THE 1997–98 EL NIÑO AND ITS EFFECTS ON THE COASTAL MARINE ECOSYSTEM OFF PERU

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ABSTRACT

We summarize the important effects of the extraordinary El Niño 1997–98 on the Peruvian marine ecosystem, and we compare these with what was observed during the extraordinary El Niño 1982–83. The SST anomalies at coastal stations, as well as data from marine explorations carried out during 1996–98, show, among other things, that the preceding cold period ended in January–February 1997; that El Niño 1997–98 was clearly defined along all the Peruvian coast in March–May 1997 (earlier in the north) and ended between April and June 1998, beginning from the south; and that El Niño was followed by a moderately cold period, evident since August 1998 (winter in the Southern Hemisphere). The most dramatic alterations in chemical characteristics were observed in December 1997 and February 1998, when low concentrations of nitrate (0.15–1.1 μg-at/L) extended south from Callao. Apparently, chemical conditions were more extreme in the water column in 1997–98 than in 1982–83, because the oxycline and nutricline were located at greater depths.

Anomalously small volumes of plankton were observed, and abundant dinoflagellates and copepods typical of warm waters entered the coastal waters with the equatorial surface waters (ESW) and subtropical surface waters (SSW), similar to what occurred during El Niño 1982–83. Anchovy were found near the coast in the first phase; in the second phase they shifted toward the south and into deeper water, while sardine increased in the first phase, and then migrated to the south. Hake widened their distributional range to the south and also vertically, because this species inhabits the zone influenced by the southern extension of the Cromwell Current (SECC). On the other hand, subtropical, equatorial, and even tropical species widened their distribution, being observed off the Peruvian coast. Of special relevance was the samasa, because its abundance and distribution reached 18°S, which made it an important resource for the Peruvian fishery during El Niño 1997–98.

INTRODUCTION

Peruvian coastal waters have a great variety of biological resources and constitute an important fishery region of the southwestern Pacific; the main species are the anchovy among the pelagics and the hake among the demersals. Two typical phenomena regulate the spatiotemporal distribution and the abundance of these resources: coastal upwelling and El Niño.

Coastal upwelling is mainly responsible for the great biological production that feeds the different trophic levels of the coastal environment. This process takes place along the Peruvian coastline, particularly around 5° and 15°S (Zuta et al. 1978), and it is associated with the SE trade winds that are commonly weak in summer and more intense in winter in the Southern Hemisphere.

The El Niño phenomenon arises from interannual variability in macroscale interaction between the ocean and the atmosphere. Its main scenario is the equatorial zone of the Pacific, and its manifestation is spectacular off the Peruvian coast, with variable features and distinct peculiarities. Its impact on fisheries resources depends on the type of event: weak El Niño, moderate El Niño, intense El Niño, and extraordinary El Niño.

This paper will present the biological responses in the main stages of the extraordinary El Niño of 1997–98, which, according to the anomalies of surface temperature, had a moderate peak in its initial development phase and a second, great peak in its second phase of development that ended with a rapid decline in autumn 1998.

We also make a brief comparison with El Niño 1982–83, which was one of the most intense in the decade of the eighties, and about which Halpern (1996) has made interesting reflections that we should always keep in mind.

METHODS

The material used for this study was obtained from sea operations carried out by the Instituto del Mar del Perú (IMARPE) in monitoring El Niño 1997–98, mainly from evaluation cruises of pelagic and demersal resources as well as some oceanographic cruises. We also used information on sea-surface temperature (SST) at fixed stations from the coastal laboratories of IMARPE and reports from the Dirección de Hidrografía y Navegación de la Marina (DHNM).

For hydrographic profiles, Niskin bottles and CTD were used to obtain samples at standard depths to 300 m. Salinity was determined with a Plessey 6230 salinometer. The nutrient analyses were done according to Strickland and Parsons (1972), and the oxygen analyses by Winkler method, modified by Carrit and Carpenter (1966).

The phytoplankton samples were taken with standard nets of 75 μm mesh size, in horizontal tows of 5 minutes at velocities of 3 knots. Surface plankton volumes were obtained by centrifugation at 2400 rpm for 5 minutes, expressing results in ml per m^3 of seawater filtered. Samples were analyzed qualitatively, considering the main groups of phytoplankton and zooplankton, giving conventional values for the abundances of the more representative organisms. Zooplankton samples were collected with Hensen nets of 300 μm mesh size in tows from 50 m to the surface, and were preserved in a 2% formaldehyde solution. These samples were analyzed qualitatively, and the ichthyoplankton were analyzed qualitatively and quantitatively, with results expressed in number of eggs or larvae per m^2.

The distribution and abundance of the pelagic resources were monitored with an echosounding digital system and echointegration (SIMRAD EY-500 and EK-500). Information on landings of the main fish resources was obtained from the Plan of Monitoring of Pelagic and Demersal Fisheries of the Peruvian coast. The reproductive states of the anchovy and sardine were estimated from macroscopic observation and from the histological state of the gonads. Information about marine birds and mammals was obtained by sighting and recording their geographic position during sea operations.

PHYSICAL FEATURES

We present the main features at the sea surface for the period September 1996–October 1998, using selected data published in many papers by DHNM in 1997 and IMARPE in 1997 and 1998, for coastal stations and research cruises. According to maps of SST in the Climate Diagnostics Bulletin (NOAA 1997, 1998), there was a great development of a warm coastal tongue to the Peruvian-Chilean border from February to April 1997, with a great equatorial transgression in February. During the rest of the year, the warm western tongue and the warm eastern tongue remained together, creating a band of temperatures greater than 28°C, which apparently favored the start of a new equatorial transgression. This new transgression intensified in January–March 1998 and persisted until June 1998, when the equatorial cold tongue could not be completely reestablished.

The preceding, 1995–96 moderately cold period (Zuta and Otininano 1998) ended in January–April 1997, with a delayed southward displacement: in January to Paita, in February to Chicama and Chimbote, in March to Callao, and in April to Ilo.

The warm period with SST anomalies greater than 1°C lasted much longer in the north than in the south: 16 months (March 1997 to June 1998) in Talara and Paita; 15 months (April 1997 to May 1998) in Chicama-Callao; and 13 months (May 1997 to May 1998) in Ilo (fig. 1). Figure 2, from *Humboldt* cruises 9704, 9706-07, and 9709-10, shows the distribution of SST anomalies in the first phase, including values higher than 6°C north of Pimentel (7°S) and between 10° and 17°S during June–July 1997.

The positive SST anomalies of coastal stations showed two peaks (fig. 3a). The first was moderate and took place around August 1997; the second was more intense (January 1998). In between, the main decline was in October 1997 along the whole coastal band (fig. 3b). During the first phase of this warming period, the positive anomalies were as high as 6°C; during the second phase the anomalies were up to 9°. The coastal area between 7° and 12°S was much more affected by the warming period.

Cruise 9702-03 (Vásquez 1997) and cruise 9704 (Morón and Marquina 1997) recorded a strong southern intrusion of equatorial surface waters (ESW) and tropical surface waters (TSW) to 12°S and an intrusion of subtropical surface waters (SSW) south of 15°S (San Juan) during the first phase of the warm period.

Cruises 9711-12 and 9803-05 (figs. 4 and 5) showed that during the second phase of the warm period there was another intrusion of ESW between 81° and 84°W, and southward displacement up to 12°S, with salinities of 32–34.8 ppt and temperatures of 25°–29°, at the time when SSW were in the coastal band south of 8°S (Salaverry), with salinities of 35.1–35.6 ppt and temperatures of 19°–25°. In fact, the SSW was much more permanent than was the ESW.

The decline of the positive SST anomalies and consequently the end of El Niño 1997–98 started in March 1998 at Ilo and in June 1998 at Paita. Around August–September 1998 a negative SST anomaly appeared, and then the post–El Niño conditions started. They were characterized by a moderate cold period that remains evident. Between June and July 1998, there was evidence of normalization of the coastal zone from Huarmey northward, in both temperature and salinity. The SSW off Paita had temperatures from 19° to 21°.

The extraordinary El Niño event of 1997–98 was not expected to reappear sooner than 100 years after the extraordinary El Niño event of 1982–83.

CHEMICAL FEATURES

The presence of warm equatorial and subtropical water masses along the Peruvian coast was well defined at the beginning of El Niño in April (cruise 9704), June–July (9706-07), November–December (9711-12),

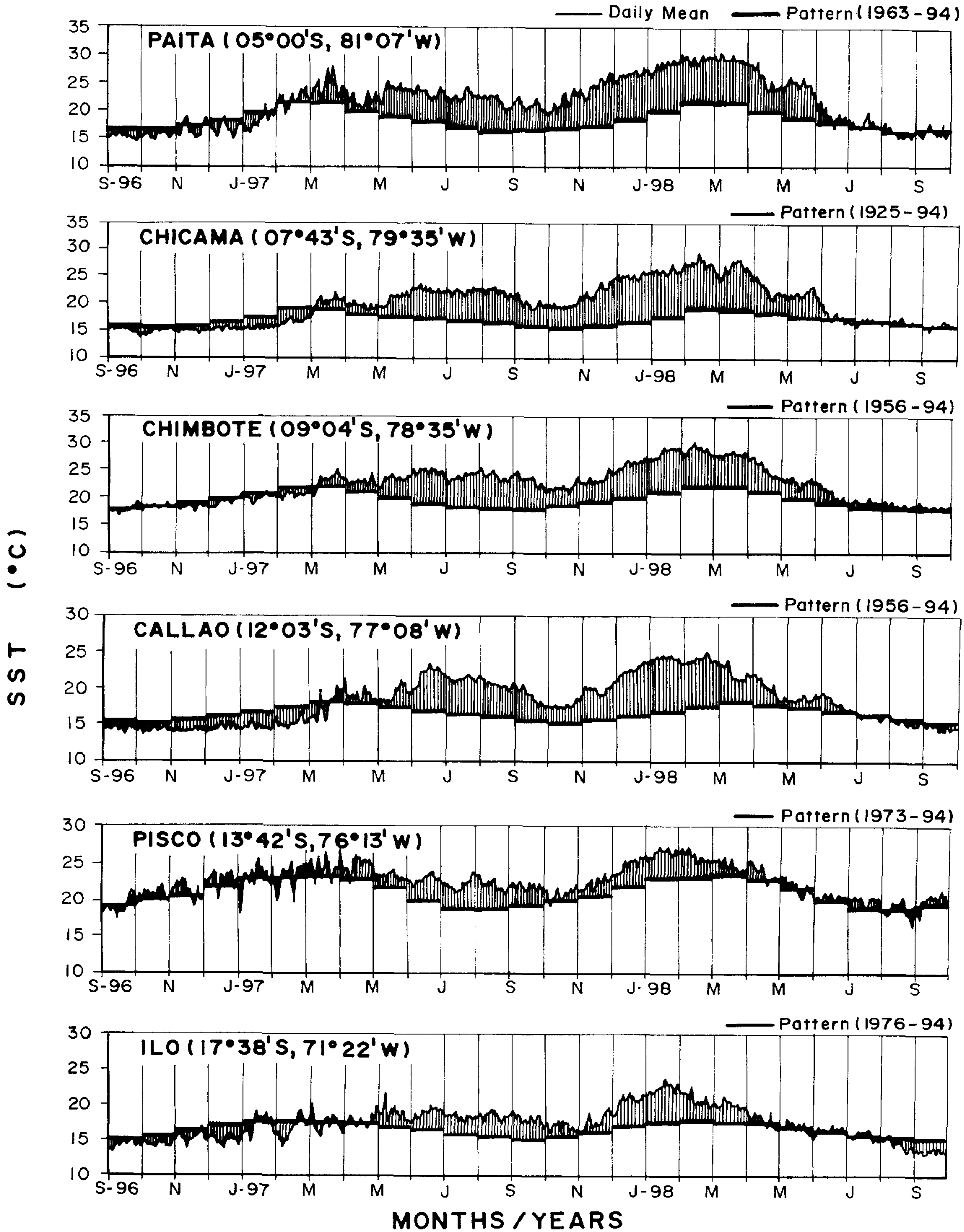

Figure 1. Time series of daily mean SST (thin line); the thicker line represents the long-term monthly mean.

