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The fishery for jack mackerel (*Trachurus murphyi*) off Northern Chile.

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CONTENT

INTRODUCTION

Jack mackerel (Trachurus murphyi) is part of a multispecies pelagic fishery in northern Chile, which together with anchovy (Engraulis ringens) and sardine (Sardinops sagax), account for more of 75% of the weight and 90% of the value of the entire Chilean fishery. Catches of anchovy, which are used mainly for fish meal production, have decreased appreciably since 1970, while catches of the jack mackerel have increased. In 1978 jack mackerel comprised 33% by weight of the fish catch of Chile.

This report reviews previous studies and presents original data on the biology, habitat, fisheries biology and fisheries oceanography of the jack mackerel fishery of Chile, and has been written as a contribution for a future management of this fishery.

General biology of Trachurus murphyi

Trachurus is one three closely related genera (with Decapterus and Selar) of the carangid subfamily Carangidae. The genus includes 13 species that inhabit neritic and nearshore oceanic areas of most tropical and temperate marine waters (Berry and Cohen, 1974, Figure 1). Several species are of commercial importance.

The major characters used to distinguish that 13 species are: position of termination of the dorsal accessory lateral line beneath the dorsal fin, numbers of gill rakers on the lateral side of the first gill arch,

numbers of scales and scutes in the lateral line and relative heights of scales in the curved lateral line and scutes in the straight lateral line (Berry and Cohen, 1974).

The species of jack mackerel from the southeastern Pacific is known by two scientific names. Aleyev (1957), Fowler (1927), Hildebrand (1946), Roedel and Fitch (1952) and Berry and Cohen (1974) consider it a separate species and use the name Trachurus murphyi Nichols. Berry and Cohen recognized that T. murphyi is closely related morphologically and geographically to Trachurus symmetricus, the northeastern Pacific species. Mann (1954), Santander and Castillo (1971) and Kotlyar (1977), on the other hand, recognize it as subspecies of T. symmetricus (Ayres) and use the name Trachurus symmetricus murphyi (Mann).

Kotlyar (1977) compared his data on 250 T. symmetricus murphyi caught off Peru with Roedel and Fitch's data on T. symmetricus off California and showed that all the meristic characters examined were consecutive or overlapped completely.

In Chile and Peru the official name for jack mackerel in fisheries statistics is jurel. Other names in Chile are furel and pavo. Jack mackerel in other countries are called horse mackerel, spanish mackerel, jackfish, saurel, ogii, macarella, caballa and maasbanker.

Distribution T. murphyi is widely distributed near the coasts of Ecuador, the Galapagos Islands, Peru and Chile (Aleyev, 1957). According to Kaiser (1973) southern and western limits of T. murphyi off Chile are 42^{0}S latitu

de and 80°W longitude, near the Juan Fernandez Island (Figure 2).

Jack mackerel is caught commercially between Arica (lat. 18° 30'S) and Coquimbo (lat. 30°S) in the northern zone of Chile, with largest landings in the area between Arica and Iquique. Schools of jack mackerel are usually caught between the coast and 46 Km. off shore. The maximum western extension of the Chilean industrial fleet is 92 Km. offshore. However, echosounder targets believed to be this species, and/or visual observations of this species in nearsurface waters have occurred up to 185 Km. offshore, the maximum western limit of recent research cruises.

Santander and Castillo (1971) and Basten and Contreras (1978) found jack mackerel eggs out to 100 miles offshore. Since this was the westward limit of their sampling of eggs and larvae of T. murphyi off Peru and Northern Chile it es likely that spawning occurs even further from shore. The highest densities of eggs were found off Iquique (20°S) and Mejillones (23°S) Chile, between 111Km. and 185Km. offshore.

With respect to vertical distribution, T. murphyi usually lives between surface and the top of the transient or seasonal thermocline, which varies between 15 meters off Arica in summer to 60 meters off Chanaral (lat. 26°S) in winter (Ravello, 1979). On the continental shelf T. murphyi performs daily offshore-inshore movements. During summer period (January-March) jack mackerel move toward shore during period of sunrise and sunset when they prey on schools of anchovy (Engraulis ringens). On occasion I have observed schools of anchovies and jack mackerel in very shallow water near the surf zone at those times.

Reproduction Jack mackerel are sexually mature after two years of age (230 mm. fork length) off Northern Chile (Basten and Contreras, 1978). Fertilization is external. Spawning occurs between 18° and 30 S, but the main area of spawning es between Iquique (20° S) and Mejillones 23° S) from 111 to 185 Km. offshore (Basten and Contreras, 1978). The season of spawning varies with latitude. It occurs in August in Arica and Iquique, in October in Antofagasta and in December in Coquimbo. Spawning occurs over a wide temperature range, 13 - 22°C (Basten and Contreras, 1978).

According to Santander and Castillo (1971), eggs and larvae are very morphologically similar to those of Trachurus symmetricus as described by Alhstrom and Ball (1954). Eggs are pelagic, non-adhesive, from 0.90 to 1.08 mm in diameter. The incubation time is 2 days at 17.9°C or 4 days at 14.5°C. The larval development is also similar to that of T. symmetricus (Santander and Castillo, 1971). The vertical distibution of larvae has not been studied in detail, but they must be epipelagic as they were taken in tows to 50 and 100 meters depth off Peru and Chile (Santander and Castillo; Basten and Contreras, 1978).

Mc Gregor (1976) calculated the fecundity T. symmetricus in terms of advanced eggs per gram of fish. He found that age class II fish (23.5 cm) had a fecundity of 65.8 egg/g fish. Larger fish (51.9 cm) had a value of 152.3 egg/g of fish.

Age and growth Age and growth of Trachurus murphyi off Chile were studied by Kaiser (1973) using the otoliths. He collected fish 34.0 cm to 63.5 cm fork length from a large zone between Antofagasta (23^{o}S) and Valparaiso (33^{o}S). His results are shown in Table I. Growth is rapid: 26% of maximal length is achieved during the first years of life. A maximum length of 65.8 cm was calculated for L_{oo} for fish in age class XII from the Von Bertalanffy equation.

Feeding habits Euphausiids and small pelagic fishes constitute the two principas food groups of Trachurus murphyi off Northern Chile (Basten, unpublished). Crustacea, principally euphausiids are the most important on a basis of percentage frequency of occurrence while fish were important on a wet weight basis (Table Ia). Food habits differed among different latitudes. Crustacea were more important on a weight basis off Arica and Iquique than Antofagasta and Coquimbo. Other prey such as copepods, isopods, larvae of decapods, juvenile cephalopods and pteropods were found but were not important on a weight basis. Engraulidae and Clupeidae were the most common families of fishes found in stomachs of jack mackerel. Anchovy, Engraulis ringens,was the most important food by weight for jack mackerel larger than 37 cm F.L. off Arica, Iquique and Antofagasta, but sardine, Sardinops sagax was most important off Coquimbo

Oceanographic characteristics of coastal waters off Northern Chile.

Several authors have described the oceanography of the Chilean sector of the South Eastern Pacific, usually as part of studies of larger areas (e.g., Gunther 1936; Wooster 1960, 1970; Wooster et al. 1961; Wyrtky 1963, 1966, 1967; Reid 1973; Neshyba et al. 1976; Inostroza 1972; Silva and Nashyba 1979; Enfield and Allen 1980). Other studies deal with the northern zone of Chile (Robles 1966; Inostroza 1973; Robles et al. 1974; Sievers and Silva 1975; Silva and Sievers 1978; Basten 1978).

Catches of jack mackerel occur in the coastal surface waters of Northern Chile which are transitional between warm and salines waters of subtropical origin and relatively cold and less saline waters of subantarctic origin (Figure 3). There are seasonal and yearly variations in the relative strength and degree of intrusion of each of those water types.

Some of the general features of the Chilean coast that affect the oceanographic environment are:

a) The arid or desert zone along the coast with practically no precipitation and no run off.

b) The narrow continental shelf, which averages only 9 to 13 Km wide.

c) Straight coast line oriented in a North-South direction which affects the circulation pattern.

Currents The surface flow along the coast of Chile is the predominantly northward flowing Peru or Humboldt Current. It originates from the division

of the Antarctic Circumpolar Current or West Wind Drift at about 40°S into two branches, one eastward, crossing the Drake Passage toward the Atlantic Ocean and the other northward against the west coast of South America. This northward flow is sustained partially by the S and SW winds produced by the relatively stationary high pressure cell of the eastern South Pacific.

Robles et al. 1974 reported horizontal velocities of 0.1 to 0.3 knots; volumes of transport of 10 - 15 Sv between surface and 200 - 400 m for the Peru Current off Chile. The Peru Current has a coastal branch between 40°S to approximately 26°S and an oceanic branch that originates at about 40°S and diverges to the west at approximately 25°S. A counter flow occurs between Chañaral (26°S) and Southern Peru (18°S) (Sievers and Silva, 1975).

An undercurrent flows southward off Chile from its origin at about 10°S off Peru to 48°S off Chile (Silva and Neshyba, 1979). Off Antofagasta (23°S) this current has speeds between 4 and 6 cm/sec at depths of 100 to 250 meters as determined from parachutes drogues by Wooster and Gilmartin (1960). This undercurrent, which is found at depths between 100 and 400 m is called the Gunther Current or the Peru-Chile Undercurrent of Northern Chile. An oxygen minimun of less than 0.5 ml/l of O_2 is associated with this undercurrent in the area of study.

Water masses Four water masses are present in the upper 1000 m off Chile. The subtropical surface water mass (SSW), as defined by Wyrtki (1965) has relatively high salinity (35.00 °/oo , Figure 3) high temperature (19°C - 24°C), a sigma-t of about 25.00 and is usually found as a thin

layer between 15 to 30 meters deep. The subantarctic water mass (SAW) originates in the northern part of the Polar Front. It has comparatively low salinity values (34.30 °/oo - 34.70 °/oo), low temperature (12°C to 16°C) and a sigma-t at the core of 26.00. It is found in or near the surface of the southern sector of northern zone (23°S - 26°S) and usually between depth of 100 to 150 meters off northern Chile. This water mass is usually the source of water for upwelling. A longshore vertical section (90 Km. offshore) with salinity values characteristics of SSW and SAW is shown in Figure 4. The core of low salinity subantarctic waters was less than 34.30 °/oo at about 100 meters deep of Chañaral (26° 30'S), and was clearly distinctive as 34.5 °/oo water until Mejillones 23°S during fall 1975 (May). In the same period comparatively high salinity values (35.00 °/oo) were restricted to a small area off Arica (18°30'S).

Equatorial subsurface water mass (ESSW) originates in equatorial regions of high temperature and high biological productivity. After sinking organic matter is oxidized resulting in a minimum of oxygen (0.50 to 0.25 ml/l). This oxygen minimum, salinity values of 34.75 °/oo and sigma-t of 26.3 are good indicators of this water mass.The low oxygen content of ESSW is shown in Figure 5 at a 100 - 300 m by the low dissolved oxygen content of the water which has apparently been transported from the north as a subsurface countercurrent 37 - 110 Km. offshore.

The Antarctic Intermediate Water Mass (AIW), formed in the Antarctic convergence (60°S) is found at depth of 400 to 500 m. It has low temperatures (less than 7°C), a sigma-t value of 27.2 a salinity minimum of about

34.50 °/oo and oxygen values of 2 ml/l. The 0_2 values in this minimum, produced by the sinking of organic matter from high latitudes, are higher than those associated with equatorial waters at depths of 200 - 400 m.

Upwelling Upwelling has been detected during all seasons along the coast between 18°S to 26°S. It is strong in spring and summer of Southern Hemisphere (September-March), when the S and SW winds are strongest. The upwelled waters arises from depths of 80 to 120 meters, bringing to the surface waters of low temperature, low oxygen, high nutrients and high density. (Basten, unpublished).

The principal areas of upwelling detected in the region are: Iquique-Loa (20°S - 21°S), Mejillones (23°S) and Punta Buitre (25°S). The headlands at Mejillones may intensify upwelling in this area. The effects of upwelling can often be detected out to 37 to 46 Km offshore, and occasionally to 90Km. off 23°S.

Thermal structure A well developed seasonal thermocline occurs between 0 and 100 meters during summer, with a steep gradient between 0 and 40 meters and a mixed-layer depth of 10 to 20 meters. Gradients of 8 to 10°C/100 m are common in this upper layer in summer. In winter the thermal gradient is comparatively weak 2 to 3°C/100 m. (Figure 6).

The Chilean fishery of jack mackerel

In a historical review of the fishery in the northern zone of Chile,

Basten and Contreras (1977) pointed out the predominance of pelagic catches (Figure 7). As the catch of anchovy declined from 1971 - 1976 in the northern zone of Chile, the contribution of jack mackerel and sardine increased in the total pelagic catch (Figure 8). In 1976, jack mackerel composed 25 °/oo of the total pelagic catch in this area.

The pelagic fisheries of Chile use purse seines. A purse seiner boat usually locates schools with the help of of an airplane, which first locates general areas where usually more of one school occur and then comunicates this location by radio to the fishermen, who use echosounders and/or sonar to determine the exact depth and location of the school.A powerful auxiliary boat, called a "panga", is launched from the stern of the purse seiner and the panga and the vessel encircle the school with the net and close the bottom of the net with a pursing line so that fish cannot escape downwards. After fish are ceoncentrated within the net they are lifted from the water with brailers or large dip nets into the purse seiner.

Almost all the catches of pelagic fishes are utilized for fish meal and fish oil products. The average value of these products in 1968 - 1978 was US$ 75 x 10^6. Because the price of fish meal increased from US$ 90 per metric ton in 1965 to US$ 322 per metric ton in 1975, the value of all pelagic fishes in 1975 was US$ 107.2 x 10^6, or approximately 7% of the value of all Chilean exports. The principal customers for Chilean fish meal are Germany Fedral Republic, Unites States and Japan; secondary buyers are United Kingdom and Netherlands. (Caviedes, 1981).

Jack mackerel are also used canned and fresh. The fresh market is supplied by artisanal fleet (small boats, hook and hand line mainly).

The industrial fishing fleet is composed by 114 boats with hold capacity ranging between 40 to 350 metric tons. Iquique, Arica, Antofagasta and Coquimbo are the major ports. Hold capacity of the fleet totals 19,820 metric tons and ranges from 120 to 160 THC for individual boat.The composition of the fleet is given in Table II. The composition of fishing factories, their location, storage capacity, processing capacity, personel employed and value of the production is shown in Table III for 1977.

METHODS

Four coastal fisheries laboratories, located in Arica (18° 30'S), Iquique (20° 10'S), Antofagasta (23°S) and Coquimbo (30°S) (See Figure 9) proveded the following data on jack mackerel catches: total length, total weiht, sex, stage of sexual maturity, stomachs contents, gonads, total catches, fishing effort, areas of fish catches, characteristics of boats, nets and methods of fishing. Monthly catches for each location were grouped into five categories (1 - 500; 501 - 2000; 2,001 - 5,000; 5,001 - 15,000; 15,000 tons). These data were available on a daily basis from June 1975 to July 1978. The number of fish analized for length frequency, weight, sex ratio, sexual maturity, and stomach content studies were as follow: Arica n = 15,538; Iquique n= 18,243; Antofagasta n = 26,668 and Coquimbo n = 11,933. These samples were obtained on ramdom basis, principally from the fishing factories in each port, ranging from 20 to 40 fish per day.

For feeding studies, whole stomachs were preserved in 10% formalin with sea water. The exterior of the stomach was washed, excess water remo-

ved, and weights were obtained of the complete stomach and the empty stomach after removal of contents. Volumes of total gastric contents were measured and the weight and volume of each of the major taxonomical groups were obtained. The area of catch, size and sex of the fish were considered in subsequent analyses.

Ten seasonal cruises were conducted with the R/V STELLA MARIS of the Departament of Fisheries of the University of the North. This is a 22 - m purse seiner, modified for basic oceanographic work. The area of study and location of oceanographic and biological stations are shown in Figure 9. All ten cruises occupied the same locations. The dates of each cruise, type of measurement, sampling depth and other imformation are given in Table IV.

Data on sea temperature, salinity, oxygen, nutrients (phosphate, nitrate, nitrite), transparency and color of water were obtained. Nansen bottles, reversing thermometers, bathythermographs, Seechi discs and a Forel-Ule scale used. Salinity was measured using an inductive salinometer Auto-Lab model 601. Oxygen values were determinèd aboard the vessel utilizing the Winkler method (Strickland and Parsons, 1968). Nutrient samples were frozen on the vessel and analysed a shore by spectrophotometric methods (Strickland and Parson, 1968).

Zooplankton samples were collected in vertical tows with a conical 50 cm diameter net with 0.22 mm polyester mesh and in oblique tows with stramin nets of 100 cm of diameter with 1.2 mm of mesh. Total volumes of zooplankton, seasonal distribution of eggs and larvae of fishes, faunistic composition and abundance estimates were made from these zooplankton samples.

