections using this net have not yet been studied.

Historical Development of Research on the Anchoveta

The rapid development of a large fish-meal oriented fishery in the last decade in Peru and Chile after the decline of the sardine along the coast of California gave rise to a series of intensive studies concerned with the biology of the anchoveta in both South American countries.

In Peru, however, biological studies on the anchoveta population were initiated early in 1941 by scientists of the Campañia Administradora del Guano.

In 1954 the Peruvian government created a Consejo de Investigaciones Hidrobiologicas. This Council began a systematic research of the sea in February 1958, using the navy ship B.A.P. Bondy (Freyre, 1967).

In July 1960 a marine research institute, Instituto de Investigaciones de los Recursos Marinos, was founded by the Peruvian government with technical and financial assistance of the United Nations Special Fund. The advising agency was the Food and Agriculture Organization of the U.N. (F.A.O.). The principal aim was to study the anchoveta resource and the complex biological, oceanographical, technological and economical factors affecting conditions of catch and utilization. The Institute stopped functioning in June 1964, at which time the present Instituto del Mar del Peru (IMARPE) began operations. The budget for this new Institute, which was in fact a continuation of the old F.A.O. program, consisted of grants from the Ministry of the Navy, the Sociedad Nacional de Pesqueria, and the fishing industry. In 1970 a new program was organized by the recently created Ministry of Fisheries. It was supported by a five year UNDP/FAO grant. Officially FAO's interest in Peru was in assisting the government to develop an industry utilizing fishery products for human consumption, but some support for anchoveta research was also supplied by F.A.O. However, the main investigation of the anchoveta industry is being continued by the Instituto del Mar del Peru (IMARPE) with direct support from the government of Peru.

The anchoveta received little special attention in Chile before it became the basis for the present fish meal industry. Before that time the species was considered only in general studies of the fisheries as a whole (Lubert, 1928; Lobell, 1944; and Poulsen, 1952).

In 1958 De Buen, working under an F.A.O. assignment and later as a staff member of the University of Chile in Valparaiso, made the first biological study of anchoveta populations in Chile. The great increase in the catches in Peru and also in Chile in 1960 made the Chilean government aware of the potential value of this fishery. The government established a cooperative program which involved the German Program of Technical Assistance in Chile, the Laboratorio de Biologia Pesquera y Oceanografia, a branch of the Ministerio de Agricultura, and the Departamento de Pesca y Caza. This program cooperated with the Estación de Biologia Marina of the University of Chile in Montemar to study the biology of the anchoveta and the oceanographic conditions that could affect its distribution and abundance. Sampling began in 1961, with studies of subpopulations, size distributions, sexual cycles and reproduction. Insufficient staff and the lack of a research vessel limited the work of this group. The first oceanographic expedition was launched through the joint efforts of this group with the support of the Corporacion de Fomento de la Produccion (CORFO) of Chile. The Chilean Navy provided a ship for the expedition. More than ten scientist from several institutions participated in the Expedition which was named MARCHILE I. It took place during February and March 1960.

During 1962 a large fishery was developed in the northern part of Chile which landed nearly a half million tons of anchoveta. The Chilean government then petitioned the Special Fund of the United Nations for support of a fishery research project to establish a technological base for the development of the resource, establish policies for the rational utilization of the fisheries, and serve as a coordinating center. The project became effective in November of 1963 with the creation of the Instituto de Fomento Pesquero (IFOP). Most of the staff of the Laboratorio de Biologia Pesquera y Oceanografia who had previously worked in the program with the German Technical Mission were involved in the beginning of the new agency, thereby guaranteeing continuity of the studies already initiated. For five years F.A.O. was the advisory agency, then the Institute became a national governmental agency supported jointly by the CORFO and the Ministry of Agriculture.

The Peruvian Fishery

The blossoming of the anchoveta fisheries in Peru exemplifies an industrial growth pattern unequalled in the history of fisheries development. In less than a decade the anchoveta has replaced cotton, copper, and sugar as the main export product in Peru and has become the main source of foreign exchange for the nation.

According to statistics published by the Ministry of Fisheries of Peru, the registered catch of anchoveta in 1955 was 58,707 metric tons. It was made with a fleet of 175 small boats and processed in 16 factories. In 1959 the effort was more than doubled with 426 boats and 63 factories in operation. Nearly two million tons of anchoveta were landed. Eleven years later in 1970 with a fleet of nearly 1,500 boats and over a hundred factories, a record 12.4 million tons were processed.

Studies made by IMARPE in 1968 show that the average maximum sustainable catch of Peruvian anchoveta stock is about 9.5 million tons.

A present evaluation of the industry according to recent figures (Vasquez, Hidalgo, and Perez, 1972) shows that about 1,473 boats are in use and one hundred and sixteen factories are active. Some companies have gone bankrupt, as a result of fish catch fluctuations, the fact that maximum sustainable yield has probably been exceeded, lower prices brought about by high fish meal production. In an effort to prevent overfishing the government permitted only 83 fishing days for the entire year of 1971. Restrictions in number of boats and new factories have been in effect since 1970.

During 1972 the Peruvian government took complete control of the industry including marketing. To implement its new policies, the government created the Empresa Publica de Servicios Pesqueros (EPSEP), a state food fish entity, and the Empresa Pesquera de Comercializacion de Harina y Aceite del Peru (EPCHAP), the state fish meal and fish oil marketing entity.

The Fishery in Chile

The development of the fish reduction industry for anchoveta in Chile followed a pattern of growth similar to that in Peru, but the amount of effort expended and the size of the catches were far less. In 1954 the total amount of anchoveta landed was nearly 1,100 tons, most of which was used for fish bait and for canning. In 1966 the catch had grown to a maximum of 1,050,000 tons with most of the fishing taking place between the latitudes of Arica and Antofagasta. More than 30 factories had been installed in Chile by the end of 1965 with a total processing capacity of 1,200 tons/hour. This increase in processing capacity was partly in response to the success achieved in Peru and partly in response to a very optimistic evaluation of the magnitude of the resource in Chile. The estimation was based only on economics and neglected the biological aspects of the anchoveta population.

In 1960, the government in an attempt to cut down unemployment in northern Chile that had been caused by the closure of several nitrate mines, passed a law that gave special treatment to the fishing industry. One of the most important concessions was a reduction of 90% in taxes and an exemption of import taxes for all machinery and fishing gear used in the anchoveta industry in the northern part of the country. This governmental action brought about an increase in the number of factories to far beyond the number required to handle the available stock. As a result, by the end of 1966 the industry had increased its handling capacity to nearly 5 million tons/year.

Anomalous oceanographic conditions in 1965 drastically reduced the availability of fish, making the problem of excess capacity in the fish meal industry more acute. Several plants went bankrupt. By assuming foreign debts contracted by the industry, the government became principal shareholder in nearly all of the factories by 1967.

Restrictions in the granting of permits to operate new factories and a new policy of integrating small industries that could not survive the depression of 1965-1966 changed the nature of the industry by the end of 1967. The number of factories in northern Chile decreased from 27 to only 10 integrated factories. Two hundred fishing vessels supplied these factories.

By the end of 1971 the Chilean goverment had taken control of the fishing industry. All of the companies were placed under control of a single government company which had the responsibility of obtaining a better economic return for the investments the state had made in the area.

Fishing Techniques

Fishing is done exclusively by purse seine boats in an operation that employs 12 or 13 crewmen including the master and the engineer. The boats are built locally, following the pattern of the American Pacific coast seiner. The present tendency is to construct large boats of over 145 gross registered tons rather than small boats that had been used previously. The number of boats is decreasing but the total tonnage of the fleet remains about constant.

Boats are equipped with radio, echo sounder and navigational aids (compass). Probably less than 10% of the boats have Sonar in addition to an echo sounder. Most of the boats are built of steel but a small number of wood or fiberglass boats are registered.

The fishing gear consists of a net and a skiff called a "panga" which is equipped with a large inboard motor. The skiff is used to purse the net. The nets are between 130 to 350 fathoms long and 25 to 42 fathoms wide. The average net is 225 by 35 fathoms. A power-block is used to assist in recovering the net.

When the school is enclosed and concentrated by the net, the fishes are transferred to the hold of the boat with a fish pump, instead of the former technique of using a landing net. Each fishing trip is usually limited to one day. During longer trips catches may decompose unless refrigeration or preservatives are used. In a typical trip, the vessel usually leaves port between midnight and 4 a.m. and travels to a possible fishing ground at a mean speed of 7 to 12 knots. Aerial reconnaissance conducted during the day before helps to determine the best locations for fishing. Airplanes cooperate with the skippers in the search of schools early in the morning. Occasionally pilots direct the operation from the air where the schools are sometimes easily observed. The vessels return late in the afternoon or at night. In Peru, two trips in a single day may sometimes be made whenever the concentrations are close enough to the reduction plants.

The boats of each company operate to a large extent as a unit in their efforts to locate and catch fish. Each company, at least in the northern part of Chile employs one airplane that is either owned outright or rented. Bad weather is unusual. Only in winter are weather conditions important to the fishing effort.

Both Peru and Chile claim 200 n. miles as their territorial sea. Each country restricts its fishing to its own waters. Occasionally boats cross the border, but when this occurs it is usually ascribed to errors in navigation due to the poor condition of the equipment used. All the boats have either Peruvian or Chilean ports of registration. Some are owned by the large companies, others by individuals who sell the catches directly to the factories.

Dynamics of the Fisheries

An analysis of data on the size distribution of anchoveta that were captured during the initial phase of the exploitation of the stock in Peru (1954 to 1956) did not show any tendency toward consistent changes of the stock with time. However studies on the size distribution of the catches for the years from 1961-1964 (Boerema *et al.*, 1967) showed changes in the composition of stock as a consequence of variations in recruitment and mortality. In general, studies have shown that the abundance of recruits in the catches off Peru is greatest during summer and autumn with the maximum median size generally occurring during the months of April or May. Statistics vary slightly from port to port.

Boerema et al. (1967) have studied fluctuations in the adult stocks indicating that from 1961 to 1964 the total mortality rate has been increasing. The decrease in the average size of fish in the commercial catch during this period also suggests that the increase in total mortality has reached a rather high level. They predicted that fish catch per unit effort and mean length would decrease as a result of decreased mortality and lower average size and age. However, highest catches occurred from 1966-1971.

In the report of the panel of experts on population dynamics of Peruvian anchoveta (1970) several types of analyses were discussed in order to determine the level of maximum sustained yield of the anchoveta fishery in Peru. The average maximum sustainable catch of anchoveta by man was estimated at 9.5 million tons, while birds consumed about 1.1 million more.

The higher catch obtained in 1971, about 12 million tons, suggests that if no regulations are taken in the future the stock could be seriously damaged.

PART II. THE PHYSICAL ENVIRONMENT IN PERUVIAN AND NORTHERN CHILEAN WATERS

Only a few hydrographic stations had been made in the area inhabited by the *E. ringens* before 1950. The results of these early expeditions have been summarized by Gunther (1936), Muromtsev (1958), Wooster and Cromwell (1958), and Wyrtki (1968).

In the past ten years the economic importance and abundance of the anchoveta fisheries in this area has drawn the attention of scientists to the oceanographic characteristics of this exceptionally rich environment. This chapter summarizes what is known, giving special attention to the upper layer of the ocean in which the anchoveta lives. The importance that upwelling has in the fisheries is also reviewed along with the El Niño phenomenon with its profound effects on the ecological balance of the region.

Most of the area occupied by the anchoveta is a part of the vast oceanographic region known as the Eastern Tropical Pacific Ocean which Wooster and Cromwell (1958) have defined as the region lying between the Tropic of Cancer and the Tropic of Capricorn, the American coast and longitude 130°W. Wyrtki (1965a) later extended the limits of this area to include 30°N to 40°S.

This description of conditions refers mainly to the area off the west coast of South America from the Equator to 40°S with special emphasis on the immediate coastal area, though references to the oceanography of the entire region are made throughout the chapter.

There is a significant contrast in the amount of available information on this coastal sub-region in comparison to the eastern northern Pacific where strong oceanographic programs have been carried out by the California Cooperative Oceanic Fisheries Investigation group, Oregon State University, the University of Washington, and the University of British Columbia, Canada. The oceanographic programs by Peruvians and Chileans and by some American , Japanese and Russian institutions furnish the basis for a reasonably good understanding of the South American coastal waters.

The Meteorological Regime in the Area

The area from the Equator to 40°S includes parts of several climatic and oceanic regions, principally the subtropical region of the Peru Current that was recognized by Schott (1935).

Between the Equator and about 25°S the climate is mainly determined by the southeast tradewinds and changes in character progressively from subtropical to tropical the farther west and the closer to the Equator one goes.

In the southern portion of the counterclockwise circulation centered around the Eastern South Pacific Anticyclone strong westerly winds blow the surface waters of the Antarctic Drift towards the Chilean coast. This is more marked during the winter months. The Peru Current then flows northward between the atmospheric anticyclone to the west, which is centered normally to the northwest of the Juan Fernandez Islands(34°S

-80°W approximate), and the continental low pressure to the east. Changes in position and strength of the Anticyclone and the continental depression influences the variations of the atmospheric circulation of this area. However, the scarcity of meteorological information in this region as a whole makes it difficult to study these variations.

Winds from the south and southeast are predominant along the coast. They are stronger during winter than during the summer with a mean speed of 9 m/sec. Off San Juan, Peru (15°S), the winds are the strongest on the Peruvian coast (Zuta and Guillén, 1970) and blow mostly from the southeast. North of 6°S winds are weaker and vary in direction from south to southwest during the year. In the northern part of Peru the weakest winds usually appear during November while in central Peru they occur in January and October. In the southern part of Peru and northern part of Chile the weakest winds occur in March and May. The strongest winds in northern Chile occur during June and July and vary in direction from south to southwest.

Seasonal Temperature Distribution

Fluctuations in environmental conditions have a profound influence on the aperiodical and seasonal distribution of the anchoveta. The extremely complex interactions in the marine environment are difficult to study as a whole, therefore each factor has been studied separately, and then an attempt has been made to work out more complex relationships. Water temperature is among those physical factors of primary importance to the fish distribution and also is one of the most easily measured.

Early information on sea surface temperature is scarce. Most of the later surface data were gathered by the Compañia Administradora del Guano in Peru, which published monthly maps from January 1939 through August 1956 in a series called "Mapas Mensuales del Litoral Peruano." Fuenzalida (1950) published oceanographic sea surface temperatures for the north and central Chilean coast for the years 1944 to 1946. In recent years there have been many additions to the above data that have been published in several Atlases by the British Meteorological Office (1956), the U.S. Navy Hydrographic Office (1944, 1960), and more recently by Stevenson, Guillén and Santoro (1970). Monthly charts of sea surface temperature have been issued since 1960 by the U.S. Bureau of Commercial Fisheries (Johnson, Flittner, and Cline, 1965). Average monthly charts for the coastal regions as well as monthly anomaly charts, dating back as far as 1947, are currently published by the National Marine Fisheries Service (Renner, 1963). Since 1960 nearly one hundred cruises in Peruvian and Chilean coastal waters have been carried out by the Instituto del Mar del Peru and the Instituto de Fomento Pesquero of Chile. The information collected by these two institutions represents by far the most numerous data for the region inhabited by the anchoveta.

Brandhorst and Cañón (1968) have published the results of aerial infrared measurements of the sea surface off the northern part of Chile during 1965. Similar information that was collected during the period 1966 to 1967 remains unpublished (Cañón, 1968).

Temperature variations have been studied in detail by Wooster (1961), Wooster and Sievers (1971) and Wyrtki (1965a). There are three significant surface features of the region: a strong horizontal thermal gradient during most of the year, a seasonal intrusion of warm subtropical water, which is present from October to May, and colder waters in coastal areas due to strong upwelling.

Temperatures as great as 24°C or even higher are found near the northern limit of distribution of anchoveta during the summer. During this season the penetration of warm water extends as far south as Iquique, Chile, where the temperature begins to decrease monotonically with increasing latitude. The warm water appears in the seasonal chart prepared by IFOP (Figure 2) as an offshore tongue located between 60 and 80 miles off the northern coast of Chile. This intrusion of warm water does not represent the most extreme conditions. The greatest extremes occur when the equatorial front disappears. Then an intrusion of water, mostly of equatorial origin with temperatures exceeding 26°C, appears off the northern coast of Peru.

During early autumn warm waters still remain off northern Chile with temperatures as great as 20°C. Cooling begins in late autumn and according to Zuta and Guillén (1970) extends from March to October in the waters off central Peru. During winter the 20 C isotherm disappears in the coastal waters and is located about 250 miles offshore from northern Peru in the latitude of Pimentel (6°30'S).

The Oceanography Branch of IFOP constructed average seasonal maps of surface temperature for the region extending from Arica to Caldera, Chile, using all the hydrographic information available from 1963 to 1968. These are shown in Figure 2.

Seasonal maps of surface temperature off Peru based on data from IMARPE cruises have been published recently by Zuta and Guillén (1970) and Stevenson, Guillén, and Santoro (1970).

Thermal Structure

The thermal structure of the Eastern Pacific Ocean has been extensively studied by Wyrtki (1963, 1965a, 1966). Recent detailed studies of the thermal structure off Peru (Zuta and Guillén, 1970) and Chile (Brandhorst, 1971) have been made.

Defant (1936) pointed out in his study of the Atlantic Ocean that in most parts of the tropical and subtropical oceans the thermal structure is characterized from the surface down by a near surface mixed layer where temperature is almost constant, a thermocline layer where temperature decreases sharply, and a subthermocline layer in which temperature continues to decrease slowly with increasing depth. The thermocline is defined by Defant as the layer in which temperature gradient exceeds a value of 0.2C in 10 meters. The depth of the mixed layer is controlled by the wind speed and the rate of heating and cooling at the surface, with stronger winds causing a deeper mixed layer. The depth of the mixed layer is also influenced by the tilting of the thermocline in relation to circulation.

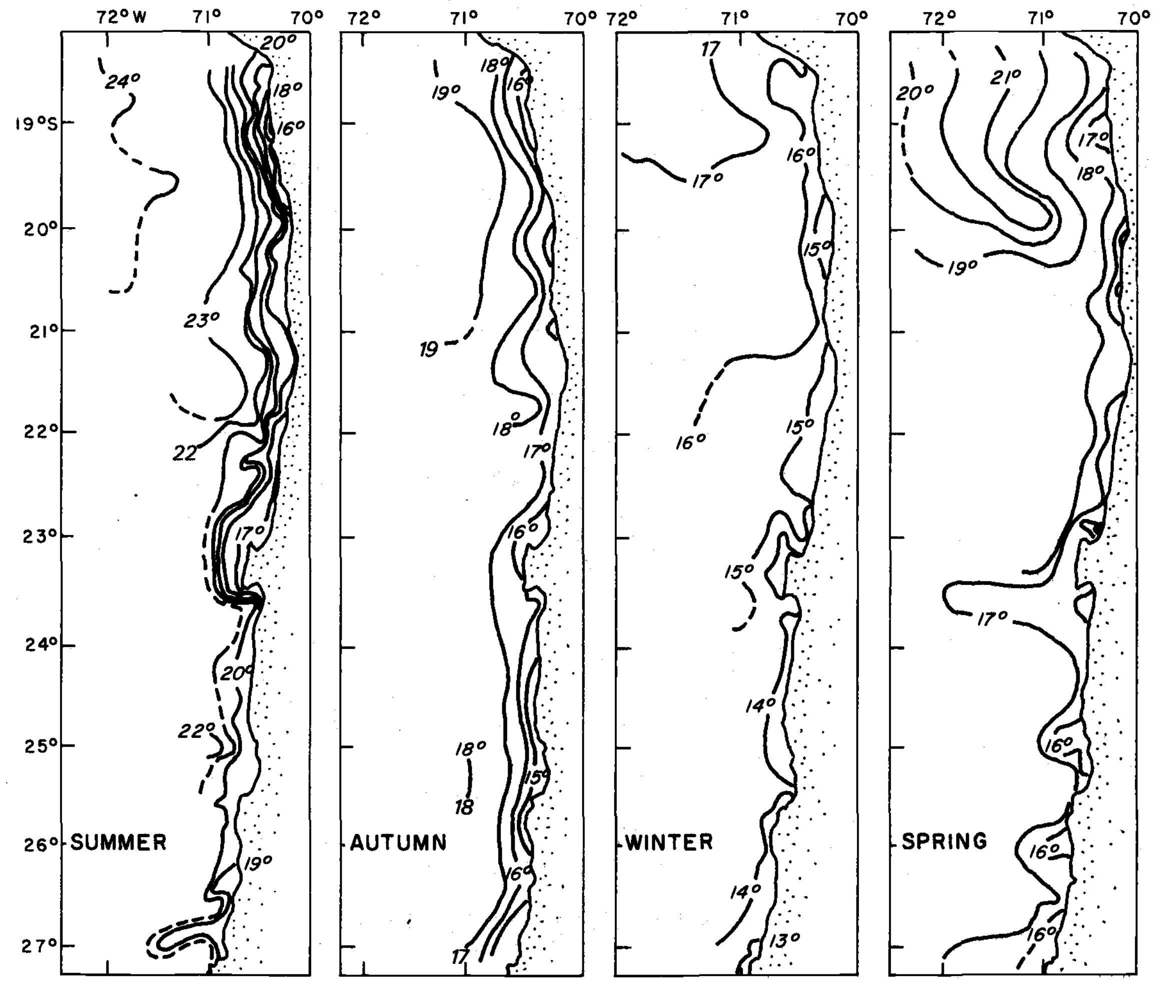


Figure 2. Average seasonal distribution of sea surface temperature (°C) (based on IFOP oceanographic cruises during 1964-1968). Seasons correspond to southern hemisphere.

Zuta and Guillén (1970) have found four types of thermoclines off the Peruvian coast: a permanent surface thermocline, found mostly north of 4°S above 75 m; a moderate permanent subsurface thermocline from 75 to 150 m, found in all the waters off Peru; a seasonal surface thermocline found off Peru during the summer. Finally a weak permanent deep thermocline is found from 300 to 600 m deep.

In northern Chile the mixed layer depth reaches almost 200 m during the winter months, while close to the coast the variations of the mixed layer depth during the year are relatively small, due to the effect of upwelling.

Off Arica (18°30'S) the summer thermocline overlies a permanent thermocline at greater depths. The vertical temperature gradient is stronger in this summer thermocline than in the deeper permanent thermocline. This is similar to conditions found off Peru found by Zuta and Guillén (1970).

Wyrtki (1963, 1964) has suggested that the summer thermocline can be considered as an extension of the upper parts of the permanent thermocline.

Heat Exchange at the Surface

Large scale heat budget studies of the world ocean, such as Budyko's (1956) show very little detail along the Peru-Chile coast. Wyrtki (1965a, 1966) has recalculated the values for heat exchange along the Peruvian and northern Chilean coasts from 0° to 20°S, which Wooster and

Sievers (1970) have discussed in detail. According to their study the total heat flux is significantly greater during January, February, and March than it is in July, August, September, the average differences being 255 cal $cm^{-2}day^{-1}$. The total heat flux decreases with increasing latitude from the Equator south.

The period of greater heat gain extends from December to April while the period of low heat gain extends from June through September. During the entire year the values of heat flux are positive, indicating that a surplus of heat must be removed by advection or diffusion.

The northern part of the area inhabited by the anchoveta shows only a small variation of incoming radiation between winter and summer. Evaporation increases from east to west with a maximum during the summer. Since evaporation is relatively small in the coastal area, heat is gained during the entire year. Between 10° and 20°S the coastal area has a higher evaporation due to the action of stronger winds. Although the amount of incoming radiation is more or less the same, the higher evaporation causes a net cooling during winter. The role played by upwelling in coastal area is important in maintaining low sea surface temperatures even in areas in which evaporation is small.

Seasonal Salinity Distribution

Until recently the only information available on surface salinity was reported in charts of surface salinity drawn by Schott (1935). More recently Bennett (1965) and Stevenson *et al.* (1970) have presented maps of surface salinity for the entire Eastern Equatorial region.

Seasonal distributions of surface salinity are shown in detail for Peru in the maps constructed by Zuta and Guillén (1970) and by Stevenson, Guillén, and Santoro (1970). The Oceanographic Branch of IFOP has prepared seasonal maps for northern Chile which are presented in Figure 3 (IFOP, 1968).

Seasonal variations seem to be relatively weak due to the extremely low rates for precipitation and runoff. Seasonal effects are mostly due to advection, upwelling, mixing and evaporation.

The annual range of salinity in Peruvian waters varies from 0.8 (34.3 to 35.1 ‰) in the area off Punta Falsa (6°0'S) to 0.2‰ off Callao (34.9 to 35.1‰). Two salinity maxima are found: one at the surface and the other below the surface between 70 and 350 m. The first is associated with the advection of Subtropical Surface Waters and the other with the Subsurface Equatorial Waters from the Cromwell Current. South of 12°S a salinity minimum is found between 100 and 200 m. It is associated with the northward advection of Sub-Antarctic Waters by the Peru Current. Figure 3 shows that water of high salinity of more than 35 ‰ is found all year round from 20 to 50 miles off Arica, Chile. South of Antofagasta salinity begins to decrease with increasing latitude as Sub-Antarctic Waters are encountered. The position of the Subtropical Convergence coincides with the 35‰ isohaline which moves north in winter and spring and south in summer and autumn (see Figure 3).