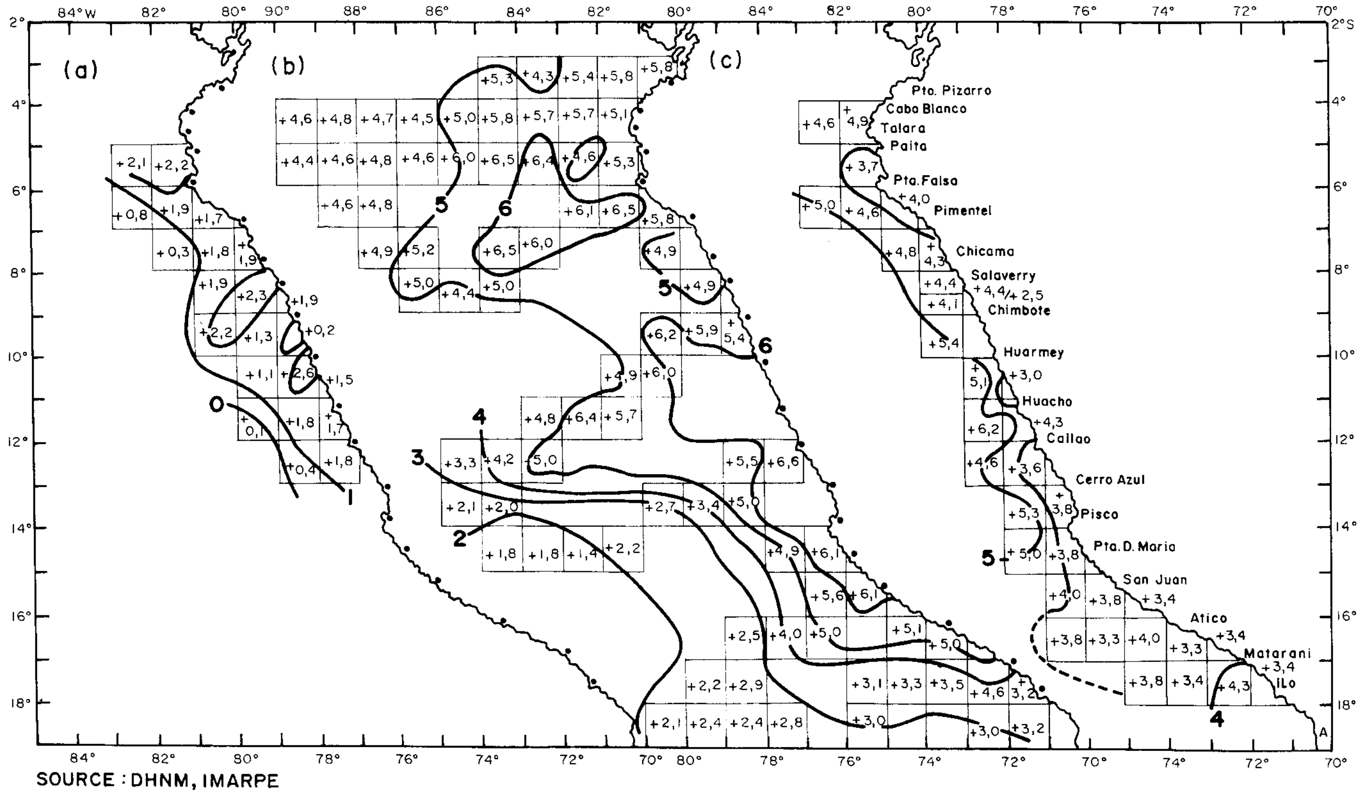

Figure 2. Maps of monthly mean SST anomalies for research cruises of autumn (*a*, *b*), and winter (*c*) of 1997. Adapted from Morón and Marquina 1997, and Gutierrez et al. 1998.

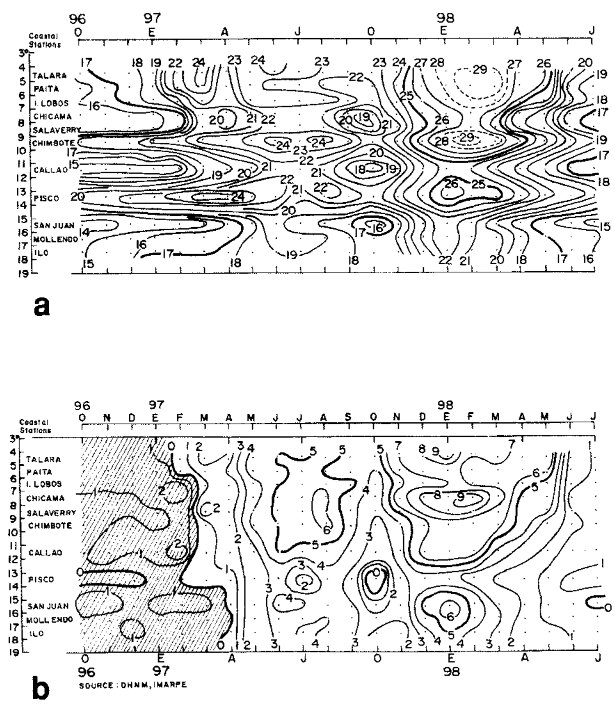

Figure 3. Composite structure of the monthly mean SST (*a*) and SST anomalies (*b*) for the stations along the entire Peruvian coast (October 1996–July 1998).

and February–March (9802-03) by thermohaline features (Gutierrez 1997; Pizarro 1997a, b; Garcia 1998). The distribution of oxygen and nutrients at the sea surface also characterized these periods. Among the nutrients, nitrate was selected as an indicator of anomalous distribution for comparison with preceding events, since it was reported by other authors.

Seasonal Variation of Oxygen and Nutrients

Figures 6 and 7 describe the seasonal sequence of changes in dissolved oxygen and nutrients in the sea surface, providing indicators for monitoring the warm event.

At the beginning of autumn 1997 in the Southern Hemisphere, *Humboldt* cruise 9704 detected the first hydrochemical alterations of El Niño in the initial movement of equatorial waters, which mixed with coastal waters to produce an irregular distribution of dissolved oxygen with high values between 5 and 7 ml/L. The nitrate concentrations were lower than 5 µg-at/L beyond 20 nmi, and changes were not observed in the coastal band.

At the end of autumn and beginning of winter 1997 (9706-07) the dissolved oxygen had a different distribution than in April, being more homogeneous, where values <5 ml/L (4.8–4.9 ml/L) corresponded in general to the equatorial surface waters (ESW; <34.8 ppt), which

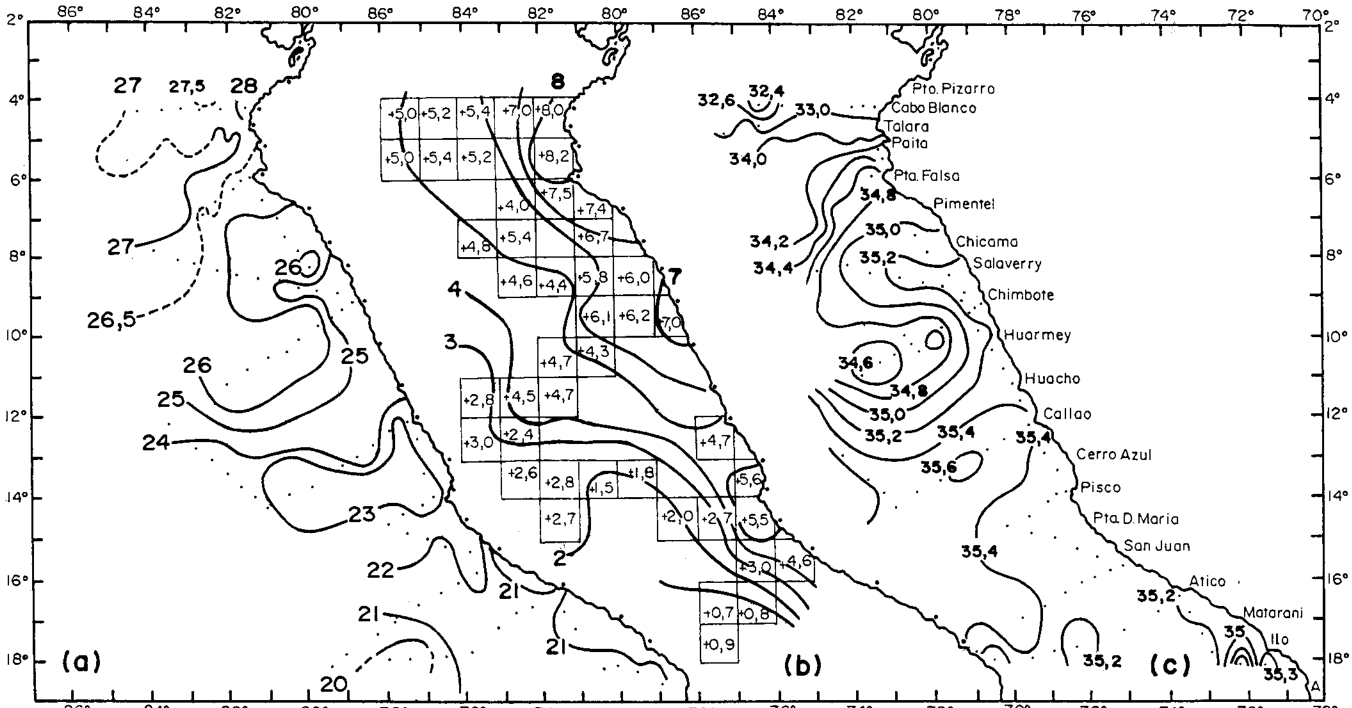

Figure 4. Maps of SST (*a*), SST anomalies (*b*), and salinity (*c*) for BAP *Carrasco* cruise 9711-12 (spring). Adapted from Pizarro 1997.