RESULTS

Catch, effort and catch per unit effort of jack mackerel The industrial catches of jack mackerel from 1971 - 1978 show distinct seasonal variations, as well as a general trend for total catches to increase (Figure 10). Most of the catches in the northern zone of Chile were landed in Iquique and Arica. Highest catches were usually made during the summer (January-March), with the highest peaks occurring in 1976 - 1978 during these eight years.

The average catch by month for this 1971 - 1978 period also occurs in March and April (Figure 11). October, November and December are usually months of lowest.

The purse seine was the only method used in the industrial catches. The fishing boats were of diffefent size (see section about the fleet) and usually operated only 12 hours per day.The mild weather in this zone allows more than 220 days of operation per year. Cosidering the hetereogenity of the fleet, the unit of fishing effort choosen was Tons of Hold Capacity (THC) x days of operation. The monthly value of fishing effort for all the area during the period of study(Figure 12) showe that fishing effort was practically constant during all months and increased slightly from 1975 to 1978.Hence seasonal variations of effort do not account for the seasonality of catch (Figure 11) and monthly variations of the relative availability (CPUE) in Northern Chile (Figure 13) apparently follow the trend of total catches (Figure 10)

Size composition in the jack mackerel fishery Length frequency distribu_ tions are shown in Figure 14 for catches off Northern Chile, 1975 - 1978. The mode in the industrial catch was about 32 cm fork length (F.L.) for fish landed at Arica, Iquique and Coquimbo. Artisanal catches off Antofa_ gasta have several modes: 25, 31, 39 cm F.L.

The size range of Trachurus murphyi landed between June 1975 and July 1978 is shown below for the major landing perts:

	Minimum length or length of recruitment F.L. (cm)	Maximum length F.L.(cm)
Arica ($18^{o}30'S$)	20	63
Iquique ($20_{o}10'S$)	18	63
Antofagasta ($23^{o}S$)	18	66
Coquimbo ($30^{o}S$)	11	62

Using Kaiser's (1973) growth curve, age group fish of 3 to 4 years old (30 - 37 cm) were the most abundant age-group in industrial and arti_ sanal catches (Table VI). Age-group 2 (22 - 29 cm) were the second most important group.Antofagasta showed percentages of age-group IV and V fish were caught. The difference in age composition between and the other ports is a results of the an artisanal fishery. The industrial fleet uses purse siners which catches a narrow size range of fishes while the artisanal fleet of small boats use hook and hand line, which is selective for large fish. Catches from Iquique, Arica and Coquimbo were over 87% industrial (purse seine). Catches from Antofagasta were 69% of artisanal origin. The contri_

bution of fish of age 4 years old or older is negligible in the industrial catch of Chilean jack mackerel (Table VI).

Length-weight relation Weight and the fork length (F.L.) were measured for fresh whole fish and the relationship between the logarithm of length and the logarithm of weight was determined for jack mackerel between age I and age VII for all seasons. The slope, b, in the equation:

$w = a\ l^b$, where w = weight (fresh whole)

l = fork length

was essentially the same for different ports, 2.81 to 2.94 with an average value of 2.85 (Table VII). Differences among slopes were not significant (F - statistics; P 0.05). Therefore there is no evidence for average length-weight relationships of fish to differ among ports. The average relationship, $w = 0.0162\ L^{2.85}$, was based on average length-weight data of more than 50,000 specimens collected in four years of study.

A comparison of observed and back calculated average weights for fish at 32 cm fork length, by port, gave maximum differences no longer than 19 g (5.8 %) (Table VII).

Seasonal variation of weight To learn if seasonal variations in length-weight relationships occur that are possibly related to spawning and food availability, the weights of fish at 32 cm F.L. a common size of fish at all ports were plotted for different seasons, 1975-1978, and landing ports in Figure 15. Average weight was usually lowest in winter (June, July and August), coincident with the most important of two spawning periods of jack mackerel,

and increased during spring-summer months (November to February) in Arica, Iquique and Antofagasta (Figure 15 a, b and c).This increased was sometimes correlated with the occurrence of large schools of anchovy (Engraulis ringens) in nearshore waters where feeding aggregation of jack mackerel have been observed. The seasonal variation of weigth showed a different pattern at Coquimbo ($30^{o}S$), with a decreasing average weight during spring (September to December) and an increased in Winter (Figure 15 d). The increase in November - December is coincident with summer spawning season in this area. These differences in weight may have appreciable effect on the weight of total landing between different season.

Recruitment Jack mackerel are recruited into the purse seine fishery at lengths between 18 and 24 cm, but fish smaller than 25 cm are not common in catches. These recruits, which are between 1 and 2 years old according to Kaiser's (1973) curve of growth, appear in catches during the winters (mainly August) of some years and remain in the fishery for only two or three months before declinig to low or zero catches. These fish are then fully rerruited during the next summer, most frequently in March, when they compose a large portion of the catch. Examples of this pattern are shown for Arica (Figure 17) between August 1977 through March 1978, and for Coquimbo during August 1976 through January 1977 (Figure 18). These data suggest that fish of 24 - 26 cm length are not accessible to the nearshore fishery zone (18 - 46 Km offshore) and that they migrate into oceanic waters beyond the fishery during spring.

The monthly best catch in all the four years of this study, was March

of 1978, and it was the only one that had three distinct modal groups (20, 25 and 33 cm F.L.) in Arica and Iquique (Figures 16 and 17).These large catches are associated with the presence of the 20 and 25 cm groups which contributed 37.000 tons to the catches and represented 41% in weight of the total catch for March 1978.

Catches of jack mackerel and oceanographic conditions

The catches of jack mackerel off Northern Chile are related to selected oceanographic factors in Table VIII for eight months in 1975 - 1978. Catches occurred over a range of temperatures at 10 m from 12.9 to 21.7°C (Table VIII). Salinities varied between typical subantarctic values(34.39 - 34.70°/oo) and subtropical waters (larger than 35.00 °/oo). The catches occurred in waters with value of oxygen content between 6.4 ml/l and 0.9 ml/l. Good catches were obtained in subantarctic and subtropical water masses, but 3 of 4 times when subtropical conditions occurred the geographical distribution of catches was more scattered than during subantarctic conditions. The schools of jack mackerel during subtropical condition were always located in the coastal boundary of this water mass, never in the horizontal core.

Good catches were made during both strong upwelling (March 1978) no upwelling (March 1976). The lowest catch (2.5×10^3 tons), occurred in October of 1975 (usually a month of low catches) and coincided with the minimum temperature of 12.9°C at m deep, the presense of subantarctic waters and strong upwelling. The highest catch (90×10^3 tons) occurred in March of 1978 (the month of highest catches), and was associated with

high sea water temperature of 21°C, presence of the subtropical water mass and strong upwelling.

Geographical distribution of catches and oceanographic conditions

October of 1975 and March 1978 were selected for a more detailed examination of catches and associated oceanographic conditions during relatively. The oceanographic data obtained with the cruises of spring of 1975 (October) and summer of 1978 were used together to the catch data coming from the industrial fleet.

OCTOBER 1975

Geographical distribution of catches and sea water temperature A total of 2,500 tons of jack mackerel were caught during this month, a value close to the monthly average value of 3,000 tons calculated from 8 years of data. Catches were obtained nearshore and mainly off Iquique. There, the temperature of sea water at 10 meters deep was lower than 14.0°C (Figure 19). However small catches were obtained off Antofagasta where the temperature of water was lower than 13.0°C.

Geographical distribution of catches and salinity The range of salinity for occurrence of cathces was $35.00^{o}/oo > S > 34.60^{o}/oo$. However the largest fraction of catches were obtained in salinities larger than $34.90^{o}/oo$ (Figure 20). Only the catches off Antofagasta were in waters with salinity value smaller than $34.70^{o}/oo$.

Geographical distribution of catches and oxygen content Low values of oxygen in shallow waters near shore, lower than 1.0 ml/l off Arica and lower than 2.0 ml/l off Iquique, were measured in the same areas where the catches were obtained. The horizontal (E - W) gradient of oxygen was high, about 5.5 ml/l/9Km off Arica and 4.7 ml/l/9Km off Iquique. Southward the gradient is smaller with comparatively larger values near shore, larger than 3.5 ml/l (Figure 21).

MARCH 1978

Geographical distribution of catches and sea water temperature During this summer month a total catch of 90,194 tons were caught, corresponding to $2\frac{1}{3}$ the monthly average. The catches were obtained mainly between Arica ($18^{o}30'S$) and south of Iquique ($20^{o}30'S$), and to a distance shorter than 37Km offshore (Figure 22).The catches were localized in waters with temperatures lower than $21^{o}C$ and larger than $14.3^{o}C$, corresponding in the northern sector to a zone of high horizontal thermal gradient.

Geographical distribution of catches and salinity The waters where the catches were made off Airca and Iquique had salinity values between $35.30^{o}/oo$ with the largest catches near Arica with salinities larger than $35.00^{o}/oo$ (Figure 23). However some fish were caught off Antofagasta too, where salinities were smaller than $34.80^{o}/oo$.

Geographical distribution of catches and oxygen content Good catches were

obtained in a range of oxygen content between 2.0 and 5.0 ml/l in the Arica-Antofagasta sector. The larger catches were obtained however off Arica and Iquique where a large horizontal gradient of oxygen was detected (Figure 24).

Monthly catches by areas and sea water temperature

The temperature range from the upper part of the transient thermocline (lower limit) and the sea surface temperature (upper limit) are shown versus monthly catches of jack mackerel off Iquique and Arica in Figures 25 and 26. Off Iquique the highest catches of jack mackerel were in March 1976 (68,866 tons) when temperatures ranged from 16.0 to 17.0°C (Figure 25). The overall range of occurrence of catches was between 14.0°C to 17.6°C, but highest catches were from 15.5°C to 17.2°C.

Catches off Arica were obtained in waters with a wider range of temperature than Iquique, with 14°C as lower limit and 19.6°C as the upper limit, (2°C higher than Iquique, Figure 26). The best catches (60,168 tons) were obtained in March 1978 when temperatures were 14.7 to 16.8°C. Catches above 4×10^4 tons were located in waters at 14.0°C to 16.8°C, the low end of the total range.

Catch per unit of effort (CPUE) and temperature of sea water Based on data from 1975 to 1978 water temperatures off Arica and Iquique between the surface and 10 meters deep ranged between 13.0°C to 24.5°C (Figure 27). The

low temperatures (13 - 14°C) correspond to subantarctic, upwelled waters near coast and high temperatures (22 - 24°C) correspond to subtropical surface water mass in offshore areas. So the total variation in temperature for the shallow-water zone where Trachurus murphyi occurs was of 11°C horizontally or seasonally and no more of 12°C vertically (24 - 12°C).

Jack mackerel were caught in only a fraction of this total temperature range (Figure 27). Off Arica the total variation of temperature for catches was only 3.9°C (from 14.7°C to 18.6°C), with the best catches in the narrow window from 15.2 to 15.9°C. Off Iquique the total variation for occurrence of catches was narrower than Arica, corresponding to a difference of only 2.1°C (between 14.5 and 16.6°C), with the best catches between 14.7 to 16.5°C.

Another environmental factors related to CPUE

CPUE and horizontal (E - W) gradient of temperature Considering that a thermal front can act as an environmental barrier in the geographic distribution of several species of fishes, this idea was tested with jack mackerel of Northern Chile. The results showed that the better catches were obtained in high horizontal thermal gradients (4.5 to 9°C/37 Km) but also low values of catches were gotten in the same gradients. (Table IX and X).

CPUE and mixed layer depth (MLD) Knowing that Trachurus murphyi is an epipelagic species and that occurs mainly above the transient thermocline, the relationship between CPUE and MLD was explored. The Tables IX and X, shows that both parameters were very scattered with the highest and lowest value of CPUE with the same value of MLD. But high catches per unit effort

were all at mixed layer depth of 10 m or less.

CPUE and distance offshore of subtropical waters As an attempt of quantify the effect of proximity of the subtropical waters, the distance offshore of the related to catch, 35°/oo isohaline (a typical value of this water mass) was but no coherent patternt was observed, with both high and low catches when the subtropical waters were near the coast. (Tables IX and X).

CPUE and upwelling The slope of the 26.00 σ_t isopycnal was determined by the vertical change in its depth is shown with each 36Km offshore.This measure of upwelling with CPUE is in Tables IX and X. However no consistent pattern was observed off Arica and Iquique. Highest values of CPUE were associated with the strongest and the weakest values of upwelling.

CPUE and zooplankton Since food is an important factor influencing geographical distribution of fishes, and zooplanktonic euphausiids,copepods and isopods are known to be food items for jack mackerel, the relative abundance of total zooplankton is shown in Tables IX and X. However no consistent relationship was apparent.

ACKNWLEDGMENTS

I gratefully acknowledge Dr. William Pearcy for his help and guidance during the preparation of this report. Stve Neshyba also furnished valuable suggestions and information. I am also greatly indebted to Katia Elqueta, my wife, who typed the manuscript and Nena Enfield who drew the figures.

This research was originally supported by the Universidad del Norte and the Gobierno Regional de Antofagasta, Chile.

List of tables

TABLE I.- Age and growth of the jack mackerel off the coast of Chile.(From Kaiser 1973).

Age group	Number measured	Otolith;annual (na) average (mm)	Fish			Growth in respect to maximal length (L_∞) (%)
			Length (cm)	Annual (cm)	Increment (%)	
I	86	1.50	17.5 [a]	17.5	25.8	25.8
II	80	2.15	25 [a]	8.0	12.0	38.0
III	74	2.85	33 [a]	8.0	12.0	50.0
IV	77	3.45	40.5 [b]	7.5	11.3	61.3
V	54	4.05	47 [b]	6.5	10.0	71.3
VI	43	4.35	51 [b]	5.0	7.6	78.9
VII	24	4.85	55.5 [c]	3.5	5.3	84.3
VIII			59.13 [c]	3.6	5.4	89.5
IX			61.50 [c]	2.4	3.6	93.4
X			63.50 [c]	2.4	3.0	96.5
XI			64.00 [c]	1.5	2.3	97.2
XII			65.80	L		100.0

[a] Back calculated through otoliths .
[b] Modal lengths of length frequency distribution of fish of Valparaiso.
[c] Calculated by Walford's method.
L Calculated by Von Bertalanffy's function.

Table Ia . Principal food groups of T. murphyi off Northern Chile. June 1975 - December 1977.

Location	% Frecuency occur.			% in weight		
	Crust.	Fish.	Other	Crust.	Fish.	Other
18°S, Arica	57.3	21.1	21.5	36.2	62.1	1.7
20°S, Iquique	63.4	22.4	14.2	36.5	61.1	2.4
23°S, Antofagasta	2.4	90.3	7.3	0.2	99.1	0.7
30°S, Coquimbo	41.7	38.8	19.5	8.7	88.2	3.0

TABLE II. Composition of the industrial fishing fleet in Northern Chile. *1978*

PORT	TONS OF HOLD CAPACITY (T.H.C.)	Nº OF BOATS	Nº OF BOATS BY PORT	T.H.C. TOTAL
ARICA (18°30'S)	140	28	35	5,300
	180	6		
	300	1		
IQUIQUE (20°10'S)	120	6	58	11,060
	140	20		
	165	2		
	180	2		
	200	14		
	250	3		
	300	11		
ANTOFAGASTA (23°S)	40	1	14	2,370
	120	1		
	140	5		
	165	4		
	200	1		
	300	1		
	350	1		
COQUIMBO (30°S)	120	1	7	1,090
	140	1		
	160	3		
	170	1		
	180	1		
TOTAL BOATS			114	
TOTAL T.H.C. ARICA - COQUIMBO				19,820

Source of data : Departamento de Pesquerias
Universidad del Norte (Antofagasta).

TABLE III. Fishing Companies of the Three Major Ports of Northern Chile. (From Caviedes, 1981)

PORT	COMPANY	VESSELS	STORAGE CAPACITY (all vessels)	PROCESSING CAPACITY (tons/hour)	PERSONNEL	VALUE OF PRODUCTION (1,000 US$)
ARICA	Pesq. Coloso	11	1,540	60	312	6,306
	Pesq. Indo	10	1,400	140	356	12,416
	Pesq. Eperva	5	900	50	257	11,962
	Pesq. Guanaye	5	700	50	144	3,499
	Chilemar	5	720	55	103	b
IQUIQUE	Pesq. Coloso	14	2,940	70	368	14,224
	Pesq. Tarapaca	12	1,810	100	535	6,670
	Pesq. Guanaye	7	1,510	40	224	5,587
	Pesq. Iquique	10	1,440	105	412	5,841
	Pesq. Eperva	7	1,400	70	253	11,035
	Pesq. Indo	7	1,220	60	226	8,972
	Corpesca	a	a	23	37	b
	Pesq. De Lucchi	a	a	27	29	b
ANTOFAGASTA	Pesq. Guanaye	7	1,510	70	142	6,487
	Pesq. Zlatar	4	800	50	82	3,600

a Does not own boats. Fish is supplied by independent fishermen.
b Value of production not reported.
Source : Anuario Estadistico de Pesca. Servicio Agricola y Ganadero. Division de Proteccion Pesquera, Santiago, 1977.