North of the convergence, Sub-Antarctic Waters show up as a salinity minimum at depths between 50 and 100 m. Whenever low salinities are

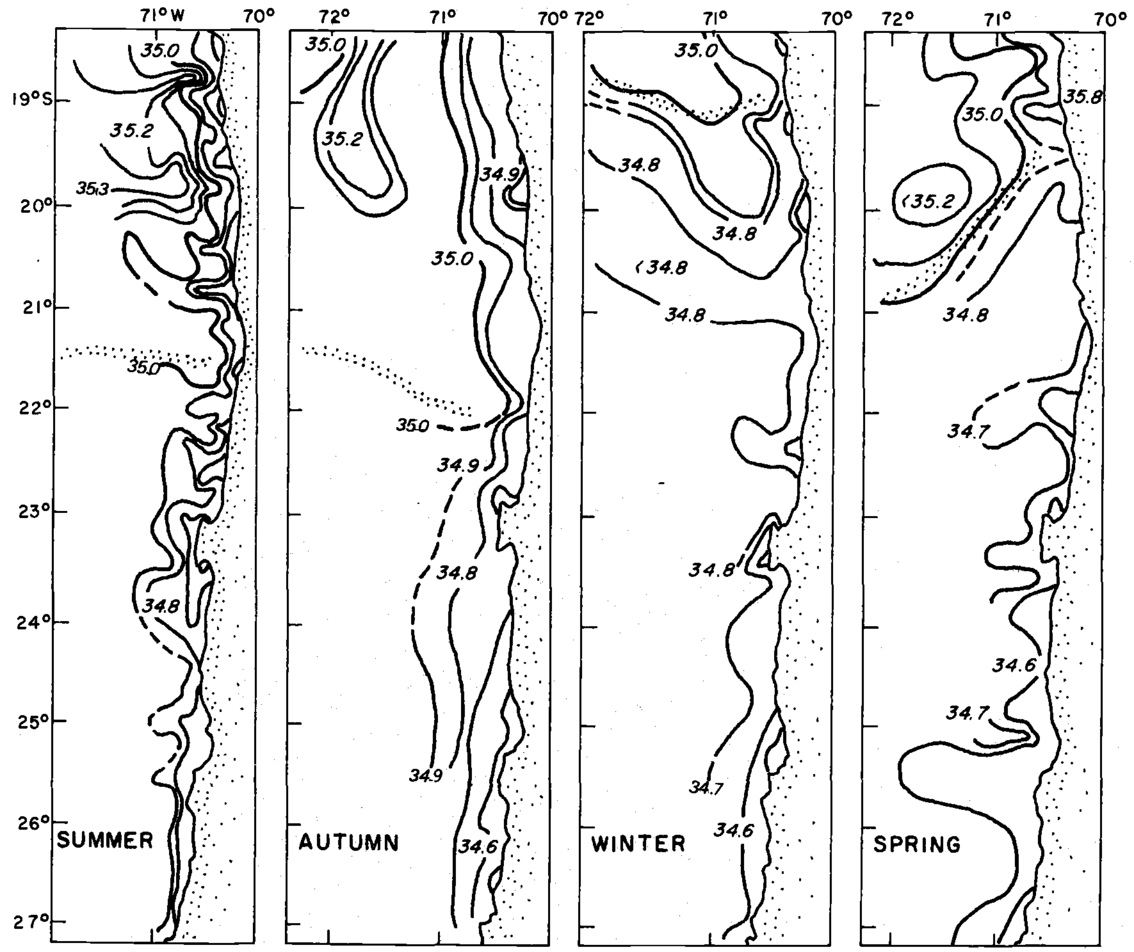


Figure 3. Average seasonal distribution of sea surface salinity (‰). Based on IFOP oceanographic cruises during 1964-1968. (Seasons correspond to southern hemisphere). Dotted area show approximate position of the Sub-Tropical convergence.

found near the coast north of the convergence, it is a good indication of weak upwelling south of 15°S where water is upwelled from depths between 50 and 150 m. The fact that salinity is conservative in the absolute sense, i.e. since there is very little precipitation or runoff, means that low salinities near the coast must correspond to upwelled Sub-Antarctic Waters at least in this part of the region.

Oxygen Distribution

In this region oxygen plays an extremely important role. It is not only useful in the study of biological processes but also can be used as an index to the biological history of the water and as a tracer in studies of currents and mixing processes.

In general, high values of dissolved oxygen are found in the surface waters with relatively low seasonal fluctuations. Values range between 6.0 and 2.5 ml/l. Concentrations are slightly greater farther offshore than inshore. Occasionally minimum values of less than 2.0 ml/l are found in the upwelling areas. The range, at least off Peru, is more pronounced during the summer and autumn than in winter and spring (Zuta and Guillén, 1970).

An oxygen minimum layer with extremely low oxygen concentrations of less than 0.5 ml/l is usually found below the oxygen-rich surface layer. The change is so abrupt that it forms a discontinuity. The oxygen minimum layer coincides with the surface permanent thermocline north of 6°S and with the deep permanent thermocline south of this point. South of 14°S the oxygen discontinuity layer coincides with the halocline in the coastal areas. Offshore it is at the depth of the salinity minimum (Brandhorst, 1971).

Underneath the discontinuity, a layer of low oxygen content is found, which extends from 50 to 800 m. It is found as far south as Chiloe, Chile (43°S). The oxygen minimum is closer to the surface in the south than in the north. Off Peru the lowest values are found in the upper 400 m (Zuta and Guillén, 1970).

Oxygen concentrations increase rapidly with depth below the minimum and close to the salinity maximum associated with Antarctic Intermediate Water.

The importance that the oxygen has to the distribution of Merluccius gayi (Chilean hake) in Chilean waters has been discussed by Brandhorst (1958) but no studies have been made showing the relationship between oxygen and the distribution of anchoveta.

Nutrients and Other Elements

Nutrient studies in the waters off Peru and Chile were initiated by Gunther (1936). Later studies are reported by Fleming *et al*. (1945), Posner (1957), Wooster and Cromwell (1958), Wooster, Chow, and Barnett (1965), and Strickland, Eppley and Rojas de Mendiola (1969).

During the last few years the study of nutrients has become an important part of the present programs in IMARPE and IFOP. Guillén (1964, 1966) studied the phosphate distribution off Peru and estimated the productivity in the area using phosphate as an index. Guillén and

Izaquirre de Rondan (1968) used the ^{14}C technique to study primary production in Peruvian coastal waters, and Dugdale and MacIsaac (1971) used a ^{15}N technique to study primary production in the same area. The production and utilization of organic matter in the Peru coastal current was studied by Ryther et al. (1971). Despite the great effort being made in the last few years there are still many unknowns. The study of seasonal fluctuations has just started.

Classification of Water Masses in the Region

The study of water masses is important in the physical description of the oceanography of any area. The character of a water mass depends mainly upon the latitude, mixing, diffusion, advection and air-sea interaction. The terminology used here was suggested by Sverdrup, Johnson and Fleming (1942), and used by Wyrtki (1965a) and Wooster (1970).

The water masses in the North Pacific Ocean have long been the center of interest of scientists from U.S.A., U.S.S.R., Germany and Japan, but only in the last few years have studies of the South Pacific become common.

Wüst (1929) was the first to study and describe water masses in the South Pacific using T-S diagrams. Many of his conclusions are still valuable. Wüst's analysis and one made by Sverdrup, Johnson and Fleming (1942) for the entire Pacific Ocean deal chiefly with sub-surface water masses. It was not until Schott studied the principal features of the circulation in the South Pacific (Schott, 1935) that the study of surface layer water masses was undertaken.

Figure 4 shows T-S curves for four selected oceanographic stations in Peru and Chile, located from 60 to 80 n. miles from shore. Peruvian stations were taken during the IMARPE cruise of April, 1965; Chilean stations during the MARCHILE II cruise of July, 1962. The exact station locations are as follows:

Cruise	Station #	Latitude	Longitude
IMARPE	8(a)	5°47'S	83°26'W
IMARPE	51(a)	16°10.5'S	77°38'W
MARCHILE II	8(b)	18°28.8'S	71°14.3'W
MARCHILE II	51(b)	20°48.2'S	72°01.2'W

The fact that station numbers selected from the two cruises are the same is mere coincidence. Subscript (a) refers in the figure to Peruvian stations and subscript (b) to Chilean stations.

The indicated water mass ranges correspond to those described in the text.

Surface Water Masses Off Peru and Chile

Sverdrup *et al.* (1942) and Sverdrup and Fleming (1944), probably due to a scarcity of information, suggested that a single south-central water mass existed above the Intermediate Antarctic Water. Following Deacon (1937), they stated that this water moved in a large clockwise gyre.

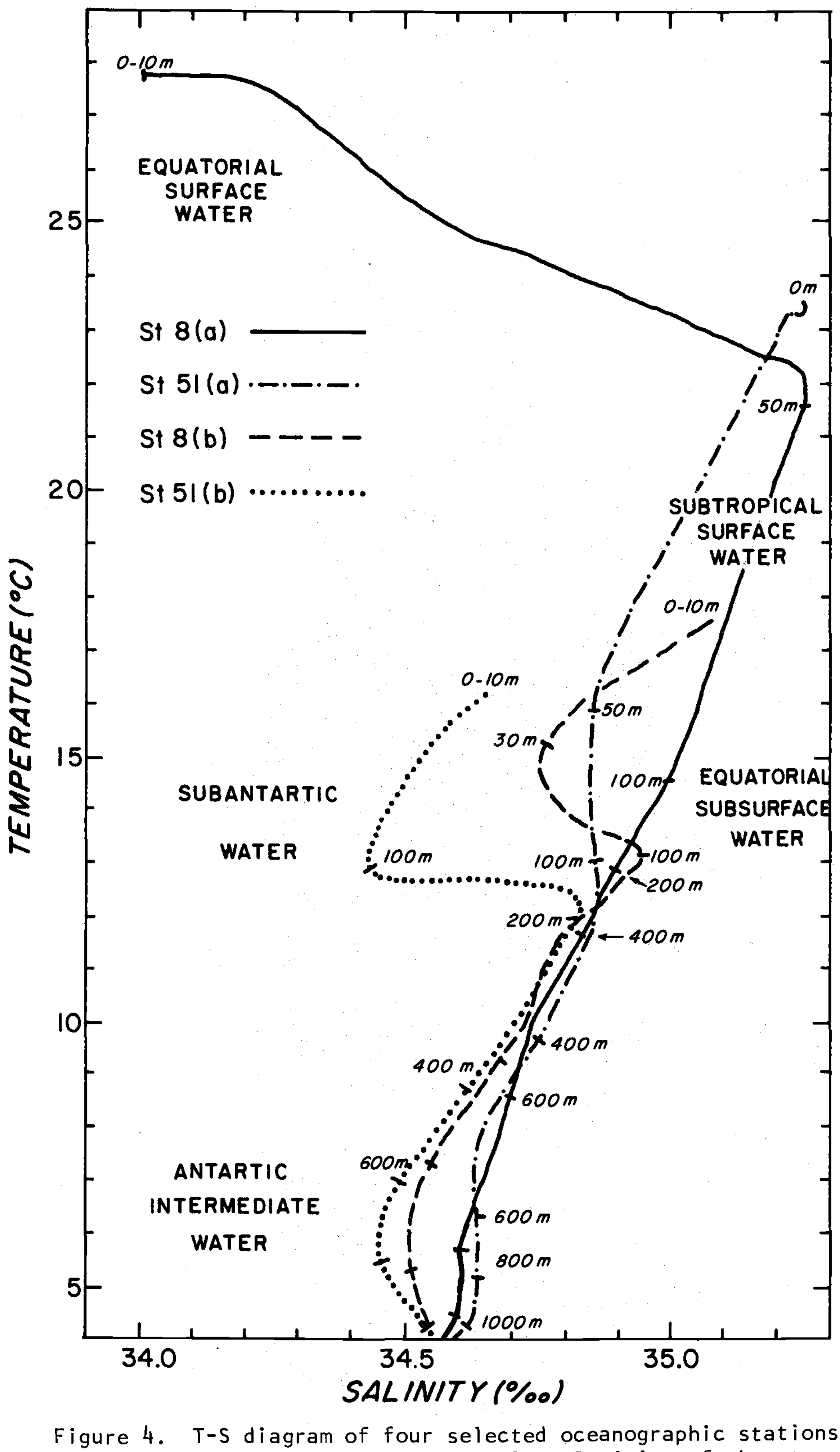


Figure 4. T-S diagram of four selected oceanographic stations off Peru and northern Chile. Position of the stations are indicated in the text.

Muromtsev (1958) discussed the distribution and characteristics of the surface water masses of the Pacific Ocean in detail. His terminology differed from the one used by Sverdrup et al. (1942) and by Deacon (1937). He placed the Peru Surface Water in the Eastern Pacific south of 6°S and Equatorial Sub-surface Water north of this latitude.

Wyrtki (1963, 1965a, and 1966) found four basically different types of water masses at the surface in the entire Eastern Tropical region (Figure 5a): Tropical Surface Water of high temperature and low salinity; Sub-tropical Surface Water of high salinity, which is generally warm but variable in temperature; Equatorial Surface Water of high temperature but slightly more saline than the Tropical Surface Water, and Temperate Surface Water of the Peru Current which is cool, of low salinity, and originates in higher latitudes (Figure 5a). More recently Wooster (1970) reviewed the surface masses in the region and proposed a new terminology which differs from the one suggested by Wyrtki. He recognized a Sub-Antarctic Surface Water (Temperate in Wyrtki's terminology) lying between the Antractic and Sub-tropical Convergences, a Sub-tropical Surface Water that is also called Sub-tropical by Wyrtki and is placed between the Sub-tropical and Southern Tropical Convergences, a Tropical Surface Water and an Equatorial Surface Water which corresponds to the water of the same name in Wyrtki's description.

Tropical Surface Water

Tropical Surface Water is formed in regions where temperature has a small seasonal variation and remains high almost all year. Salinity is low (less than 33.8 ‰) because rainfall exceeds evaporation. This water is low in nutrients and normally occurs north of 4°S near the Ecuador-Peru boundary. Under abnormal "El Niño" conditions it moves as far south as 10°S. Its depth is limited to the upper 20-30 m immediately above a strong thermocline.

Sub-tropical Surface Water

This water mass is characterized by high salinity of 35.0 to 35.5 ‰ and even greater than 36.0 ‰ in the center of its distribution which coincides with the center of the South Pacific anticyclone. Temperatures vary from 15 to 28C and evaporation exceeds precipitation. Off Peru and northern Chile it is separated from the coast by a narrow band of upwelled water. The Sub-tropical Water intrudes coastward in the form of a front during summer, especially in northern Chile.

Equatorial Surface Water

Equatorial Surface Water is situated along the Equator west of the Galapagos Islands; its properties are intermediate between those of the Tropical Surface Water to the north and the Sub-tropical Surface Water to the south. This water is characterized by salinities less than 34.0 ‰ and temperatures more than 25C.

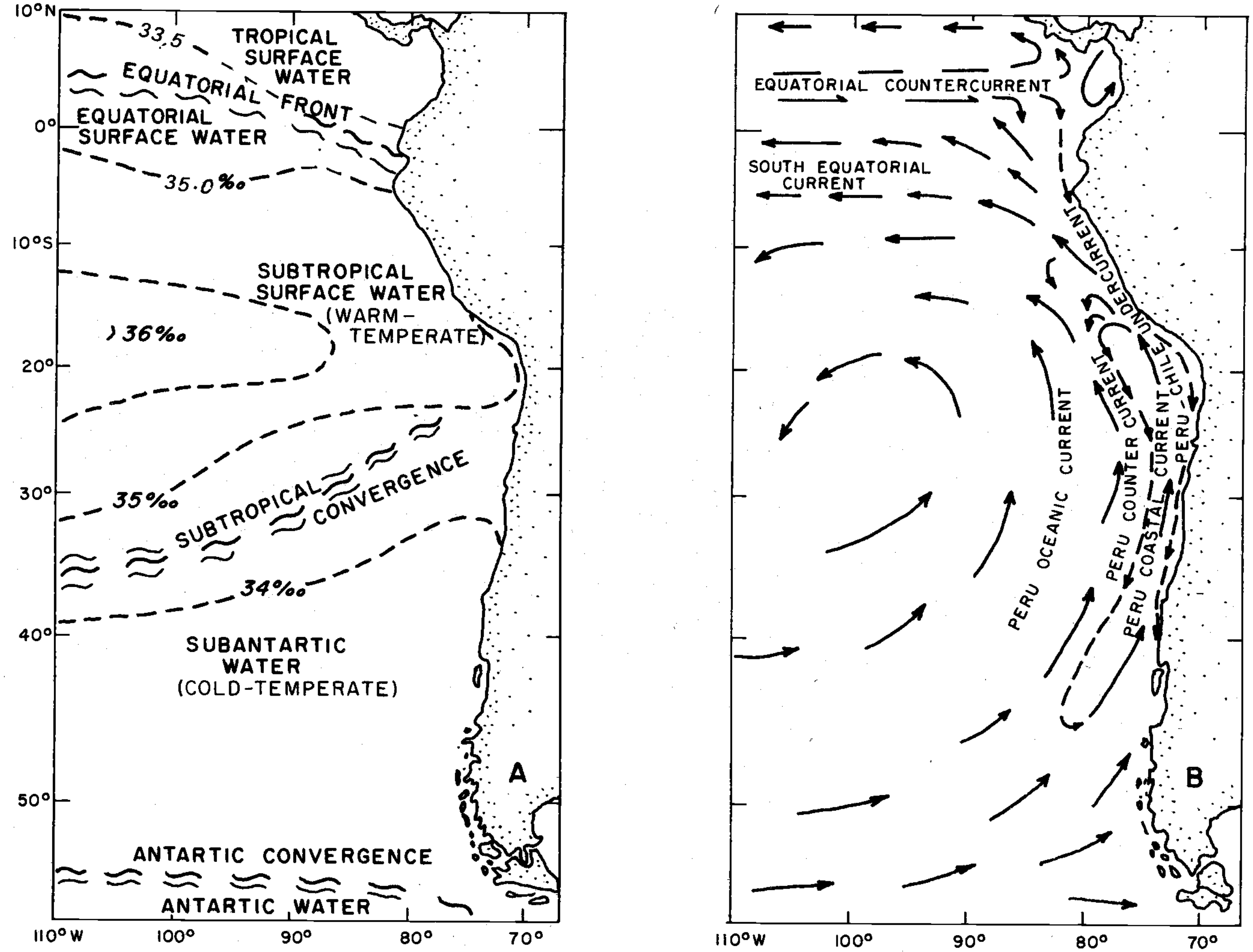


Figure 5. (A) Distribution of main water masses in the Eastern South Pacific Ocean and (B) Distribution of principal currents in the region (———— Surface current; ------ Subsurface current.) Modified, after Wyrtki, 1965.

Sub-Antarctic Water

Sub-Antarctic Water is a cold temperate surface water between the Sub-Antarctic and Sub-tropical Convergences. Wyrtki (1965) gives a lengthy discussion of this water which he prefers to call South Pacific Temperate Water or simply Temperate Water.

Temperatures vary from 8 to 15C while salinities of less than 34.5 ‰ are typical. It has its most northern extension near the west coast of South America, where it is advected northward by the Peru Current System.

A subsurface salinity minimum develops within this water between 30° and 40°S, due to evaporation-induced increases in surface salinity. West of 90°W the formation of the salinity minimum seems to take place near the Sub-tropical Convergence at 35°S. North of 23°S off the Chilean coast this water is present mainly as a subsurface water mass; surface salinities north of 23°S are usually more than 35 ‰ , typical of Sub-tropical Surface Water. Close inshore the Sub-Antarctic Water is found at the surface in a narrow upwelled band. The subsurface salinity minimum and corresponding upwelled water is found as far north as 15°S.

Subsurface Water Masses

All of the surface water masses in the region are formed outside the region itself and are brought in by horizontal flow or by processes of horizontal mixing. Only the Sub-tropical Subsurface Water is formed in the region. The most important subsurface water masses are:

Equatorial Subsurface Water

Water of high salinity of more than 35‰ and extremely low oxygen content (less than 1.0 ml/l) is found everywhere below the Equatorial Surface Water. This Equatorial Subsurface Water is a mixture of Sub-tropical Surface Water and Antarctic Intermediate Water. Near the Equator it occupies the depth range between 50 and 500 m. Knauss (1960) suggested that it results from Equatorial Undercurrent transport. East of the Galapagos Islands the Equatorial Subsurface Water is transported southward by the Peru-Chile Undercurrent as far as 35°S (Brandhorst, 1971) where it provides the water for upwelling north of 15°S and sometimes along the northern part of Chile, when strong upwelling develops.

Antarctic Intermediate Water

Antarctic Intermediate Water has a salinity minimum and originates in the Antarctic (Reid, 1965). It is characterized by temperatures between 3 to 6C, salinities from 34.1 and 34.5‰ and oxygen from 0.3 to 5.8 ml/l. As it moves equatorwards at depths of 800 to 1,300 m, its salinity increases and its oxygen diminishes (Wüst, 1929). The layer is about 1,000 m thick with its lower boundary being the isohaline of 34.6‰. The upper boundary is defined by the 34.6‰ salinity surface and coincides with the depth of the main oxygen minimum.

The Circulation in the Area

The water masses are related to circulation which is dominated by the eastern and Equatorial part of the anticyclonic gyre. The Peru Current System consists of the Peru Oceanic Current and the Peru Coastal Current. These two northward currents are separated by the southward-flowing Peru Countercurrent near 80°W. In the northern part they merge and turn westward into the South Equatorial Current. Subsurface currents are present in the area, the most important being the Peru-Chile Undercurrent.

The circulation pattern was first suggested by Humboldt (1810) and described later by Gunther (1936), Wooster and Gilmartin (1961), and Wyrtki (1965b). The following section is a summary of water movements in the area. The currents are graphically presented in Figure 5b.

Surface Currents: The Peru Current System

North of 40°S a strong northwestward flow brings Sub-Antarctic Water toward the Equator. This flow is called the Peru or Humboldt Current. It is part of the huge anticyclonic system in the South Pacific. Based on data from the CARNEGIE (1928-29) and W. SCORESBY (1931) expeditions Gunther recognized two branches of the current: a Peru Coastal Current and a Peru Oceanic Current. The Coastal Current is the better known of the two currents as a result of the recent coastal research by the Peruvian and Chilean fisheries research institutes (IMARPE and IFOP).

During the winter months the South Pacific (atmospheric) Anti-cyclone and its associated southeast Trade Winds reach a maximum in intensity. From April to September the Current appears stronger than in other months and the Countercurrent virtually disappears as the two branches flow together advecting more water to the South Equatorial Current.

Both the Coastal and the Oceanic portions of the Peru Current originate in the Sub-Antarctic region. Sverdrup (1944) calculated the transport of the whole Peru Current System to be between 10 and 15 sv (1 Sverdrup = 1 million cubic meters per second).

The Peru Coastal Current, Coinciding approximately with the up-welling region off Peru and Chile, the coastal branch flows to the northwest while farther offshore the Peru Oceanic Current flows in the same direction.

The Coastal Current flows with velocities of about 0.2 to 0.3 knots leaving the coast at Punta Aguja (5°S) where it increases its speed to 0.5 to 0.7 knots and joins the South Equatorial Current. On the basis of information collected during the Step I expedition (September-December, 1960), Wyrtki (1963) calculated the transport of the Coastal Current at 25°S to be about 6 sv. Off Punta Aguja it transports 10 sv and at 15°S about 7 sv.

The coastal bathymetry appears to have considerable influence on the Peru Coastal Current. Eddies are found wherever the Coastal Current is deflected strongly from the coast, especially near 15°S, supporting this idea.

The Peru Oceanic Current. The Peru Oceanic branch presents a less complex pattern of circulation than the Coastal branch and does not have much interaction with coastal processes. The surface speeds are always more pronounced than in the coastal branch and its influence extends deeper, reaching from the surface down to a depth of 700 m (Wyrtki, 1963). At latitude 24°S, west of 82°W, it transports about 8 sv.

Subsurface Currents

The Peru Countercurrent. The Peru Countercurrent flows southward at about 80°W between the Peru Coastal Current and the Peru Oceanic Current. It is primarily a subsurface current (Wooster and Reid, 1963). Its transport has been calculated at 6 sv across 24°S (Wyrtki, 1966). At about 15°S it turns away from the coast. The Countercurrent is usually found immediately below a shallow equatorward wind drift layer.

The Peru-Chile Undercurrent. Gunther (1936) first described a subsurface southward countercurrent close to the South American coast. Wooster and Gilmartin (1961) confirmed its presence by direct measurements with parachute drogues, with analysis of the distribution of properties, and with geostropic computations. It flows under the Peru

Coastal Current from northern Peru to southern Chile (35°S), with speeds of 4 to 10 cm/sec during early spring. Wooster and Gilmartin (1961) calculated geostrophic transport to be 21 sv at 5°S and about 3 sv at 15°S. Off Peru, especially the northern part, the principal flow appears to be farther offshore but south of 15°S it runs closer to the coast. Water of the Undercurrent is characterized by relatively high salinities and by low oxygen (Brandhorst, 1971).

Upwelling in the Peru Current System

One of the most remarkable oceanographic features off the coast of Peru and northern Chile is year-round coastal upwelling. Upwelling has been defined by Smith (1968) as the vertical ascending movement of water of some minimum duration and extent by which water from subsurface layers is brought into the surface layer and is removed from the area by horizontal flow. The study of the upwelling, therefore is of primary importance in understanding the mechanisms of nutrient-induced productivity.