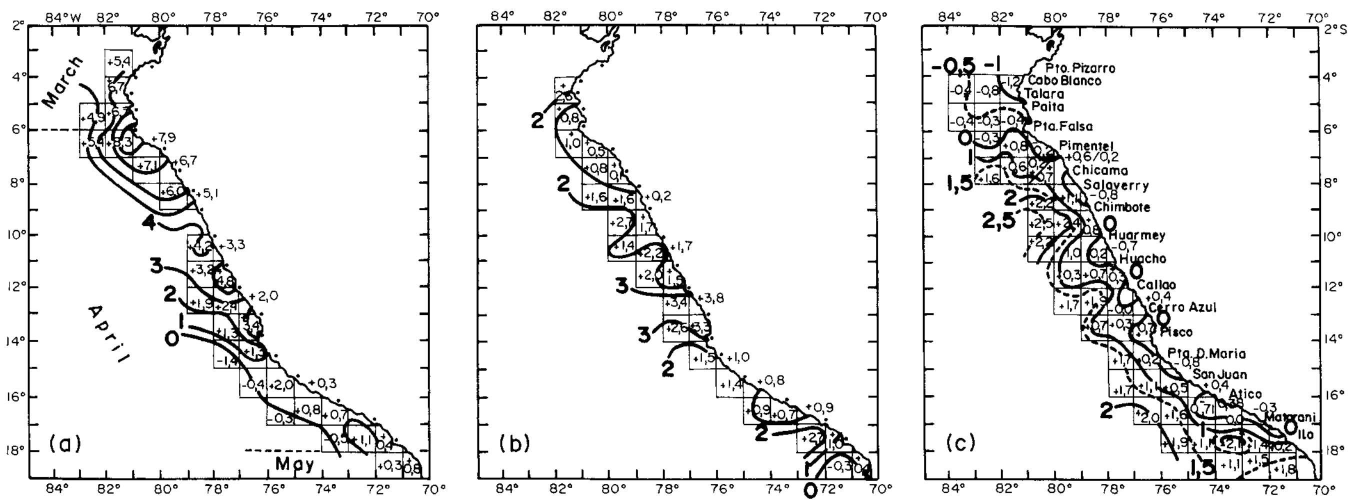

Figure 5. Maps of monthly means of SST anomalies: *a*, cruise 9803-05 (20 March–7 May, 1998); *b*, cruise 9805-06 (20 May–25 June 1998); *c*, cruise 9808-09 (20 August–18 September 1998). Adapted from Vasquez and Tello 1998; Morón 1998; and Morón et al. 1998.

extended past 12°S, and concentrations >5 ml/L belonged to subtropical surface waters (SSW; >35.1 ppt) south of Callao; this relation was not quite accurate in defining the limit between these waters. Both water masses had nitrate concentrations <3 µg-at/L, except for a small coastal band. The 5 µg-at/L isopleth of nitrate that usually surrounds the cold coastal waters in normal conditions for more than 150 nmi in autumn (Calienes and Guillen 1981; Calienes et al. 1985) was discontinuous in this anomalous period.

At the end of winter (9709-10) the attenuation of the warm conditions on the Peruvian coast was reflected in a limited recovery of the normal oxygen and nutrients. The oxygen range indicated coastal waters mixed with predominant subtropical waters (Gutierrez et al. 1998), especially to the south of 6°S, while equatorial waters were north of Paita. Values of 5 ml/L of oxygen were related to the salinity of 35.2 ppt, and concentrations <4 ml/L that delimited the areas of upwelling occurred with high concentrations of nitrate (10–15

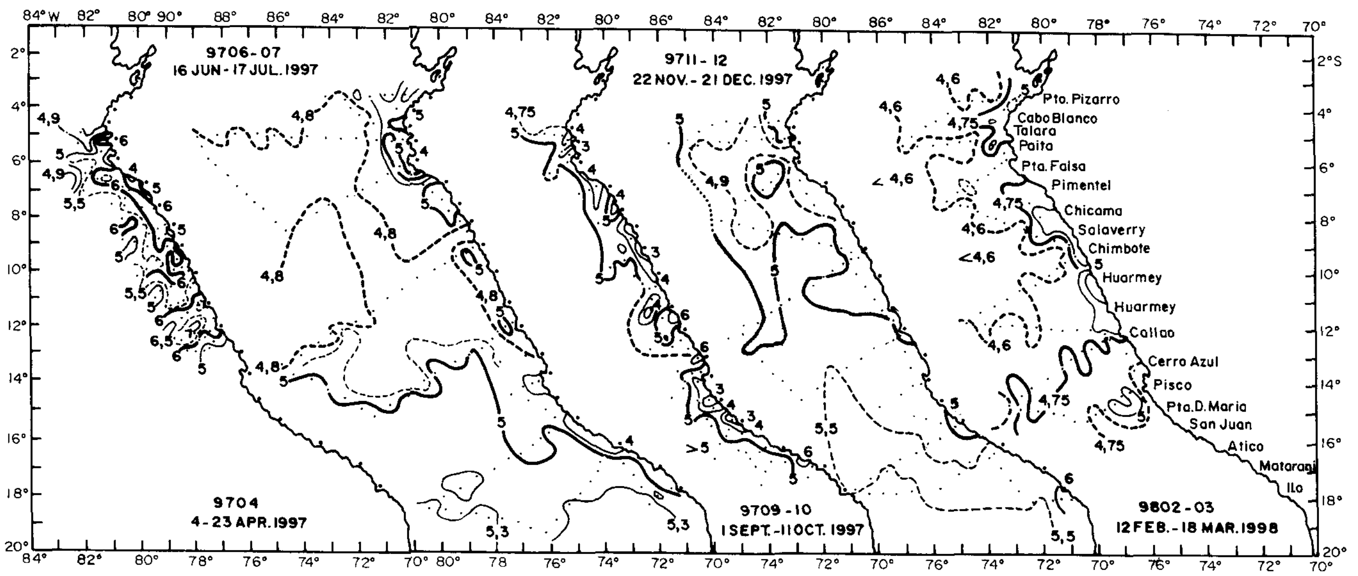

Figure 6. Seasonal distribution of oxygen (ml/L) at the sea surface along the Peruvian coast (April 1997–March 1998). Small dots indicate cruise track.

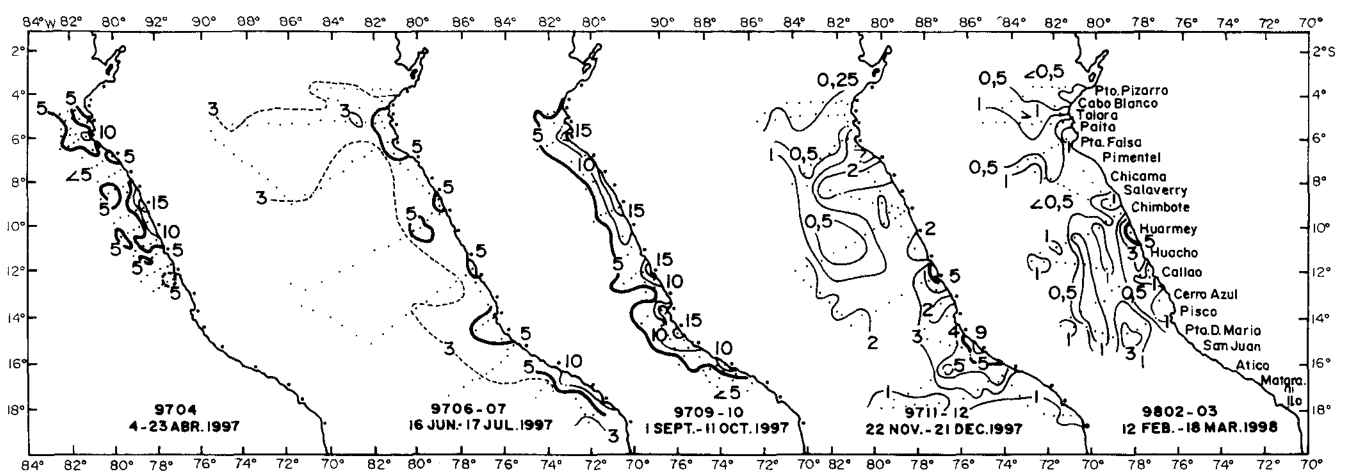

Figure 7. Seasonal distribution of nitrate (µg-at/L) at the sea surface along the Peruvian coast (April 1997–March 1998).

µg-at/L), which broadened its distribution in relation to autumn, especially in Salaverry-Huarmey and Pisco-San Juan.

The evolution of the chemical features of the warm event in spring 1997 (cruise 9711-12) showed a new advance of equatorial waters toward the Peruvian coast to 12°S, with the axis of the warm tongue far from the coast. These waters had concentrations of 4.4–4.8 ml/L of oxygen and contrasted with SSW, which had values >5 ml/L. The surface distribution of nutrients was interrupted once again, and very low concentrations were found by the cruises during 1997, with 0.15–1.1 µg-at/L nitrate in the equatorial waters north of Callao. These values were possibly lower in January (a period for which we do not have information).

For the physical features described in the first part of this review, the monthly averages of temperatures and surface anomalies of the coastal stations were higher in the second peak, between 7° and 9°S from December 1997 to January 1998. For the chemical features, the most drastic alterations in water surface were observed in December 1997–February 1998, when lower concentrations of nitrate moved south of Callao (9802-03). In this final month the oxygen distribution had values lower than 5 ml/L in most of the studied area (3°30'–15°S), not only in equatorial waters, but also in subtropical waters, which formed a front between Salaverry and Chimbote (8°–10°S).