TABLE IV Summary of data obtained with the cruises from jack mackerel project.

Cruise N	Date	Season	N°of Stations Oceanographic	Physical data	Max depth	Biology & Fishery
J - 01	May 17-31/75	F	29	T, S% , O_2, Tr, Col, M	300 m	Z: V (100 m), H,O; F: NB (50 m); Ch
J - 02	Aug 12-30/75	W	50	T , S% , O_2, N, Tr, Col, M^2	300 m	Z: V, H, O ; F: NB (0-50 m); Ch
J - 03	Oct28-Nov19/75 Dec11-Dec13/75	Spr	48	T , S% , O_2, N, Tr, Col, M^2	300 m	Z: V,H ; F: V (NB 0 - 50 m); Ch
J - 04	Feb20-Mar18/76	Sm	51	T , S% , O_2, N, Tr, Col, M^2	300 m	Z: V ; F: V (0 - 50 m), H, NB; Ch
J - 05	Jun28-Jul28/76	W	70	T , S% , O_2, N, Tr, Col, M^2	500 m	Z: V ; F: V,H,NB ; Ch
J - 06	Dec 1-19/76	Spr	50	T , S% , O_2, N Tr, Col, M^2	300 m	Z: V ; F: V,H,NB ; Ch
J - 07	Aug 3-23/77	W	47	T , S% , O_2, N Tr, Col, M^2	300 m	Z: V ; F: V,H,NB ; Ch
J - 09	Mar 2-23/78	Sm	48	T , S% , O_2, N Tr, Col, M^2	500 m	Z: V ; F: V,H,NB ; Ch
J - 10	Jun 7-Jul 2/78	W	51	T , S% , O_2, N Tr, Col, M^2	500 m	Z: V ; F: V,H,NB ; Ch

Abreviations:

Tr : Transparency
Col : Colour
Z : Zooplankton samples
F : Fitoplankton samples
Ch : Samples of ind. catch
T : Temperature C
M : Meteorological
S% : Salinity
O_2 : Oxygen
NB Nansen Bottles
V : Vertical
O : Oblicuo
H : Horizontal
N : Nutrient samples (NO_3, NO_2, PO_4).

TABLE V : Summary of data of fishing effort. North zone of Chile 1975-1978.

	AUG - 75	OCT - 75	MAR - 76	JUL - 76	DEC - 76	AUG - 77	DEC - 77	MAR - 78
ARICA	130,510	68,360	51,240	77,500	81,240	86,860	71,380	207,710
IQUIQUE	141,960	189,320	298,130	239,460	248,600	301,810	236,290	153,770
ANTOFAGASTA	31,160	57,400	41,830	54,360	48,960	42,970	69,740	36,240
COQUIMBO	14,100	15,390	22,040	19,420	26,150	23,360	23,090	21,940
TOTAL	317,730	330,470	413,240	390,740	404,950	455,000	400,500	419,660

TABLE VI Size and age composition of the jack mackerel fishery off Northern Chile. June 1975 to July 1978.

Landing Ports and size of sampling / Age groups Lengths Freq.	AGE I (until 21 cm) (%)Frequency	AGE II (22-29 cm) (%)	AGE III (30-37 cm) (%)	AGE IV (38-43 cm) (%)	AGE V (44-49 cm) (%)	AGE VI (50-53 cm) (%)	AGE VII (54-57 cm) (%)	AGE VIII (58-61 cm) (%)	AGE IX (62-63 cm) (%)
ARICA (18°30'S) n = 15,538	2.43	13.25	76.87	5.77	1.06	.24	.13	.002	.006
IQUIQUE (20°10'S) n = 18,243	3.29	16.16	76.04	3.46	.81	.02	.01	.01	.005
* ANTOFAGASTA (23°S) n = 26,668	1.37	29.51	30.93	18.03	15.21	2.88	1.42	.34	.04
COQUIMBO (30°S) n = 11,933	1.96	23.86	63.81	5.88	3.27	.58	.28	.10	.03

* NOTE : In all the port the sampling from industrial fleet (purse seiner) was between (87 to 99.5 %) except in Antofagasta where was only 31 %, the remainder 69 % come from artisanal fleet, (hook and line) which is a selective system (toward larger sizes).

TABLE VII. Summary of relations length weight in Trachurus murphyi off Northern Chile. June 1975 to July 1978.

	n	log a	b	r	formula L/W	observed average weight at 32 cm F.L. (g)	back calculated weight at 32 cm F.L. (2)	difference in grams
ARICA	7,900	-1.86	2.89	.9985	$w = 0.0138\ l^{2.89}$ (1)	328	309	19
IQUIQUE	13,201	-1.92	2.94	.9999	$w = 0.0118\ l^{2.94}$ (2)	312	314	-2
ANTOFAGASTA	23,810	-1.79	2.84	.9994	$w = 0.0162\ l^{2.84}$ (3)	304	305	-1
COQUIMBO	6,209	-1,73	2.81	.9995	$w = 0.0185\ l^{2.81}$ (4)	309	314	-5
Average Σ=	51,120	-1.79	2.85	.9992	$w = 0.0162\ l^{2.85}$ (5)	313	316	-3

TABLE VIII. Catches of jack mackerel off Northern Chile and associated oceanographic parameters at 10 m deep.

MONTH / FACTOR	AUGUST 1975	OCTOBER 1975	MARCH 1976	JULY 1976	DECEMBER 1976	AUGUST 1977	DECEMBER 1977	MARCH 1978	NOTES
Catches of jack mackerel (Tons)	29×10^3 (3 times higher)	$2{,}5 \times 10^3$ (Equal average)	80.8×10^3 (2 times higher)	8.5×10^3 (.5 times lower)	12.5×10^3 (3 times higher)	12.5×10^3 (Equal average)	15×10^3 (3.5 times higher)	90.1×10^3 (2.66 times higher)	Contrasted with monthly average
T°C (of occurrence at 10 m) Max and Min	15.0 to 13.5	14.0 to 12.9	17.0 to 13.9	17.7 to 16.6	18.0 to 15.1	17.4 to 14.2	21.7 to 14.5	21.0 to 14.3	Min of the period = 12.9° Max of the period = 21.7°
S ‰ (of occurrence at 10 m) Max and Min	34.80 to 34.55	34.90 to 34.65	34.90 to 34.65	35.02 to 34.91	34.81 to 34.39	35.09 to 34.78	35.70 to 34.59	35.25 to 34.80	Max of the period = 35.70 ‰ Min of the period = 34.39 ‰
O_2 (ml/l) at 10 m.	6.1 - 3.3	4.0 - 1.8	5.3 - .9	5.0 - 4.0	6.2 - 4.7	6.4 - 2.3	5.8 - 4.6	5.0 - 2.0	Max = 6.4 Min = .9
Water masses	Sub-antarctic	Sub-antarctic and Equatorial	Sub-antarctic and Sub-tropical	Sub-tropical	Sub-antarctic	Sub-tropical	Sub-tropical	Sub-tropical	Identified by their σ_t T° and S ‰ values
Upwelling	Weak	Strong	None	Strong	Strong	None	Weak	Strong	Detected by the slope of isoline σ_t=26.0
Max distance offshore of catches (Miles)	5	5	5	5	5	20	20	15	

TABLE IX. CPUE off Arica and environmental indicators.

MONTH	CPUE	HORIZ. GRADIENT °C/20 Miles)	MIXED LAYER DEPTH (m)	DISTANCE OFFSHORE ISO-HALINE 35 ‰	INDEX OF UPWELLING (m/20 Miles)	RELATIVE ABUNDANCE OF ZOOPLANKTON $cm^3/1$
AUG. 1975	.0958	2.0	10	30	20	15
OCT. 1975	.0004	5.0	0	100	27	15
MAR. 1976	.2059	9.1	30	10	73	7
JUL. 1976	.0144	.6	0	0	-15	15
DEC. 1976	.0481	2.0	0	50	35	15
AUG. 1977	.0421	1.4	0	0	28	15
DEC. 1977	.0086	4.0	0	0	20	15
MAR. 1978	.2897	4.4	0	0	14	15

TABLE X. CPUE off Iquique and environmental indicators.

MONTH	CPUE	HORIZ. GRADIENT OF T° (°C/20 nm)	MIXED LAYER DEPTH (m)	DISTANCE OFFSHORE ISO HALINE 35 ‰	INDEX OF UPWELLING (m/20 nm)	RELATIVE ABUNDANCE OF ZOOPLANKTON cm^3/l
AUG. 1975	.0697	1.8	0	17	45	15
OCT. 1975	.0100	3.7	0	45	64	2
MAR. 1976	.2310	4.4	10	25	-29	15
JUL. 1976	.0224	1.2	10	40	84	7
DEC. 1976	.0291	5.9	0	80	169	15
AUG. 1977	.0134	3.5	0	25	53	7
DEC. 1977	.0543	3.6	0	0	38	15
MAR. 1978	.1610	6.0	5	0	12	7

List of figures

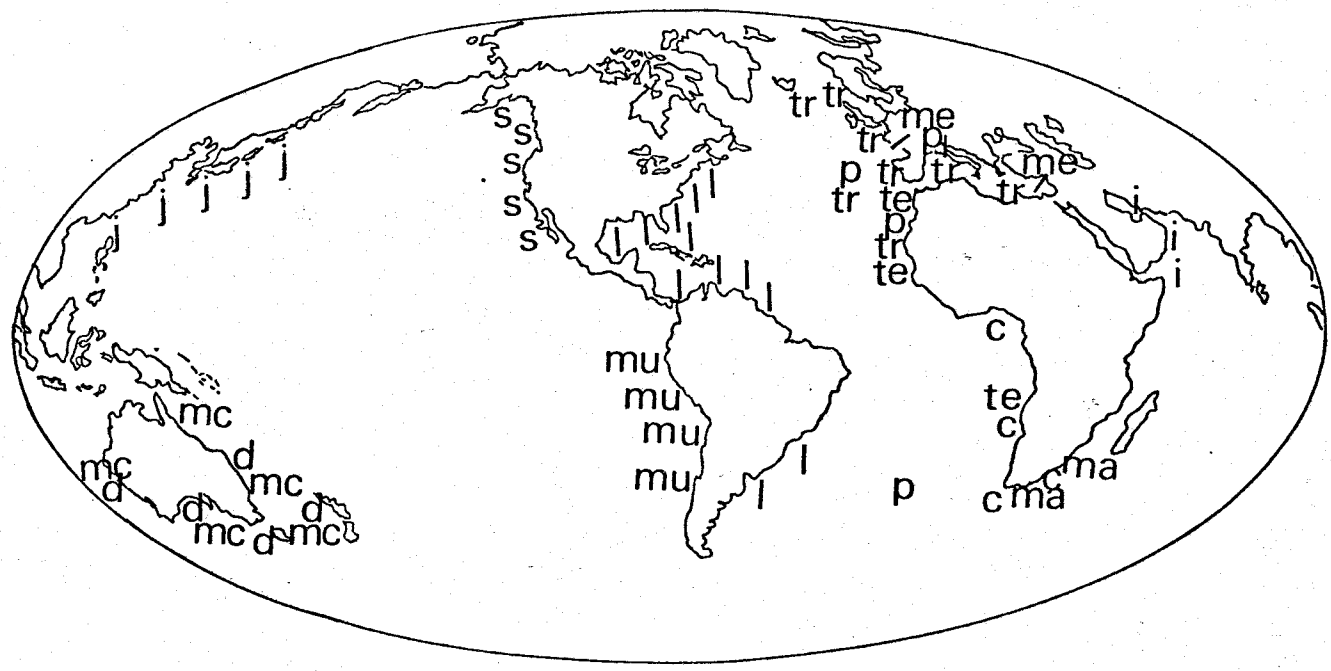

Figure 1. The general zoogeographic distribution of the 13 species of Trachurus (From Berry and Cohen, 1974).

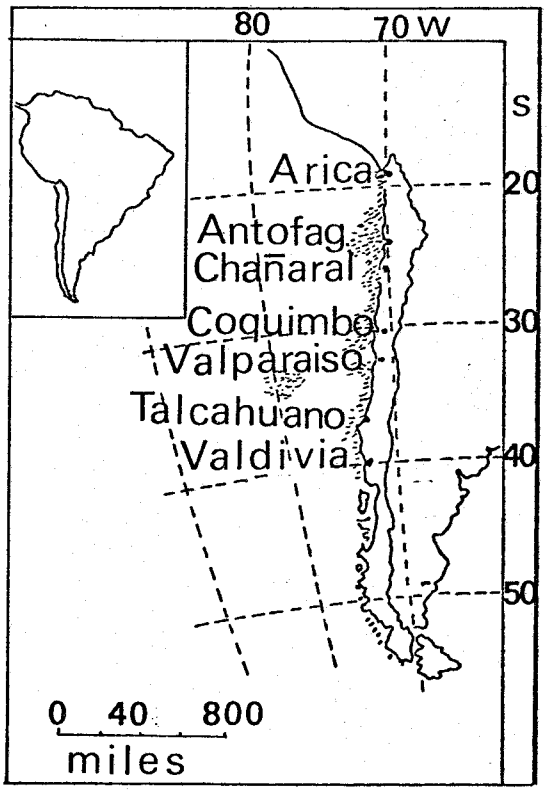

Figure 2. Geographic range of jack mackerel (Trachurus murphyi) in Chile. Dashed lines indicate location which it has been cited (From Kaiser, 1973).

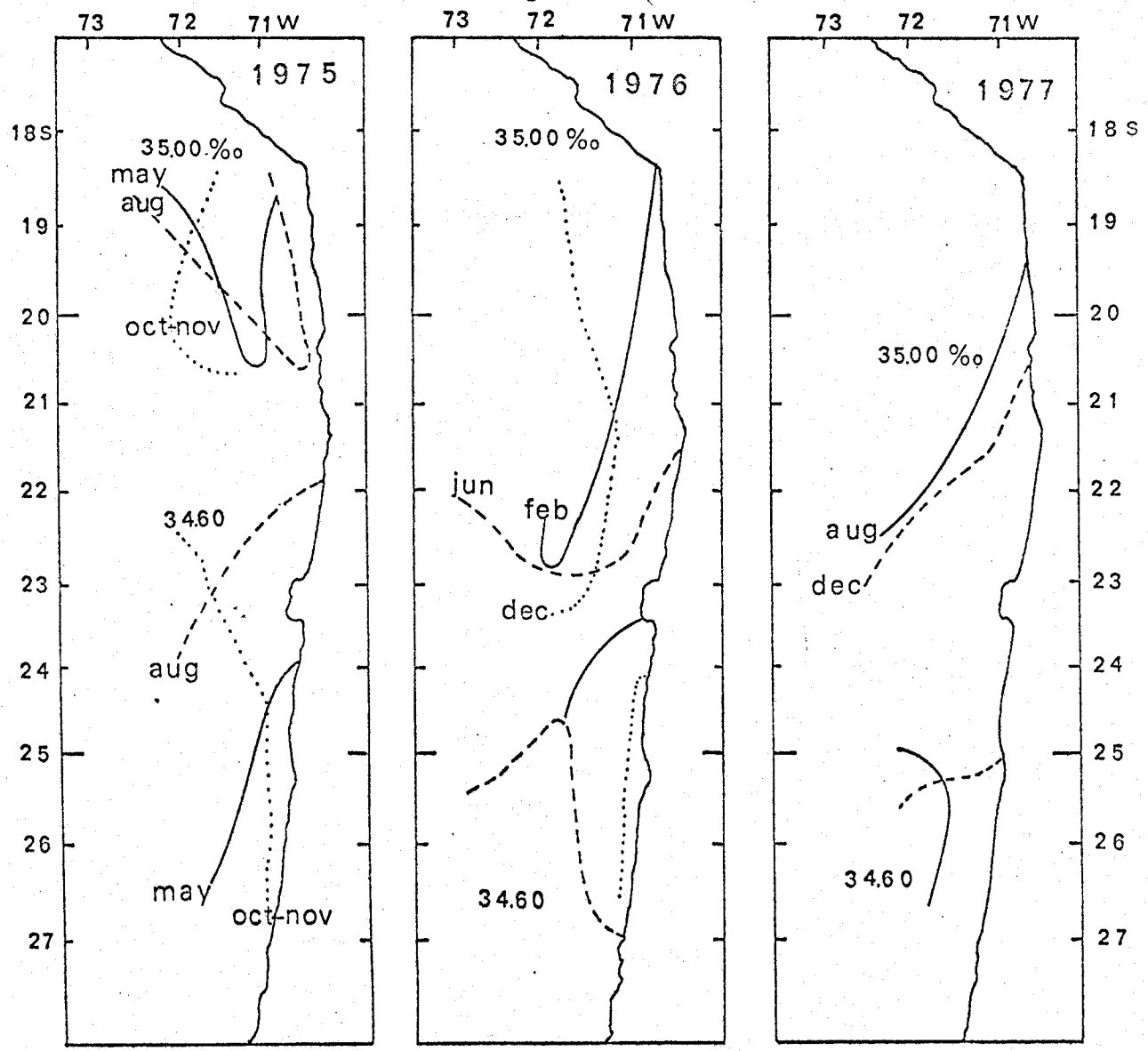

Figure 3. Location of the isohalines of 35.00 ‰ and 34.60 ‰ off Northern Chile during 1975, 1976 and 1977.