A complete review of the physical and theoretical aspects of upwelling was made by Smith (1968). Recently Cushing (1971) and Dragesund (1971) have studied upwelling in relation to fisheries.

Cold water in Peru Current system was noted by the early Spanish conquistadors who attributed its origin to advection of water from the Antarctic region. The first scientific report to mention upwelling as the cause for the cooler coastal waters in the area was in 1844 by De Tessan.

Gunther (1936) using W. SCORESBY cruise data shows that upwelling is an intermittent process greatly influenced by local winds. Reversals of wind direction frequently lead to relaxation of the upwelling and re-establishment of stratified conditions. The most active upwelling areas are separated by regions of less intense upwelling. Schott (1931) recognized four centers of upwelling along the Peruvian and northern-central Chilean coast; Gunther (1936) found similar centers differing in extent but not in location.

Wooster (1965) on the basis of sea surface temperature found that upwelling is more intense in winter (June-August) than summer (December to February). Smith, Mooers and Enfield (1971) pointed out, from PISCO cruise data (March-April, 1969), that upwelling is more intense near 15°S, between Pisco and San Juan, Peru, and is found there throughout the year.

Wyrtki (1963, 1965) described two hydrographically different upwelling regimes to the north and south of 15°S, respectively. In the north, off Trujillo, water is upwelled from depths of less than 100 m while off central Peru upwelled water comes from depths as great as 250 m. In the south water is upwelled from depths of 50 to 180 m.

Different water masses are involved in the upwelling process. North of 15°S Equatorial Subsurface water is upwelled. It is characterized by a monotonic salinity decrease with depth. This water is advected southward by the Peru-Chile Undercurrent which at those latitudes is found immediately below a shallow northward wind drift layer. South of 15°S, Sub-Antarctic Water, characterized by a subsurface salinity minimum at 100-200 m, is advected northward by the Peru Coastal Current and upwells. The southward flowing Peru-Chile Undercurrent is found at greater depths.

Brandhorst (1964) has suggested that the frequency and strength of winds off the central part of Chile could be used as a possible index of upwelling in northern Chile. In an attempt to eliminate the continental effects, he used the monthly means of the pressure differences at sea level between meteorological stations at Juan Fernandez Island (34°S-79°W) and Valparaiso (33°S and 74°W) in central Chile. During late autumn and early winter (June-July) negative pressure values were observed indicating winds with a northerly component. These winds are usually related to storms of short duration off the central coast of Chile. Although northern Chile is not directly affected by such storms, weaker than average winds occur from time to time. This weakness or absence of the wind weakens the upwelling and increases the intensity of the southward surface tongue of warm and saline water of the Countercurrent from March to April. The strong positive correlation with fish landing statistics in the northern zone supports this idea.

The Equatorial Front and the El Niño Phenomenon

The importance of the study of the Equatorial front in the Peru Current system is twofold: first, it is an interesting oceanographic feature, and second, it is an important factor in the El Niño phenomenon. It also acts as the northernmost limit of anchoveta distribution.

The Equatorial front can be defined as a narrow band where strong gradients in temperature and salinity separate the Tropical Surface Water from the Sub-Tropical Water of the Peru Current (Wooster and Cromwell, 1958; Wooster, 1969).

The front extends from the coast of Peru north of 4°S to the Galapagos Islands (Figure 5a). Cromwell and Reid (1956) have extended the western limit as far as 172°W, where mixing destroys its structure. North of the front surface waters are warmer and less saline; contain less dissolved oxygen, phosphate, and silicate; and are separated from deeper water by a shallower and more intense thermocline than to the south, where waters are cooler, more saline and contain more oxygen.

The position of the front is related, in part, to the Southeast Trade winds which are stronger in winter than in summer. Seasonal changes in surface winds thus affect the position and intensity of the front.

Meridianal changes are confined to the upper 50 m. The dynamic aspects of the front have been studied by Bjerknes (1961), Fedorov (1963) and Wooster (1969).

The El Niño phenomenon appears to be a southward extension of the Equatorial front. It is manifested as a shallow layer, 20 to 30 m thick, of surface water with high temperatures (more than 28°C) and low salinities (less than 33.8 ‰) and may cover the Peru Current as far as 10°S (Guillén, 1967; 1971). The phenomenon is generally accompanied by a weakening or reversal of the normal Southeast Trade Wind regime. Some Niño occurrences are accompanied by torrential rains along the normally arid northern Peru coast.

There is some confusion in the literature between the intrusion of Sub-Tropical Water and the true El Niño which consists of Tropical Water. Posner (1957) believed that during the period of his observations in the Peru Current (March-May, 1953) the El Niño was present, but his salinities suggest that he may have been dealing with Sub-Tropical Water. Guillén (1967) suggested that during March-April, 1965, an El Niño occurred off the Peruvian coast. High temperatures indicated an anomalous warming period, also observed at Christmas Island (2°N, 157°22'W), indicating that the succession of major temperature changes that took place in 1965 were of a greater extent than the usual extent of the El Niño. (Bjerknes, 1972).

The Peruvian fisheries dropped drastically in 1965 and an extensive mass mortality of guano birds was noticed (Jordán, 1968). This occurrence of the phenomenon, like that documented by Posner, lacked the low salinities typical of a southward intrusion of Tropical Surface Water.

Quinn and Burt (1970, 1972) reviewed some early explanations for the phenomenon and used extensive meteorological information to suggest that the El Niño is associated, in some degree, with three major meteorological events: the weakening of the Southeast Pacific Sub-Tropical High, a southward penetration of the Northern Hemisphere system in the Southeastern Tropical Pacific, and a blocking of the Antarctic circumpolar circulation.

A hypothesis that has received little attention in connection with the El Niño phenomenon is that warming 'in situ' could result in anomalous warming of coastal waters. If a weakness of the southerly winds causes the Equatorial front to move south of its usual limit, weakened upwelling and 'in situ' warming could be a natural result.

International cooperation is necessary to provide the large scale meteorological observations needed to understand the phenomenon. A more extensive study among oceanographic institutions of Ecuador, Peru, and Chile is advisable. A permanent meteorological base on San Felix Island (26°05'S, 80°W) could supply valuable information on the fluctuations within the eastern limb of the South Pacific Anticyclone.

Summary

The characteristics of the area under study may be summarized as follows:

1. Water masses originate in four climatic regions of the Pacific Ocean and are transported by currents to the area. Surface water masses are: Equatorial Surface, Tropical Surface, Sub-Tropical Surface, and Sub-Antarctic Surface. Subsurface water masses are Equatorial Subsurface, Antarctic Intermediate and Sub-Antaractic Water.
2. Circulation patterns change seasonally. In summer and autumn (January to June) the Peru Coastal Current is separated from the Peru Oceanic Current by the Peru Countercurrent, while in winter and spring the Countercurrent weakens and the two equatorward branches combine.
3. The Peru Coastal Current is affected by a large series of fluctuations of which upwelling and orographically induced permanent eddies are the most prominent.
4. A southward sub-surface flow is present underneath the Peru Coastal Current as far as 35°S. It is characterized by a low oxygen content.
5. Upwelling is present all year round, being more intense in Peru during winter (June to August), but in northern Chile it is more intense in early spring. A permanent strong upwelling zone is found between 14° and 16°S. This is a transitional zone between two different hydrographical regimes, with Equatorial Subsurface water being upwelled to the north and Sub-Antarctic water to the south.

6. As a result of circulation, upwelling, meteorological, and climatic changes, both temperature and salinity change seasonally. Changes in salinity result mainly from advection, evaporation, precipitation, upwelling and surface circulation. The last is by far the most important factor in determining salinity concentration.
7. A layer of minimum oxygen of Equatorial origin, with values of less than 0.5 ml/l, is found throughout the region between 50 and 700 m.
8. The Equatorial front, present in northern Peru, is subject to fluctuations which in extreme cases result in the occurrence of El Niño. The effect that El Niño has had on the ecology of the region suggests that a cooperative international study should be made of the phenomenon in order to better understand its causes.

PART III. DESCRIPTION OF AVERAGE SEASONAL OCEANOGRAPHIC CONDITIONS AND ANCHOVETA DISTRIBUTION AND SPAWNING DURING NOVEMBER 1967 TO NOVEMBER 1970.

Material and Methods

Up to this point the biology of the anchoveta has been reviewed and a detailed description of its habitat has been given as reported in the literature. Now the details of the Chilean anchoveta fishery from November 1967 to November 1970 will be dealt with specifically.

Most of the information, collected by the personnel of the IFOP-Department of Natural Resources, was made in Project NORTE. Cruise IFOP 13 on the R/V "Carlos Darwin" and cruise Anchoveta I on the R/V "Stella Maris" were especially important because of the studies of vertical distribution of oxygen and salinity that were carried out. In Appendix 2 a complete list of the cruises used in this study is presented. Appendix 3 summarizes the number of cruises by season.

The Project NORTE resulted partially from the fact that the major research vessel of IFOP was assigned to study the southern part of Chile during 1968 and no cruises were scheduled for the northern part. The anchoveta fishing industry requested continuous surveys in the area at this time. At the end of 1967 IFOP proposed to start a series of cruises in northern Chile similar to the successful cruises of Project EUREKA that were made by IMARPE in Peru. Financial support was granted by the Instituto Corfo-Norte, the Junta de Adelanto de Arica, and by the local fishing industry. As coordinator of the program, from its official starting date in June 1968, the author had to select personnel and

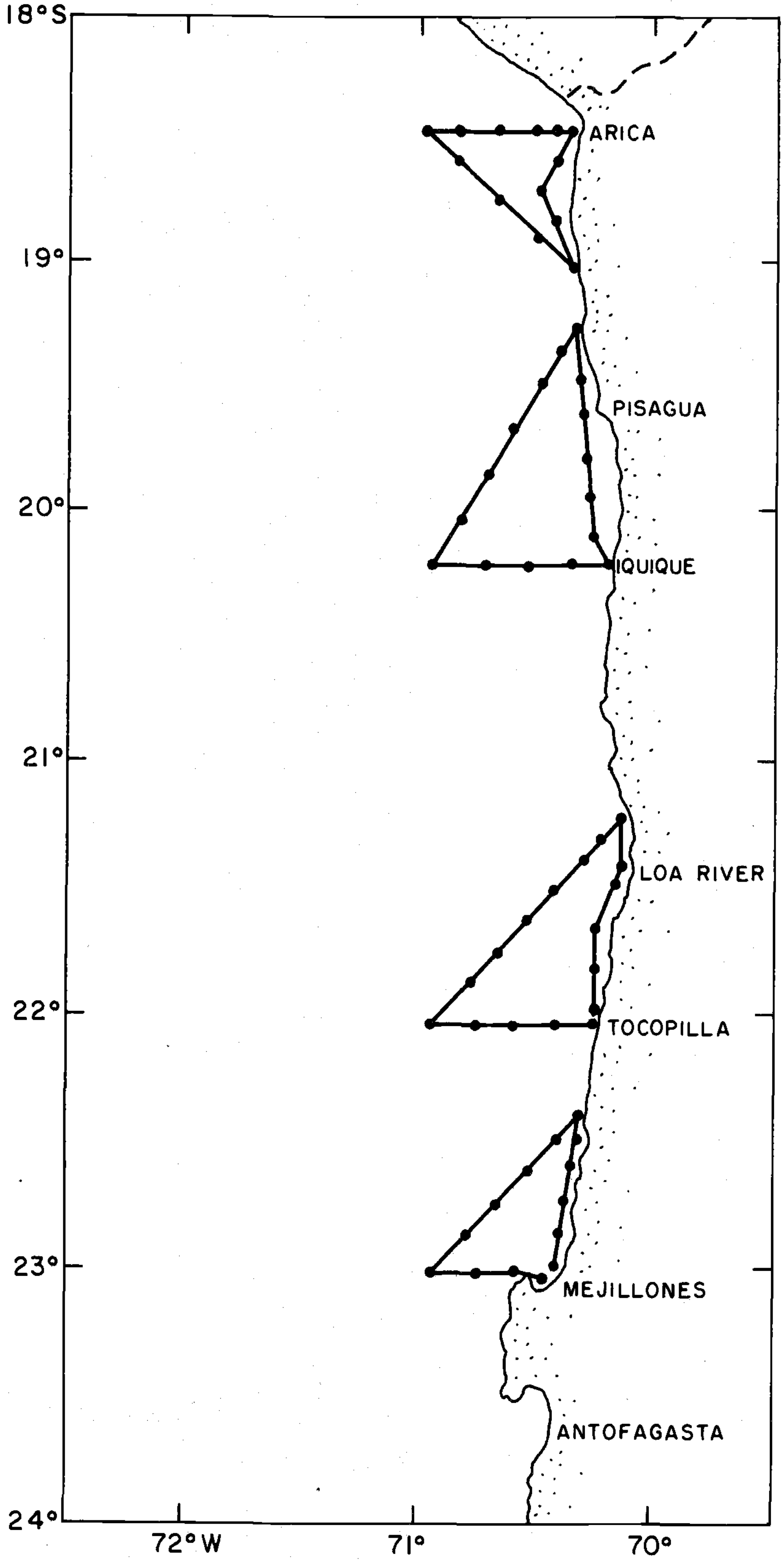


Figure 6. Map of the northern Chilean region under study which show the usual pattern followed by the Project NORTE cruises.

distribute resources for the monthly surveys, and then to elaborate on and publish the preliminary results. I also had the opportunity to personally collect much of the information and make many of the observations that are discussed below.

The main objectives of the project were to study environmental conditons, mainly temperature and salinity, and their effects on anchoveta distribution and abundance. Secondary objectives were to study the distribution of anchoveta eggs and larvae. The surveys covered the area from Arica (18°25'S) to Mejillones del Sur (23°06'S) and from the coast to 50 miles offshore (Figure 6). This is the area where most of the anchoveta are fished off Chile.

After the first year of surveys an arrangement was made with IMARPE to coordinate EUREKA cruises in the southern part of Peru with those of Project NORTE in the northern part of Chile. This made information from a larger area available for study.

In accordance with an IFOP proposal the fishing industry provided one fishing boat from each of the main anchoveta fishing ports in northern Chile (Arica, Iquique, Tocopilla and Mejillones). Each boat was equipped with Echosounder, SONAR, radio, and navigational equipment to meet the specifications of IFOP. The Institute provided the required biological and oceanographic sampling instrumentation. A competent scientist and a technician from IFOP worked with the crew of the boat to carry out the survey.

Each boat started its work at the same time, usually Saturday night, because few companies fish on weekends. The survey track was established in advance (Figure 6). If conditions dictated, slight modifications were made. At one-hour intervals the boat stopped and a station was made. The boat's speed averaged about 10 knots so stations were about 10 miles apart.

The following information was obtained at each station: (1) Sea surface temperature (2) Vertical profiles of temperature (3) Surface salinity (4) Transparency of the water (5) Color of the water and (6) Zooplankton samples (eggs and larvae of anchoveta). Observations of birds, marine mammals, "red tides," number of fishing boats operating in the area, meteorological conditions, etc., were recorded on a special sheet of paper.

During each cruise, which usually lasted 20 hours, an estimate of anchoveta populations was made with echosounding or SONOR gear. Echosounders and SONAR were operated continuously by IFOP personnel. The equipment varied from boat to boat. The most common instrument used was Simrad type EH-2. Elac Mini Lodar (30 k.c.), Simrad SK-580 (Sonar), and Simrad 512-P (38.5 k.c.) were also commonly used. All were previously calibrated to operate in the same intensity and depth range (0-75 m), making the records comparable for all the instruments (Vestnes and Saetersdal, 1966). The records were later analyzed and graphed in the following relative fish abundance scale:

0. No fish

1. Very scattered: One or two schools per mile traveled, schools small, not fishable.

2. Scattered: Up to five schools per mile, schools small, usually not fishable.

3. Dense: Up to five schools per mile, schools larger, most of them fishable.

4. Very dense: Number of schools per mile often up to 10, schools larger, most of them fishable, some large enough for more than one fishing vessel.

Surface temperatures were obtained with a mercury thermometer and a plastic bucket. Vertical profiles were made by means of a conventional bathythermograph with a depth range of 275 m. Salinity samples were sealed in glass bottles and analyzed for chlorinity in the laboratory following the Mohr-Knudsen method (Riley and Chester, 1971). The values were converted to salinity using tables prepared by Knudsen (1901) and presented in parts per thousand of salinity (‰). Oxygen determinations in the IFOP 13 and Anchoveta I cruises were made following the method of Winkler (1888) modified by Carpenter (1965). Zooplankton samples were obtained using a Hensen net. The mouth is 1 m in diameter, the mesh size is about 0.25-0.31 mm and the net was hauled vertically from 50 to 0 m at a speed of about 0.5 m/sec. Estimates of the amount of zooplankton were obtained by displacement. Later, the eggs and larvae of anchoveta were removed from the zooplankton samples and counted.

Water color was observed on two boats using a Forel Scale but the information obtained were scattered and no chart was constructed. A Secchi Disc was used during daylight hours to measure transparency of the water. The records were graphed using a relative scale which groups observations in different ranges as follows: (1) transparencies from 0 to 5 m (2) transparencies from 6 to 10 m (3) transparencies from 11 to 15 m (4) transparencies from 16 to 20 m and (5) transparencies of more than 21 m.

Seasonal mean charts for distribution of sea-surface temperature, sea-surface salinity, transparency, fish abundance, volume of zooplankton, eggs and larvae of anchoveta were constructed on a 5 by 5 mile square grid. Vertical profiles of temperature, salinity and oxygen were constructed using the IFOP information. Some profiles from the published results of the "Anchoveta" cruise are also used in the discussion. Profiles presented in the preliminary reports are included. Fish capture data for the period were provided by the Statistical Branch of the IFOP. Tables of data are included in the Appendix.

Information in this study is presented by seasons (Southern Hemisphere). For convenience Summer represents the months of January, February and March, Autumn April, May and June, Winter July, August and September, and Spring October, November and December.

Seasonal Temperature Distribution

Surface temperatures averaged by season and by 5 mile squares for the entire period revealed important features that are not apparent when larger scales are used. Latitudinal differences and seasonal thermal fronts were most easily seen in such a small scale treatment. All the information for each cruise was collected in a single day, by multiple vessel techniques, eliminating much of the uncertainty that arises when scattered and aperiodic information is used. The seasonal distribution pattern in the area from 18° to 24°S and from the coast to 71°W is shown in Figure 7. In Appendix 4-5-6 and 7 percentages of the areas covered by different temperature ranges are shown.

Summer (January-February and March)

High water temperatures and strong horizontal gradients were characteristic of the summer months (Figure 7). The temperature range was somewhat greater in the north than in the south. Most of the area had surface temperatures ranging between 19 and 23 C. Cooler temperatures occurred near the coast and the coldest temperatures (less than 16 C), were usually associated with upwelling, and covered only about 1% of the area under study. A local thermal front occurred between 19° and 21°S with water of temperatures greater than 23 C. The importance of these fronts to the fisheries, will be discussed in Part IV.

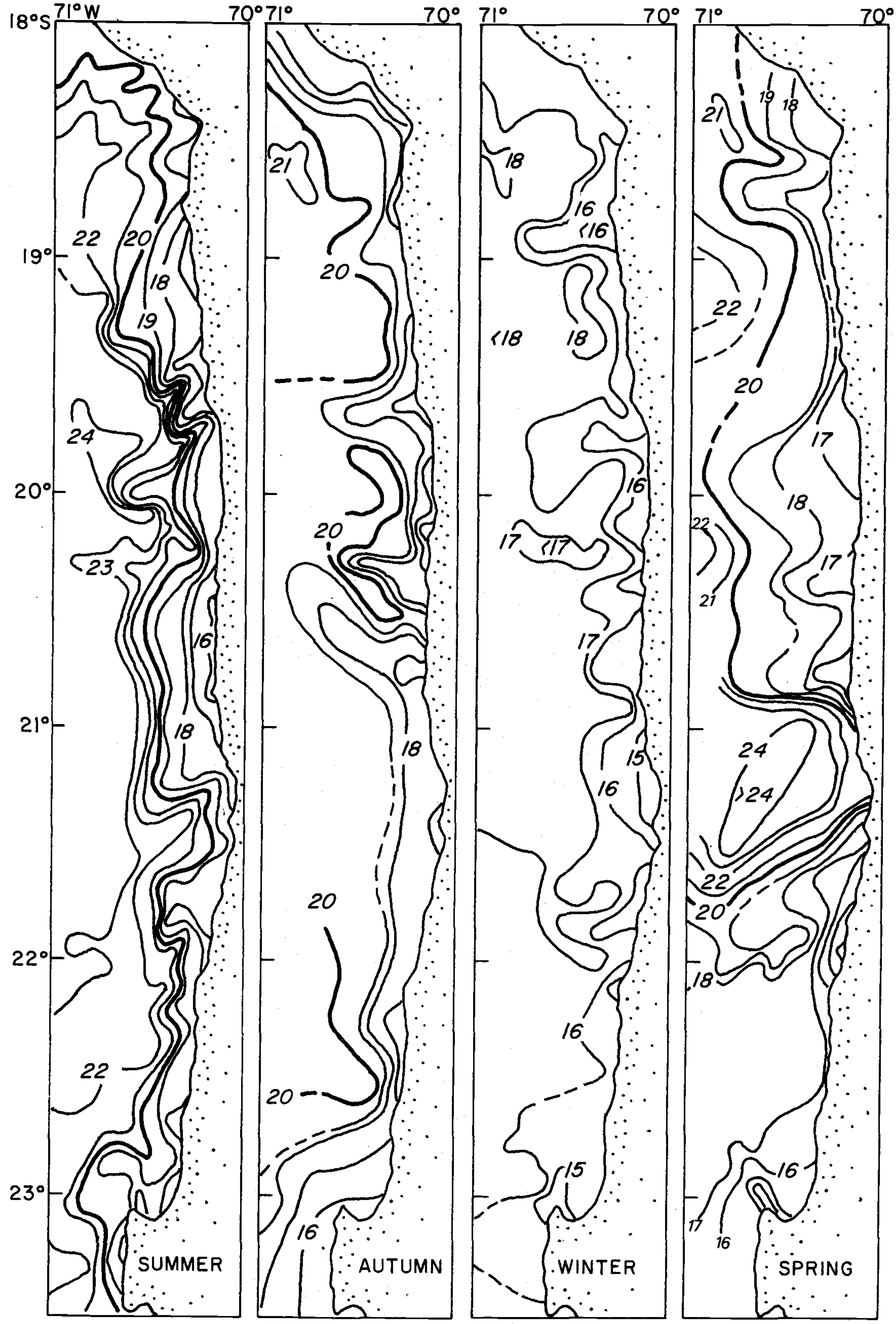


Figure 7. Seasonal average distribution of sea-surface temperature (°C) from 1968 to 1970 in northern Chile.

Autumn (April, May and June)

Autumn brought gradual temperature decreases over the whole area. Temperatures in the north were variable with a seven degree range (15-22 C) while in the south the range decreased to about four degrees (15 to 19 C). The temperatures in about 70% of the area ranged from 17 to 20 C characteristic of the transitional autumn months.

Waters became gradually cooler toward the south. In the northern part of the area temperatures were only one degree lower than in summer and the position of the 20 C isotherm was nearly the same in both seasons, while further south the differences were increasingly more remarkable. The 20 C isotherm was present in this area only in the form of two small lenses.

Winter (July, August and September)

The sea-surface temperature pattern showed the annual minimum in winter over the entire area. There was a great uniformity of temperatures resulting from a low thermal horizontal gradient, with only a gradually latitudinal variation from the north, which was relatively warm, to the south which was relatively colder. Large pockets of cold water were present in coastal areas.

In the north, 80% of the area had temperatures between 16 and 19 C. South of 22°S, 97% of the area had temperatures between 15 and 17 C.

As was characterisitic of the entire year, low temperatures near-shore revealed upwelling. The 20 C isotherm was completely absent during winter.

Spring (October, November and December)

The spring pattern was distinctive, differing from the autumn transitional pattern period, and was characterized by abrupt changes, rather than a gradual transition. The range of temperatures increase, strong thermal gradients were present, local warm temperate fronts developed, and extensive areas were covered with relatively cold waters.

Large temperature ranges (from 13 to 25 C) were found in the middle latitudes while to both the north and south temperatures were more uniform, being warmer in the north and colder in the south.

South of 22°S the waters were more uniform with a range of four to six degrees. No temperature higher than 20 C was found here but temperatures lower than 14 C were present. Nearly 70% of that region had temperatures from 17 to 18 C.

In general, temperatures were higher in the north and lower in the south. There was an important addition of warm water in the central area which showed a wider range of temperatures than either the northern and southern regions.

Seasonal Salinity Distribution

Seasonal maps of salinities were constructed following a method similar to that used for temperatures (Figure 8; Appendices 8 to 11).

In general high salinities were correlated with high temperatures characteristic of the presence of Sub-Tropical waters. Lower salinities associated with low temperatures were usually found restricted to coastal areas where water of Sub-Antarctic origin upwells.

Salinities were more uniform than temperatures throughout the year. The highest salinity throughout the year (35.4 ‰) occurred in autumn at latitude 23°-24°S, and the lowest (34.5 ‰) at latitude 19° to 21°S also during autumn.