Changes in Vertical Patterns

The oxycline associated with the thermocline was found at greater depths than usual due to the circulation

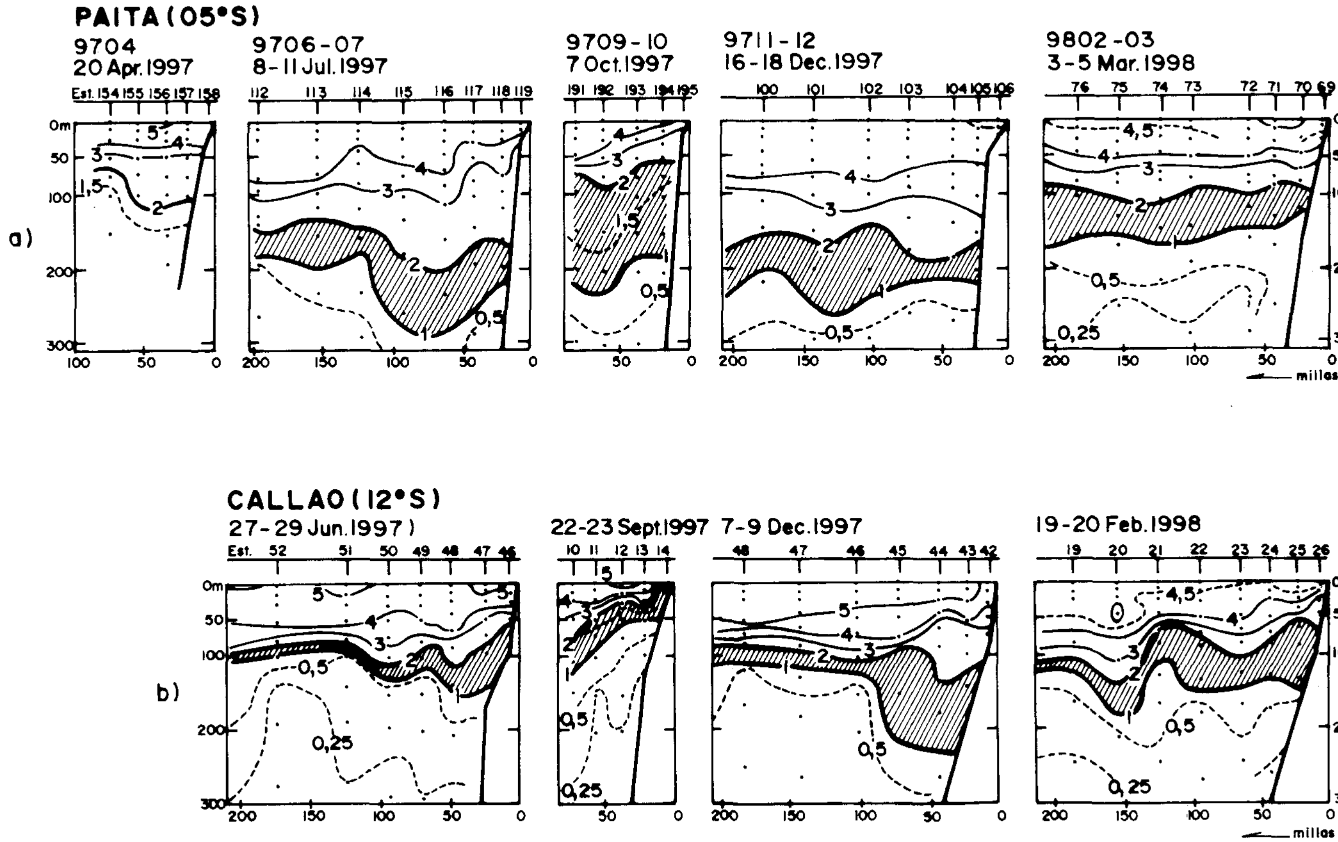

Figure 8. Profiles of dissolved oxygen (ml/L) at Paita (5°S) and Callao (12°S; April 1997–March 1998).

changes, including the intense effect of the coastal current of the SECC, which had seasonal variations.

The location and features of the oxycline in the water column in the area of Paita during the phenomenon (fig. 8a) indicate a greater deepening in winter 1997, during the development of El Niño (9706-07), and in spring (9711-12), during the second peak, when concentrations of 1 ml/L of oxygen were found deeper, north of Callao. In February 1998 (9802-03), this feature was weaker. At the same time the effect was less intense in the area of Callao, except for December 1997 (fig. 8b).

The nutricline was at 50 m when the alterations started in April 1997, increasing in depth in June–July to 100 m. In winter (9709-10) the nutrient-poor layer shoaled again to 50 m in Paita and to 80 m in Chimbote. In the period of main intensity (December 1997), nitrate concentrations <5 µg-at/L were found to 100 m along almost all the Peruvian coast except at the southern extreme (fig. 9).

The trend toward normalization in the hydrochemical conditions began in autumn 1998 in small coastal nuclei (Chimbote-Huarmey, Pta. Doña María-San Juan and Atico-Mollendo), being more remarkable in the southern area (Flores, Cordova et al. 1998; Flores, Ledesma, and Solis 1998). Afterwards, normalization widened, with the slow retreat of warm waters and the progressive recovery of the upwelling areas along the coast, with characteristic oxygen values and nutrient concentrations.

VARIATIONS IN TROPHIC LEVELS

The warm event affected the distributions and abundances of many species that constitute important resources of the Peruvian ecosystem. The initial alteration was the presence of the ESW in April 1997, when the anchovy *Engraulis ringens* was found near the coast, especially north of Callao. This distribution continued during September and October along the coast, when there were still acceptable conditions for the species. In November 1997 the anchovy schools began to be displaced southward, and could be found in higher concentrations between Cerro Azul (13°S) and Ilo (18°S). In 1998, coinciding with the normalization of the environment, anchovy maintained a coastal distribution in low abundance.

Plankton

During summer 1996, plankton volumes fluctuated from 0.04 to 10.2 ml/m^3, with upwelling diatoms and several species of *Chaetoceros* being common. In winter

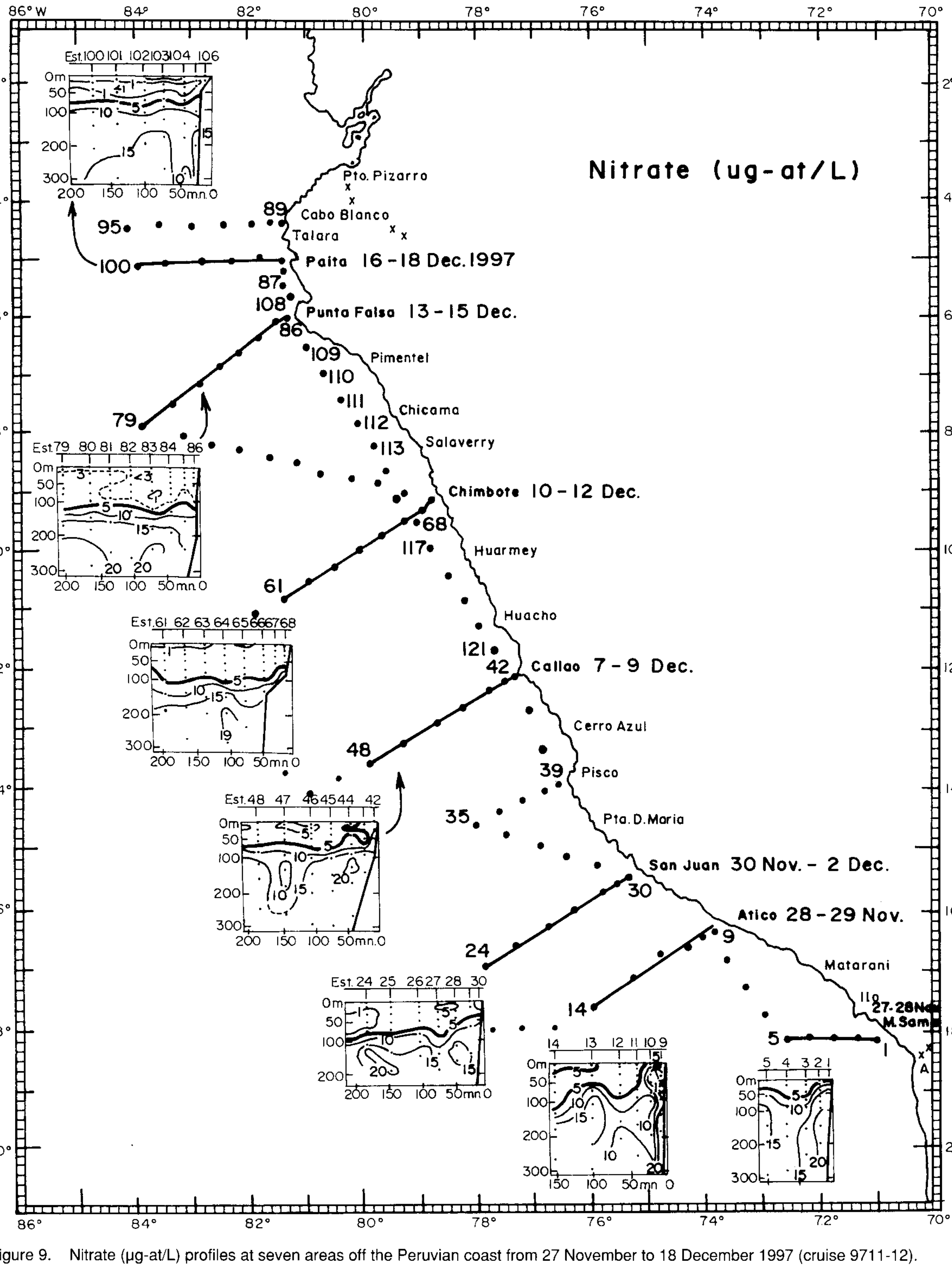

Figure 9. Nitrate (µg-at/L) profiles at seven areas off the Peruvian coast from 27 November to 18 December 1997 (cruise 9711-12).

of the same year, the dominance of diatoms typical of upwellings, such as *Chaetoceros debilis*, *Ch. socialis*, and *Skeletonema costatum* continued, indicating normal distribution patterns for water masses in that period of the year (Ayón et al. 1996).

In 1997, at the end of summer and the beginning of autumn (9702-03, 9704), when the warm event took place along the Peruvian coast, the volumes of plankton varied between 0.1 and 6.0 ml/m^3, with the highest mean values of 2 ml/m^3 within 30 nmi of the coast (fig. 10a). These values were lower than those obtained for the same period during the two previous years. This