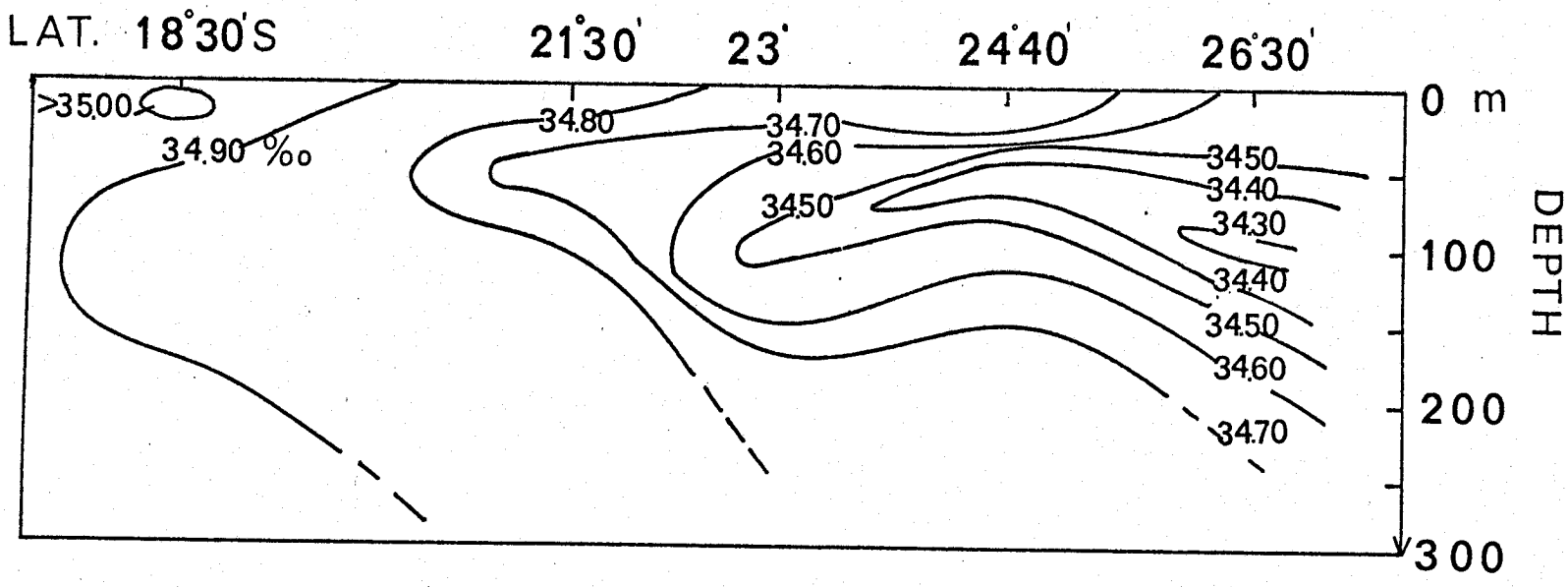

Figure 4. Vertical distribution of salinity, 50 miles off Northern Chile. May 1975 (From Basten, 1978).

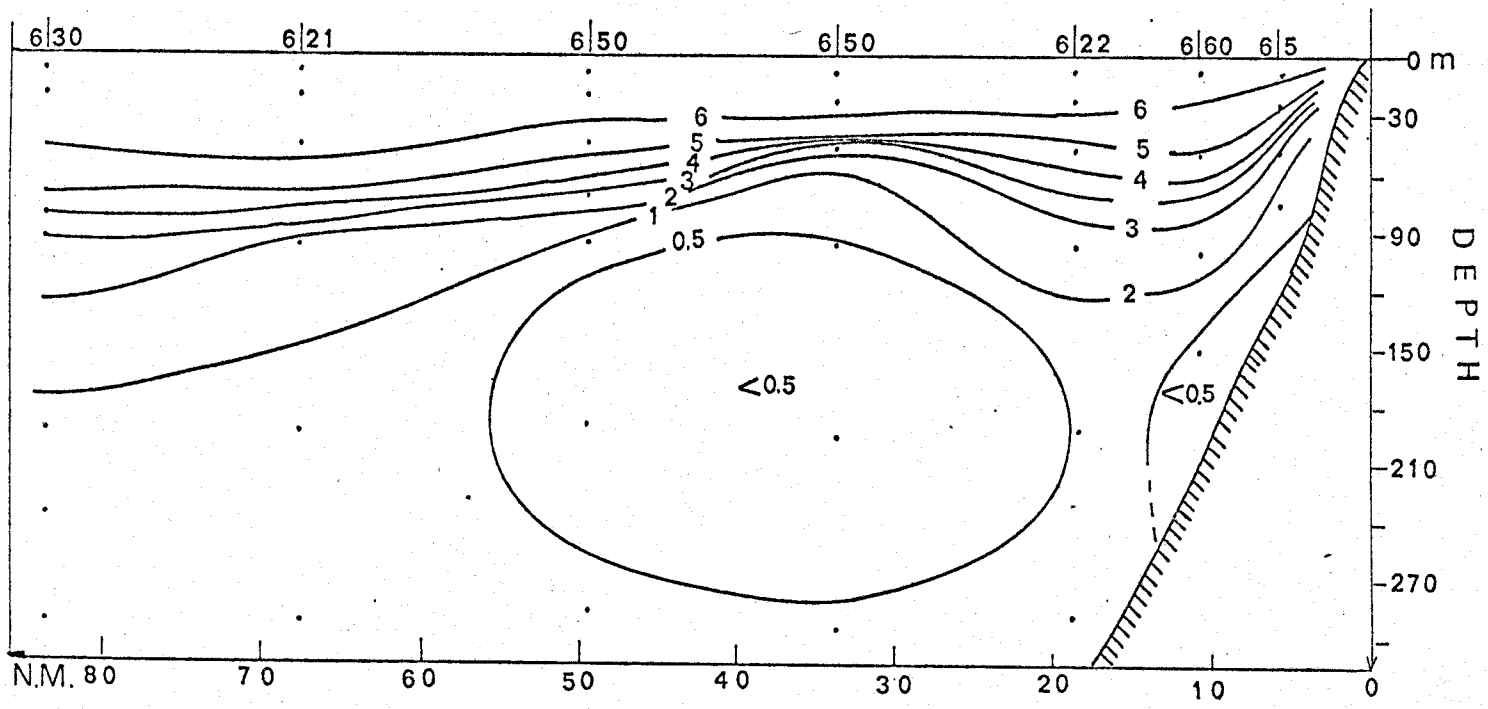

Figure 5. Vertical distribution of oxygen off Northern Chile (26°21'S)

August 1975.

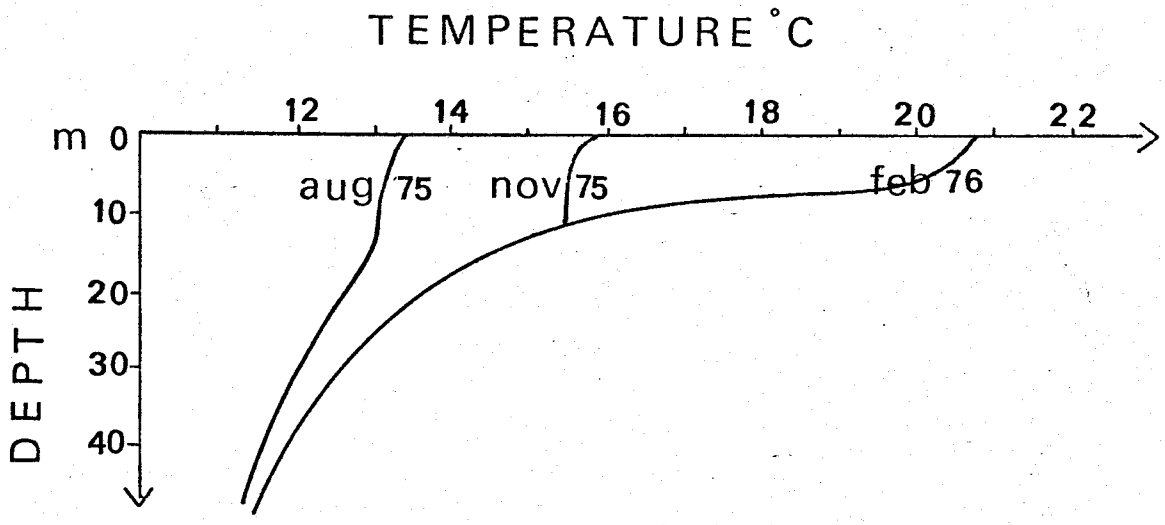

Figure 6. Thermal structure of coastal waters 20 miles off Northern Chile (Lat: 26° 21'S, Long: 71° 05'W) 1975 - 1976.

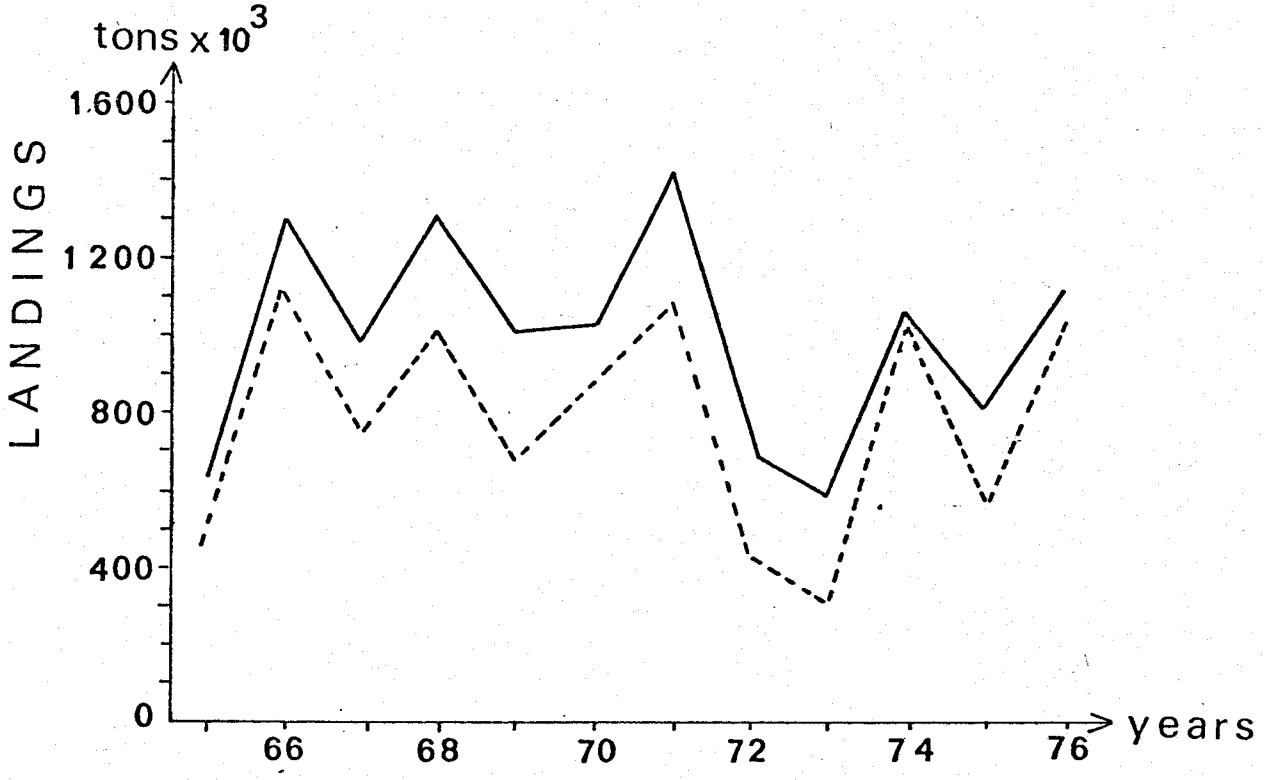

Figure 7. Annual landings of all species of fishes (solid line) and total pelagic fishes in Northern zone of Chile (From Basten and Contreras, 1977).

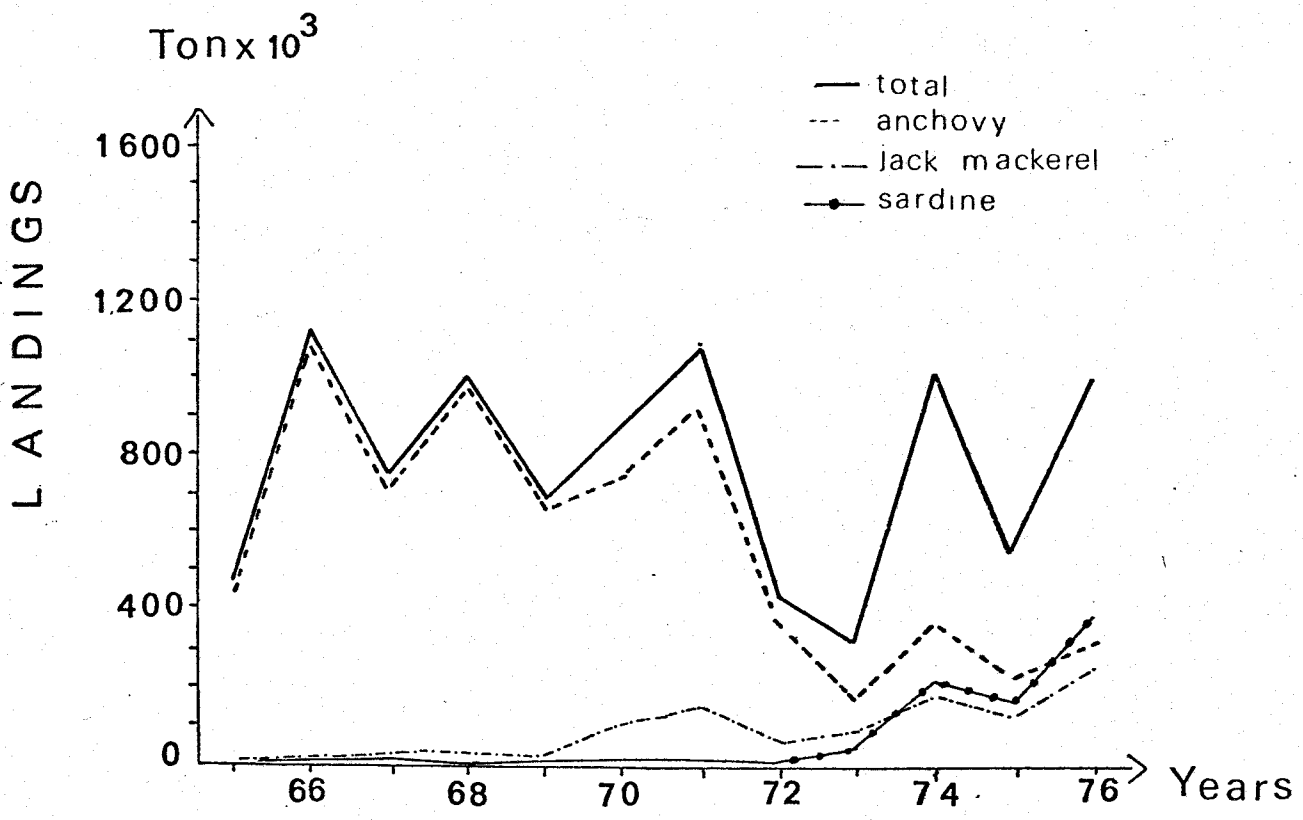

Figure 8. Annual landings of pelagic fishes in Northern zone of Chile (From Basten and Contreras, 1977).