The principal characteristics of the seasonal distribution follow:

Summer (January, February and March)

High salinities were characteristic of the summer season. The range was from 34.7 to 35.3 ‰ and 63% of the entire area was covered by waters with salinities greater than 34.9 ‰ indicating Sub-Tropical origin. The range was smaller in the north and south than in the center area where a tongue of highly saline water from the NW appeared. Salinities were highest in the north and lowest in the south. Nearly 80% of the water in the north had salinities between 34.9 to 35.1‰ , but only 15% of the southern area had similar salinities.

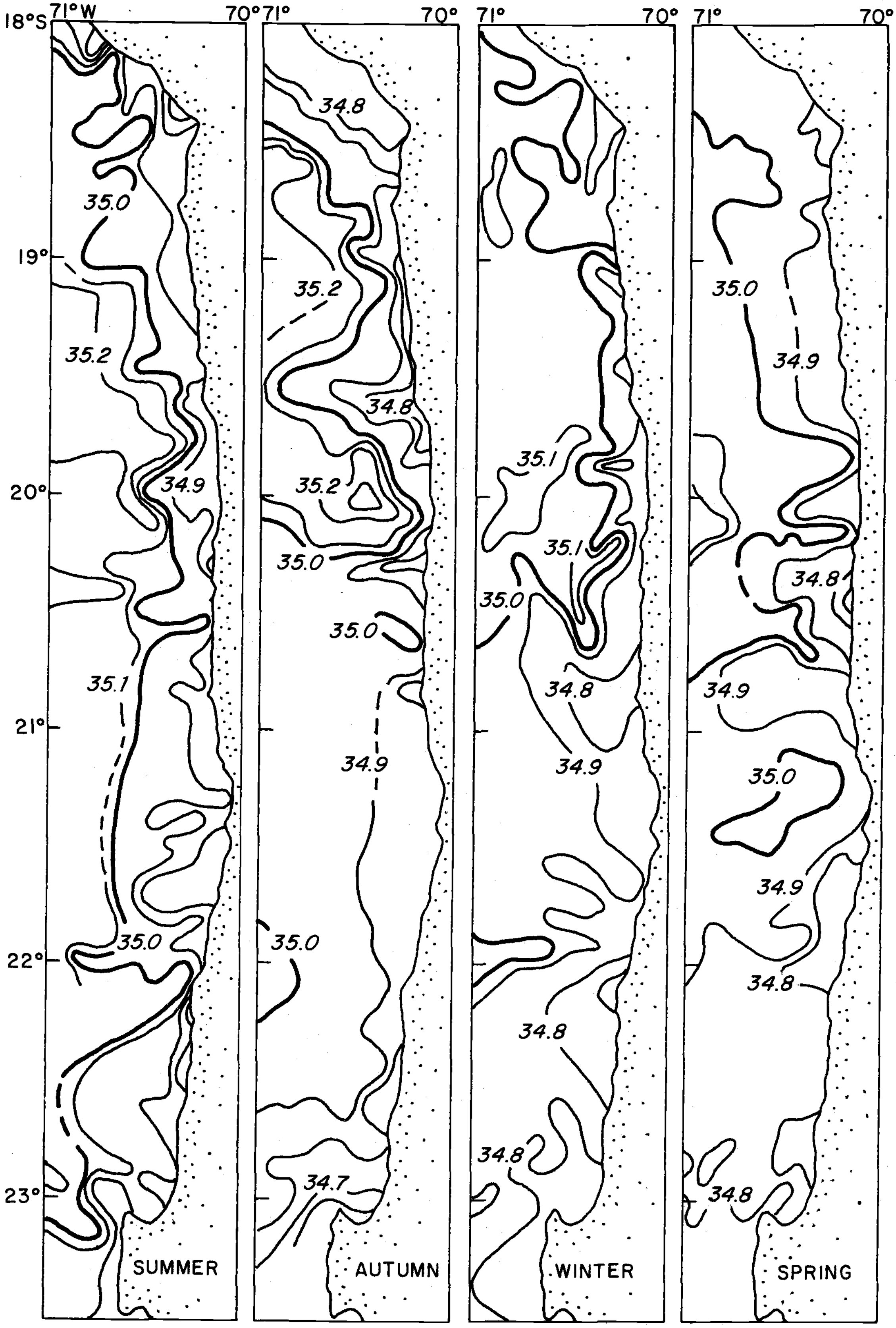


Figure 8. Seasonal average distribution of sea surface salinity (‰) in northern Chile from 1968 to 1970.

Autumn (April, May and June)

During autumn salinity gradients were greater in the northern part, especially around 20°S where a high saline lens was present. South of this point salinity gradients became less significant.

Salinities between 34.8 to 35.0 ‰ predominated. South of 20°S more than half of the area was covered by a single 0.1‰ -salinity increment (34.9 to 35.0 ‰) indicating the beginning of the uniform conditions characteristic of the coming winter.

Winter (July, August and September)

Salinities during winter were restricted to a narrow range between 34.7 to 35.2 ‰ . Waters of 34.8 to 35.1 ‰ covered 82% of the area resulting in a very uniform pattern. This uniformity in salinities was somewhat similar to that of temperatures. A very clear latitudinal zonation between highly saline water in the north and less saline waters in the south was found in this period. Almost 90% of the northern area was covered by the waters with salinities between 34.9 and 35.1 ‰ , while south of 22°S more than 90% of the waters shows slightly lower salinities in the order of 34.7 to 34.9 ‰ .

Spring (October, November and December)

Salinities in the spring were characterized by transitional distributions between those of winter and those of summer. The salinities appeared to be a mixture of both seasonal patterns. However, almost 93% of the area was covered by waters of 34.8 to 35.1‰, more closely resembling winter conditions than summer conditions. A single 0.1‰ increment covered a wide area in southern latitudes rather than in northern latitudes, as it is found during winter.

The large horizontal thermal gradients were not reflected in similar haline gradients. A correlation between high temperatures and high salinities was apparent.

Seasonal Distribution of Water Transparency

Water transparency was measured with Secchi Disks during daylight. A conventional scale was used to present the information which was graphed following a similar methodology as for temperature and salinity (Figure 9). In general transparencies increased offshore. Seasonal variations were not great but generally reflected hydrographical and biological changes that took place in the area. Runoff was almost negligible, therefore, coastal waters with poor transparencies usually represented upwelled and highly productive waters and were characterized by greenish and blue-greenish colors. Greater transparencies were related to intrusion of Sub-Tropical, less productive waters into the areas which were blue in color.

The seasonal descriptions of water transparency follow:

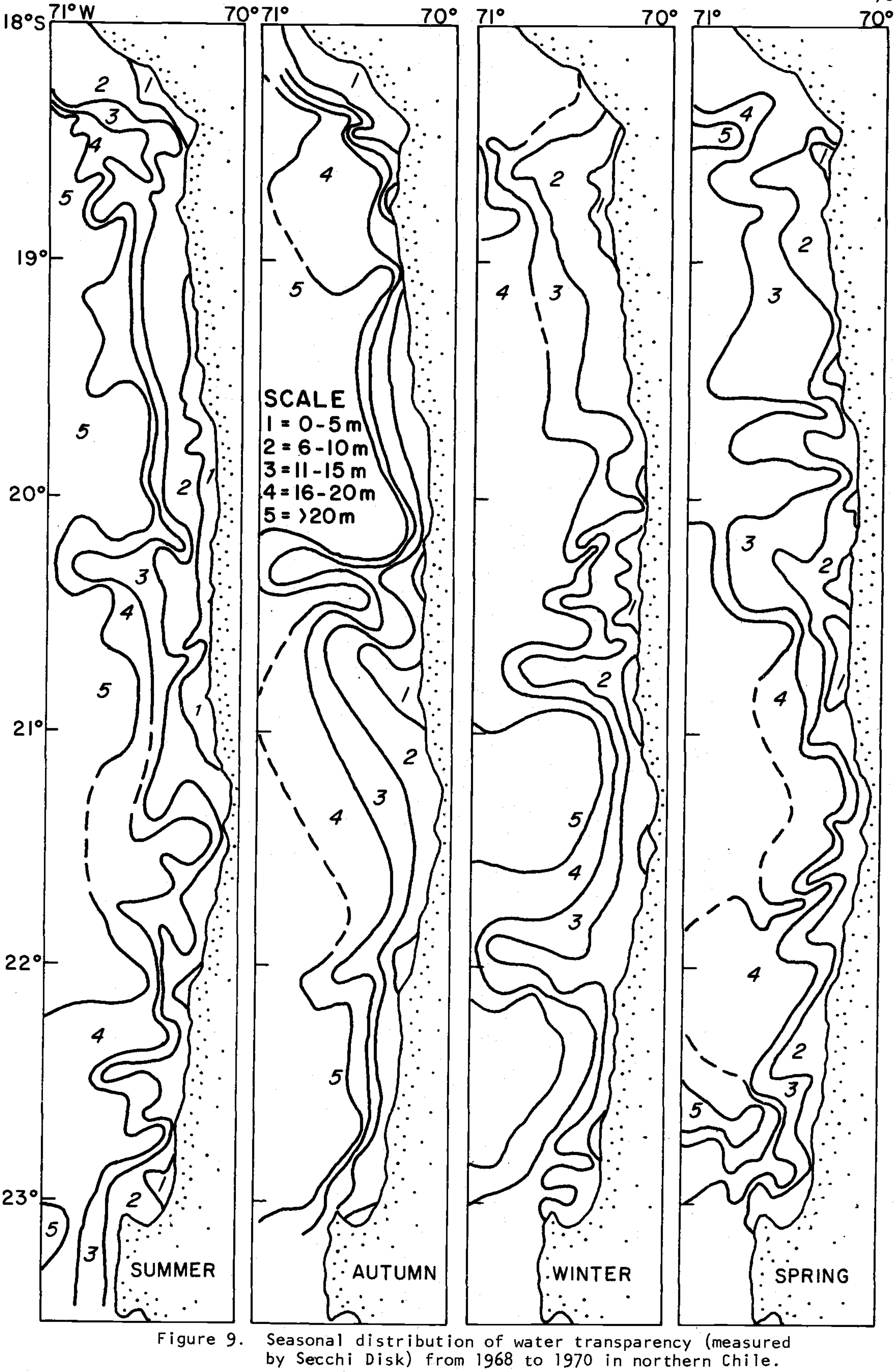


Figure 9. Seasonal distribution of water transparency (measured by Secchi Disk) from 1968 to 1970 in northern Chile.

Summer (January, February and March)

Low transparencies in coastal waters and high transparencies offshore were characteristic in summer. Transparencies of less than 5 m occurred along a long narrow band close to most of the coast. Values from 5 to 10 m covered an important fraction of the area. More than 50% of the entire area was covered by waters of high transparencies of between 15 and 20 m characteristic of the summer intrusion of Sub-Tropical water.

Autumn (April, May and June)

During this season the area of higher transparencies increased accompanied by a diminution of the low transparency coastal band. This increase arose mainly from sharp tongues of highly transparent water moving into the coastal margin in some areas, suggesting that warm Sub-Tropical waters were still an important factor during autumn.

Winter (July, August and September)

Conditions during winter were more uniform with lower gradients than those found during autumn, and to a lesser degree during summer.

Waters with lower transparencies, suggesting high productivity were reduced to very small areas close to the coast. Waters with high transparencies were restricted to the southern part of the area.

Spring (October, November and December)

During spring, when the phytoplankton blooms, waters with low transparencies began to cover wider areas. Waters of high transparencies indicative of an oceanic origin were almost absent except well offshore of Rio Loa (21°30'S). Waters of moderately low transparencies, between 5 and 10 m, were dominant in coastal areas during this season.

Seasonal Fish Distribution Determined by Echosounder

Fish distribution was indicated on a scale of estimated densities based on acoustic observation. The scale, comprising five grades incorporated observations on the number, size and density of the schools, and the identification of species from the echosounding records.

The information has been summarized in the same manner that for above environmental parameters in Figure 10 and in Appendices 12 to 15. Commercial landings in northern Chilean ports during 1968-1970 are presented in Figure 11 and Tables 1 to 4.

Summer (January, February and March)

In general, during the summer no fish were detected in almost 2/3 of the total area surveyed, while the remaining area showed fish concentrations in some degree, mainly Very Scattered (1) concentrations. Only 2.3% of the area had Dense (3) concentrations.

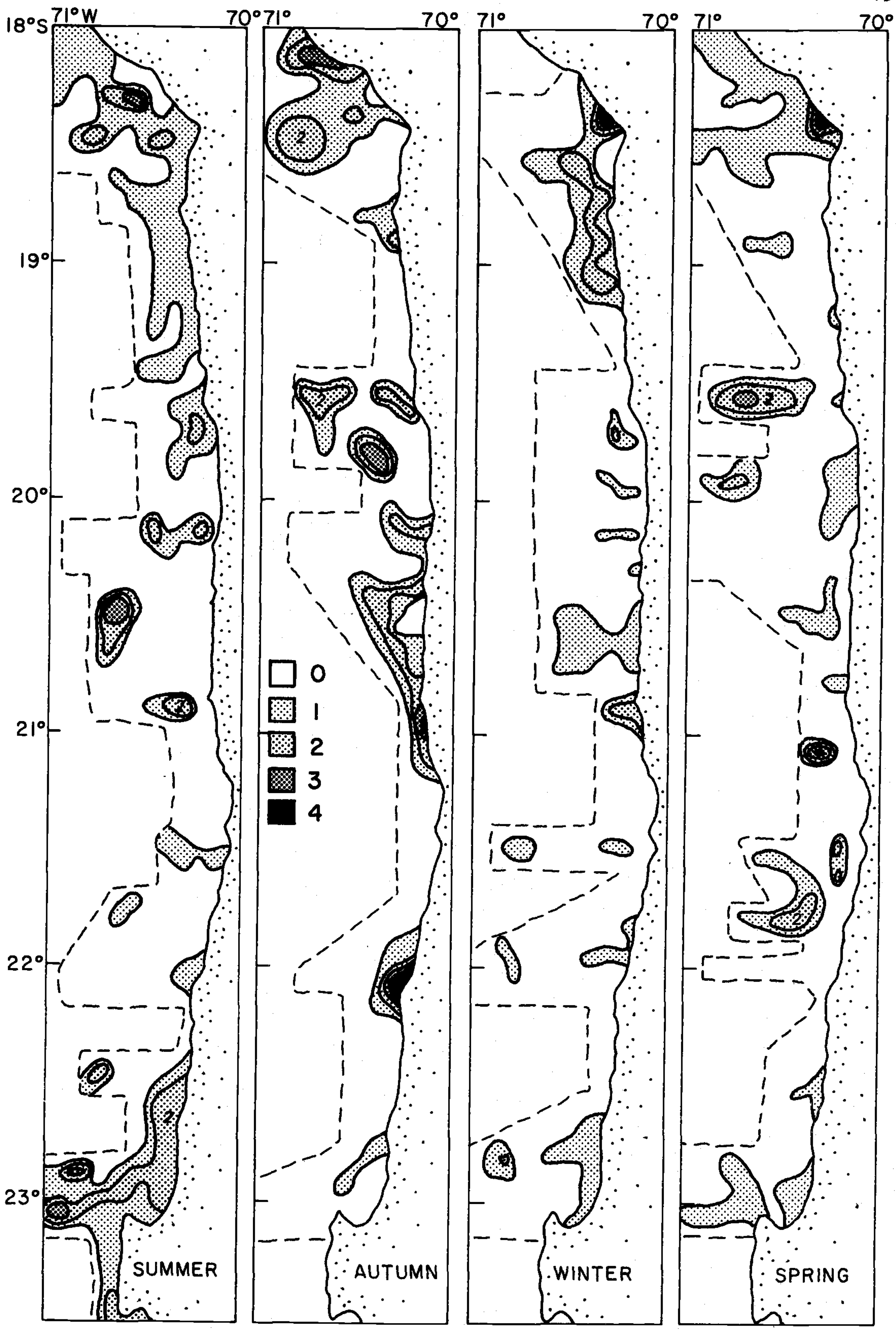


Figure 10. Seasonal average distribution and abundance of anchoveta based on echosound records from 1968 to 1970 in northern Chile.

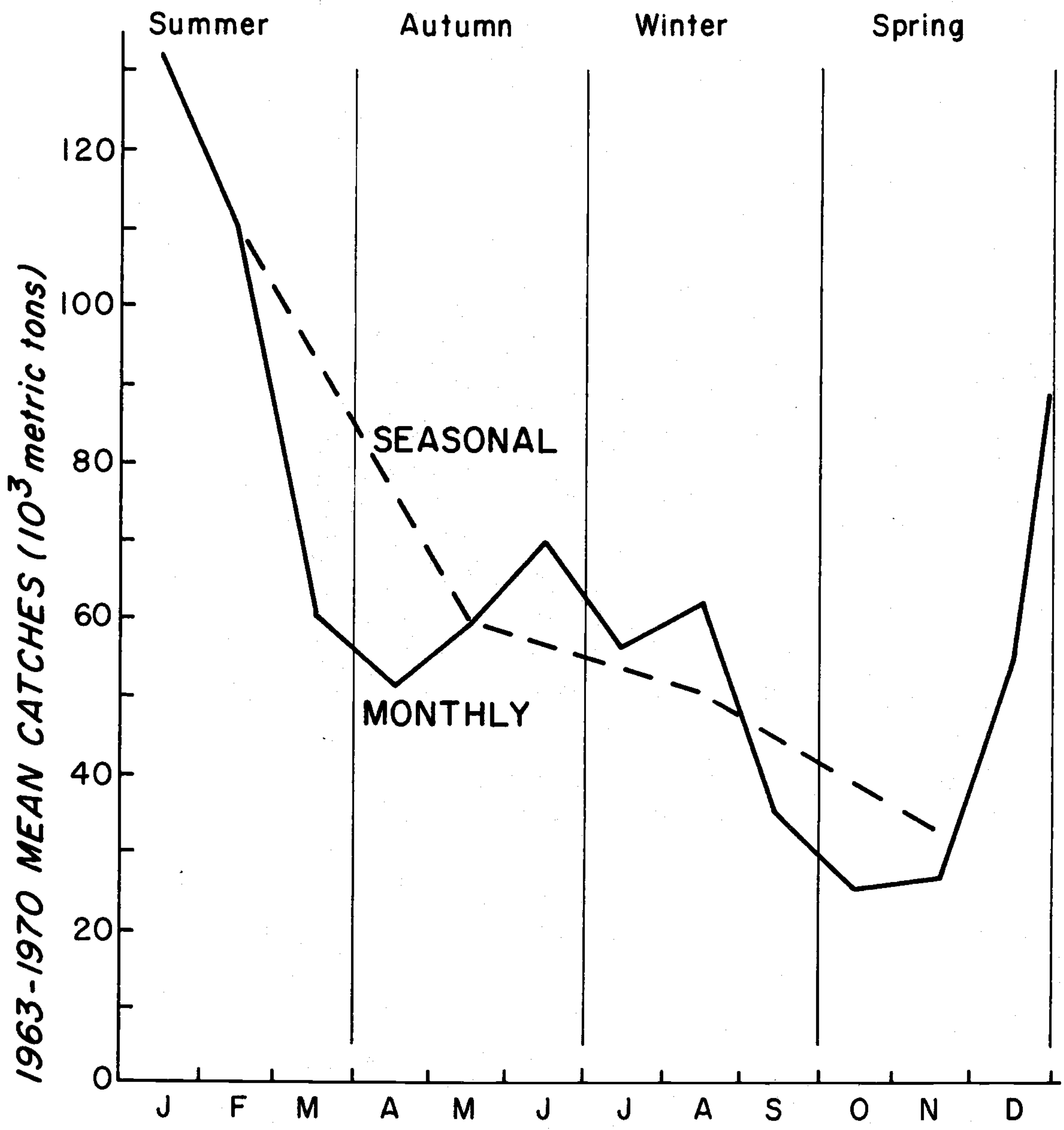


Figure 11. Mean seasonal and monthly catches of anchoveta in northern Chile from 1963-1970 (based on IFOP data).

The main bulk of the total yearly catch was obtained during the summer period (Figure 11, Table 1). For the three-year period of this study, nearly 40% of the total yearly catch was landed during summer. The major fishery occurs in January.

Table 1. Summer landings of anchoveta in northern Chilean ports ($x\ 10^3$ metric tons). The numbers are approximate to the thousand.

	1968	1969	1970	Average
January	175	155	102	144
February	129	115	49	98
March	62	62	13	46
Total Summer	366	332	164	290
Total Year	980	640	630	750

Very Scattered (1) concentrations of anchoveta covered 1,300 sq. n. miles or 43.5% of the total area between 18° to 20°S. Scattered (2) and Dense (3) concentrations were found between 18° and 19°S (10.6%) while between 19° and 20°S these two types were not found.

Between 20° and 21°S much of the area (84.2%) lacked anchoveta schools, but the remainder had a relatively high occurrence of Dense (3) concentrations. In contrast to other areas, the anchoveta were concentrated in denser schools resulting in better catches. From 22° to 23°S Scattered (2) concentrations were found in 22% of the area while small Dense (3) concentrations were found only near Mejillones. South of this area there was an increase in Dense (3) concentrations.

Autumn (April, May and June)

In general no fish schools (0) were found in 64.9% of the total area, and the remaining area had Very Scattered (1) 22.8%; Scattered (2) 10.8%; Dense (3) 0.7%; and Very Dense concentrations (4) 0.7%.

Although these numbers differ only slightly from summer values, fish captures, determined from landings of anchovetas at different ports, were only 163,000 m. tons, 21.7% of the annual catch, compared to the 40% for summer. This value would be even smaller if we excluded June 1968 when an exceptional and rather anomalous catch of 147,000 tons occurred (Table 2).

Table 2. Autumn landings of anchoveta in northern Chile ports ($\times 10^3$ metric tons). The numbers are approximate to the thousand.

	1968	1969	1970	Average
April	10	61	58	43
May	29	87	21	46
June	147	36	39	74
Total Autumn	186	184	118	163
Total for the Year	980	640	630	750

Between 18° and 19°S nearly 50% of the region had no fish and, as in summer, Very Scattered (1) concentrations covered a relatively large percentage of the area (38.5%). Scattered (2) concentrations were found along the southern Peruvian coast and Dense (3) concentrations accounted for less than 2% of the area.

From 19° to 20°S less area was covered with fish but those with fish were more concentrated than during summer. Between 20° and 21°S there were relatively more fish, but they were more dispersed. South of 21°S fish schools decreased and south of 23°S no fish were found.

Winter (July, August and September)

A high percentage (31.5%) of the area showed fish schools from Very Scattered (25.7%) to Very Dense (0.9%). These unexpectedly high values resulted mainly from the high concentrations in July and August of 1968. During these two months 317,000 tons represented nearly 40% of the annual catch. During the other two years only 10% of the annual catch was taken in these two months, as was the case for most years for which statistics are available (Table 3; Figure 11).

The latitudinal distribution shows a considerable increase in fish schools in the area off Arica where 48% of the area was covered with fish. To the south a decrease in schools was noted, but 14% of the area had schools classified as Very Scattered.

Table 3. Winter landings of anchoveta in northern Chile ports ($x\ 10^3$ m. tons). The numbers are approximate to the thousand.

	1968	1969	1970	Average
July	145	34	17	65
August	172	20	11	68
September	32	16	32	27
Total Winter	349	70	60	160
Total for the Year	980	640	630	750

Spring (October, November and December)

During springtime the general pattern of distribution of schools approached mean conditions, as the influence of anomalous high concentrations during winter 1968 were dissipated.

In general 75.4% of the area lacked fish schools. Of the rest of the area, 18.3% showed Very Scattered concentrations; 5.9%, Scattered; 0.3%, Dense; and 0.3%, Very Dense. Apparently the shift to summer conditions occurs in late November or early December.

A high occurrence of schools was found between 18° and 19°S. This number decreased southward to its lowest point between 21° and 22°S. Farther south the number of fish schools increased especially in the area of Mejillones. This observation was supported by catch statistics (Table 4).

Yearly fluctuations in catches are also important in this season. December of 1970 was an exceptionally good month, biasing the results of this study.

Table 4. Spring landings of anchoveta in northern Chilean ports (x 10^3 m. tons). The numbers are approximate to the thousand.

	1968	1969	1970	Mean
October	6	14	37	19
November	36	17	63	39
December	64	21	180	88
Total Spring	106	52	280	146
Total for the Year	980	640	630	750

General Considerations About Fish Distribution

1. An important finding of this study was the presence of anchoveta in the Very Scattered (1) category of the fish density scale over wide areas during most parts of the year. Such areas contained a considerable quantity of fish although they were too disperse for fishing with present techniques.
2. The second category Scattered (2) sometimes covered relatively wide areas with small centers of high concentrations.
3. The acoustic method used in the surveys have proved successful and fish landings confirm the observations made.

4. In general the anchoveta were distributed in large units over the entire study area during most of the year. These units extended over areas ranging from one to several square nautical miles. The largest fish concentration throughout the year appeared in the north near Arica. Concentrations decreased gradually to the south. At the southern extreme of the region, near Mejillones, a small peak occurred.
5. From this study it is apparent that anchoveta concentrations along the coast, and sometimes offshore, concentrate seasonally in certain areas, mostly between 10 and 15 nautical miles offshore.
6. Finally, the seasonal distribution of fish schools confirms that anchoveta are found mainly in a narrow band within 25 nautical miles of the coast and concentrate only sporadically in large detectable schools farther offshore.