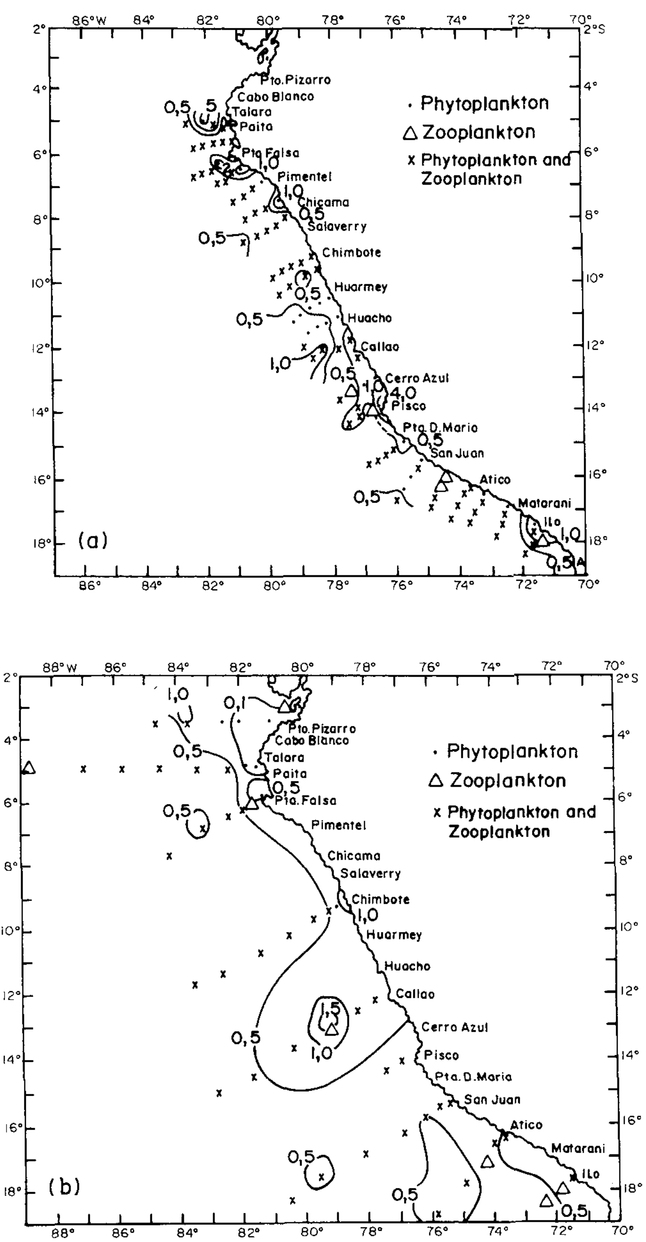

Figure 10. Maps of plankton volume (ml/m^3): *a*, R/V *SNP-I* cruise 9702-03 (13 February–13 March 1997) and R/V *Humboldt* 9704 (4–23 April 1997) and *b*, R/V *Humboldt* cruise 9706-07 (16 June–17 July 1997). Adapted from Chang et al. 1997; Sánchez et al. 1997.

phenomenon is related to the cooling process. The greatest concentrations were found at 5°, 8°, and 18°S inside 30 nmi (Sanchez et al. 1997). Species considered as indicators of equatorial water masses were *Ceratium breve* and *Ornithocercus steinii* and, within the zooplankton, *Centropages furcatus* and *Sagitta regularis*.

In June and July 1997 (9706-07), near the first peak of the warm event, there were very small volumes of plankton all along the coast (fig. 10b). Around the end of winter 1997 (9709-10), the peak decayed, and phytoplankton volumes increased, with values fluctuating

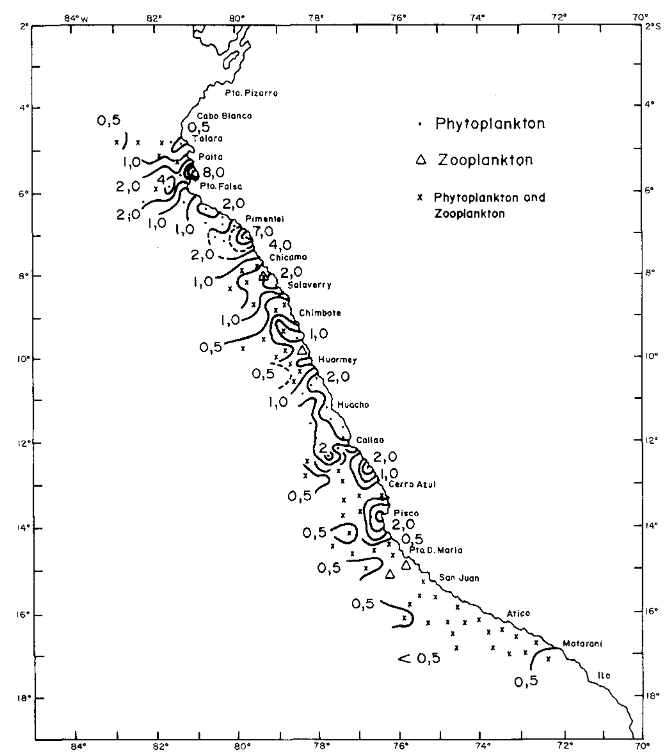

Figure 11. Map of plankton volume for R/V *Humboldt* cruise 9709-10 (1 September–11 October 1997). Adapted from Delgado and Villanueva 1998a.

between <0.5 and 8.0 ml/m^3 (average of 3.5 ml/m^3) associated with a temperature range of 17.7°–24.7°C and salinities lower than 35.2 ppt (fig. 11). According to Delgado and Villanueva (1998a), diatoms characteristic of coastal upwelling were present within 30 nmi. Warm-water species were found between Pta. Falsa and Paita, in addition to species of zooplankton indicating warm waters. The common zooplankton species were *Acartia danae*, *A. negligens*, and *Calocalanus pavo* between 5° and 17°S and *Rhincalanus nasutus* and *Centropages furcatus* between Paita and Chicama and from Chimbote to Pisco. Also, chaetognaths such as *Sagitta enflata*, *S. regularis*, and *S. pacifica* remained in mixed waters during the temporal decline of the warm event (Girón 1998).

Thereafter, in the spring season (9711-12), between Pto. Pizarro and Callao, the volume declined markedly (reaching a value of 0.44 ml/m^3). In the southern region between San Juan and Atico two small nuclei appeared, with values greater than 1 ml/m^3, related to temperatures that fluctuated between 21.0° and 28.0°C, with salinities of 35.0 to 35.4 ppt. The volumes of plankton during summer (February–March 1998) varied between 0.12 and 5.9 ml/m^3, with maximum values north of Pta. Falsa and Pto. Pizarro in the coastal region (fig. 12a).

At the end of summer and beginning of autumn 1998 (9803-05), in the decline of the second peak of thermal anomalies, the average volumes of phytoplankton

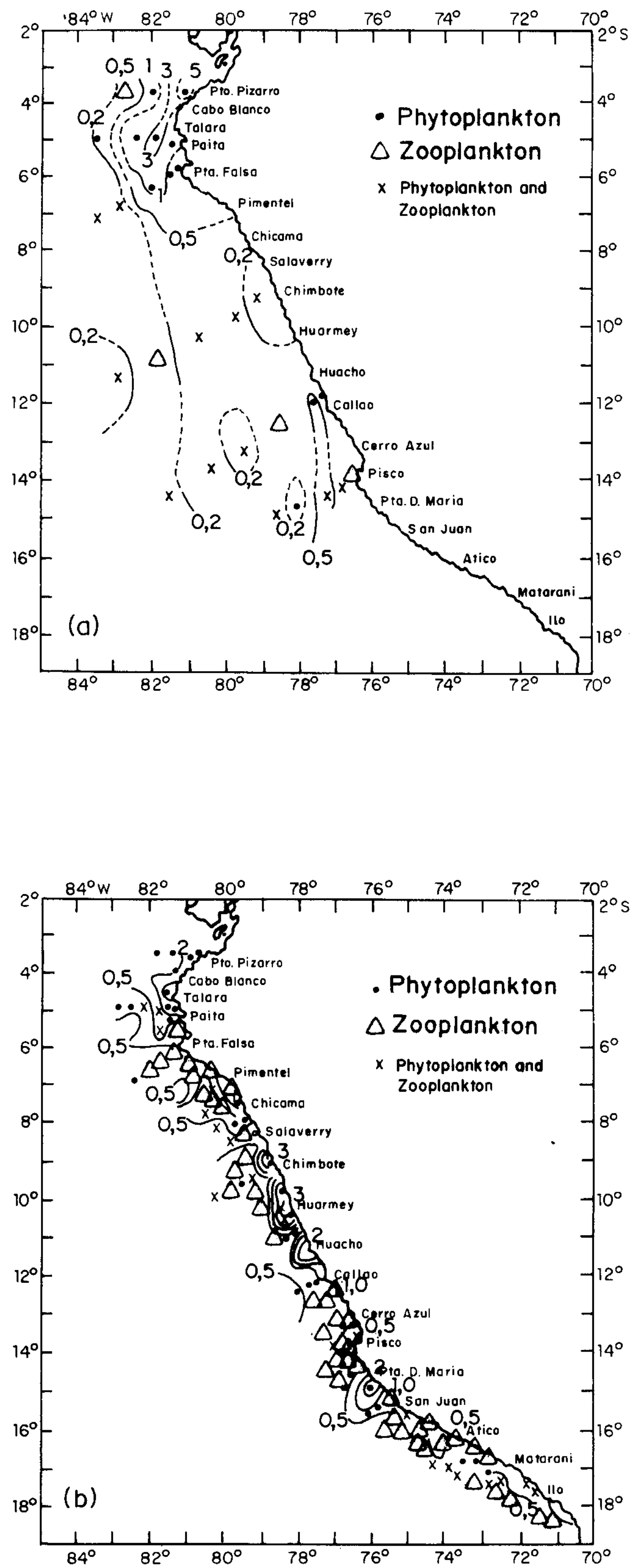

Figure 12. Maps of plankton volume: *a*, BAP *Carrasco* cruise 9802-03 (18 February–12 March 1998); *b*, R/V *Humboldt* 9803-05 (20 March–7 May 1998). Adapted from Delgado and Fernandez 1998; Delgado and Villanueva 1998b.

were still low (0.5–3.0 ml/m^3, means 0.64 ml/m^3 overall, and 2.6 ml/m^3 within 30 nmi; fig. 12b). The greater values belong to isolated coastal patches (>1 ml/m^3) between Mancora-Paita, Chimbote, Huarmey, and Pta. Doña María, with species typical of upwelling, indicating a recovery of the environment (Delgado and Villanueva 1998b).

During the beginning of winter (9808-09), the planktonic community recovered, with volumes that varied between 0.01 and 23.3 ml/m^3 (mean 1.16 ml/m^3). This increase in plankton volumes indicated that the normal conditions had intensified along the Peruvian coastline, with temperatures fluctuating between 15° and 17°C and salinities of 35.1 ppt, except for the area in front of Pta. Falsa (17°–18°C and 35.4 ppt).

In winter, during the start of the post–El Niño period, neritic species such as the diatoms *Coscinodiscus perforatus*, *C. wailesii*, *C. centralis*, *Chaetoceros* spp., *Lithodesmium undulatum*, *Thalassiosira subtilis*, and *Skeletonema costatum* were present. Thermophyllic dinoflagellates were found at distances greater than 30 nmi (Villanueva et al. 1998).

It is very unfortunate that during the 1997–98 event no information on chlorophyll and primary productivity was collected to permit evaluation of the mechanisms of interaction between nutrients and primary production, and to compare with the data reported by Barber and Chavez (1986). Nor were plankters smaller than 75 µm sampled. However, the larger plankton reflected the sequence of ecological effects produced during the different phases of El Niño 1997–98.

Fish Eggs and Larvae

Ichthyoplankton plays an important role in the marine community life cycle and indicates the reducing or broadening of the distributions and concentrations of some species.

***Engraulis ringens*, anchovy.** In normal conditions, this species spawns in summer (February–March) along the entire coast from Paita to Ilo, with a second important spawning in August–September. The spawning relates closely to environmental conditions, and normally takes place within 60 nmi of shore, the principal spawning area being from Pimentel (6°50'S) to Chimbote (9°S).