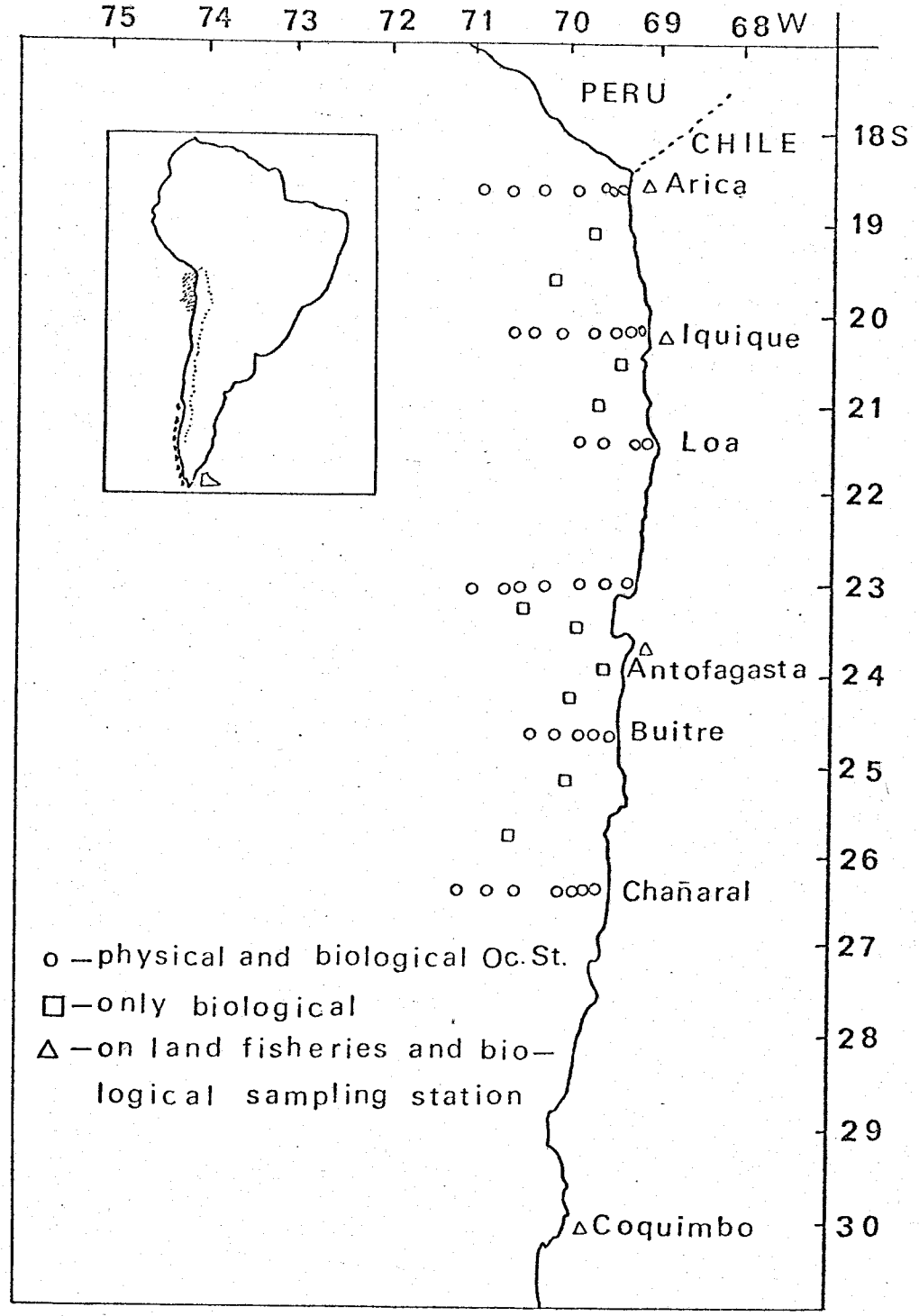

Figure 9. Area of study of the Chilean jack mackerel project.

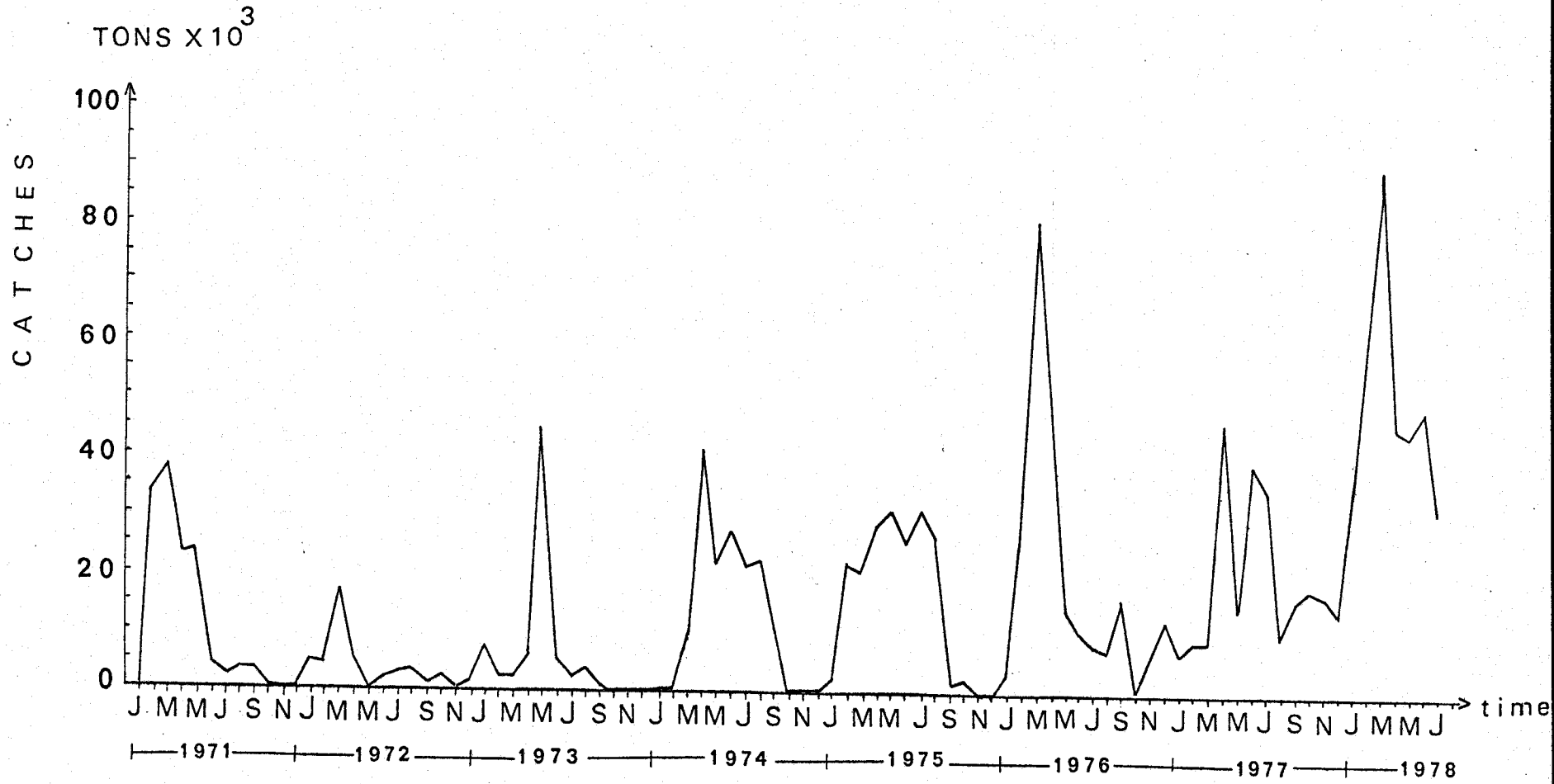

Figure 10. Industrial catches of jack mackerel (Trachurus murphyi) in Northern Chile. January 1971 to July 1978.

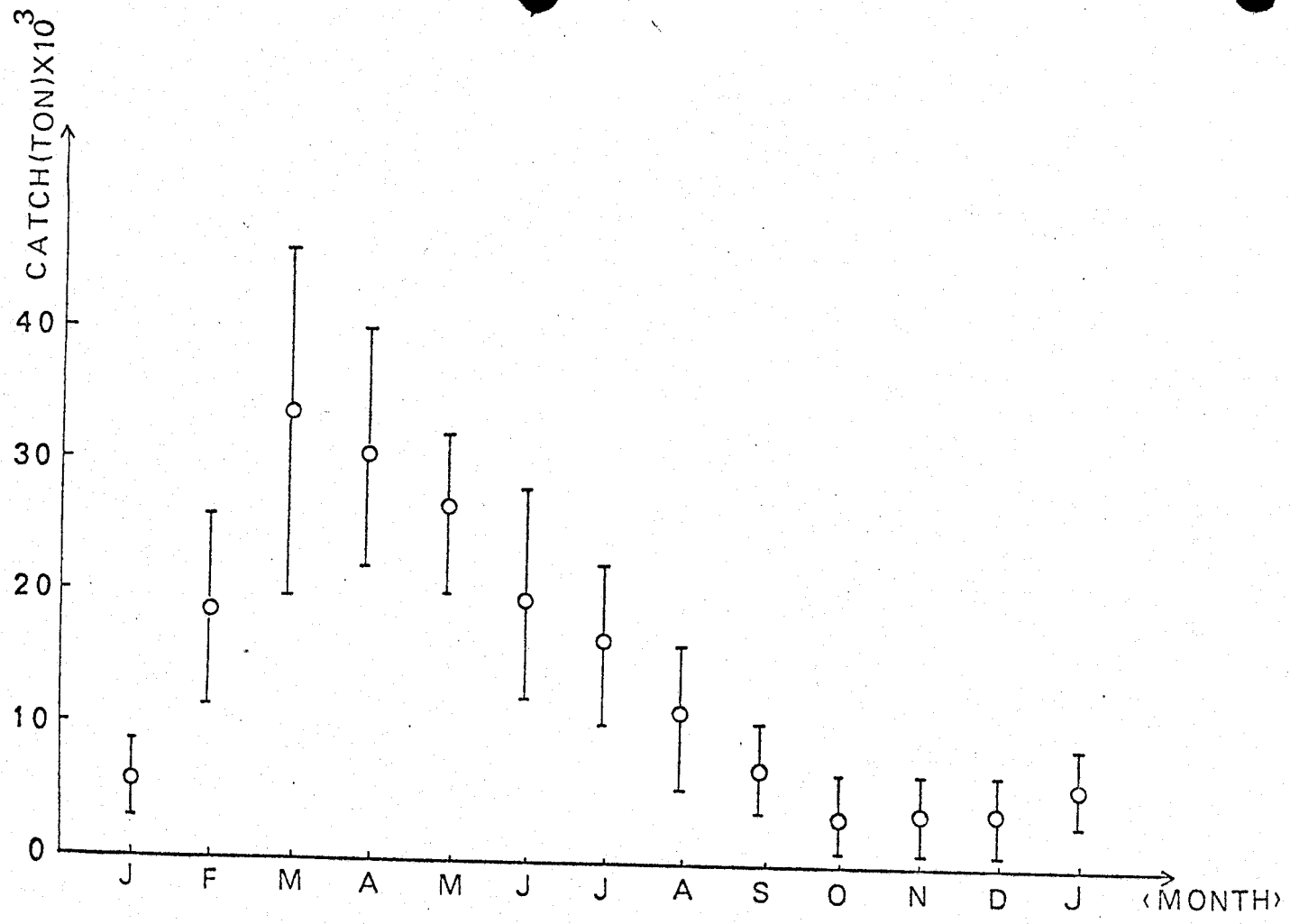

Figure 11. Seasons of the Northern Chilean fishery of jack mackerel (Trachurus murphyi). Average 1971 - 1977.

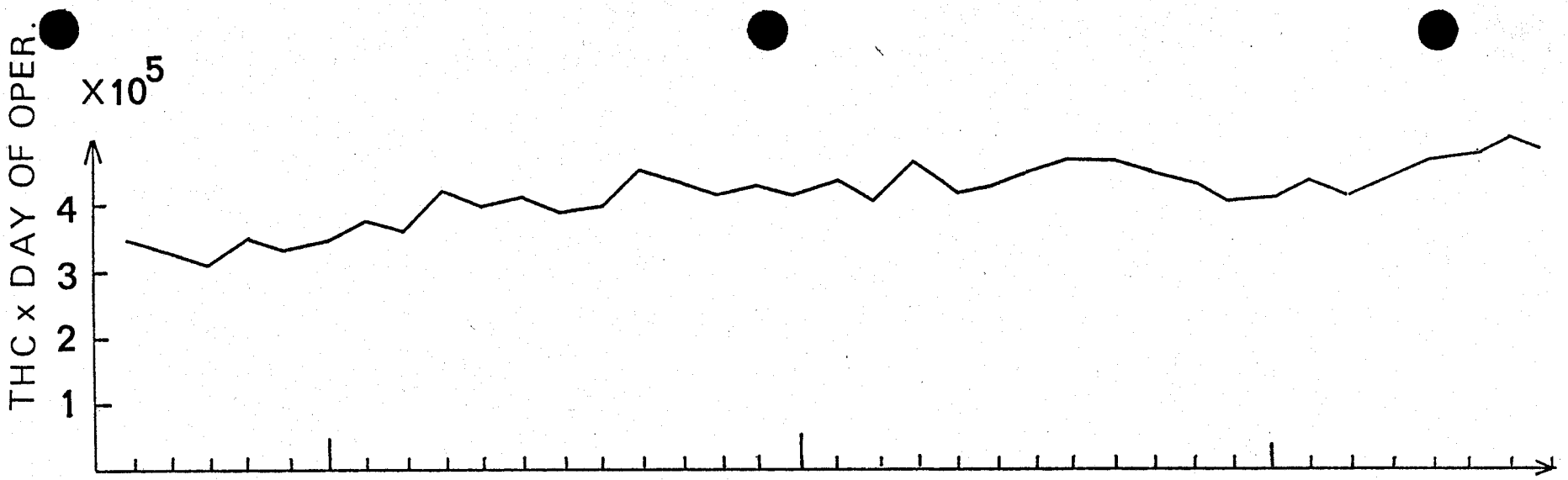

Figure 12. Monthly values of fishing effort in the north zone of Chile 1975 - 1978.

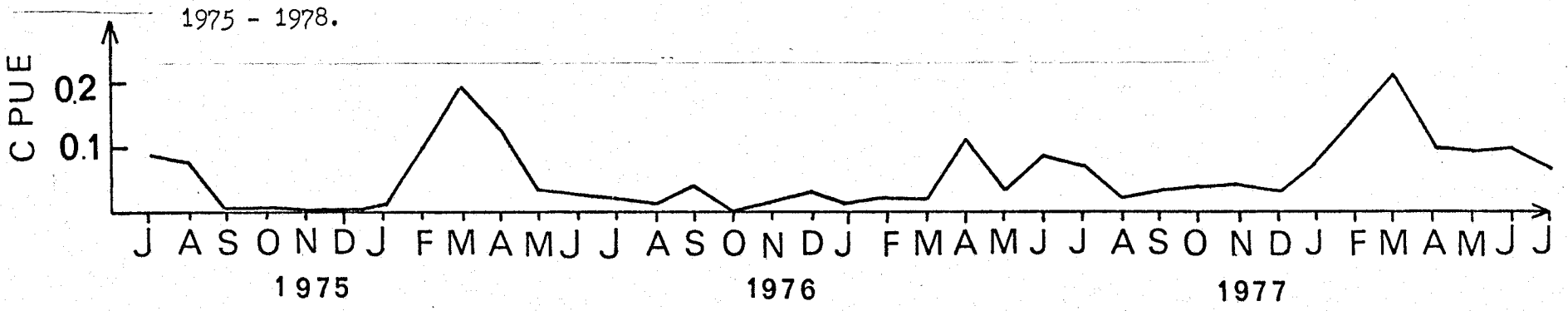

Figure 13. Monthly values of catch per unit effort in the North zone of Chile 1975 - 1978.