Seasonal Distribution of Zooplankton Volumes

The seasonal zooplankton distributions obtained in this study reveal some facts not previously reported in other studies and represents the first seasonal study made in the area. Previous works were limited to some brief preliminary remarks (Gunther, 1936; Brandhorst and Rojas, 1968). Studies over more extensive areas, such as the study of Reid (1962) for the entire Pacific Ocean, revealed little detail in the northern Chilean area. Recently Beers et al. (1971) studied plankton populations off the coast of Peru in relation to upwelling.

In this study zooplankton were collected in 50 m hauls with a Hensen net. Quantitative estimates were obtained by measuring displacement volumes of preserved samples. These values were placed on an arbitrary scale:

0 - No zooplankton	4 - 21 to 30 ml/m^2	8 - 101 to 150 ml/m^2
1 - 1 to 5 ml/m^2	5 - 31 to 50 ml/m^2	9 - 151 to 200 ml/m^2
2 - 6 to 10 ml/m^2	6 - 51 to 75 ml/m^2	10 - more than 200 ml/m^2
3 - 11 to 20 ml/m^2	7 - 76 to 100 ml/m^2	

Data were handled very much like other data in this study, using five by five mile squares and plotting the average values on a regional chart (Figure 12).

One of the most important facts revealed in this study appears to be that zooplankton reached its maximum during spring (48 ml/m^2) when anchoveta were still dispersed and the main spawning period had already taken place. This is important as food habits of larvae suggest a preference for copepods and other zooplankters, which then are available in great quantity.

During summer when the anchoveta become concentrated in large schools and the phytoplankton concentrations has decreased after the spring bloom, zooplankton volume decreased also (27 ml/m^2). These values were lowest during autumn when zooplankton reached 8.5 ml/m^2 (average for a 1° square).

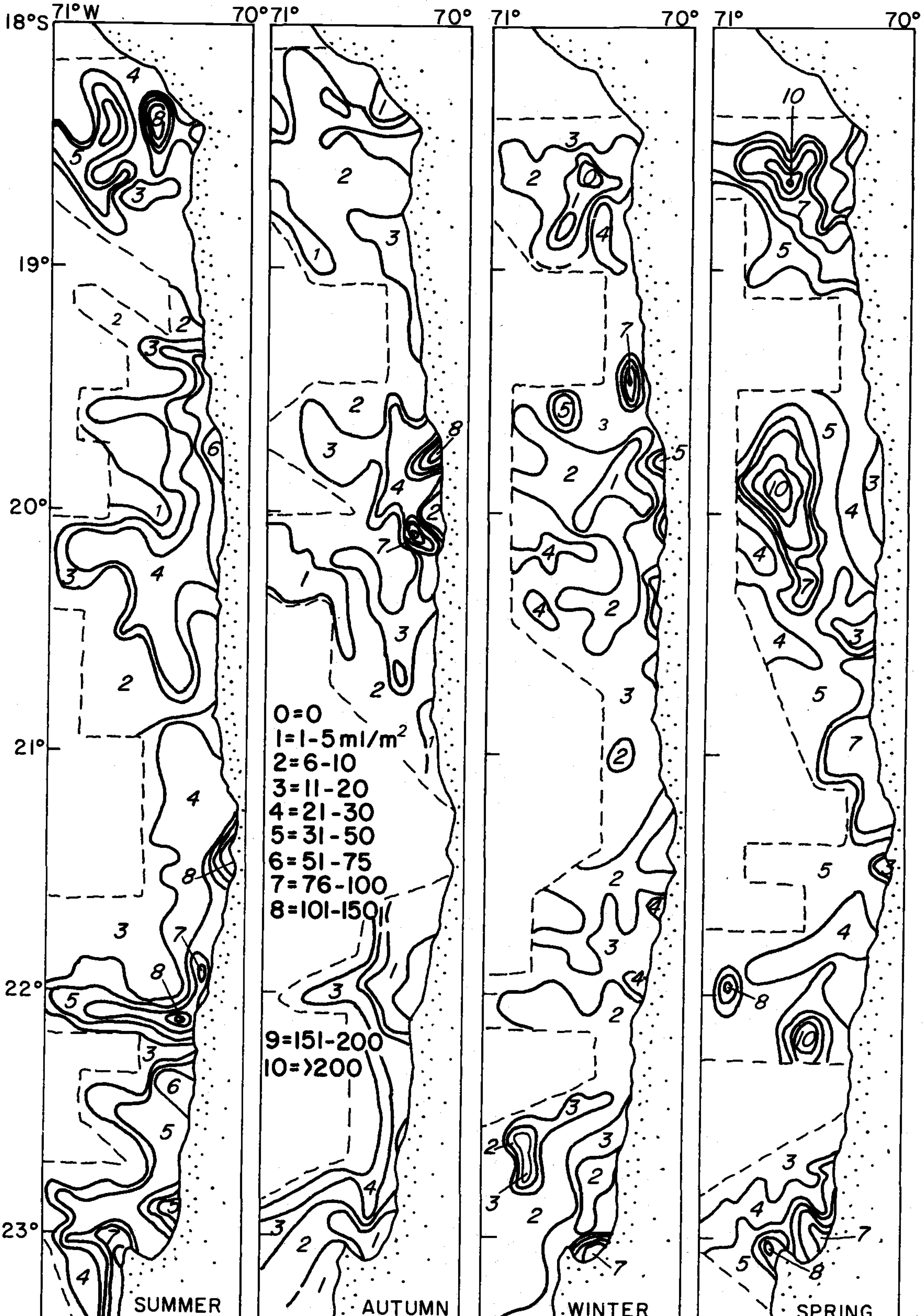


Figure 12. Seasonal distribution of zooplankton volume (in ml/m^2 under 1 m^2 of the surface).

During winter the zooplankton values were still low but had begun to increase slightly (11 ml/m^2).

Latitudinal variations indicated by the zooplankton index were not statistically significant, but certain restricted areas as off Arica, off Rio Loa, and off Mejillones always presented higher values than surrounding areas.

An arbitratry index of zooplankton abundance has been constructed based on the same information but averaged for 1° by 1° latitude areas (Table 5).

Table 5. Index volume zooplankton (in parentheses in ml/m^2).

	Summer	Autumn	Winter	Spring	Mean Total
18-19°	4.9 (30)	2.3 (7.5)	2.7 (9.5)	6.3 (58)	3.8 (26.2)
19-20°	3.7 (18)	3.4 (15)	3.0 (11)	5.2 (33)	3.8 (19.2)
20-21°	3.7 (18)	2.6 (8.0)	3.0 (11)	5.0 (31)	3.6 (17.2)
21-22°	4.4 (25)	1.9 (5.5)	2.8 (10)	6.5 (64)	4.1 (26.1)
22-23°	4.7 (28)	2.6 (9)	2.3 (7.5)	6.2 (55)	4.0 (24.9)
23-24°	5.7 (45)	1.8 (5)	4.2 (23)	6.0 (51)	4.4 (31.0)
TOTAL	4.5 (27)	2.4 (8.5)	3.0 (11)	5.8 (48)	(3.9) (23.6)

Seasonal Anchoveta Eggs Distribution

The eggs, calculated as number per square meter of surface in a column 50 m deep, were studied by methods similar to those used by Einarsson and Rojas de Mendiola (1967) and Brandhorst and Rojas (1968). As with temperature, salinity, and zooplankton, an arbitrary scale was established to show egg density (see Appendix 16).

Values have been averaged by season, each season representing the average from several cruises. The spawning intensities in the entire area are shown in Figure 13.

The latitudinal distribution in more detail and the percentage of stations with anchoveta eggs by season is shown graphically in Figure 14, in Table 6 and Appendix 17.

The information describes the principal features of annual spawning intensity and the latitudinal distribution of the spawning for the area.

Summer (January, February and March)

During summer 90.7% of the area was free of anchoveta eggs. Eggs were found in small patches, usually restricted to coastal areas in the remaining 9.3%. The largest concentration was found between 18° and 19°S, with densities between 27 and 81 eggs/m^2 (4).

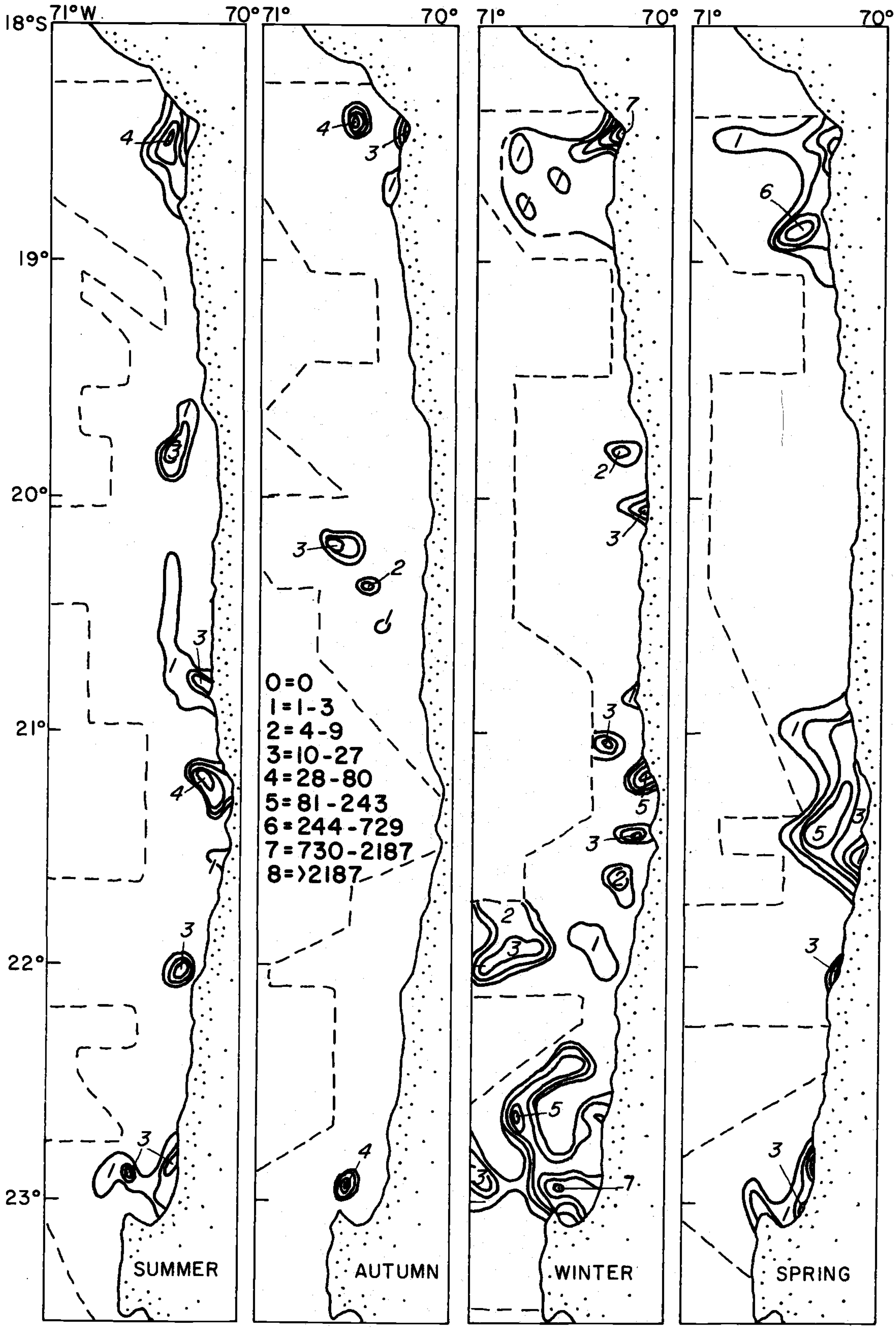


Figure 13. Seasonal average distribution of anchoveta eggs for 1968-1970 in northern Chile (---- limit of the information).

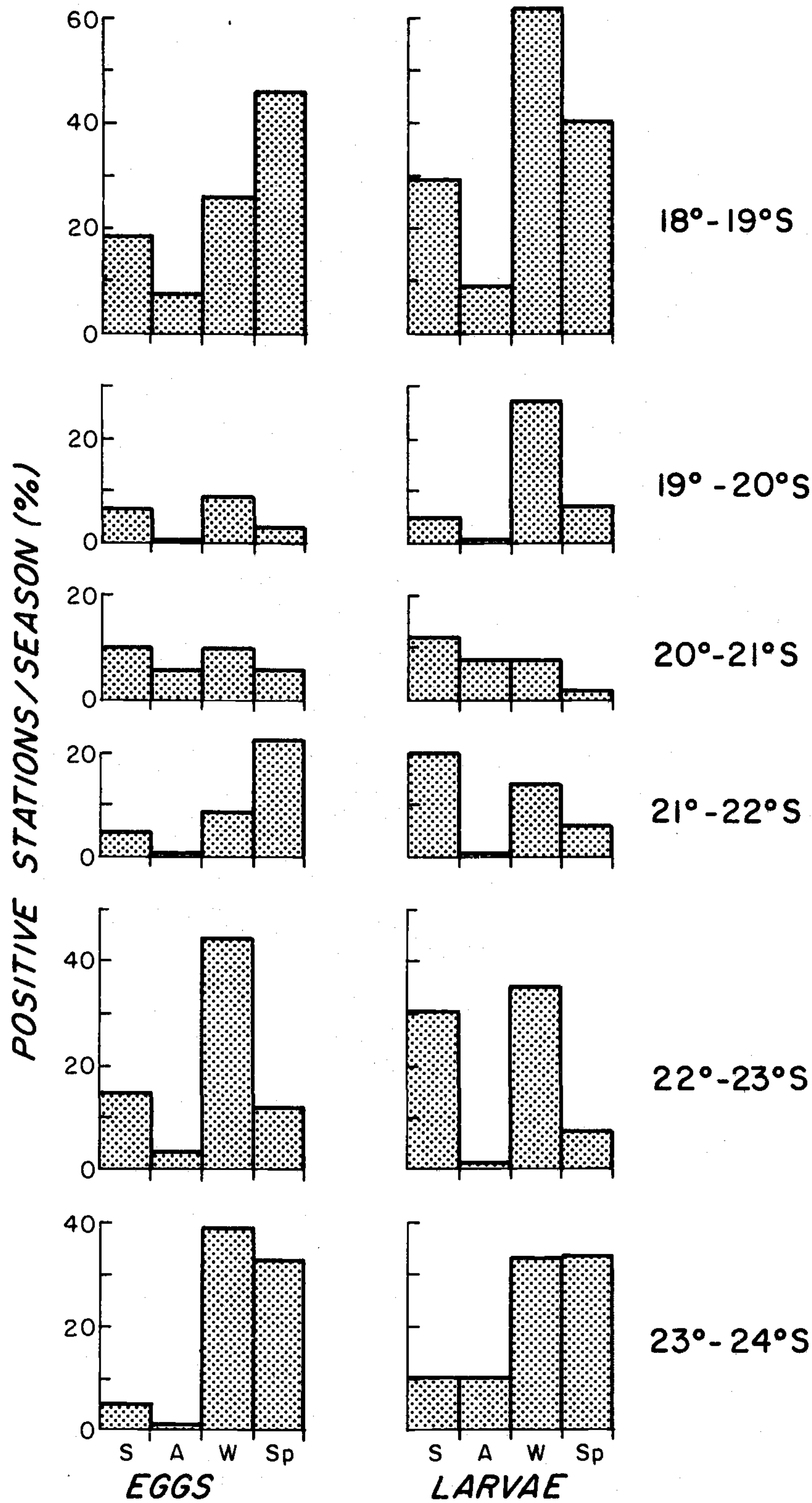


Figure 14. Percentage of stations with anchoveta eggs and anchoveta larvae distributed by seasons and by one degree latitude range in northern Chile from 1968 to 1970.

Autumn (April, May and June)

During this season spawning was reduced to a minimum. Almost 98% of the area was free of eggs, and where they occurred they were very scattered representing only a very small portion of the annual total. As in summer the area off Arica appeared most important.

Winter (July, August and September)

Winter was the most important spawning season; eggs were found in 25.7% of the area and some regions had very high concentrations indicative of important spawning grounds. The most important areas appeared to be in the southern region, especially around Mejillones. There was a secondary egg-rich area off Arica. Nearly 2,000 eggs/m^2 were found off Arica and Mejillones confirming earlier suggestions (Brandhorst and Rojas, 1968) that these two areas are the main spawning centers in northern Chile. Mejillones appears to be more important than Arica, according to my data.

Spring (October, November and December)

Spring spawning differed from winter spawning in that spawning in the area of Mejillones declined while it increased in the area between 21° and 22°S. Almost 80% of the total area lacked eggs, but eggs in the remaining area indicated that considerable spawning also takes place in spring.

An important anomalie in seasonal egg distribution was found between 19°10'S and 20°50'S, an area almost 120 nautical miles long and 50 wide where no eggs were found at any time in the three-year period. Some unidentified continuous phenomenon restricted spawning to other zones.

Seasonal Anchoveta Larvae Distribution

Larvae of anchoveta collected with a Hensen net were studied with methods similar to those employed for eggs.

Four maps with the relative seasonal averages of larvae are presented in Figure 15. Figure 14 shows the seasonal percentage of stations which had larvae. Table 6 shows the percentage of stations with anchoveta larva by season. (In Appendix 18, the latitudinal distribution of positive stations by season for the entire period of survey are shown.)

The Hensen net is very selective for larval size; only the youngest stages (less than 8 mm in length) are effectively retained. The effect of turbulence produced by the wires of the net and the relative slow upward movement makes avoidance an important factor. Therefore, larval information is only semiquantitative and must be used with care.

Summer (January, February and March)

Almost a quarter (22.5%) of all the larvae found during the year were netted during the summer months. This fraction was slightly

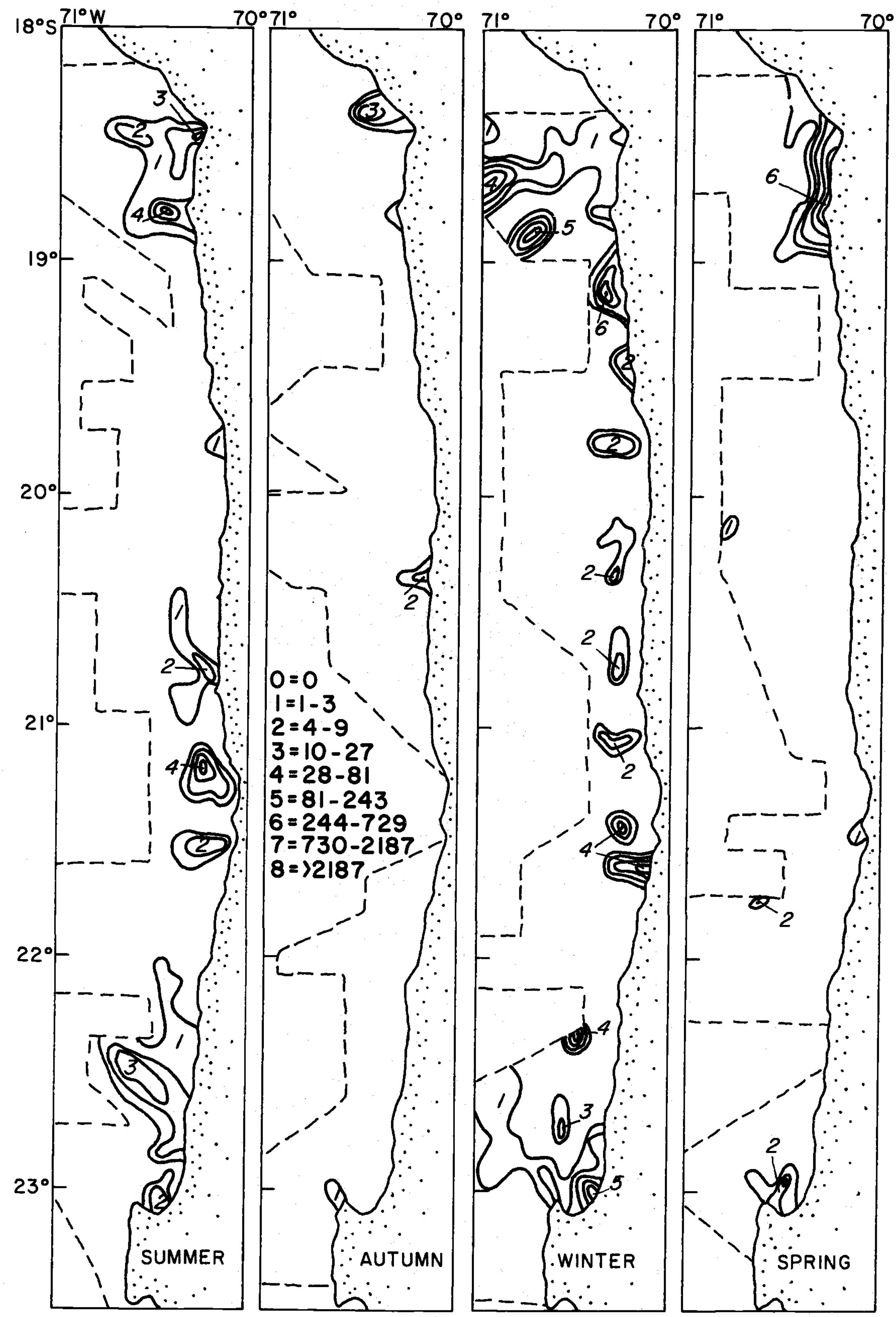


Figure 15. Seasonal average distribution of anchoveta larvae for 1968-1970 in northern Chile. (---- limit of the information)

greater than for eggs for the same period. Summer concentrations of larvae were almost four times as great as autumn concentrations.

During summer 82.6% of the total area lacked larvae. Most of the remaining area had between 1 to 3 larvae/square m. Higher concentrations were found only off Arica and Rio Loa. These were the same locations where higher concentrations of eggs were found. One might expect to find a northward drifting of eggs and larvae with the currents. However, the areas off Arica and Rio Loa probably represent zones of continuous spawning and the effect of drifting out of the area was countered by a continuous input.

Autumn (April, May and June)

Only 4.3% of the area contained larvae during autumn, and no more than 27 larvae/m^2 were found. Again the greatest concentrations were found only in the area off Arica. No larvae were captured between 21° and 23°S.

Winter (July, August and September)

Larvae reached their highest concentrations during winter. Net hauls from 30% of the area contained larvae. Half of the remaining area had low larval concentrations. Some concentrations of the order of 243-729 larvae/m^2 were found both in the northern and southern part of the region. The lowest values occurred between 20° and 22°S with the exception of a small center of Rio Loa. Unlike other seasons larvae were found further offshore, and between 18°-19°S were found 50 miles or more offshore. This was in contrast to distribution of eggs where the most offshore spawning grounds during winter were located between 22° and 23°S and were close to the coast.

Spring (October, November and December)

Larvae covered 15.5% of the total area during spring. Concentrations were greatest in the northernmost region, near Arica, where 40% of the area sampled had larvae. Between 19° and 23°S there were almost no larvae despite the fact that this area was rich in eggs during the spring months. This represents the only discordance with egg distribution. The spring distribution of larvae resembled the autumn pattern more than the winter pattern. Again Arica presented an anomalie.

Table 6. Percentage of anchoveta eggs and anchoveta larvae in the Hensen net hauls by season (1968-1970).

	Eggs	Larvae
Summer	17.0	22.5
Autumn	6.8	5.5
Winter	42.2	39.0
Spring	34.0	33.0

PART IV. THE ANCHOVETA FLUCTUATIONS IN RELATION TO TEMPERATURE, SALINITY AND OXYGEN SEASONAL CHANGES IN NORTHERN CHILE DURING 1968-1970.

Anchoveta prefer certain combinations of physical and biological conditions in their environment. Temperature, salinity, and dissolved oxygen were studied on a series of cruises to determine optimum values and effects on fish distribution and abundance. The information was treated seasonally but not correlated to growth cycles. The major emphasis was placed on the adult anchoveta which is the stage detected by echosound techniques.

Owing to the complexity of the interactions between the anchoveta and its physical environment, the conclusions presented here must be considered preliminary and subject to rigorous proof in the field. For simplicity and clarity the factors are studied more or less separately. Special emphasis has been put on relations which can be used directly or indirectly by anchoveta fishermen, through media of marine extension publications.

Seasonal Temperature Changes in Relation to School Distribution and Abundance

Studies of the temperature optimum for adult anchoveta have not yet been made. There are, however, some indications that they tolerate temperatures to 27 C in aquaria for relatively long periods (Sanchez, 1965). Reid (1962) has given a temperature range of 16 to 23 C in summer and 10 to 18 C in winter but did not suggest optima.

Brandhorst (1963) demonstrated a correlation between good catches and surface waters of 15.5 to 17.5 C. His conclusions were based on information collected by skippers of fishing vessels in northern Chile between May 1961 and February 1962. Brandhorst and Rojas (1968) later used information collected by the R/V "Stella Maris" to show that anchoveta schools were found during the late winter and early spring of 1964 in waters having sea surface temperatures between 13 and 15 C. Brandhorst _et al._ (1968) found that schools were closely correlated with temperatures between 15 to 18 C during January and February, 1965. During cruise 50 (4) 68 SM (IFOP, 1969), IFOP personnel found anchoveta associated with surface temperatures in the area of Mejillones between 14.0 and 16.0 C, in the area of Iquique between 13.0 and 17.0 C, and in the area of Arica between 14.0 and 18.0 C. Jordán (1971) found most schools in Peru located beneath surface temperatures from 14.5 to 21.0 C at all times of the year.