In the summer of 1997, anchovy spawned all along the coast, widening the area to 80 nmi. The greatest intensity of spawning occurred between Chimbote and Pisco (fig. 13a). Larvae of this species were found in almost the same areas as the eggs (Ayón and Girón 1997). The greatest concentration of larvae was offshore of Huacho (>1000 larvae/m^2; fig. 13b). Larvae were absent in the northern zone from Salaverry to Chimbote, where the ESW were close to the coast (Morón and Marquina 1997; Vásquez 1997). Eggs and larvae of anchovy were associated with temperatures <22°C and

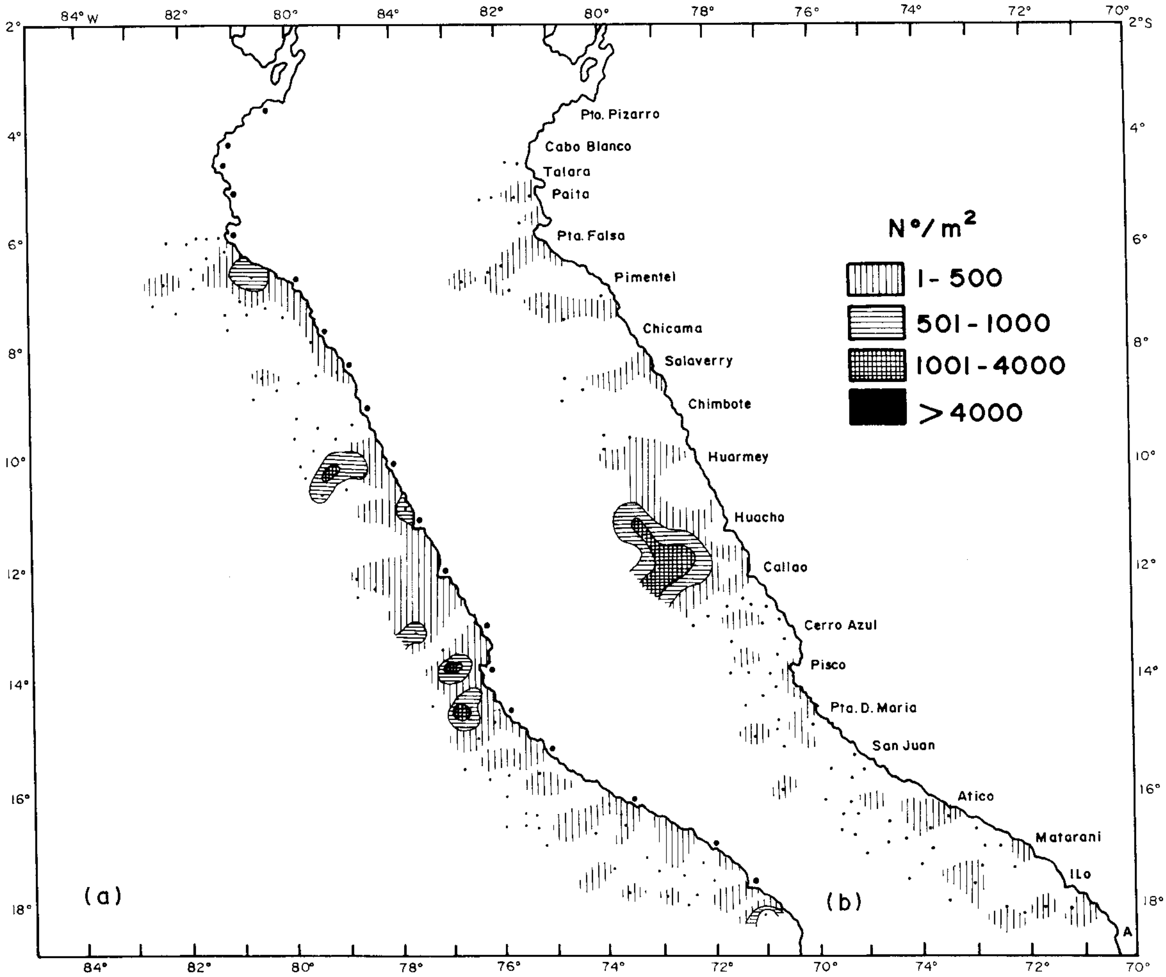

Figure 13. Distribution of anchovy eggs (*a*) and larvae (*b*), R/V *SNP-1* cruise 9702-03 (13 February–13 March 1997) and R/V *Humboldt* 9704 (4–23 April 1997). Adapted from Ayón and Giron 1997.

salinities between 34.9 and 35.0 ppt, which differs from the ranges described by Ayón and Girón (1997).

At the end of winter and beginning of spring 1997 (9709-10), in a period of momentary cooling of waters, we found eggs of anchovy all along the coast, up to 30 nmi offshore, with rare patches of high concentration. The larvae had a wider distribution, reaching 70 nmi (5°–17°S), with abundances <4000 larvae/m^2; larger patches had been found in 1996. A patch (<4000 larvae/m^2) was located near Supe at 10 nmi from the coast, and there were minor patches of fewer than 1000 larvae/m^2 at Callao and Pimentel at 30 and 20 nmi, respectively. The distributions of anchovy eggs and larvae were clearly related to the distribution of adult anchovy, which was near the coast, generally within 18 nmi (Girón 1998; Gutierrez et al. 1998).

In March–May 1998, at the end of summer and beginning of autumn, (9803-05), anchovy spawning was poor; however, there were two patches with concentrations of >1000 eggs/m^2 south of Huacho and Atico, and <500 eggs/m^2 distributed from Salaverry to south of Ilo, generally within 10–20 nmi of the coast (fig. 14a). The larvae had a similar distribution between Pta. Falsa and the southern boundary.

Relatively few anchovy eggs were also found at the end of autumn 1998 (9805-06), between 3 and 2150 eggs/m^2 (fig. 14b), when the subtropical tongue (20°–22°C, 35.2–35.3 ppt) was close to the coast. Eggs were found most frequently between Huacho and Pisco; the maximum concentration was found at the southern extreme of the coast, due to the warm, high-salinity tongue which produced a shift to that area, where the environmental conditions had recovered. In general, when compared with the distribution during the previous warm event, this distribution was restricted to within 10 nmi, and in May and June extended to 35 nmi (Ayón and Quesquén 1998). Also, the start of anchovy spawning was delayed.

***Sardinops sagax sagax*, sardine.** Normally the distribution center for eggs and larvae of this species is north of Huacho (11°S), generally with abundance <500 eggs/m^2 and related to SSW. In anomalous conditions,

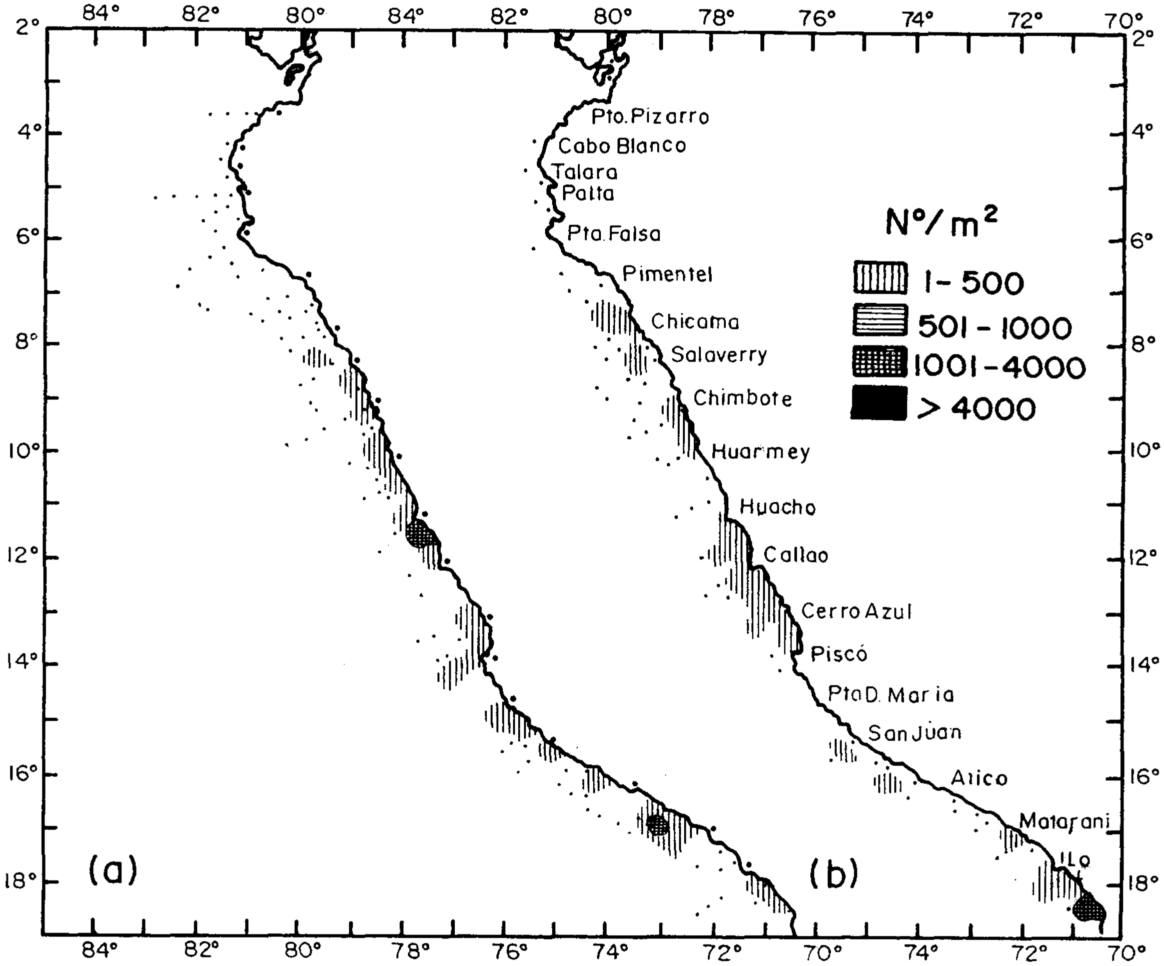

Figure 14. Distribution of anchovy eggs: *a*, R/V *Humboldt* cruise 9803-05 (20 March–7 May 1998); *b*, R/V *Humboldt* 9805-06 (20 May–25 June 1998). Adapted from Ayón et al. 1998; Ayón and Quesquén 1998.

at the end of summer and beginning of autumn 1997 (fig. 15), eggs were found within 40 nmi of the coast between Paita (5°S) and Callao (12°S). The larvae were found within 80 nmi between Paita (5°S) and Supe (11°S; Ayón and Girón 1997). In winter 1997 (9706-07), sardine eggs were distributed between Pto. Pizarro and Chimbote (Girón and Quesquén 1997).