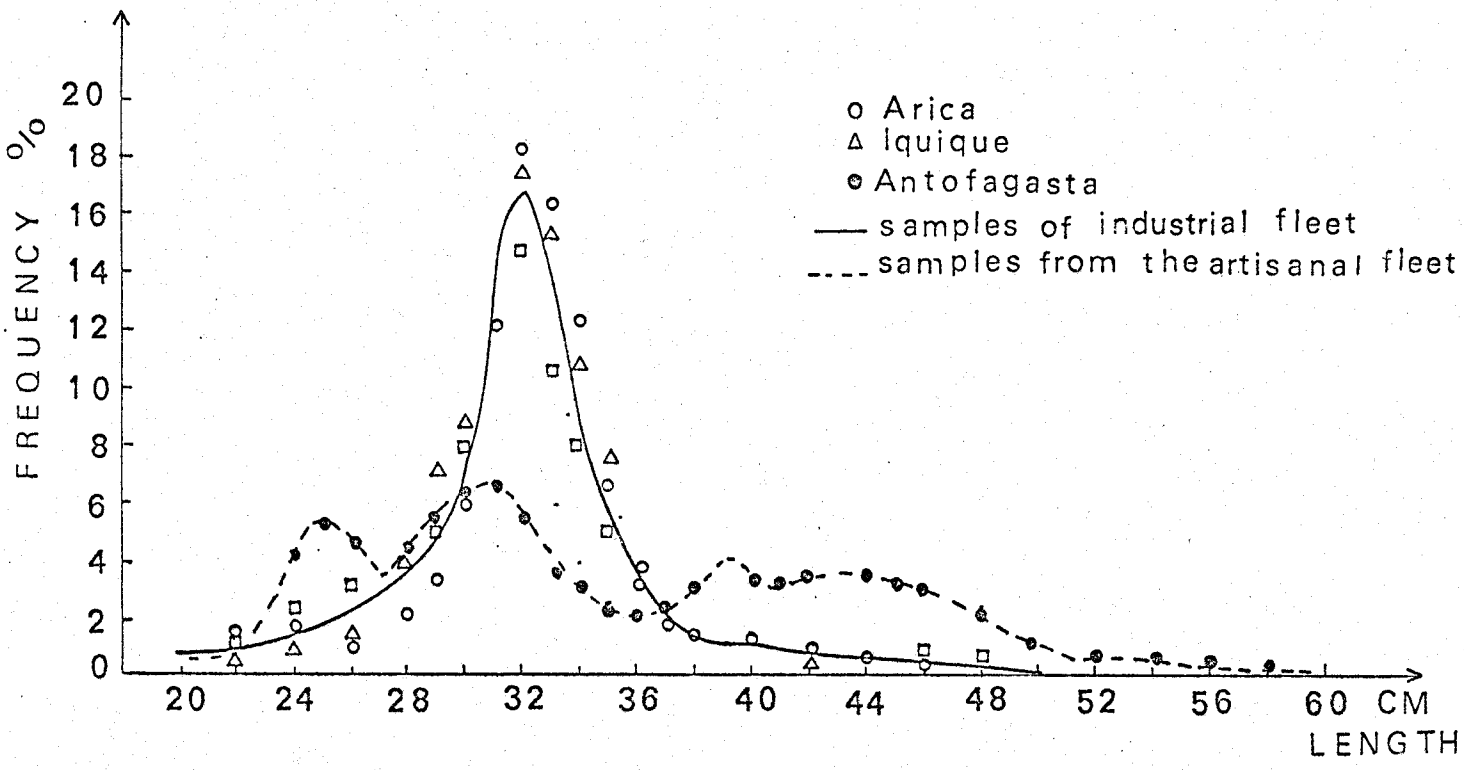

Figure 14. Distribution of length frequency of Trachurus murphyi, off Northern Chile, by ports (1975 - 1978).

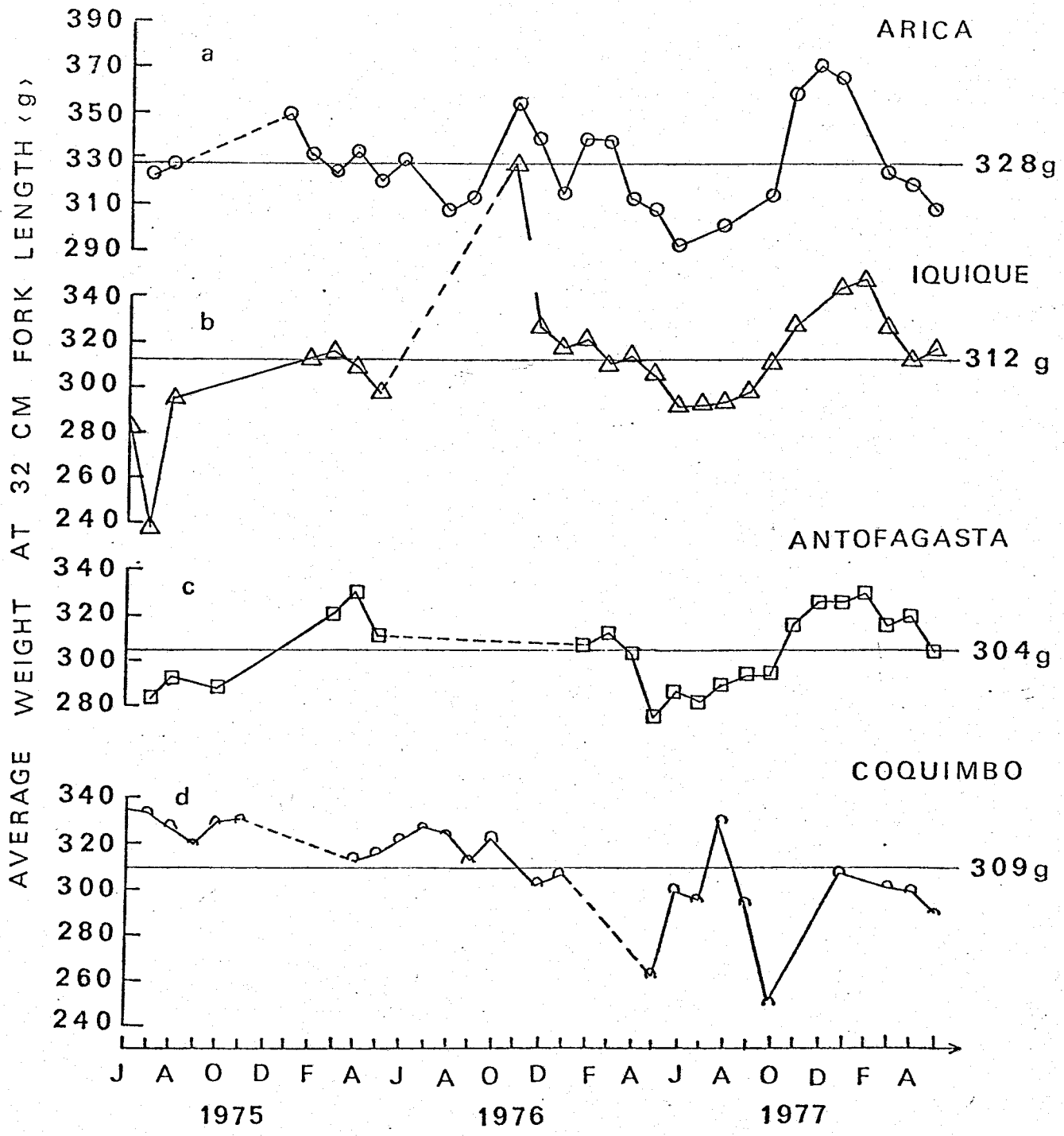

Figure 15. Monthly average weight of jack mackerel (Trachurus murphyi) of 32 cm F.L. of Northern Chile, by ports (1975 - 1978).

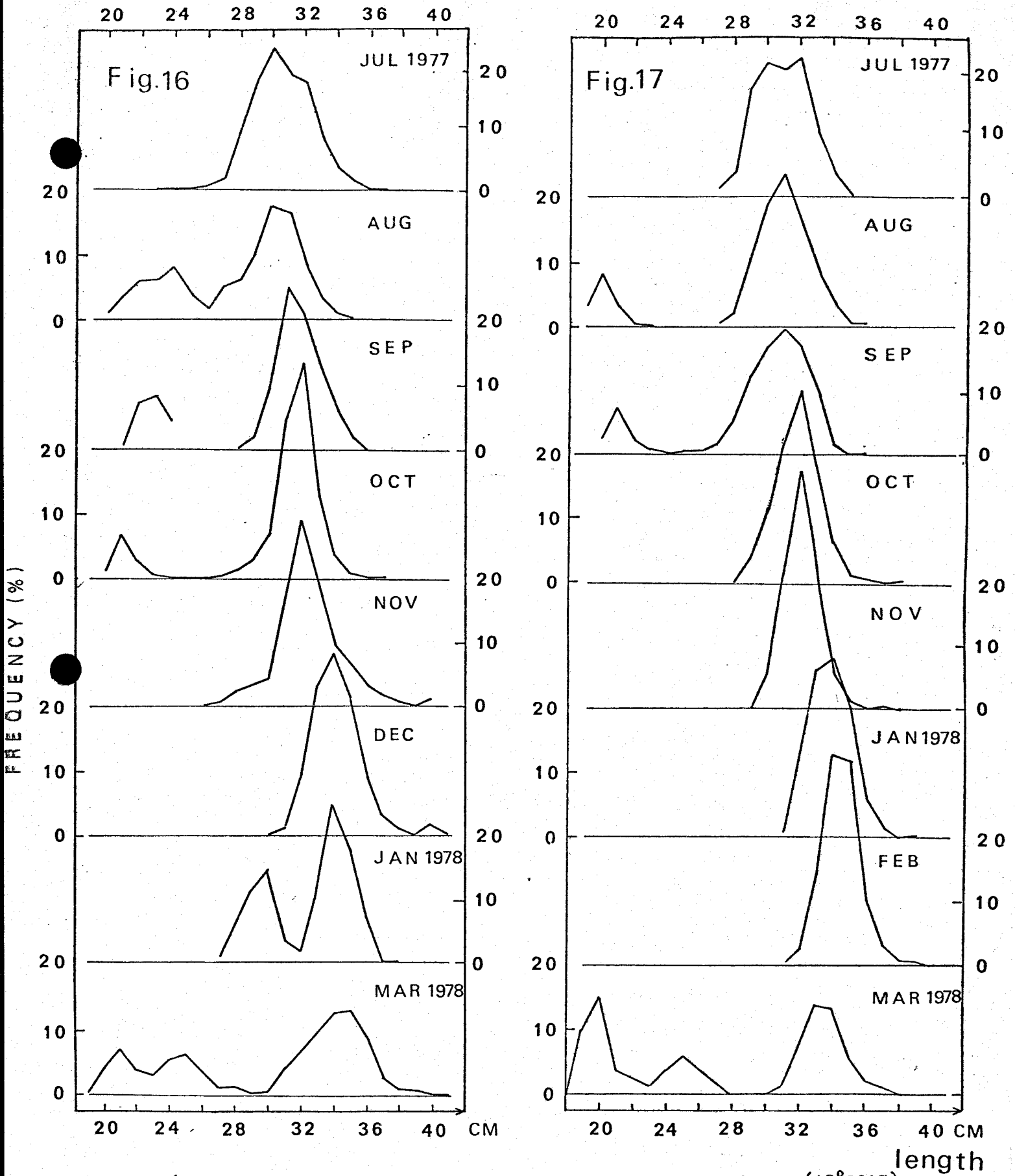

Figure 16. Distribution of length frequency of T. murphyi off Arica (18°30'S) between August 1977 and March 1978.

Figure 17. Distribution of length frequency of T. murphyi off Iquique (20°10'S) between July 1977 and March 1978.

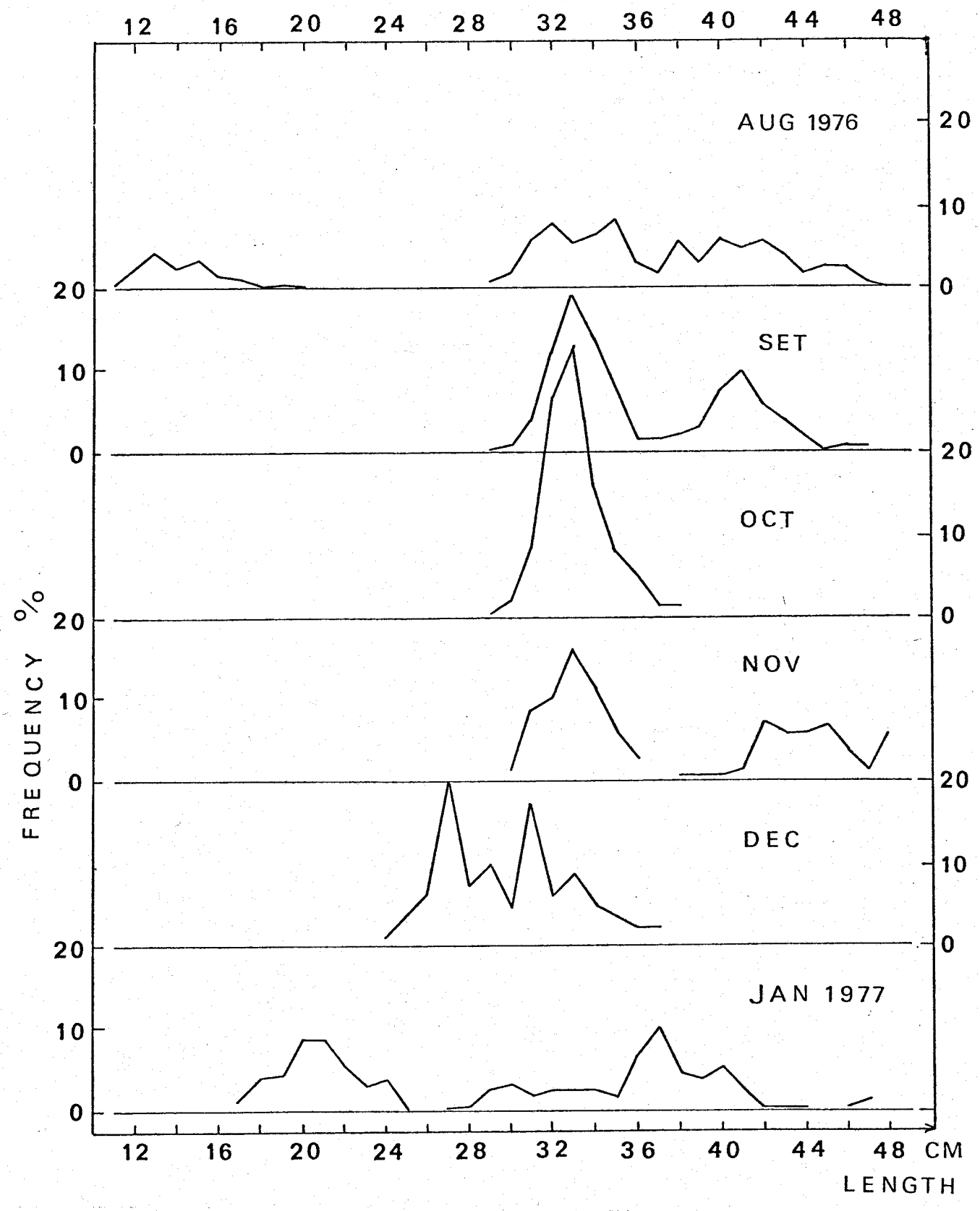

Figure 18. Distribution of length frequency of T. murphyi off Coquimbo (30°S) between August 1976 and January 1977.

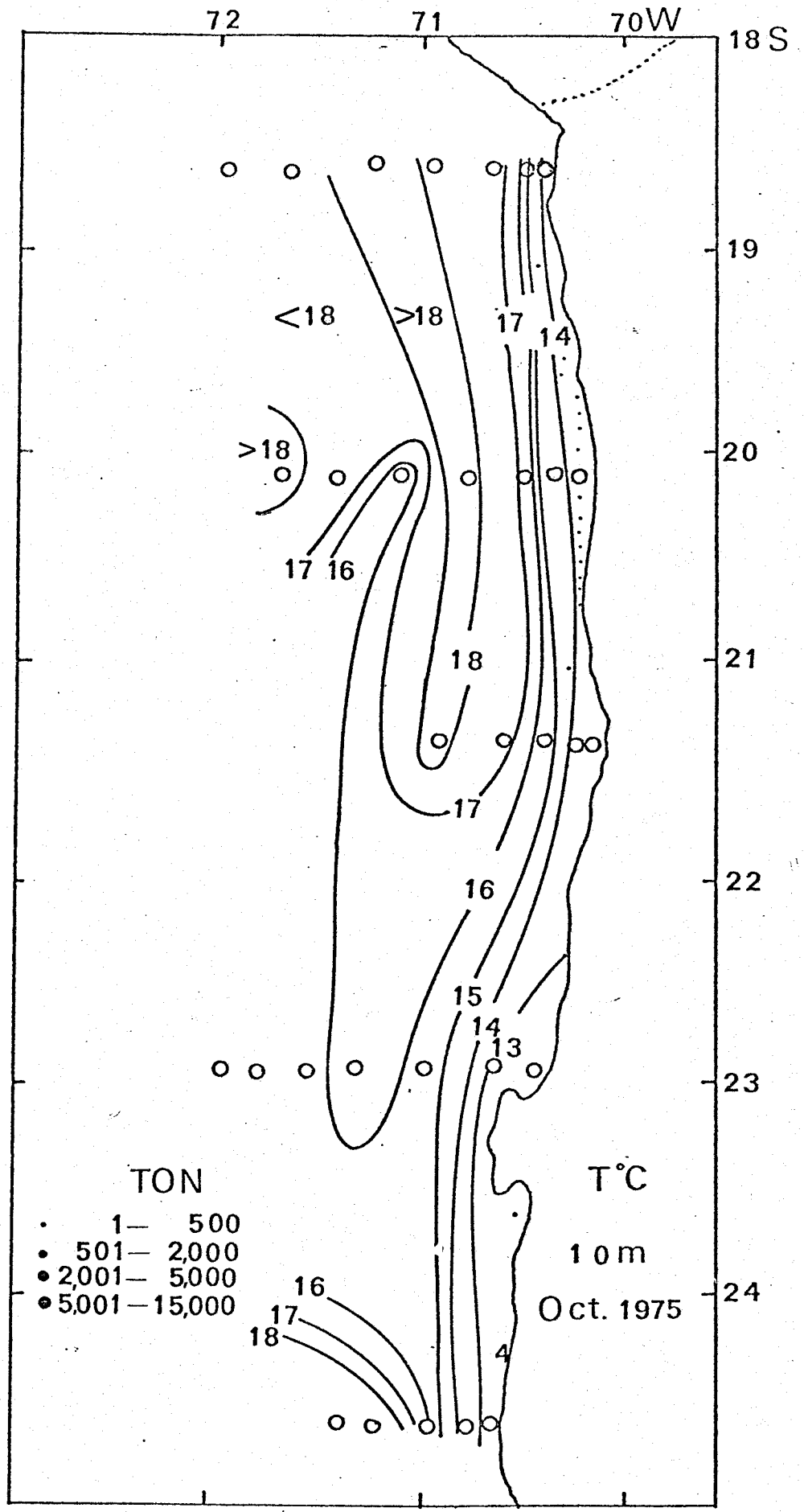

Figure 19. Geographical distribution of catches of jack mackerel during October of 1975 and horizontal distribution of temperature at 10 m.