Despite all of this information, mostly relating surface temperature to subsurface schools, there are no indications of the lowest and highest temperatures at which anchoveta can survive. If we consider that these limits depend upon previous acclimatization, sudden changes could be lethal. Extremely severe conditions may not directly kill adults, but studies of other clupeides have demonstrated that the effects on larvae can be more serious (Blaxter, 1960). In fact, herring larvae living in waters between 7.5 to 15.5 C have an upper lethal minimum varying from 22 to 27 C, which is less than adult lethal minimum.

Much valuable information was collected during the project NORTE cruises. Some relationships appear when seasonal distributions of average temperatures, both surface and vertical distributions are compared to the horizontal and vertical distribution of fish schools. The information collected in northern Chile during 1968-1970 showed that the annual temperature range for the anchoveta is 14.0 to 22.5 C (Figure 16). The relationship between seasonal differences in distribution and relative abundance of adult fish and temperature are discussed below:

Summer (January, February and March)

Off northern Chile high water temperatures and strong horizontal gradients of temperature were characteristic of the summer months. During summer, upwelling was weak. Warm, saline, Sub-Tropical water in the form of a front moved closer to the coast, resulting in a concentration of fish and a better catch per unit of effort. In certain years extreme conditions occurred and the front occasionally reached the coast resulting in poor fishing conditions (e.g. 1965). Under these conditions the anchoveta is dispersed underneath the warm, near-surface water. This phenomenon is often mistaken in Chile and southern Peru for El Niño, as its economic consequences to the fisheries are similar. During the years from 1968 to 1970 the front followed a "normal" behavior and the catches were normal.

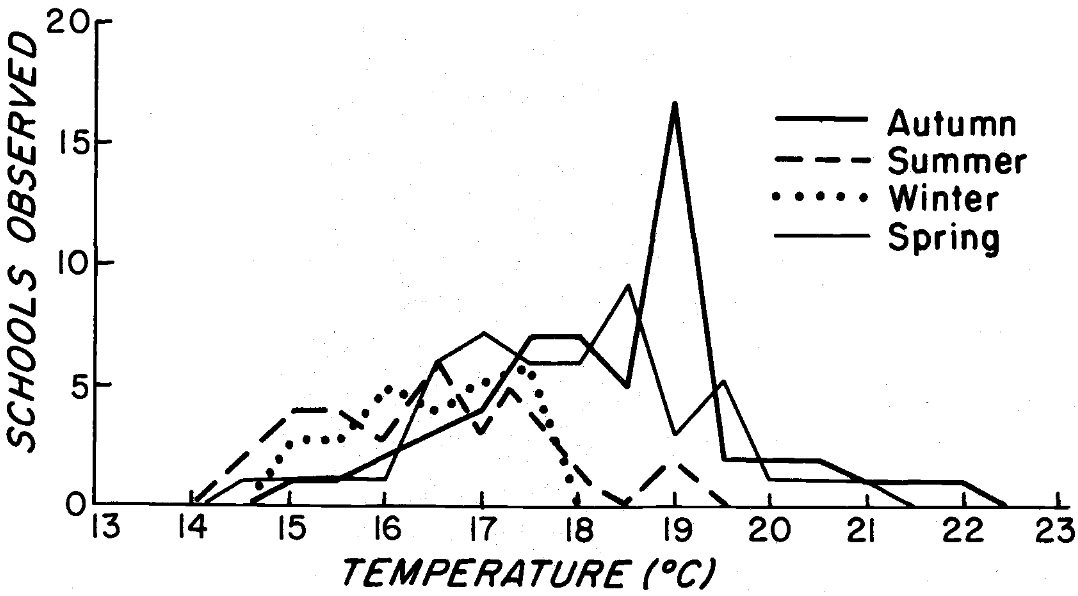


Figure 16. Number of schools of anchoveta vs. temperature of occurrence in vertical sections grouped by season (1968-1970).
A) Summer B) Fall C) Winter D) Spring

Dense anchoveta schools always appear in conjunction with strong temperature gradients. This relationship may be partially explained by the use that the anchoveta make of thermal differences to induce spawning. Several summer vertical temperature sections were obtained in areas where acoustic evidence of anchoveta schools was present (Figure 17). Anchoveta were normally found below the depth of the 20 C degree isotherm. This fact is clearly seen in Figure 18, which shows schools in relation to depth and distance from the coast. Between 0 and 5 miles from shore anchoveta were found over 10 m while from 10 miles out anchoveta were restricted to depths below 10 m, the average depth of the layer of subtropical warm water which comes into the area during summer.

If year-to-year information is compared, it appears that during the years when colder surface water nearshore was more restricted in area, the commercial catches increased, perhaps because the fish are concentrated into a smaller area and are more efficiently captured. If the warm water intrudes all the way to the coast and the cold area disappear, the catch is decreased.

Finally, Figure 16, showing the number of schools versus temperature, reveals that anchoveta were found in water with temperatures between 14 and 19.5 C. The highest concentration coincided with the 16.5 C isotherms. The 23 C isotherm in surface water acted as a barrier holding fish in cooler coastal waters. All fishable schools were found inshore from the 23 C isotherm. Fishermen can use this isotherm to limit their area of search.

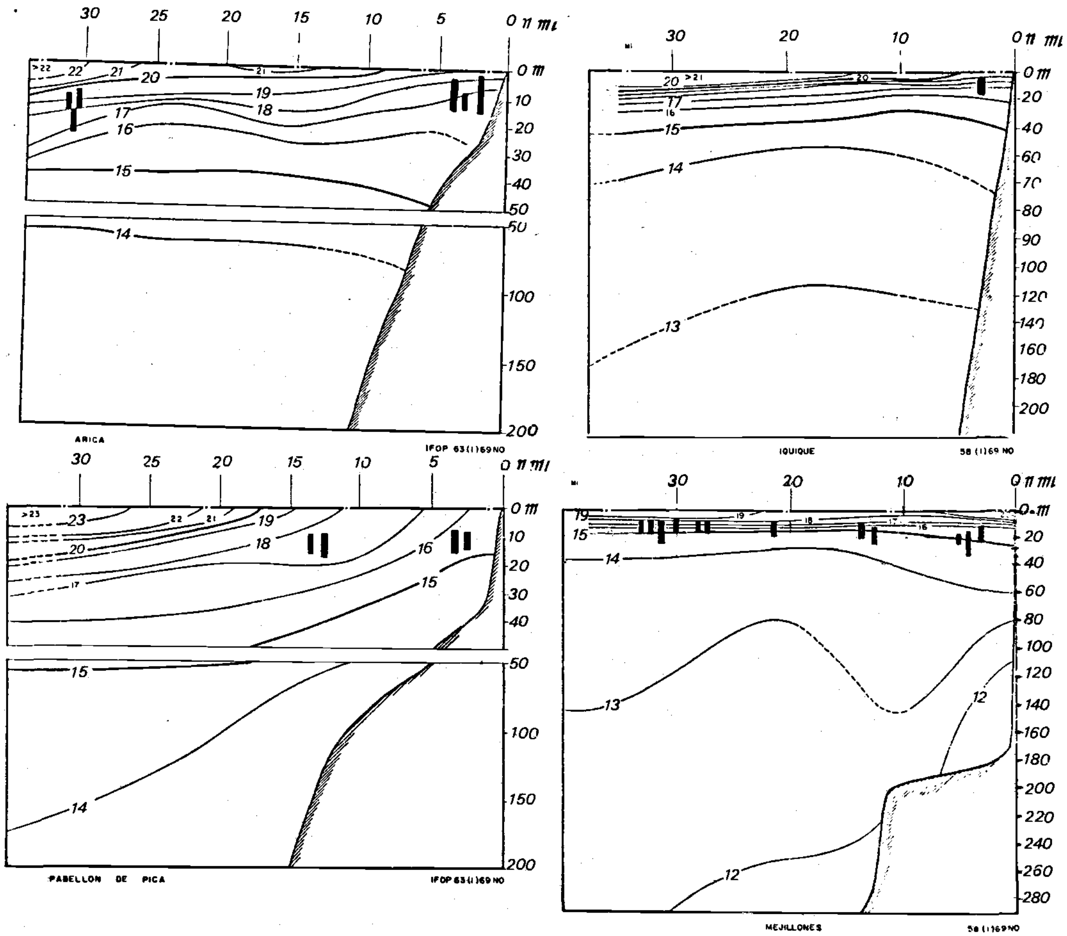


Figure 17. Selected summer temperature sections with superimposed schools of anchoveta that were detected by echosound.

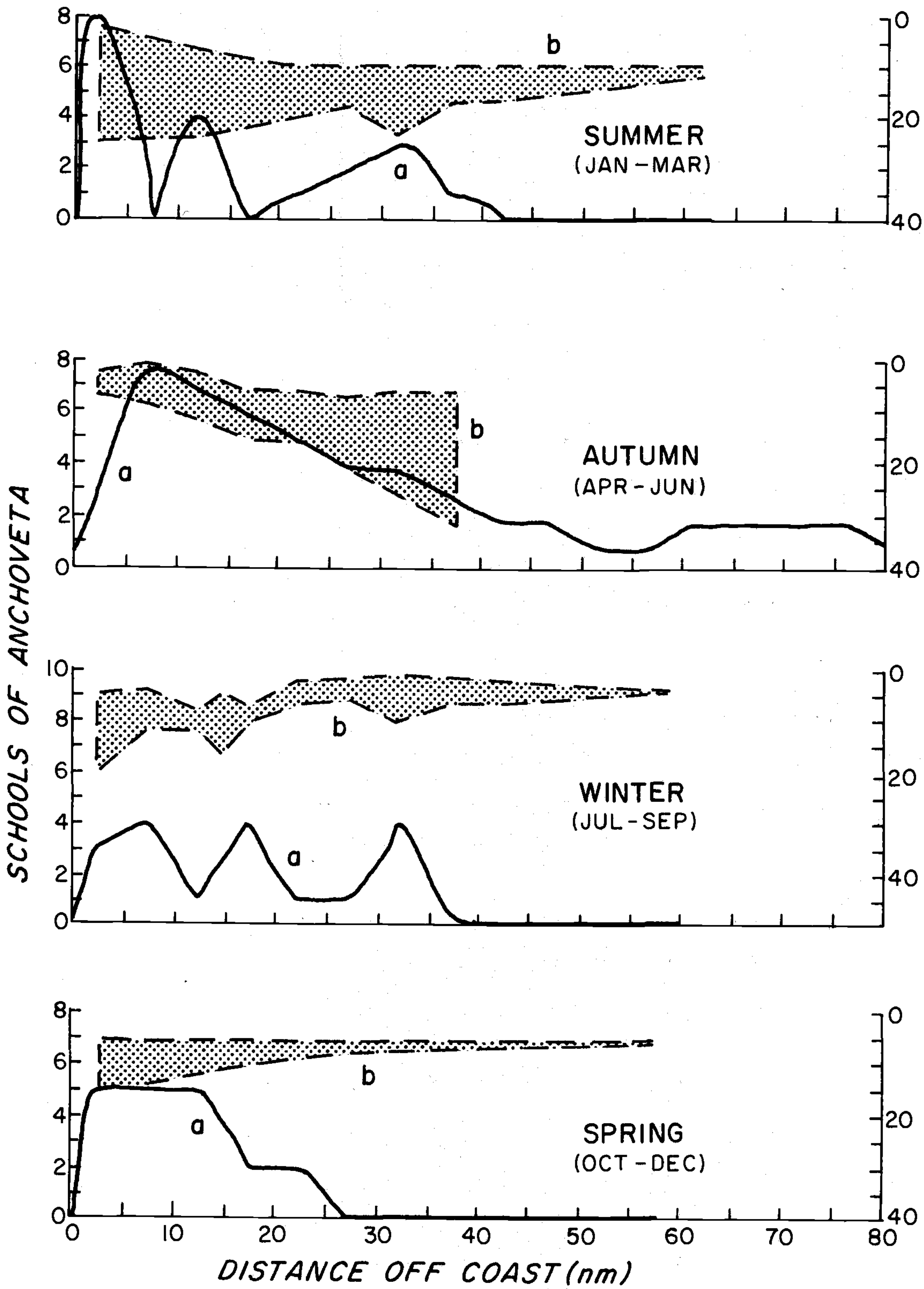


Figure 18. Number of schools of anchoveta vs. distance of the coast (a) and vs. depth (b).

Autumn (April, May and June)

During autumn schools of anchoveta were usually located where centers of upwelling had begun to develop. As the 23 C isotherm disappeared in surface waters the fish became more scattered and the resultant capture per unit of effort decreased (Figure 19). As the thermal front weakened, schools appeared widely dispersed, even as far as 60 nautical miles from shore. The relative density of schools increased from inshore to offshore. Commercial catches decreased as the fishermen had to search larger areas and travel further from shore to find schools.

Temperature profiles and echo-sounding records for autumn showed that the concentrating effect of warm water had also virtually disappeared in depth. Anchoveta now were found in warmer water than in summer. The peak of abundance of schools was found in water with a temperature of 19 C (Figure 16).

During this period the range of water temperatures in which schools were found was the widest, ranging from 15 to 22 C. It included the highest temperature (22 C) in which a school occurred during the entire period of the study.

Winter (July, August and September)

Temperatures during winter were extremely uniform in the area and ranged from 14.5 to 18.5 C. Anchoveta schools were restricted to the middle of the range (15 to 17.5 C) with a peak of abundance at 17.5 C (Figure 20).

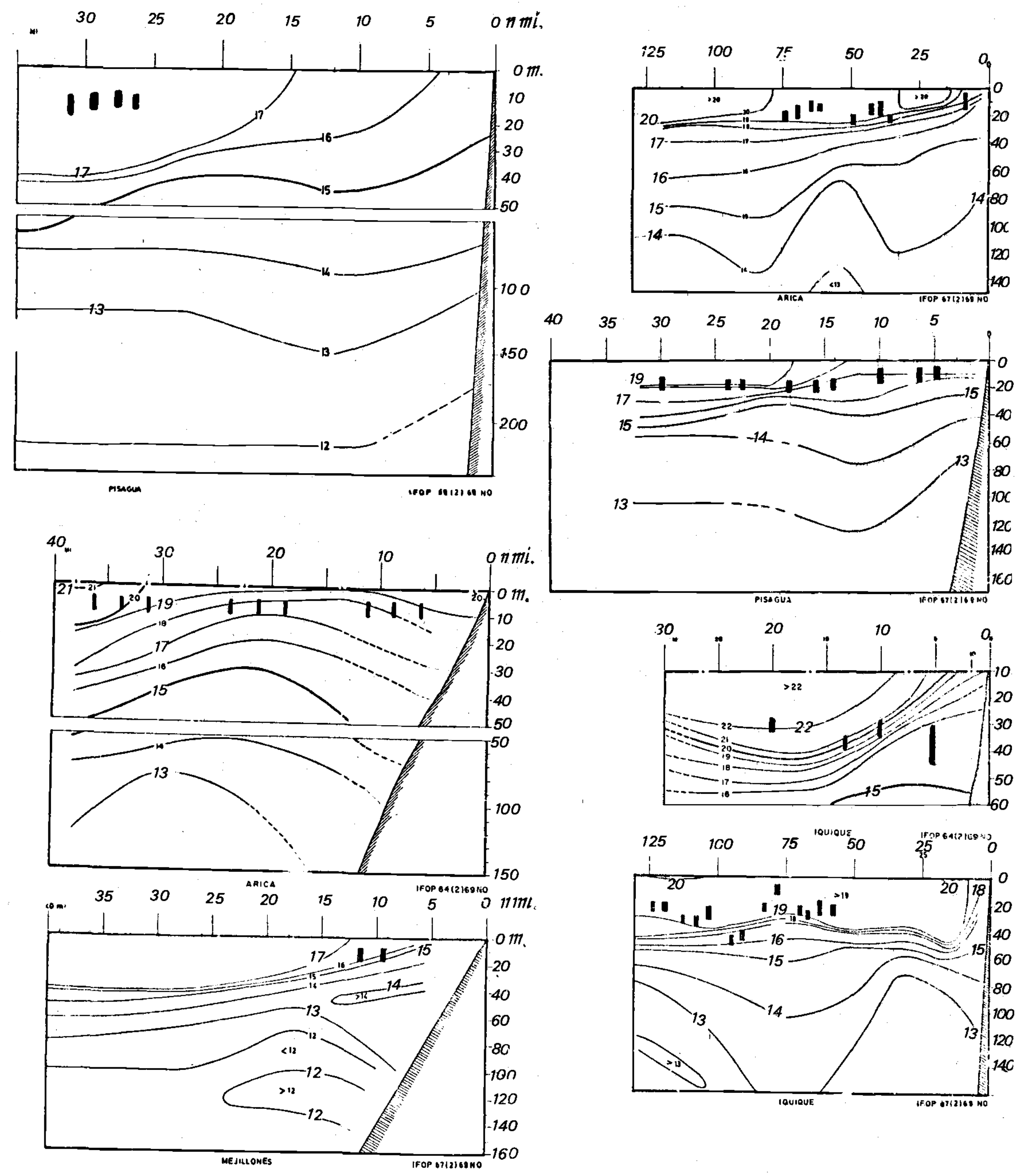


Figure 19. Selected autumn temperature sections with superimposed schools of anchoveta detected by echosound.

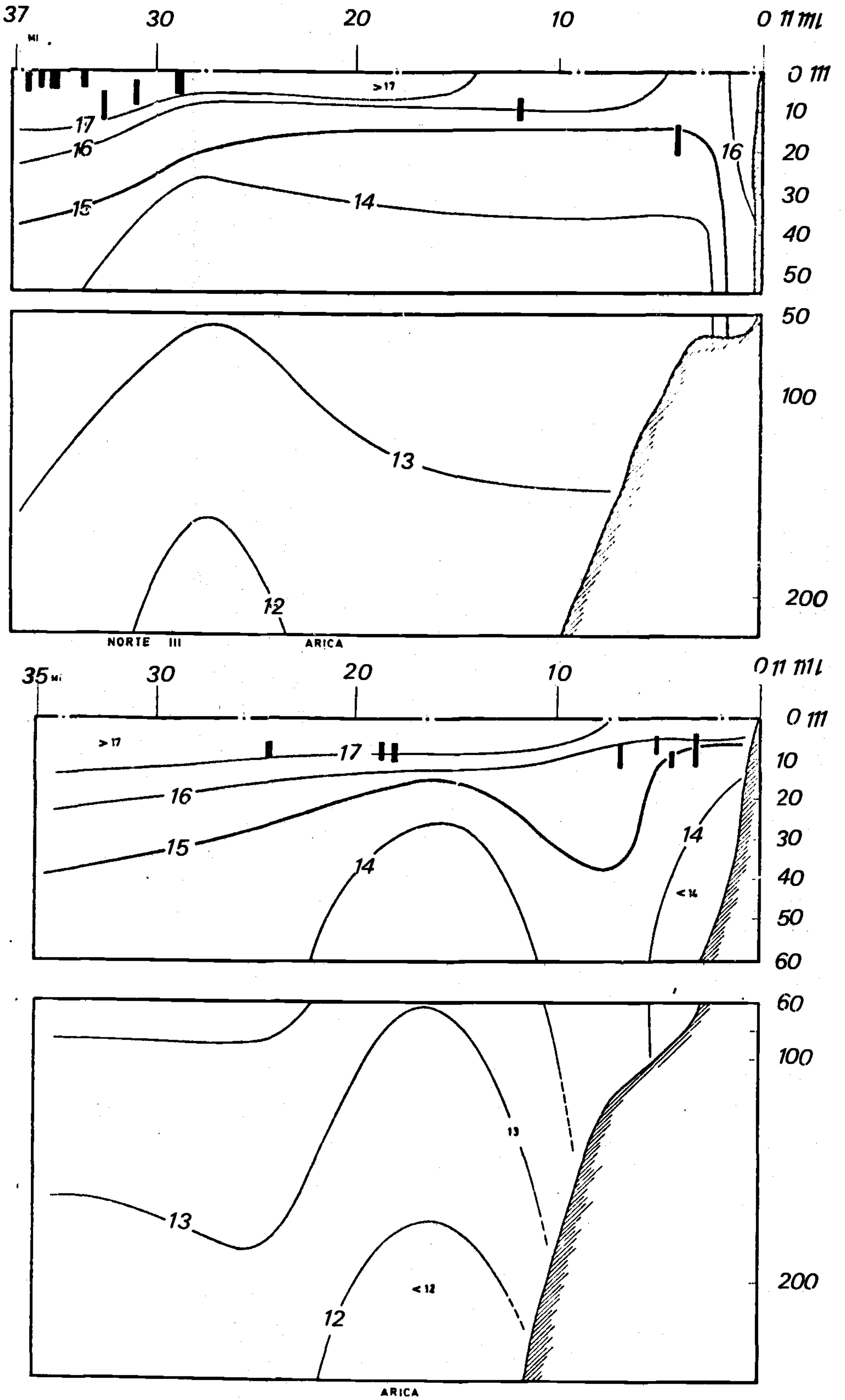


Figure 20. Seasonal selected temperature sections for Winter with superimposed schools of anchoveta that were detected by echosound.

Commercial catches were lower in winter than in autumn (Figure 11).

Schools spread in a thin layer (Figure 18) and were found uniformly distributed from the coast to offshore areas but apparently they extended farther from the coast during winter than at any other time of the year. Food may have been a limiting factor and the absence of the thermal front, especially in surface waters, permitted the fish to search for food over a larger area.

When upwelling became particularly intense in some localities, some phenomena other than temperature caused the anchoveta schools to disperse and accounted for the low catches in this season.

Spring (October, November and December)

Between 1968-1970 the lowest catches were made during spring reflecting fish distribution characteristics. Seventy-five percent of the area surveyed had no traces of anchoveta. The fish were so scattered in the remaining area that they were more difficult to fish.

Although more than 50% of the area had sea surface temperatures from 17.5 to 20.0 C, the low concentration of anchoveta far offshore suggested the development of an intrusion of warm water that pushed the anchoveta toward the coast similar to what occurs in summer.

Anchoveta schools were restricted to waters with temperatures from 15 to 20 C. The highest concentrations were found at 18.5 C (Figure 16).

There was only one temperature section, of the many made, that shows fish schools during spring (Figure 21), but it indicated that at least in this period anchoveta were distributed not by temperature but possibly by food availability. The straight line beneath which the schools were located (Figure 21) could represent the layer in which productivity and phytoplankton were maximal during spring bloom.

Seasonal Salinity Changes in Relation With School Distribution and Abundance

Salinity variations in the coastal areas of northern Chile are relatively small due to the almost complete absence of runoff and precipitation. Most of the nearshore salinity changes are related to upwelling. In the offshore area changes are considerably larger due to the intrusion of Sub-Tropical Surface Water of high salinities.

The variations affect the osmotic regulations of fish and the buoyancy of eggs. Relations between fish distributions and salinity have been observed in other species but most authors conclude advective effects are more important than the direct effects of salinity. Variations in salinity indicate changes in water mass distribution or in stability conditions (Hela and Laevastu, 1961).

Previous reports indicated that anchoveta was not present in Peruvian waters of more than 35.1‰ (Guillén et al., 1969). However, Pastor and Málaga (1966) have kept anchoveta in apparent good condition in experimental aquaria with salinities from 31.68 to 42.89 ‰ .

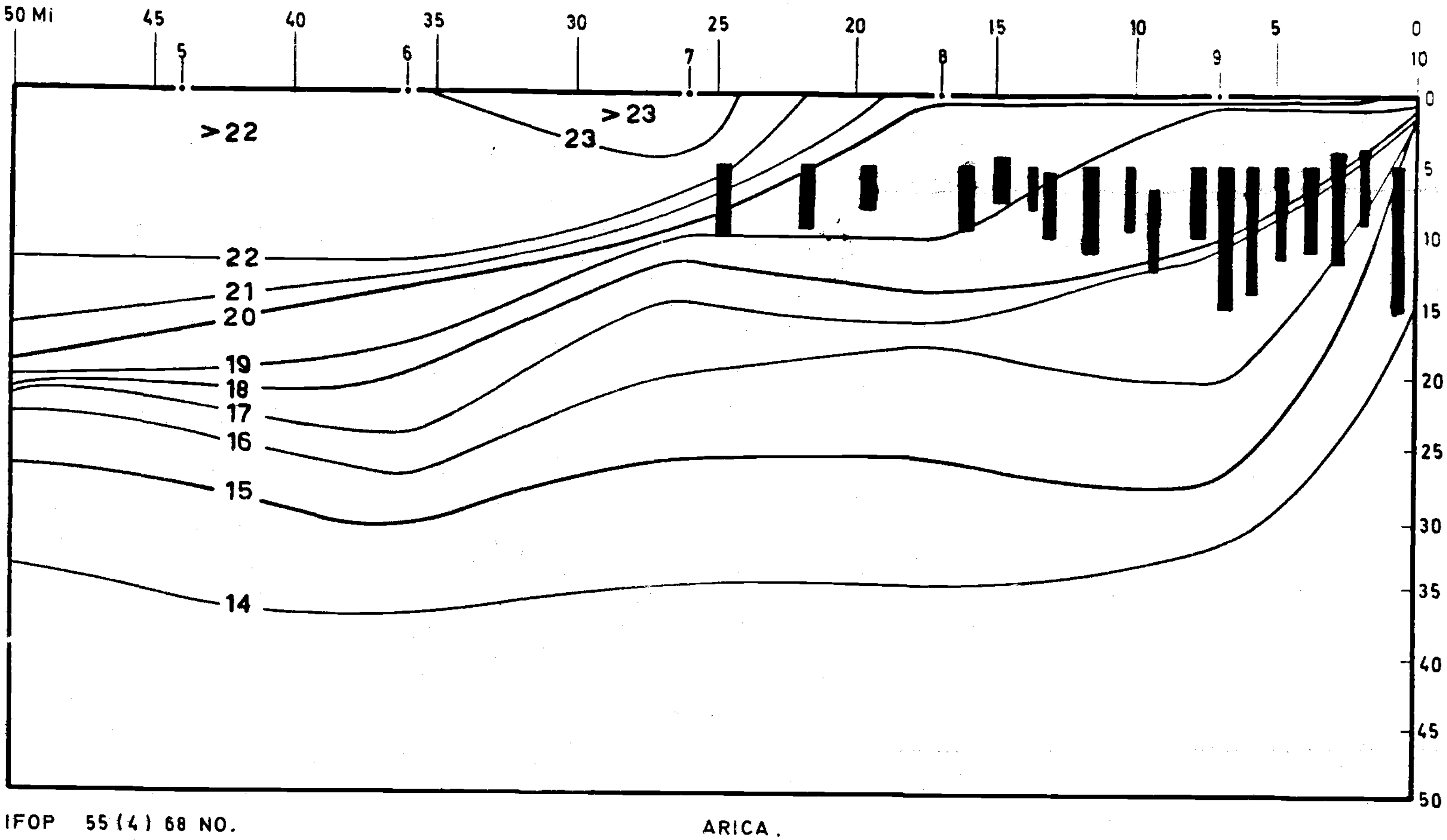


Figure 21. Seasonal selected temperature section for SPRING with superimposed schools of anchoveta detected by echosound.