In the following months of the warm event (9709-10) sardine larvae were more widely distributed than during 1996 and the first months of 1997, extending from Punta Aguja to Cerro Azul, associated with SSW. Eggs and larvae of sardine were very scarce: <500 eggs/m^2 from Paita to Pisco and 500–1000 larvae/m^2 from Paita to Callao. From March to May of 1998 (9803-05) the eggs and larvae had concentrations <500/m^2 in SSW (salinities up to 35.6 ppt).

In the autumn of 1998 (9805-06) sardine eggs were distributed between Pimentel and Callao, with abundance reaching >5000 eggs/m^2. The larvae extended less far and had a smaller concentration (fig. 16; Ayón and Quesquén 1998).

During winter 1998 (9808-09), sardine larvae were located all along the coast, generally outside 30 nmi, extending to more than 100 nmi from the coast (Guzmán et al. 1998). Both eggs and larvae extended far from the coast between Pimentel and Callao, influenced by SSW.

***Scomber japonicus*, mackerel.** In September and October 1997, mackerel larvae were found along much of the coast from Paita to Punta Doña María (5°–14°40'S) and mainly within 40 nmi of shore. This differs from the distribution in 1996, when they were limited to the central zone and farther than 70 nmi from the coast. Later, around the end of May through June 1998, mackerel eggs were found at two stations near Chicama and Pisco (fig. 17a).

***Merluccius gayi peruanus*, hake.** In autumn of 1997 (9705-06), at the beginning of the warm event, we found larvae of this species between Salaverry (8°S) and Callao in very low concentrations (1–4 larvae/m^2; Ayón and Aronés 1997), in general agreement with the distribution of adults in the same area. At the end of the warm event, autumn 1998 (9805-06), hake eggs were found

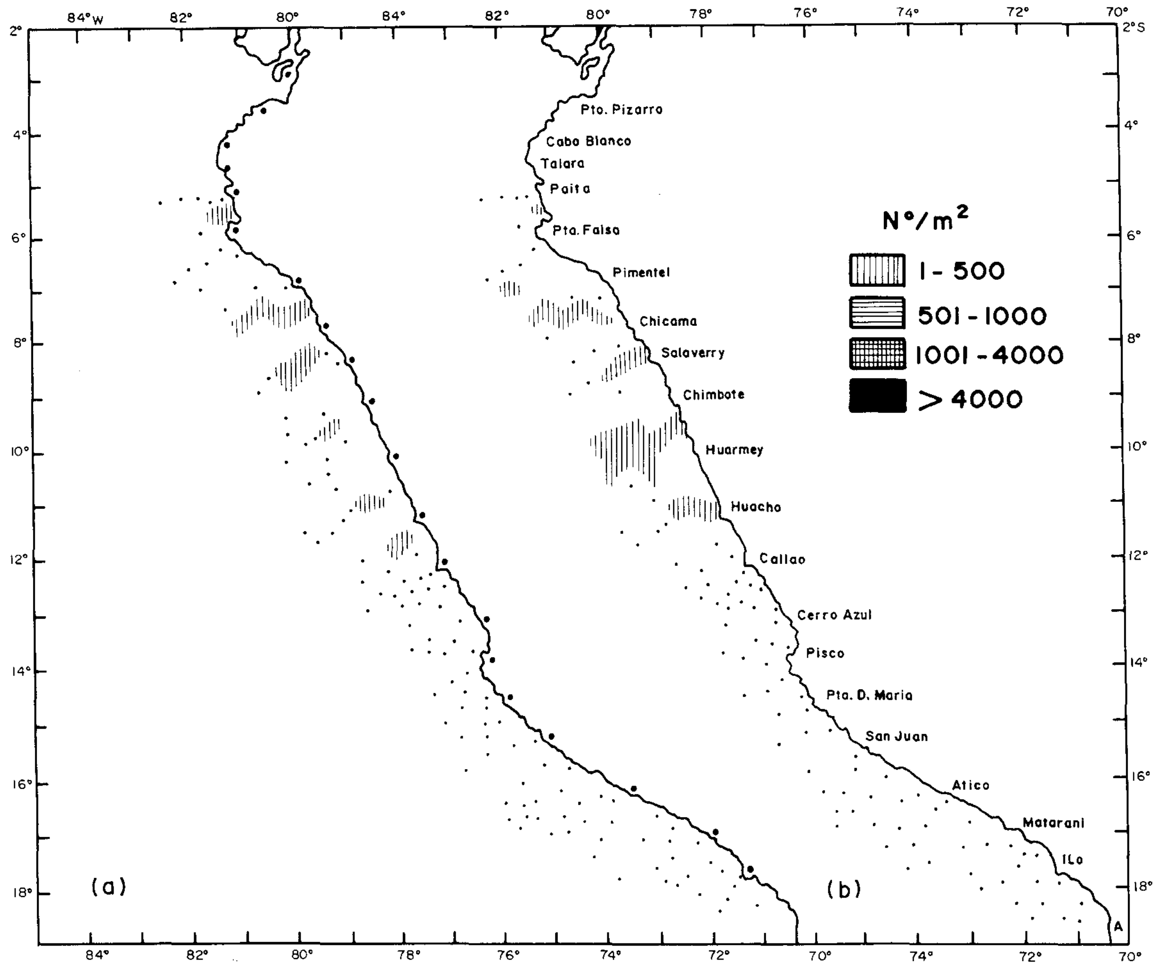

Figure 15. Abundance and distribution of sardine eggs (*a*) and larvae (*b*). R/V *SNP-I* 9702-03 (13 February–13 March 1997) and R/V *Humboldt* 9704 (4–23 April 1997). Adapted from Ayón and Giron 1997.

30 nmi from the coast at Chimbote, with abundance >3 eggs/m^2; the larvae had a wider distribution, between Paita and Supe with abundances of 3–9 larvae/m^2 (fig. 17b; Ayón and Quesquén 1998).

***Anchoa nasus*, anchoa; samasa.** In the winter of 1997 (September–October) eggs and larvae of this species, which normally is distributed to the north, were very abundant along the Peruvian coast at temperatures of 19°–22°C, occupying the space left by the anchovy (Gutierrez 1998). In the next year, from May to June 1998 (fig. 17c), the distribution broadened; larvae were present to the southern boundary of Peru, and north to Callao (Pimentel-Salaverry).

Mictophydae family, lanternfishes. The fishes of this family (*Diogenichthys laternatus*, *Lampanyctus parvicuda*, *Benthosema panamense*, and *Triphoturus nigrescens*) generally are distributed offshore of the Peruvian coast (>100 nmi). With the intrusion of warm waters, most of these species widened their distribution, and diversity reached 20 species at the beginning of autumn 1998 (Ayón and Quesquén 1998). These species were distributed all along the Peruvian coast, except for *B. panamense*, which was found only to 7°40'S.

In winter 1998, the larvae of *Diogenichthys laternatus* were distributed widely all along the coast (fig. 18a), at 44% of the analyzed stations, and were more abundant than in autumn of that year (Ayón and Quesquén 1998; Guzmán et al. 1998).

***Bregmaceros bathymaster*, unicorn cod.** Other species with wider distributions of eggs and larvae included this endemic species of the Panamanian province of ATS, which widened its distribution because of warm waters. It appeared during May and June of 1997 (Ayón and Aronés 1997) and increased to 43% of sampled stations in March and May of 1998, with a remarkable presence north to Callao and extending to the south (Atico and Matarani) when the TSW were found north of 7°S (Ayón et al. 1998). On the other hand, its frequency decreased in June 1997 (fig. 18b), decaying strongly in winter 1998 (9808-09), when it was found at only 6.8% of the total stations (Guzmán et al. 1998), related to high-salinity waters (up to 35.6 ppt).

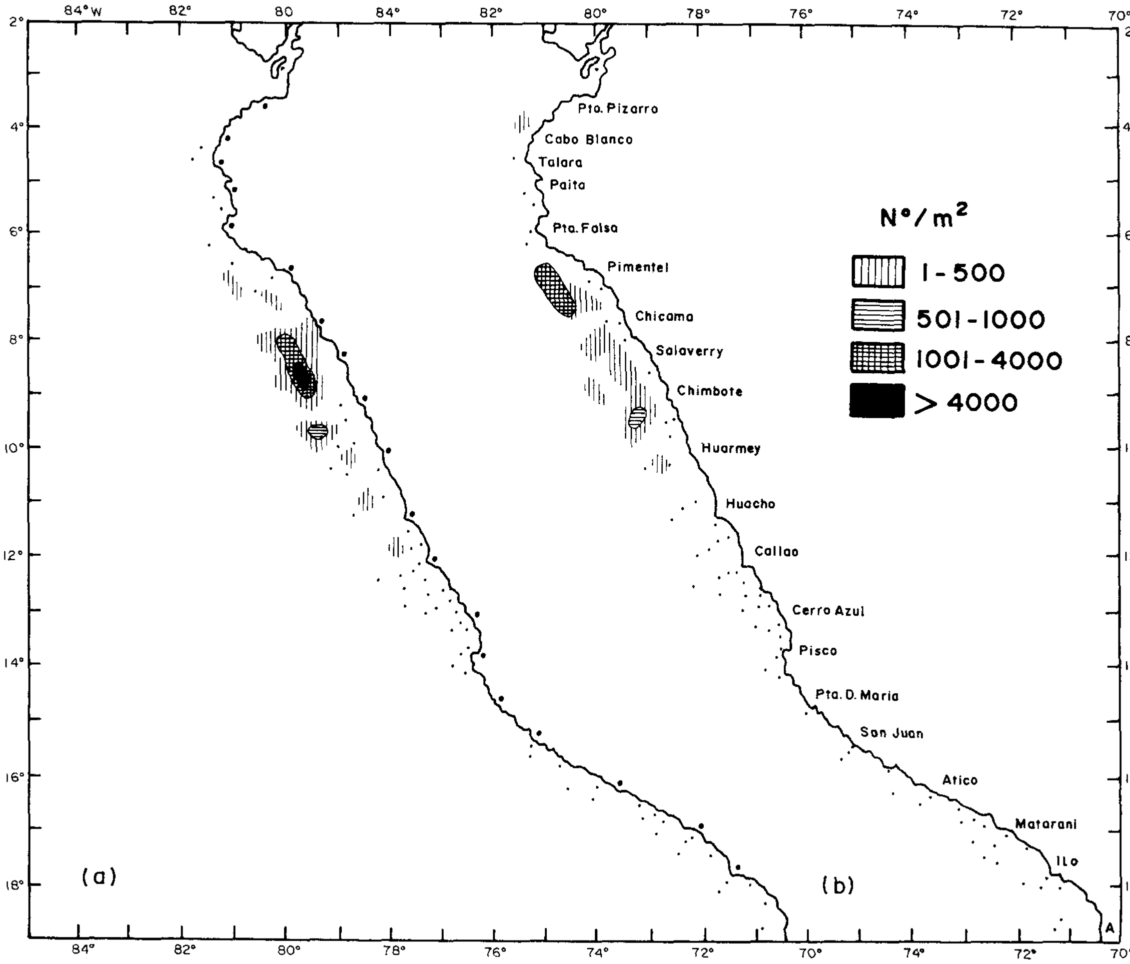

Figure 16. Abundance and distribution of sardine eggs (*a*) and larvae (*b*). R/V *Humboldt* cruise 9805-06 (20 May–25 June 1998). Adapted from Ayón and Quesquén 1998.