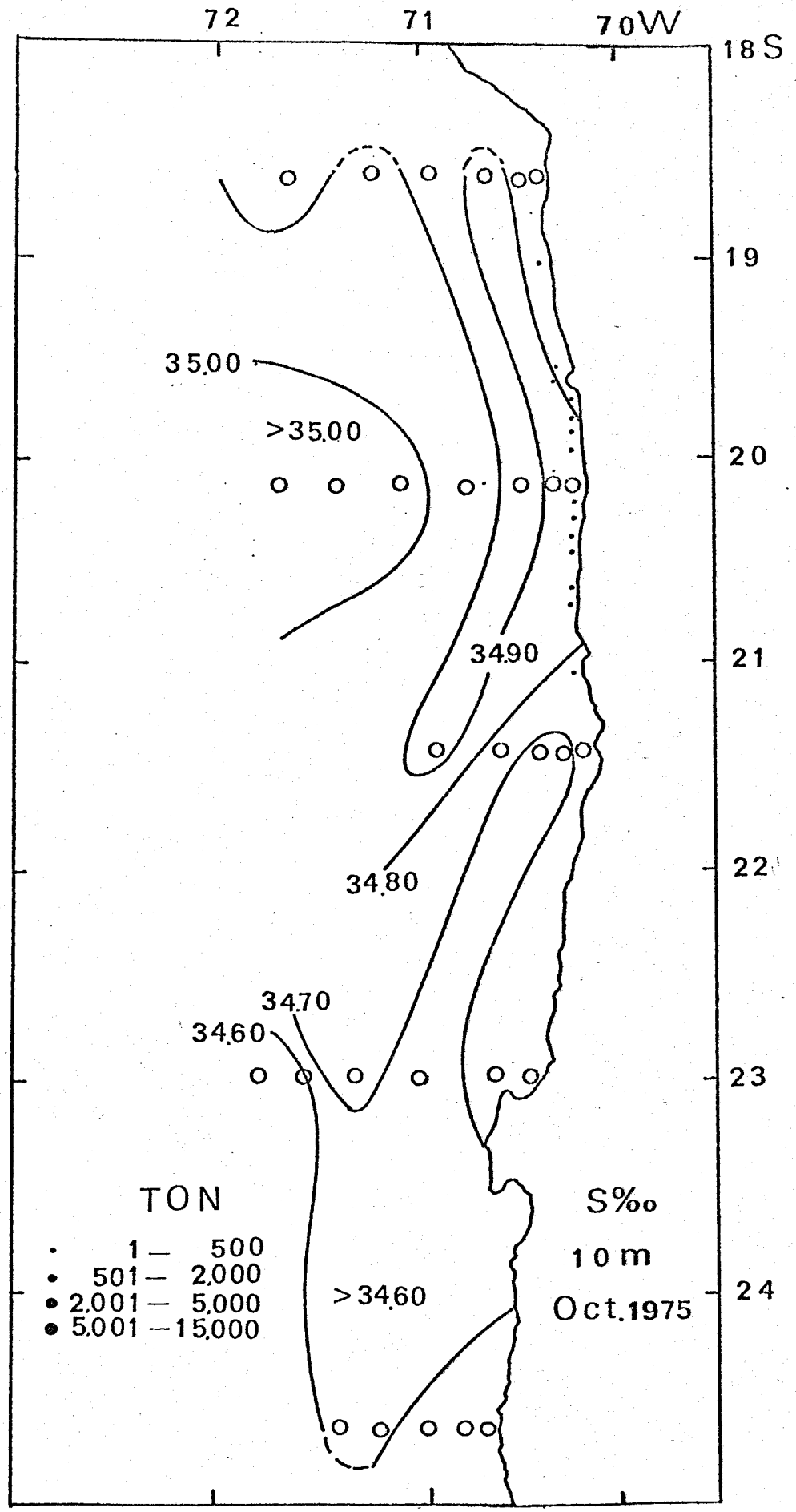

Figure 20. Geographical distribution of catches of jack mackerel during October of 1975 and horizontal distribution of salinity at 10 m.

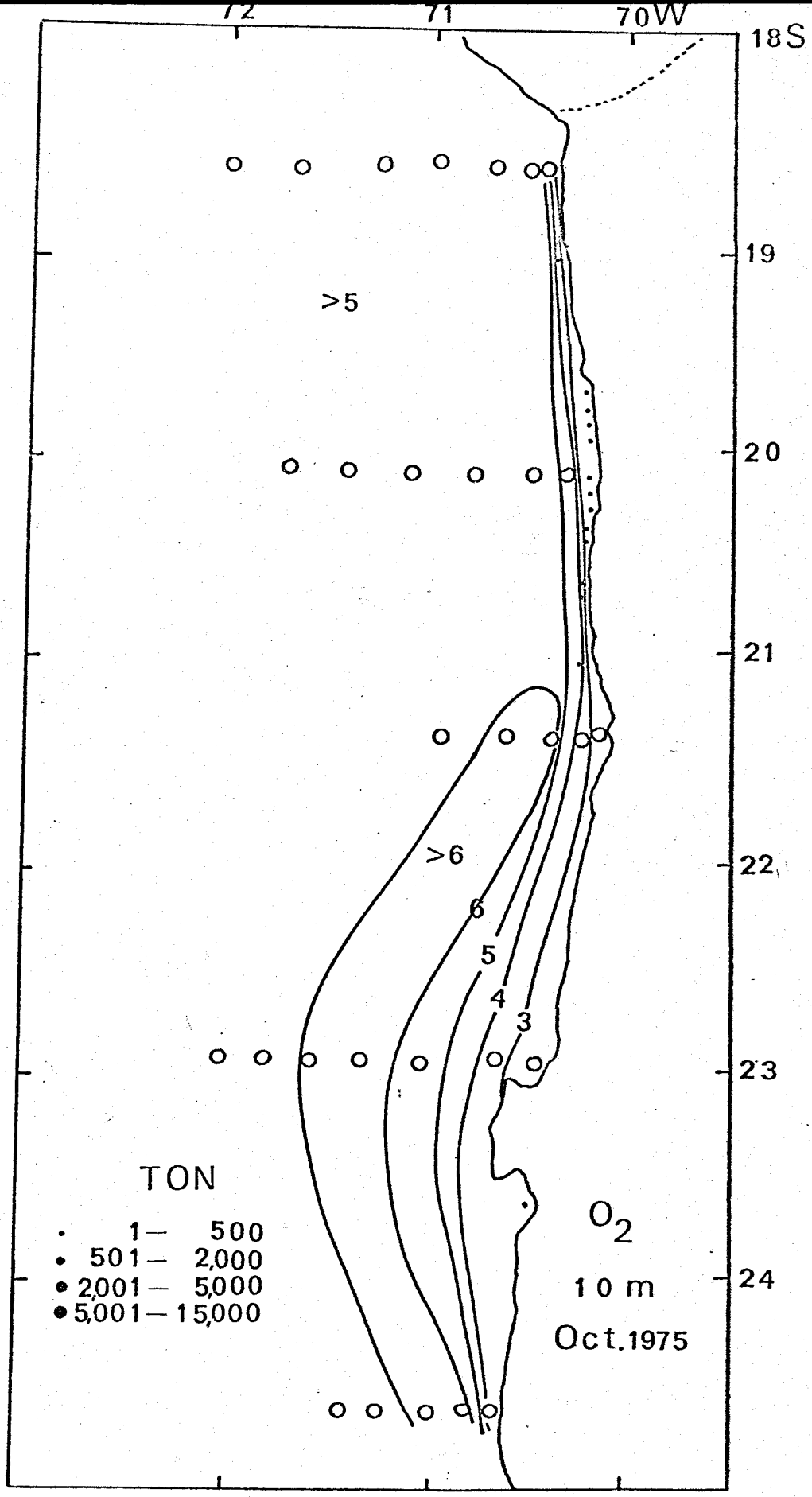

Figure 21. Geographical distribution of catches of jack mackerel during October of 1975 and horizontal distribution of oxygen at 10 m.

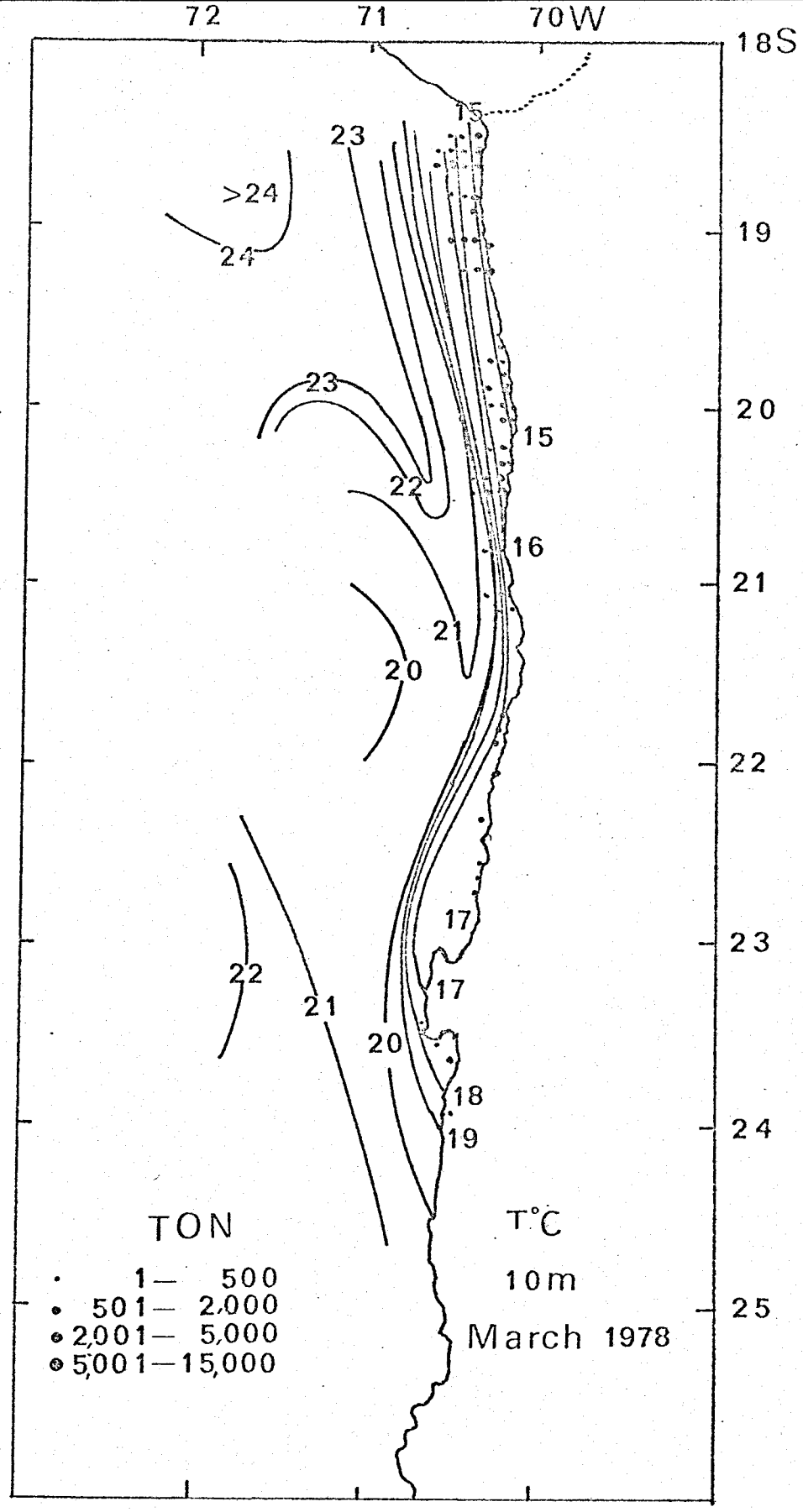

Figure 22. Geographical distribution of catches of jack mackerel during March of 1978 and horizontal distribution of temperature at 10 m.

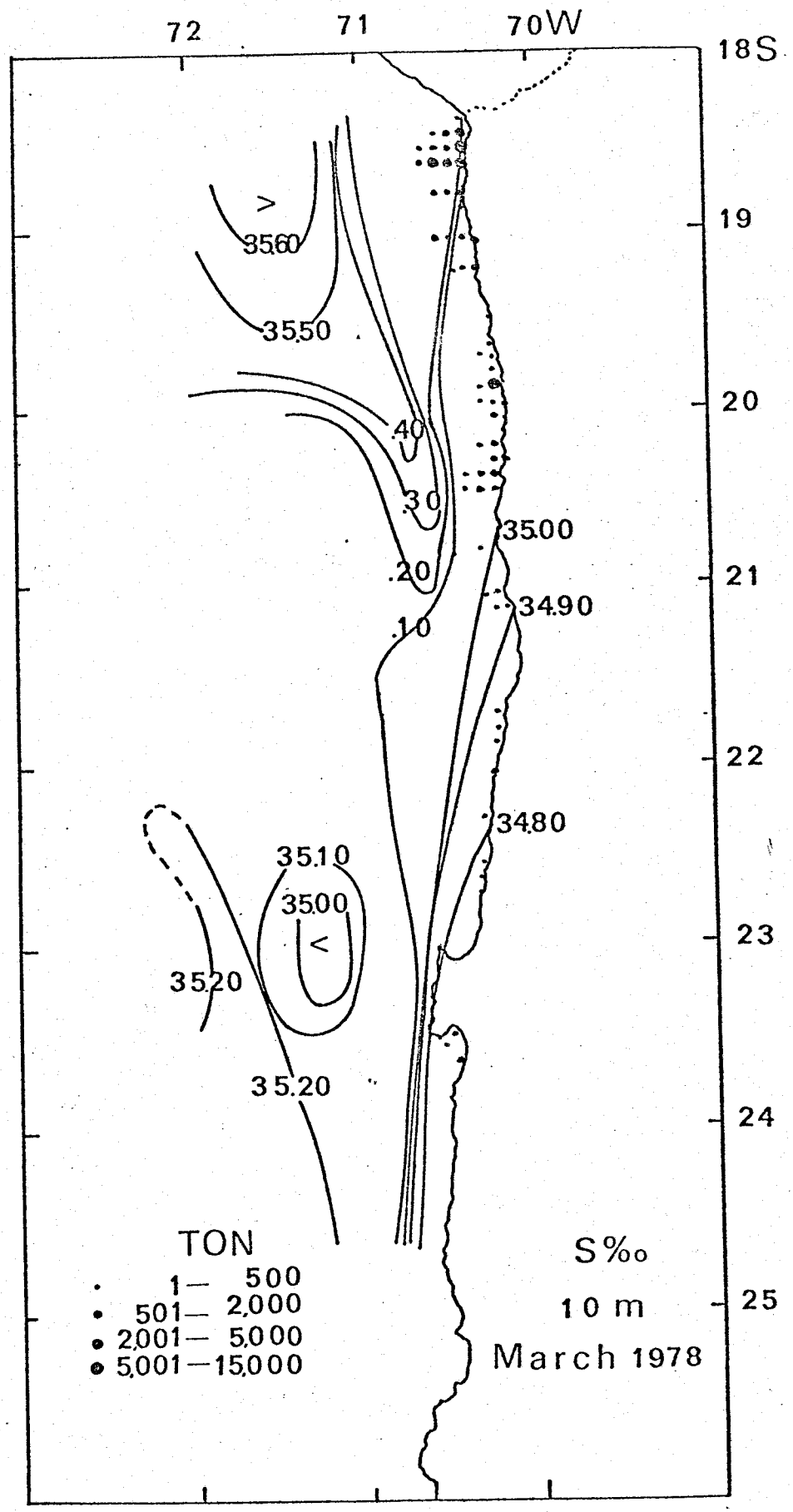

Figure 23. Geographical distribution of catches of jack mackerel during March of 1978 and horizontal distribution of salinity at 10 m.