Studies off Chile (Brandhorst et al., 1968; IFOP, 1969) indicated that most of the schools were found in water with salinities between 34.8 and 34.9‰.

The author's studies show that salinity is a useful indicator for describing the seasonal oceanographic fluctuations especially the intensity and relative extension of upwelling but salinity appears to have no influence per se in fish distribution.

Summer (January, February and March)

Schools of adult anchoveta during summer were mainly restricted to surface waters with salinities of 34.8 to 34.9‰ (Table 7). Larvae of anchoveta, during the same period, were always restricted to water with salinities lower than 34.8‰ suggesting differences in salinity tolerance between larvae and adult fish that should be studied in more detail.

Salinities of more than 35‰ indicate intrusion of Sub-Tropical water that constitutes a barrier in summer offshore from Arica to Mejillones. At the same time in some restricted nearshore areas the upwelling provides waters to the upper layer of relatively low salinity of Sub-Antractic origin.

Distribution of anchoveta apparently becomes restricted to the narrow band of mixture between these two surface waters in which the salinity ranges between 34.8 to 34.9‰.

Table 7. Temperature-Salinity Relationship With Fish Distribution

	Fish	Temperature (°C)	Salinity (‰)
Summer	0 . . . 62.9%	15-16 . . . 0.6%	34.6-34.7 . . . 0.6%
	1 . . . 26.2%	16-17 . . . 2.2%	34.7-34.8 . . . 10.0%
	2 . . . 8.4%	17-18 . . . 8.6%	34.8-34.9 . . . 19.3%
	3 . . . 2.1%	18-19 . . . 11.2%	34.9-35.0 . . . 25.4%
	4 . . . 0.0%	19-20 . . . 14.7%	35.0-35.1 . . . 21.3%
		20-21 . . . 15.8%	35.1-35.2 . . . 17.8%
		21-22 . . . 17.4%	35.2-35.3 . . . 4.9%
		22-23 . . . 14.3%	
		23-24 . . . 13.6%	
		24-25 . . . 2.2%	
Autumn	0 . . . 64.9%	15-16 . . . 1.5%	34.5-34.6 . . . 0.2%
	1 . . . 22.7%	16-17 . . . 10.0%	34.6-34.7 . . . 6.6%
	2 . . . 10.8%	17-18 . . . 21.3%	34.7-34.8 . . . 9.8%
	3 . . . 0.7%	18-19 . . . 15.1%	34.8-34.9 . . . 18.1%
	4 . . . 0.7%	19-20 . . . 33.3%	34.9-35.0 . . . 40.2%
		20-21 . . . 17.7%	35.0-35.1 . . . 9.6%
		21-22 . . . 0.7%	35.1-35.2 . . . 11.7%
			35.2-35.3 . . . 5.8%
			35.3-35.4 . . . 0.5%
Winter	0 . . . 68.5%	14-15 . . . 1.5%	34.7-34.8 . . . 13.5%
	1 . . . 25.7%	15-16 . . . 21.2%	34.8-34.9 . . . 28.0%
	2 . . . 4.4%	16-17 . . . 39.1%	34.9-35.0 . . . 26.1%
	3 . . . 0.9%	17-18 . . . 36.5%	35.0-35.1 . . . 28.0%
	4 . . . 0.9%	18-19 . . . 1.7%	35.1-35.2 . . . 4.4%
Spring	0 . . . 75.0%	13-14 . . . 0.2%	34.7-34.8 . . . 5.8%
	1 . . . 18.0%	14-15 . . . 0.7%	34.8-34.9 . . . 36.2%
	2 . . . 6.0%	15-16 . . . 2.5%	34.9-35.0 . . . 33.6%
	3 . . . 0.5%	16-17 . . . 8.8%	35.0-35.1 . . . 22.7%
	4 . . . 0.5%	17-18 . . . 24.7%	35.1-35.2 . . . 1.4%
		18-19 . . . 12.9%	35.2-35.3 . . . 0.2%
		19-20 . . . 20.5%	
		20-21 . . . 10.2%	
		21-22 . . . 6.1%	
		22-23 . . . 5.5%	
		23-24 . . . 5.2%	
		24-25 . . . 3.8%	

Autumn (April, May and June)

The concentration of anchoveta schools in waters with high salinities was more pronounced during autumn than during the summer in the northern area where salinities greater than 35.0 ‰ predominated. The fishery declined in autumn and was found mainly in the northern area.

During this period upwelling sometimes brought to the surface more saline waters of the Undercurrent rather than Sub-Antarctic waters.

Winter (July, August and September)

During winter the fisheries declined still more, while the seasonal salinity pattern remained similar to that found in autumn. Upwelling was more intense and reflected by more uniform salinities in the area as the more intense upwelling the more deeply the waters are involved, especially those of equatorial subsurface origin. However the possible explanation for low catches seems to be related more to oxygen than to salinity causes, as waters appear in the range between 34.8-34.9 ‰ which is near the optima for the anchoveta.

Spring (October, November and December)

The pattern of salinity distribution during early spring resembled that of winter, suggesting similar processes. During spring, and particularly during the month of October, the lowest catches were recorded. Concentrations of fishes began to form offshore, especially late in

November and December when the intrusion of Sub-Tropical saline waters began.

Seasonal Oxygen Changes in Relation to School Distribution and Abundance

The low oxygen concentrations of the Peru-Chile Undercurrent water have not been previously demonstrated to limit the anchoveta off northern Chile, although Brandhorst (1959) indicated a relationship between the fluctuations of the hake fishery and these low oxygen concentrations in central and southern Chile.

When the oxygen minimum layer of the Peru-Chile Undercurrent with subsurface equatorial waters of low oxygen is brought up during upwelling periods, the anchoveta appears to avoid such low oxygen concentrations and to migrate into upper layers and occasionally rise to surface waters in a phenomenon called locally "pateaderas" i.e. schools jumping in the surface waters. This behavior is frequently observed in coastal waters off northern Chile.

In the narrow coastal band where tidal action and wave action are more intense there is consequently more oxygen and we find good concentrations of anchoveta. Sometimes when anchoveta are forced to the beach, mass mortalities occur. This phenomenon has always been explained as a result of avoidance of high temperatures, but it now appears that the low oxygen explanation may be more correct.

The new hypothesis finds support from various oxygen sections drawn during Project NORTE and specifically in those sections drawn after Cruise IFOP 50 (4) 69 SM. In Figures 22, records of anchoveta schools have been superimposed on oxygen sections. In every transect the schools occur above the oxycline, and not in the oxygen poor layer of less than 0.5 ml/l.

These sections reveal that, on the average, the anchoveta lives in waters of 4.0 ml/l of O_2, and when water with low O_2 content upwells they become concentrated into the upper layers.

The effect of oxygen-poor water on the anchoveta distributions during upwelling is illustrated in Figure 23. In Figure 23a before upwelling the anchoveta appear dispersed above the O_2 discontinuity layer. After strong upwelling (Figure 23b), the anchoveta are concentrated in dense schools near shore in the upper 20 m and are easily available to the fishermen.

The fact that oxygen can be a limiting factor in the vertical distribution of anchoveta schools is partially supported by work on other clupeides. Suehiero (1951) reported that *Sardinops melanostica* and *Engraulis japonica* showed signs of difficulty at about 3 ml/l in experimental conditions. The average lethal oxygen concentrations for *S. melanostica* was 2.02 ml/l and for *E. japonica* 1.82 ml/l. Kamshylov and Geramisov (1960) found that young Murman herring died at oxygen values below 2 ml/l in experimental conditions.

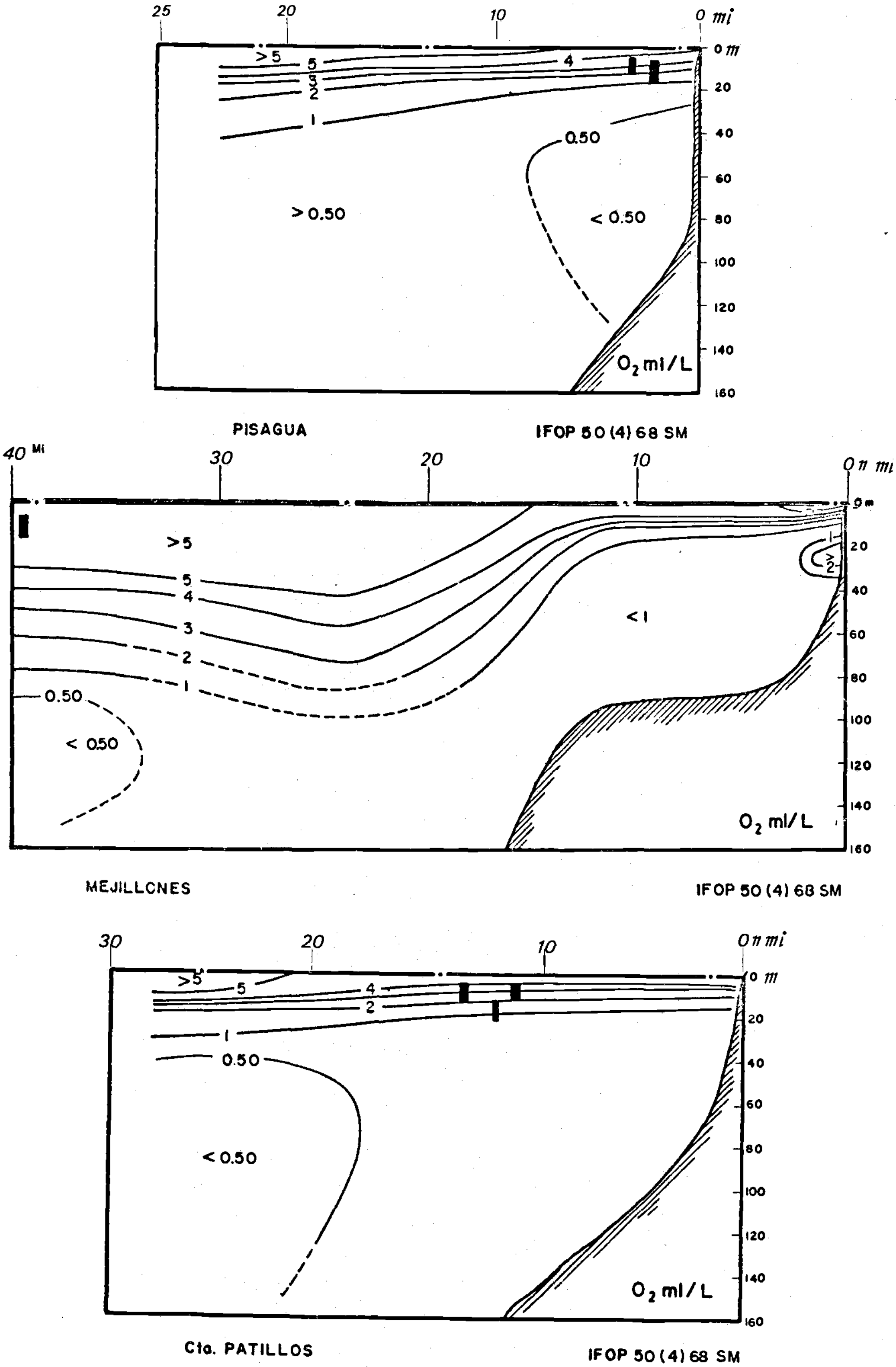
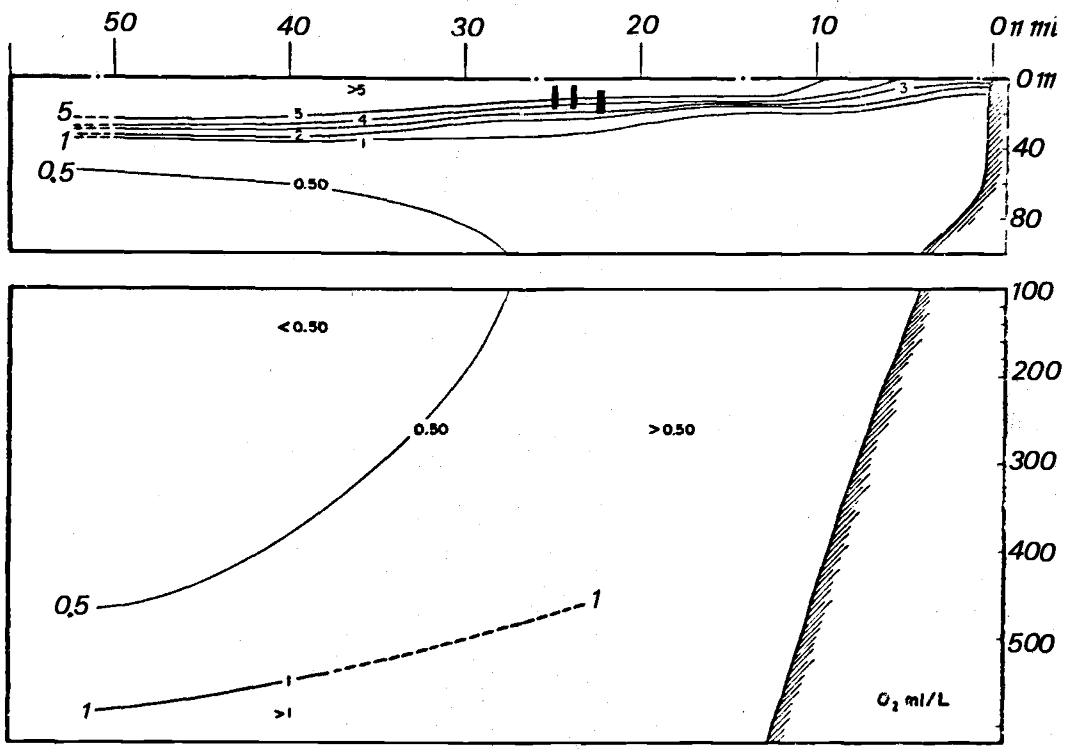
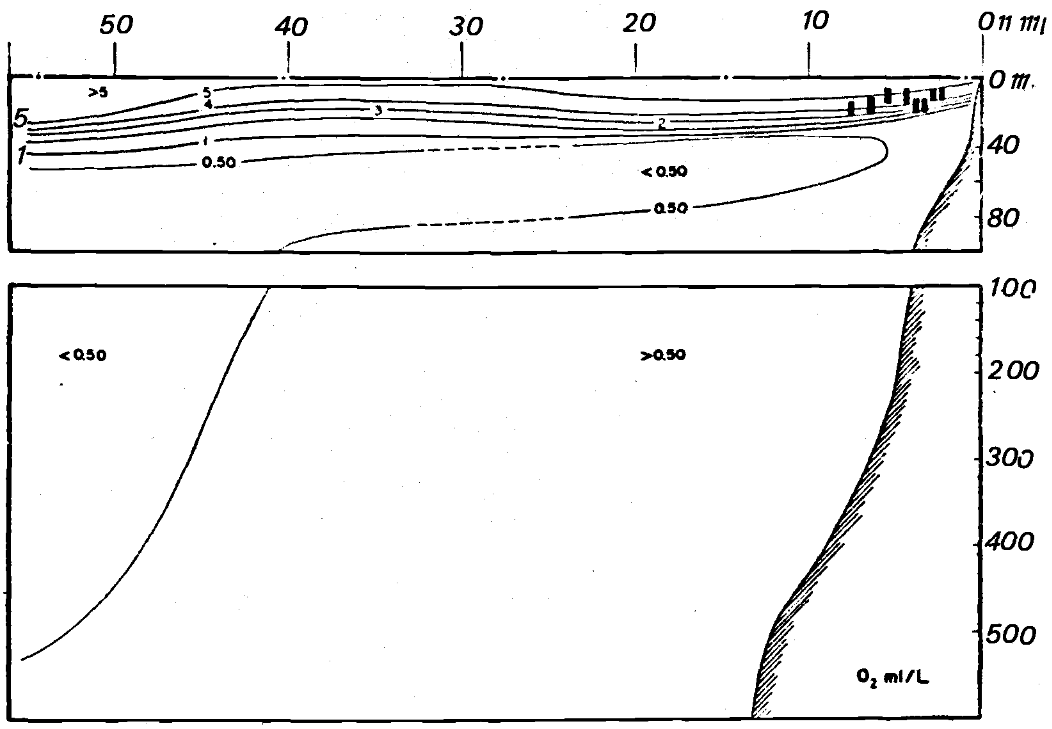


Figure 22. Selected oxygen sections off northern Chile with superimposed schools of anchoveta detected by echosound (depth in meters; distance from the coast in nautical miles).



Pta. ARGOLLA

IFOP 50 (4) 68 SM



ARICA

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Figure 22. (continued)

If *E. ringens* also avoids low oxygen concentrations, as it appears that they do, the explanation for the occasional mass mortality near-shore appears more plausibly explained by the low oxygen values reaching the surface in coastal waters than by the effect of concentration of waters of high temperature, as high temperatures affect only the surface waters and anchoveta could drop deeper where the temperature is less.

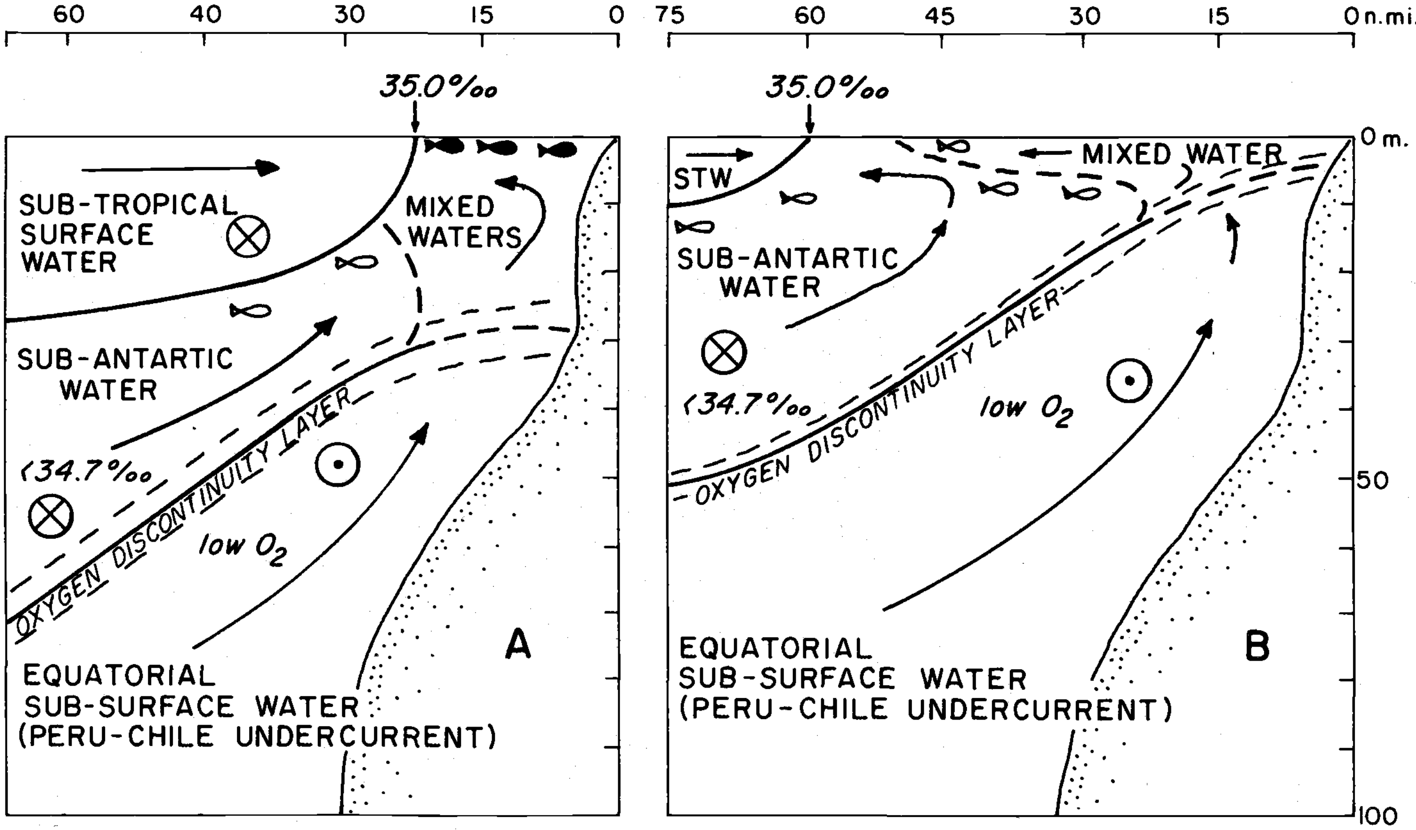
Upwelling and Anchoveta Distribution and Abundance

The upwelling mechanism in northern Chile has the well known effect of bringing nutrients to surface layers. It may also have a secondary and significant effect for the anchoveta fishery by limiting its vertical distribution. This limiting factor is related to the low oxygen concentrations of Equatorial Subsurface water of the Peru-Chile Undercurrent which appears to be avoided by the anchoveta.

Most observations suggest that a seasonal variation in upwelling intensity occurs off northern Chile. The intensity of the upwelling appears to determine which water mass is involved in the process.

During the summer (Figure 23a), when upwelling is less intense, the shallower Sub-Antarctic water is upwelled. The oxygen-poor Equatorial Subsurface water also rises, thus limiting anchoveta to the shallower upwelled water.

During the winter (Figure 23b), upwelling is more intense and the oxygen-poor water may rise so close to the surface that schools are forced further offshore.



a) Summer: low upwelling and strong intrusion of Sub-Tropical Water. Dense Anchoveta schools ( ) are mostly concentrated nearshore. Some Very Scattered schools ( ) offshore.

b) Winter: strong upwelling. No intrusion of Sub-Tropical Water nearshore. Very Scattered anchoveta schools ( ) disperse in large area.

Figure 23. Upwelling and anchoveta distribution and abundance .
a) Summer b) Winter

These conclusions are supported by the fact that most intense upwelling areas are not the most important fishing grounds, either in Peru or in northern Chile. However, despite the fact that strong upwelling tend to disperse the fish and give a low catch per unit effort over short periods, strong upwelling during a season as a whole must increase the productivity of the water and consequently the anchoveta population would yield larger catches over long periods of time.

A seasonal description of events with figures explains the oxygen hypothesis in more detail.

Summer (January, February and March)

Upwelling is present during summer in northern Chile with a low intensity pattern (Figure 23a), and serves a twofold function with the anchoveta distribution. Warm, saline, Sub-Tropical water intrudes coastward, confining the anchoveta to a narrow band of upwelled Sub-Antarctic water. Oxygen-poor water below the upwelled water limits the fish to the upper 20-30 m. These two processes permit the greatest catches per unit of effort of the entire year. A latitudinal progression of this condition from north to south appears during some years, and the fish catches follow.

During some exceptional years the process is complicated by meteorological anomalies which affect the oceanographic regime, giving rise to a false "El Niño" along the coast of northern Chile. The extreme low catches apparently are better explained by the strength of the Sub-Tropical front which is pushed to the coast covering the narrow upwelled waters with relatively well oxygenated but warm waters decreasing fish availability because the fish are forced deeper, to 40-50 m, where the net cannot reach them.

Autumn (April, May and June)

As the thermal Sub-Tropical front begins to disappear during autumn, upwelling increases slightly, shifting to a stronger pattern like the one shown in Figure 23b. The weakness of the thermal front allows both high productive zone and the anchoveta schools to disperse gradually offshore. This migration is partially forced by the low oxygen barrier being brought closer to the surface during upwelling.

The offshore migration has been suggested many times as an explanation for the sudden decrease in fish abundance after the summer season in northern Chile, but definite proof is lacking because tagging experiments have not been made in the zone. My observations of anchoveta schools during infrared aerial surveys of sea-surface temperature show that at least some schools occur offshore (Cañon, 1968). The seasonal distributions of anchoveta obtained during this study (Figures 10 and 18) indicate that the pattern of schools changes appreciably in autumn, suggesting an offshore migration.