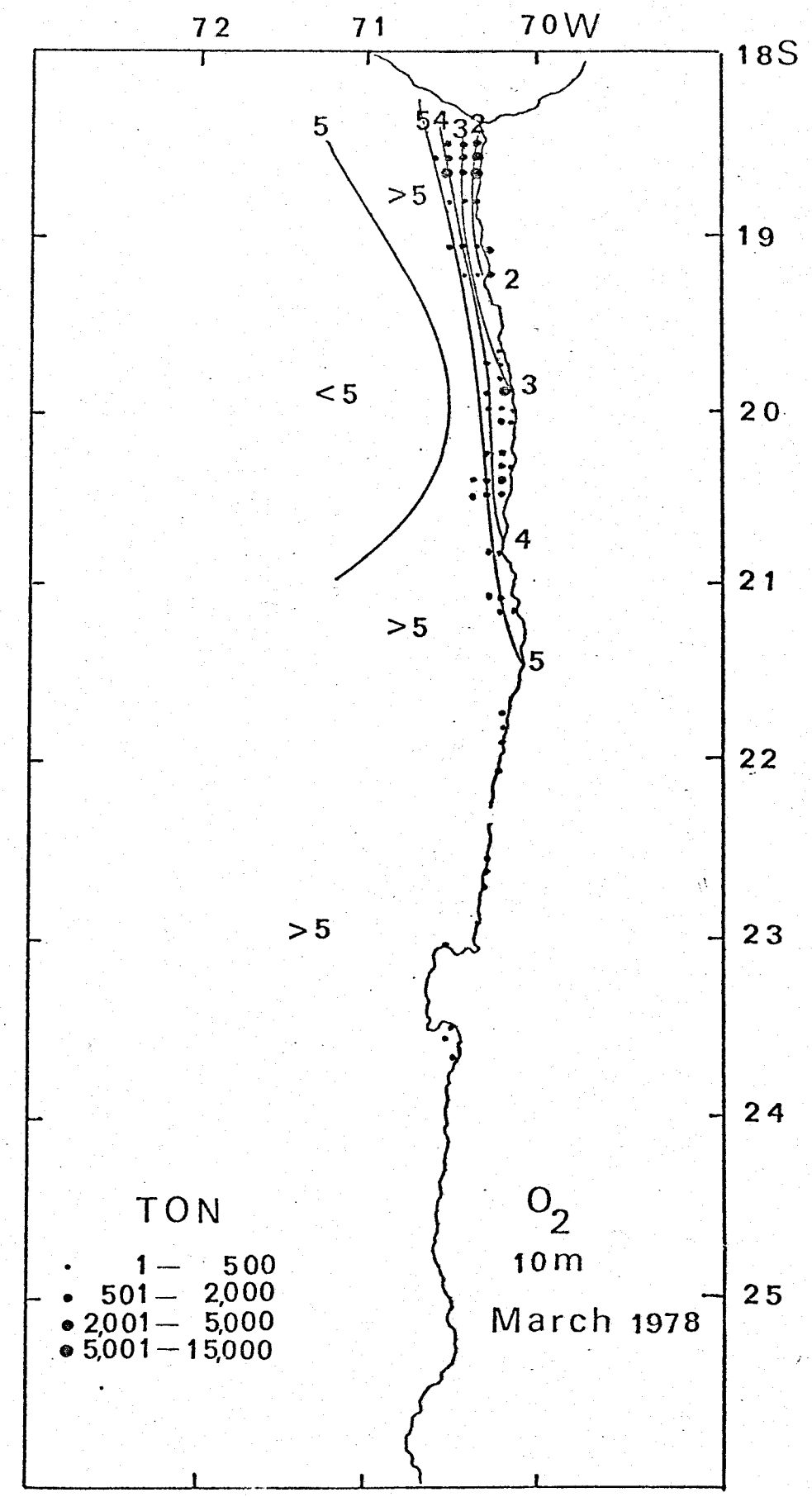

Figure 24. Geographical distribution of catches of jack mackerel during March of 1978 and horizontal distribution of oxygen at 10 m.

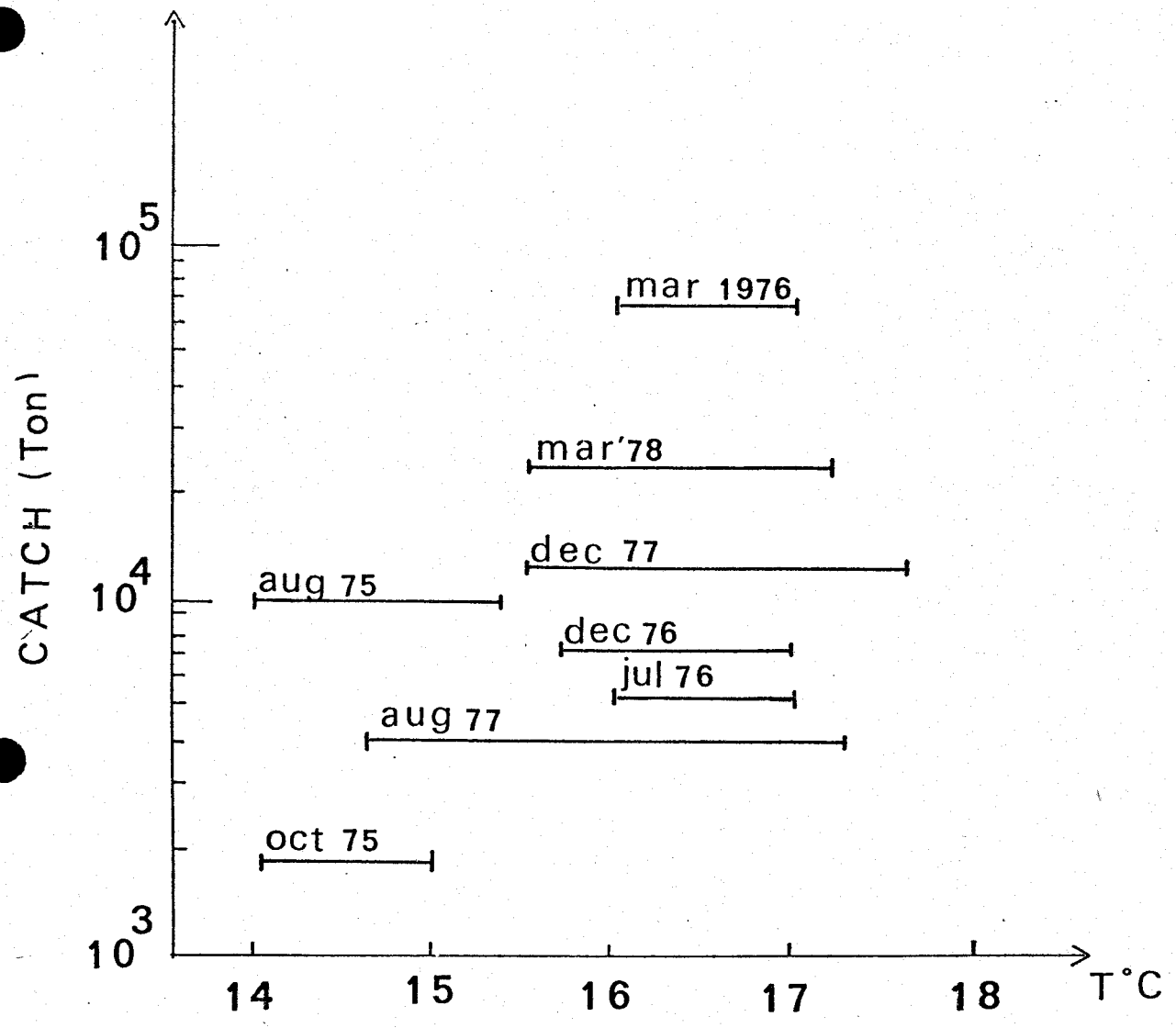

Figure 25. Monthly catches of jack mackerel off Iquique and temperature of sea water. August 1975 - March 1978.

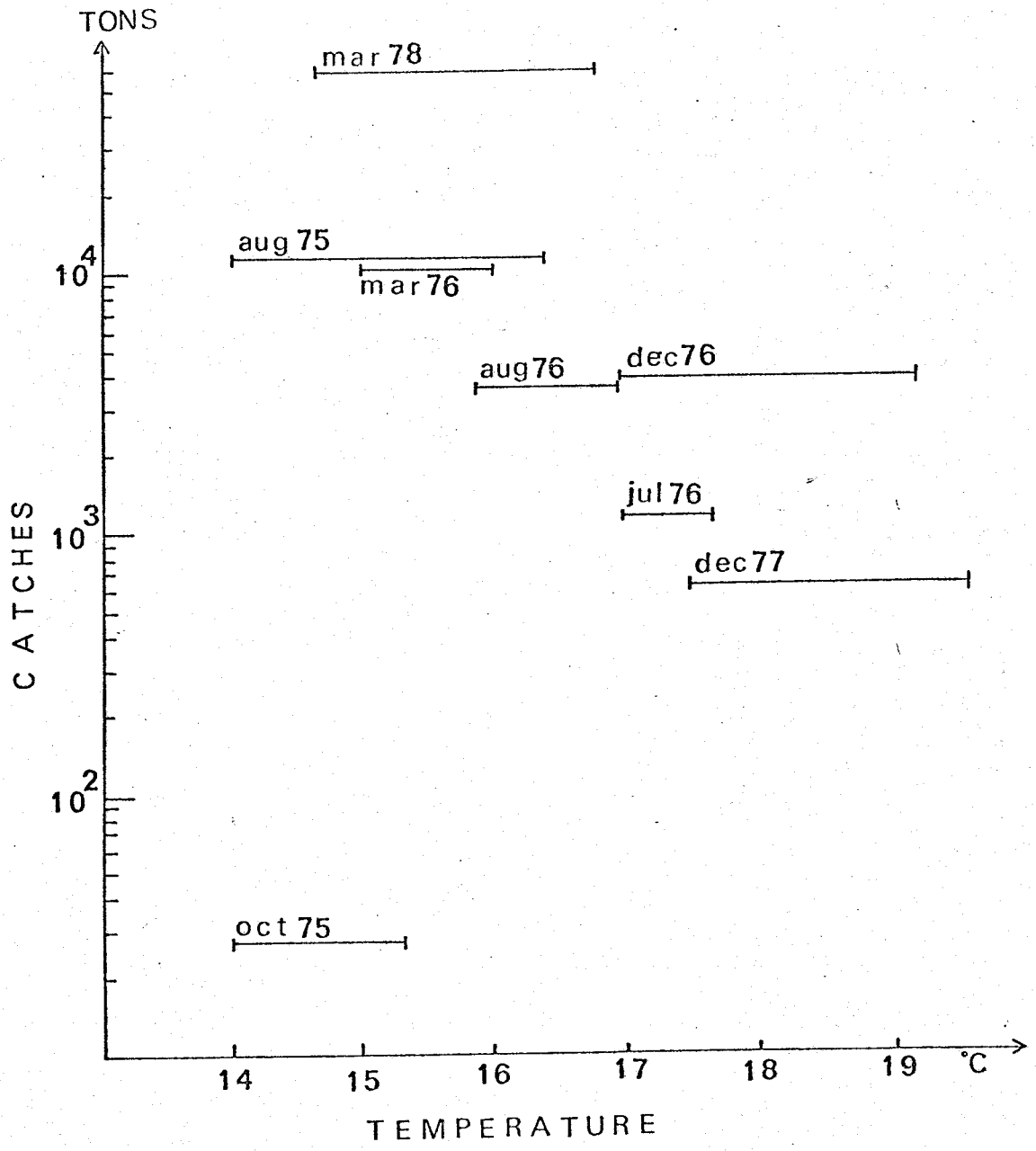

Figure 26. Monthly catches of jack mackerel off Arica and temperature of sea water. August 1975 - March 1978.

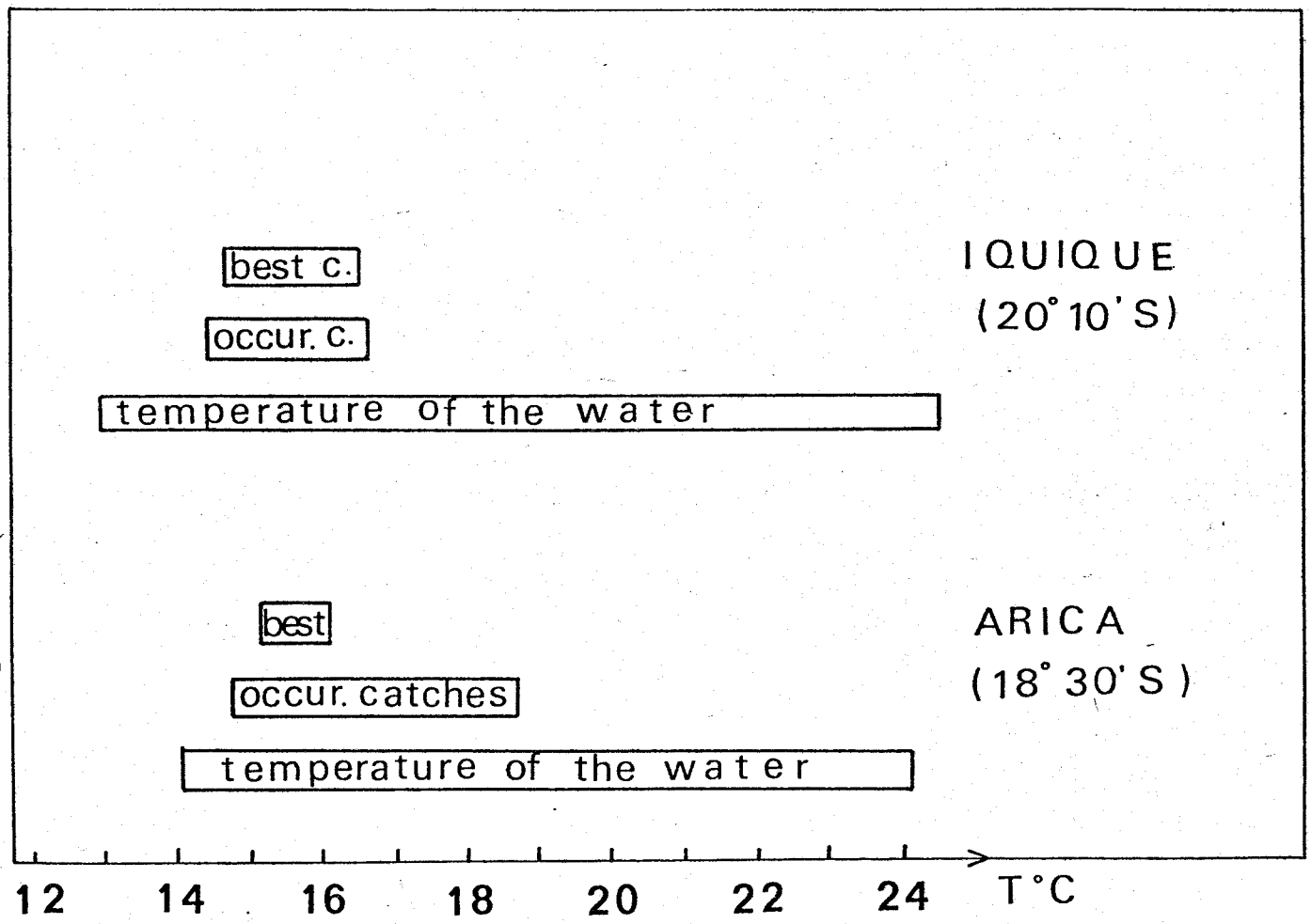

Figure 27. Ranges of temperature for waters, catches and best catches of jack mackerel (Trachurus murphyi) off Northern Chile (1975 - 1978).