Winter (July, August and September)

During winter, upwelling increases even more, and some of the oxygen-poor water of the Peru-Chile Undercurrent begins to rise closer to the surface, especially in late winter when the cumulative effect of strong southerly winds becomes more noticeable. The Sub-Tropical thermal front completely disappears and the anchoveta are no longer concentrated by temperature gradients as in summer.

However winter is also a better spawning season and some dense schools of sexually mature anchoveta appear in restricted shallow coastal areas where upwelling is weak because of localized topographic features (e.g. off Arica, Rio Loa, and Mejillones).

A possible physical oceanographic mechanism, present during this season, could also explain the low-oxygen layer of the Undercurrent near the surface, limiting the anchoveta. This is caused by strong southerly winds that produce the upwelling and increase the speed of the Peru Coastal Current. As the offshore Ekman transport becomes stronger, the isopycnals tend to deflect toward the surface in coastal areas. By the thermal wind mechanism the shear in lower layers increases and so the Undercurrent may also be increased in strength and speed. As the Undercurrent carries low-oxygen waters, oxygen could explain low catches during iwnter, especially as temperature and salinity appear to be optimum.

Spring (October, November and December)

Upwelling becomes even more intense during early spring approaching more closely the strong upwelling pattern (Figure 23b). Low-oxygen waters brought near the surface in October and middle November in coastal areas reduce the concentrations of fish schools. As the season progresses, winter spawning concentrations disappear and anchoveta are well dispersed resulting in the poorest yearly catches.

By mid-November the thermal Sub-Tropical front begins to advance toward the coast, and upwelling decreases sharply. The anchoveta are forced toward the coast where an environment rich in food is found. As these conditions develop, commercial catches increase during December, announcing the summer peak which follows.

Conclusion

The results of three years of cruises in northern Chile reveal that fish distribution apparently is dictated by an interaction of two major oceanographic phenomena: the presence of a warm Sub-Tropical front and the mechanism of upwelling. These two act together or sometimes separately. The sub-tropical warm and saline front acts mainly in the horizontal plane pushing anchoveta toward the coast especially during summer months, while upwelling, when more intense (winter and early spring) brings up low oxygen water producing a limiting effect in the vertical plane.

Anchoveta then are limited by high temperatures and high salinities of the front as well as by low oxygen concentrations of the upwelled waters. These two factors interact in different ways in different seasons; they control the migration and concentration of the anchoveta.

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APPENDICES

APPENDIX 1.

Glossary

Compañía Administradora del Guano - Perú, or Peruvian Agency for the exploitation of the Guano.

Consejo de Investigaciones Hidrobiologicas - Peru, or Conseil of Hydrobiological Research in Peru.

Corporacion de Fomento de la Produccion (CORFO) - Chile, or Agency for the Industrial Development.

Empresa Publica de Servicios Pesqueros - Peru (EPSEP), or State fisheries service corporation of Peru.

Empresa Pesquera de Comercializacion de Harina y Aceita del Peru, or State fish meal and fish oil marketing corporation of Peru.

Departamento de Pesca y Caza - Chile, or Fisheries and Wildlife Service, Chile.

Estacion de Biologia Marina - Montemar - Chile, or Marine Biological Station of the University of Chile at Montemar, Valparaiso, Chile.

Instituto de Fomento Pesquero (IFOP) - Chile, or Fisheries Development Institute.

Instituto de Investigaciones de los Recurso Marinos - Peru, or Research Institute of Marine Resources in Peru.

Instituto del Mar del Peru (IMARPE) - Peru, or Fisheries Research Institute of Peru.

Junta de Adelanto de Arica (Chile), or Council for the Development of Arica (Chile).

Laboratorio de Biologia Pesquera y Oceanografia (Chile), or Fisheries, Biological, and Oceanographical Laboratory (a dependency of the Ministry of Agriculture).

Ministerio de Agricultura - Chile, or Ministry of Agriculture in Chile.

Sociedad Nacional de Pesqueria (Peru), or Peruvian National Society of Fishermen.

APPENDIX II.

List of Cruises Used in the Study

Number of the Cruise	Name	Area Survey	Period
41 (4) 67 CD	IFOP-13	Arica-Huasco	Nov-Dec 1967
45 (3) 68 NO	NORTE I	Arica-Mejillones	July 1968
47 (3) 68 NO	NORTE II	Arica-Mejillones	August 1968
49 (3) 68 NO	NORTE III	Arica-Mejillones	September 1968
50 (4) 68 SM	ANÇHOVETA I	Arica-Antofagasta	November 1968
52 (4) 68 NO	NORTE IV	Arica-Mejillones	October 1968
53 (4) 68 NO	NORTE V	Arica-Mejillones	November 1968
55 (4) 68 NO	NORTE VI	Arica-Mejillones	December 1968
56 (1) 69 NO	NORTE VII	Arica-Mejillones	January 1969
58 (1) 69 NO	NORTE VIII	Arica-Mejillones	February 1969
63 (1) 69 NO	NORTE IX	Arica-Mejillones	March 1969
64 (2) 69 NO	NORTE X	Arica-Mejillones	April 1969
67 (2) 69 NO	NORTE XI	Arica-Mejillones	May 1969
68 (2) 69 NO	NORTE XII	Arica-Mejillones	June 1969
69 (3) 69 NO	NORTE XIII	Arica-Mejillones	July 1969
70 (3) 69 NO	NORTE XIV	Arica-Mejillones	August 1969
72 (3) 69 NO	NORTE XV	Arica-Mejillones	September 1969
75 (4) 69 NO	NORTE XVI	Arica-Mejillones	December 1969
77 (1) 70 NO	NORTE XVII	Arica-Mejillones	February 1970
79 (1) 70 NO	NORTE XVIII	Arica-Mejillones	March 1970
82 (2) 70 NO	NORTE XIX	Arica-Mejillones	May 1970
83 (3) 70 NO	NORTE XX	Arica-Mejillones	July 1970
86 (3) 70 NO	NORTE XXI	Arica-Mejillones	September 1970
89 (4) 70 NO	NORTE XXII	Arica-Mejillones	November 1970

APPENDIX III.

Seasonal Distribution of the 24 Cruises Used in the Present Study

Year	Spring	Summer	Autumn	Winter
1967-68	3	1	--	3
1969	2	3	3	3
1970	1	2	1	2
TOTAL	6	6	4	8

APPENDIX IV. Seasonal Distribution of Temperature: Summer

	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
Area Between	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	1,825 85.9	2,150 76.1	2,175 71.9	2,075 64.3	1,875 72.1	1,275 72.8	11,275 73.15%
Temperature Range (°C)							
15-16	---	---	75 3.4	---	---	---	75 0.65%
16-17	25 1.4	100 4.6	100 4.6	25 1.2	---	---	250 2.20%
17-18	50 2.7	400 18.6	200 9.2	250 12.0	50 2.7	25 2.0	975 8.60%
18-19	125 6.8	200 9.3	250 11.5	375 18.0	300 16.0	25 2.0	1,275 11.20%
19-20	425 23.3	225 10.5	175 8.0	250 12.0	300 16.0	300 23.5	1,675 14.70%
20-21	425 23.3	175 8.1	225 10.3	250 12.0	225 12.0	500 39.2	1,800 15.80%
21-22	525 28.7	125 5.8	200 9.2	350 16.9	450 24.0	325 25.5	1,975 17.40%
22-23	250 13.7	225 10.5	250 11.5	375 18.1	425 22.7	100 7.8	615 14.3%
23-24	---	500 23.3	675 31.0	250 12.0	100 5.4	---	1,550 13.6%
24-25	---	200 9.3	50 2.3	---	---	---	250 2.2%

APPENDIX V.

Seasonal Distribution of Temperature: Autumn

	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
Area Between	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	1,625	1,450	1,800	1,775	1,850	425	8,925
	76.5	51.3	59.5	55.1	71.2	24.3	57.6%
Temperature Range (°C)							
15-16	12.5	---	25	---	---	100	137.5
	0.8		1.4			23.5	1.54%
16-17	225	50	100	50	275	200	900
	13.8	3.5	5.6	2.8	14.9	47.1	10.1%
17-18	175	200	425	575	450	75	1,900
	10.8	13.8	23.6	32.4	24.3	17.7	21.3%
18-19	250	275	400	150	225	50	1,350
	15.4	19.0	22.2	8.5	12.2	11.8	15.1%
19-20	525	500	575	825	550	---	2,975
	32.3	34.5	31.9	46.5	29.7		33.3%
20-21	350	425	275	175	350	---	1,575
	21.5	29.3	15.3	9.9	18.9		17.6%
21-22	75	---	---	---	---	---	75
	4.6						0.7%

APPENDIX VI.

Seasonal Distribution of Temperature: Winter

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	2,025	1,850	2,025	2,300	2,175	925	11,300 72.7%
Temperature Range (°C)							
14-15	---	---	---	100 4.3	25 1.1	50 5.4	175 1.5%
15-16	325 16.0	100 5.4	350 17.3	350 15.2	775 35.6	500 54.1	2,400 21.2%
16-17	825 40.7	625 33.8	475 23.5	750 32.6	1,750 62.1	375 40.6	4,400 39.0%
17-18	800 39.5	1,000 54.1	1,200 59.3	1,100 47.8	25 1.1	---	4,125 36.5%
18-19	75 3.7	125 6.8	---	---	---	---	200 1.8%

APPENDIX VII. Seasonal Distribution of Temperature: Spring

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	1,400	2,050	2,250	2,750	2,375	200	11,025
	65.9	72.6	74.4	85.3	91.3	11.4	70.9%
Temperature Range (°C)							
13-14	---	---	---	12.5	12.5	---	25
				0.5	0.5		0.22%
14-15	---	---	---	25	25	25	75
				0.9	1.1	12.5	0.7%
15-16	---	---	---	50	175	50	275
				1.8	7.4	25.0	2.5%
16-17	---	200	125	100	425	125	975
		9.7	5.5	3.6	17.9	2.5	8.8%
17-18	250	275	375	150	1,650	25	2,750
	17.9	13.4	16.7	5.5	69.5	12.5	24.7%
18-19	300	250	500	300	75	---	1,425
	21.4	12.2	22.2	10.9	2.9		12.9%
19-20	300	875	750	325	12.5	---	2,262.5
	21.4	42.7	33.3	11.8	0.5		20.5%
20-21	400	325	250	150	---	---	1,125
	28.6	15.9	11.1	5.5			10.2%
21-22	125	75	125	325	---	---	650
	8.9	3.7	5.6	11.8			5.9%
22-23	25	50	50	375	---	---	600
	1.9	2.4	2.2	13.6			5.4%
23-24	---	---	75	500	---	---	575
			3.3	18.2			5.4%
24-25	---	---	---	425	---	---	425
				15.5			3.9%

APPENDIX VIII.

Seasonal Salinity Distribution: Summer

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	2,025	2,275	2,600	2,725	2,250	1,300	13,175
	95.3	80.5	86.0	84.5	86.5	74.3	84.72%
Salinity Range (‰)							
34.6-34.7	---	---	---	---	75	---	75
					3.3		0.56%
34.7-34.8	50	---	25	325	250	675	1,325
	2.5		1.0	11.9	11.1	51.9	10.05%
34.8-34.9	375	375	275	425	750	425	2,625
	18.5	16.5	10.6	15.6	33.3	32.7	19.29%
34.9-35.0	675	550	700	950	400	75	3,350
	33.4	24.2	26.9	34.9	17.8	5.7	25.42%
35.0-35.1	925	300	400	300	750	125	2,800
	45.7	13.2	15.4	11.0	33.3	9.6	21.25%
35.1-35.2	---	600	1,000	725	25	---	2,350
		26.4	38.5	26.6	1.1		17.83%
35.2-35.3	---	450	200	---	---	---	650
		19.8	7.7				4.93%

APPENDIX IX. Seasonal Salinity Distribution: Autumn

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	1,800	2,075	1,775	900	2,350	500	9.400
	84.7	73.5	58.7	27.9	90.4	28.6	60.5%
Salinity Range (‰)							
34.5-34.6	---	---	---	---	---	25	25
						5.0	0.3%
34.6-34.7	350	---	---	---	25	250	625
	19.4				1.0	50.0	6.6%
34.7-34.8	150	100	75	---	450	150	925
	8.3	4.8	4.2		19.1	30.0	9.8%
34.8-34.9	325	150	125	375	650	75	1,700
	18.1	7.2	7.0	41.7	27.7	15.0	18.1%
34.9-35.0	400	600	1,200	450	1,125	---	3,775
	22.2	28.9	67.6	50.0	47.9		50.2%
35.0-35.1	150	350	225	75	100	---	900
	8.3	16.9	12.7	8.3	4.3		9.6%
35.1-35.2	250	550	300	---	---	---	1,100
	13.9	26.6	17.1				11.7%
35.2-35.3	175	300	75	---	---	---	550
	9.7	14.5	4.2				5.9%
35.3-35.4	---	25	25	---	---	---	50
		1.2	1.4				0.5%

APPENDIX X.

Seasonal Distribution of Salinity: Winter

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Area Survey	2,125 100	2,275 80.5	2,850 94.2	2,225 69.0	2,150 82.7	800 45.7	12,425 79.9%
Salinity Range (‰)							
34.7-34.8	---	25 1.1	275 9.6	50 2.2	800 37.2	525 65.6	1,675 13.5%
34.8-34.9	100 4.7	150 6.6	800 28.1	875 39.3	1,300 60.5	250 31.3	3,475 27.9%
34.9-35.0	900 42.4	400 17.6	700 24.6	1,200 53.9	25 1.2	25 3.1	3,250 26.2%
35.0-35.1	1,000 47.1	1,500 65.9	850 29.3	100 4.5	25 1.2	---	3,475 28.0%
35.1-35.2	125 5.9	200 8.8	225 7.9	---	---	---	550 4.4%

APPENDIX XI.

Seasonal Distribution of Salinity: Spring

Area Between	18-19°S 2,125	19-20°S 2,825	20-21°S 3,025	21-22°S 3,225	22-23°S 2,600	23-24°S 1,750	Total Area (sq. n. mi.) 15,550
Area Survey	1,625 76.5	2,375 84.1	2,025 68.6	2,350 72.9	2,050 78.9	300 17.1	10,775 69.3%
Salinity Range (‰)							
34.7-34.8	---	---	50 2.4	275 11.7	250 12.2	50 16.7	625 5.8%
34.8-34.9	125 7.7	650 27.4	775 37.3	350 14.9	1,750 85.4	250 83.3	3,900 36.2%
34.9-35.0	1,060 64.6	650 27.4	525 25.3	1,350 57.4	50 2.4	---	3,625 33.6%
35.0-35.1	450 27.7	1,000 42.1	625 30.1	375 16.0	---	---	2,450 22.7%
35.1-35.2	---	75 3.2	75 3.6	---	---	---	150 1.4%
35.2-35.3	---	---	25 1.2	---	---	---	25 0.2%

APPENDIX XII.

Fish Distribution and Abundance: Summer

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Mean Area Survey	1,650 77.6	1,325 47.0	1,900 62.8	1,275 39.5	1,375 52.9	775 44.3	8,270 53.4%
No fish (0)	725 43.9	775 58.5	1,650 84.2	1,150 90.2	700 50.9	275 44.3	4,275 63.0%
Very Scattered (1)	750 45.5	550 41.5	100 5.3	125 9.8	300 21.8	350 45.2	2,175 26.3%
Scattered (2)	150 9.1	---	125 6.6	---	325 23.6	100 13.0	700 8.4%
Dense (3)	25 1.5	---	75 3.9	---	25 1.8	50 6.5	175 2.3%
Very dense (4)	---	---	---	---	---	---	---

APPENDIX XIII.

Fish Distribution and Abundance: Autumn

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Mean Area Survey	1,625 76.5	1,375 48.7	1,600 52.9	800 24.8	1,100 42.3	200 11.4	6,700 43.2%
No fish (0)	725 44.6	1,000 72.7	925 57.8	625 78.1	875 79.6	200 100	4,350 64.9%
Very Scattered (1)	625 38.5	175 12.7	450 28.1	150 18.7	125 11.4	---	1,525 22.8%
Scattered (2)	250 15.4	200 14.6	225 14.1	25 3.1	25 2.3	---	725 10.8%
Dense (3)	25 1.6	---	---	20 2.3	25 2.3	---	50 0.7%
Very dense (4)	---	---	---	---	50 4.5	---	50 0.7%

APPENDIX XIV.

Fish Distribution and Abundance: Winter

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Mean Area Survey	1,925 90.6	1,775 62.3	1,750 57.9	1,375 42.6	1,075 41.3	675 38.6	8,575 55.1%
No fish (0)	1,000 51.9	1,100 62.0	1,500 85.7	875 62.6	875 81.4	525 77.8	5,875 68.5%
Very Scattered (1)	825 42.9	475 26.8	250 14.3	300 21.8	200 18.6	150 22.2	2,200 25.7%
Scattered (2)	50 2.6	175 9.9	---	150 10.9	---	---	375 4.4%
Dense (3)	25 1.3	25 1.4	---	25 1.8	---	---	75 0.9%
Very dense (4)	25 1.3	---	---	50 3.6	---	---	75 0.9%

APPENDIX XV.

Fish Distribution and Abundance: Spring

Area Between	18-19°S	19-20°S	20-21°S	21-22°S	22-23°S	23-24°S	Total Area (sq. n. mi.)
	2,125	2,825	3,025	3,225	2,600	1,750	15,550
Mean Area	1,500	1,400	1,925	1,300	1,325	375	7,825
Survey	70.6	50.0	63.7	40.3	51.0	21.4	50.3%
No fish (0)	900	1,025	1,425	1,050	1,025	325	5,750
	60.0	73.2	74.0	80.8	77.4	86.7	75.4%
Very	325	175	425	250	275	50	1,500
Scattered (1)	21.6	12.5	22.1	19.2	20.8	13.3	18.3%
Scattered (2)	225	200	75	---	25	---	526
	15.0	14.3	3.9		1.9		5.9%
Dense (3)	25	---	---	---	---	---	25
	1.7						0.3%
Very dense (4)	25	---	---	---	---	---	25
	1.7						0.3%

APPENDIX XVI.

Arbritrary relative scale used in maps and tables to indicate numbers of eggs and larvae of anchoveta by square meter under one meter square of the surface.

No. of Eggs or Larvae	Scale
0	0
Between 1 and 3	1
Between 4 and 9	2
Between 10 and 27	3
Between 28 and 81	4
Between 82 and 243	5
Between 244 and 729	6
Between 730 and 2,187	7
More than 2,187	8

APPENDIX XVII.

Relative Abundance and Distribution of Anchoveta Eggs.
(Scale in Appendix XVI)

SUMMER

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	1,200 82.8	100 6.9	75 5.2	50 3.5	25 1.8	---	---	---	---	1,450 100%
19-20°S	1,750 94.6	25 1.4	50 2.8	25 1.4	---	---	---	---	---	1,850 100%
20-21°S	1,875 89.3	175 8.3	25 1.2	25 1.2	---	---	---	---	---	2,100 100%
21-22°S	1,500 95.2	25 1.6	---	25 1.6	25 1.6	---	---	---	---	1,575 100%
22-23°S	1,075 86.0	75 6.0	25 2.0	75 6.0	---	---	---	---	---	1,250 100%
23-24°S	600 96.0	---	25 4.0	---	---	---	---	---	---	625 100%
Total %	90.7	4.0	2.5	2.2	0.5	0	0	0	0	100%

APPENDIX XVII. (continued)

AUTUMN

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	1,600	50	25	25	25	---	---	---	---	1,725
	92.8	2.9	1.4	1.4	1.4					100%
19-20°S	1,150	---	---	---	---	---	---	---	---	1,150
	100									100%
20-21°S	1,450	25	50	25	---	---	---	---	---	1,550
	93.5	1.6	3.2	1.6						100%
21-22°S	250	---	---	---	---	---	---	---	---	250
	100									100%
22-23°S	1,000	---	---	---	25	---	---	---	---	1,025
	97.6				2.4					100%
23-24°S	250	---	---	---	---	---	---	---	---	250
	100									100%
Total %	97.3	0.7	0.7	0.5	0.6	---	---	---	---	100%

APPENDIX XVII. (continued)

WINTER

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	1,000 72.8	175 12.7	125 9.1	---	25 1.8	25 1.8	---	25 1.8	---	1,375 100%
19-20°S	1,200 92.5	50 3.8	50 3.8	---	---	---	---	---	---	1,300 100%
20-21°S	1,500 90.9	100 6.1	25 1.5	25 1.5	---	---	---	---	---	1,650 100%
21-22°S	1,150 71.9	100 6.2	175 11.0	125 7.8	25 1.5	25 1.5	---	---	---	1,600 100%
22-23°X	800 56.1	200 14.0	75 5.3	150 10.5	150 10.5	25 1.8	---	25 1.8	---	1,425 100%
23-24°S	200 61.5	50 15.4	25 7.7	25 7.7	---	---	25 7.7	---	---	325 100%
Total %	74.3	9.7	6.4	4.6	2.3	0.8	1.2	0.6	---	100%

APPENDIX XVII. (continued)

SPRING

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	500 54.0	175 18.9	75 8.1	50 5.4	25 2.7	50 5.4	50 5.4	---	---	925 100%
19-20°S	1,250 96.2	50 4.8	---	---	---	---	---	---	---	1,300 100%
20-21°S	1,425 93.4	50 3.3	25 1.6	25 1.6	---	---	---	---	---	1,525 100%
21-22°S	850 77.3	75 6.8	25 2.2	50 4.4	25 2.2	75 6.8	---	---	---	1,100 100%
22-23°S	1,275 89.5	25 1.8	75 5.3	50 3.6	---	---	---	---	---	1,425 100%
23-24°S	150 66.7	25 11.1	25 11.1	25 11.1	---	---	---	---	---	225 100%
Total %	79.5	7.8	4.7	4.0	0.8	2.0	0.9	0	0	100%

APPENDIX XVIII.

Relative Abundance and Distribution of Anchoveta Larvae
(Scale in Appendix XV.)

SUMMER

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	1,075 71.7	275 18.3	100 6.6	25 1.6	25 1.6	---	---	---	---	1,500 100%
19-20°S	950 95.0	50 5.0	---	---	---	---	---	---	---	1,000 100%
20-21°S	1,550 88.6	150 8.6	50 2.8	---	---	---	---	---	---	1,750 100%
21-22°S	725 80.5	50 5.5	100 11.0	---	25 3.0	---	---	---	---	900 100%
22-23°S	700 70.0	150 15.0	75 7.5	75 7.5	---	---	---	---	---	1,000 100%
23-24°S	450 90.0	25 5.0	25 5.0	---	---	---	---	---	---	500 100%
Total %	82.6	9.6	5.5	1.5	0.7	0	0	0	0	100%

APPENDIX XVIII. (continued)

AUTUMN

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	1,100 91.7	25 2.1	50 4.2	25 2.1	---	---	---	---	---	1,200 100%
19-20°S	650 100	---	---	---	---	---	---	---	---	650 100%
20-21°S	1,075 91.5	75 6.4	25 2.1	---	---	---	---	---	---	1,175 100%
21-22°S	400 100	---	---	---	---	---	---	---	---	400 100%
22-23°S	875 100	---	---	---	---	---	---	---	---	875 100%
23-24°S	250 90.9	25 9.1	---	---	---	---	---	---	---	275 100%
Total %	95.7	2.9	1.0	0.4	0	0	0	0	0	100%

APPENDIX XVIII. (continued)

WINTER

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi)
Area Sampled Between										
18-19°S	325	275	175	25	25	25	---	---	---	850
	38.2	32.4	20.6	2.9	2.9	2.9				100%
19-20°S	550	25	100	25	25	---	25	---	---	750
	73.3	3.3	13.3	3.3	3.3		3.3			100%
20-21°S	1,100	75	25	---	---	---	---	---	---	1,200
	91.7	6.3	2.0							100%
21-22°S	1,075	25	50	50	50	---	---	---	---	1,250
	86.0	2.0	4.0	4.0	4.0					100%
22-23°S	800	275	100	50	25	---	---	---	---	1,250
	64.0	22.0	8.0	4.0	2.0					100%
23-24°S	150	50	---	---	---	25	---	---	---	225
	66.6	22.2				11.2				100%
Total %	70.0	14.7	8.0	2.4	2.0	2.3	0.5	0	0	100%

APPENDIX XVIII. (continued)

SPRING

Scale	0	1	2	3	4	5	6	7	8	Total Area (sq. n. mi.)
Area Sampled Between										
18-19°S	575 60.5	150 15.8	50 5.3	50 5.3	50 5.3	25 2.6	50 5.3	---	---	950 100%
19-20°S	800 94.0	50 6.0	---	---	---	---	---	---	---	850 100%
20-21°S	1,425 98.0	25 2.0	---	---	---	---	---	---	---	1,450 100%
21-22°S	800 94.0	25 3.0	25 3.0	---	---	---	---	---	---	850 100%
22-23°S	1,200 94.0	50 4.0	---	25 2.0	---	---	---	---	---	1,275 100%
23-24°S	150 66.6	50 22.2	25 11.1	---	---	---	---	---	---	225 100%
Total %	84.5	8.8	3.2	1.2	0.9	0.4	0.9	0	0	100%