***Prionotus stephanophrys*, gurnads.** Normally the larvae of this species are not found on the Peruvian coast (8°S), but in summer 1997 they were found between Paita and Callao, out to 80 nmi. They were more frequent in autumn of the same year (in 56% of samples; fig. 18c; Ayón and Aronés 1997), and began to decrease in September (9.4% of samples), reaching less than 1% of the total samples in the autumn of 1998.

Pelagic and Demersal Resources

***Engraulis ringens*, anchovy.** From 1991 to 1994 (which included an El Niño event) biomasses of anchovy increased. During the cold years of 1995 and 1996 anchovy decreased, but after the negative anomalies, again started a recovery that was interrupted by the warm El Niño 1997–98 (fig. 19).

At the beginning of the warm event and during February and April 1997 (9702-03, 9704) anchovy were found near the coast between Paita and Callao in very dense concentrations, especially between 7°–8°S and 9°–12°S (fig. 20a). The strong intrusion of ESW in the north and SSW in the south considerably reduced the distribution of the resource, with a biomass (estimated by virtual population analysis) of 9.5 million metric tons (t; ERFEN 1998).

As of July 1997, positive temperature anomalies increased, mainly along the Peruvian north coast, but the distribution of anchovy was unchanged. During September and October 1997 (9709-10), anchovy remained very close to the coast from south of 5° to 17°S (fig. 20b) due to the width of the SSW. These data were obtained after the first spawning peak; apparently there was little negative effect on the adult population and very little effect on the juveniles. The biomass was 5.8 million t (Gutierrez et al. 1998).

From November 1997, when the anomalies in the north exceeded 6°C, the schools of anchovy were displaced to the central zone, especially in December, when the anomalies at Salaverry exceeded 7.9°. Large concentrations of schools were found between Cerro Azul (13°S) and the coastal band (10 nmi) to the south of Atico and Ilo (18°S). Only in Ilo did the

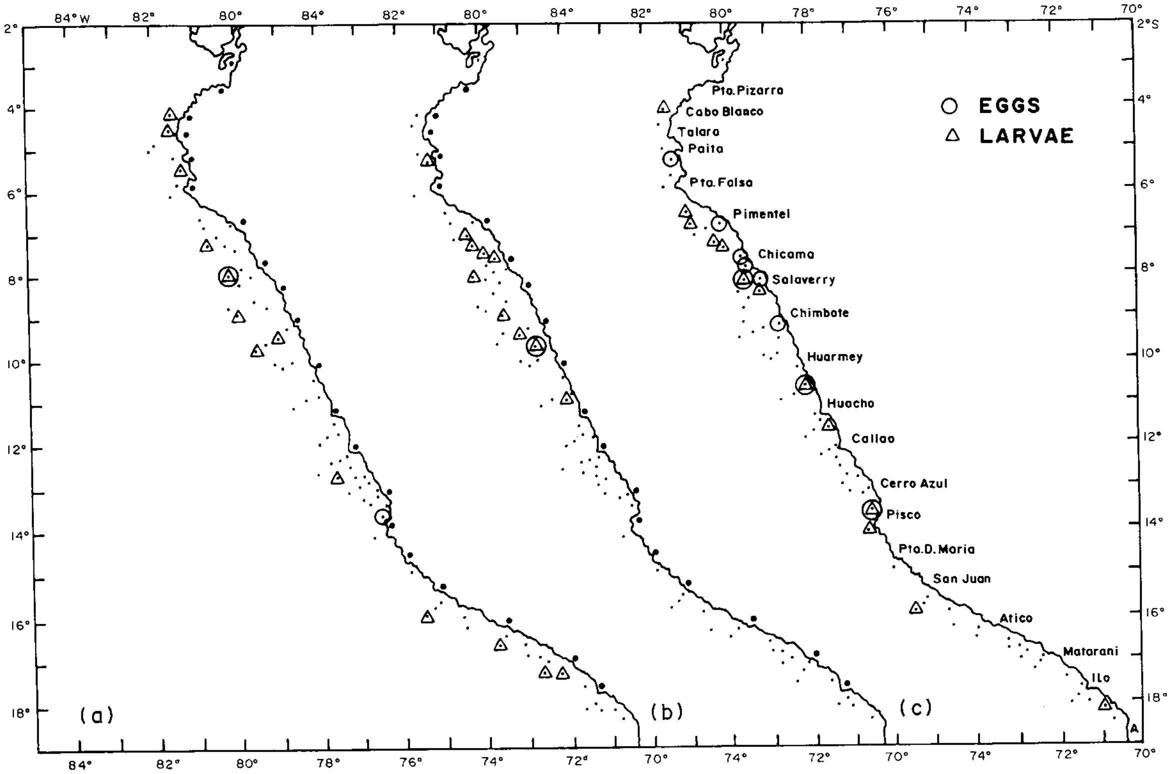

Figure 17. Distribution of eggs and larvae of mackerel (*a*), hake (*b*), and anchoa (*c*). R/V *J. Olaya* cruise 9805-06 (20 May–25 June 1998). Adapted from Ayón and Quesquén 1998.

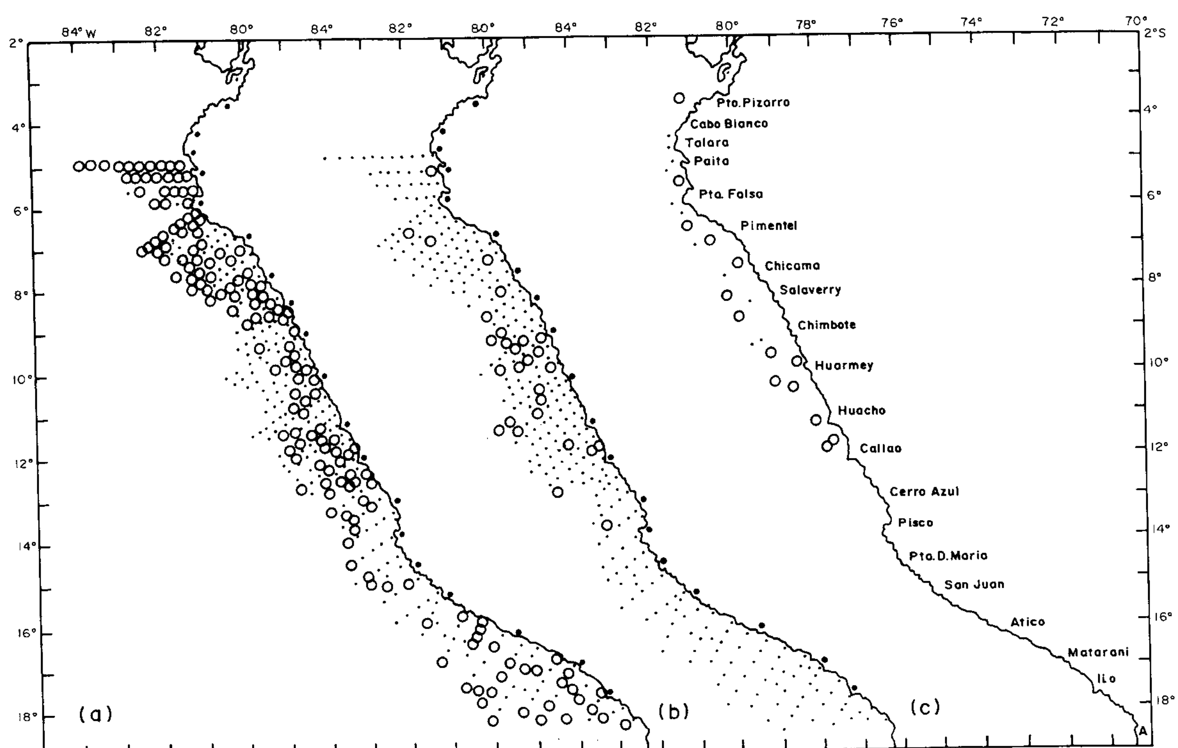

Figure 18. Distribution of larvae: *a*, *Diogenichthys laternatus*, and *b*, *Bregmaceros bathymaster*. Cruise R/V *J. Olaya*, R/V *Humboldt* 9808-09 (18 August–17 September 1998). *c*, *Prionotus stephanophry*, R/V *Humboldt* cruise 9705-06 (15 May–8 June 1997). Adapted from Ayón and Arones 1997; Guzmán et al. 1998.

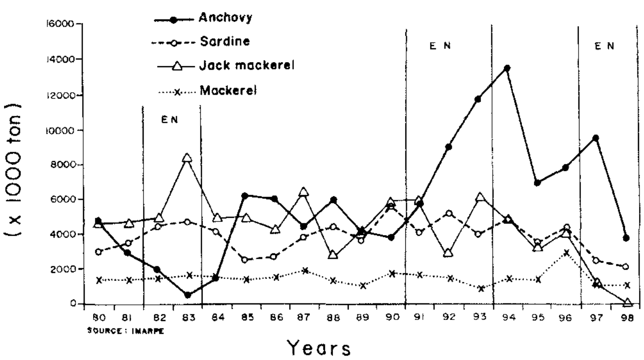

Figure 19. Biomass of the main pelagic resources, 1980–98.

distribution of anchovy reach 30 nmi (Gutierrez et al. 1998).

The pelagic resources evaluation made between March and May of 1998 (9803-05) found anchovy in coastal areas with a discontinuous distribution, including 14°S and 18°S (fig. 20c). The distribution depth ranged from 4 to 100 m, but was generally near the surface, especially at night.

From May to June 1998 (9805-06) anchovy were detected near the coast, distributed in isolated areas south of Salaverry, with the greatest concentrations between Pisco and Chorrillos. In the north, anchovy were found from the surface to 58 m depth. In the second half of 1998 (9808-09), anchovy were located between Huarmey-Huacho and Callao-San Juan in dispersed concentrations, between 3 and 20 m in depth, at a biomass of 1.2 million t (Castillo et al. 1998; fig. 19).

The reproductive cycle of the anchovy during the first months of 1997 was normal in relation to the summer spawning, with high values in the gonodosomatic index (GI). The main (but less than normal) spawning of winter and spring took place at the same time as the relaxation, which produced a change in time relative to normal. From January 1998, the GI of anchovy increased. Values higher than the historic standard of spawning were observed all along the coast (fig. 21). The spawning peaked in September, a post–El Niño period. These variations in the reproductive process reduced the population of anchovy (Mori et al. 1999).

***Sardinops sagax sagax*, sardine.** In March and April

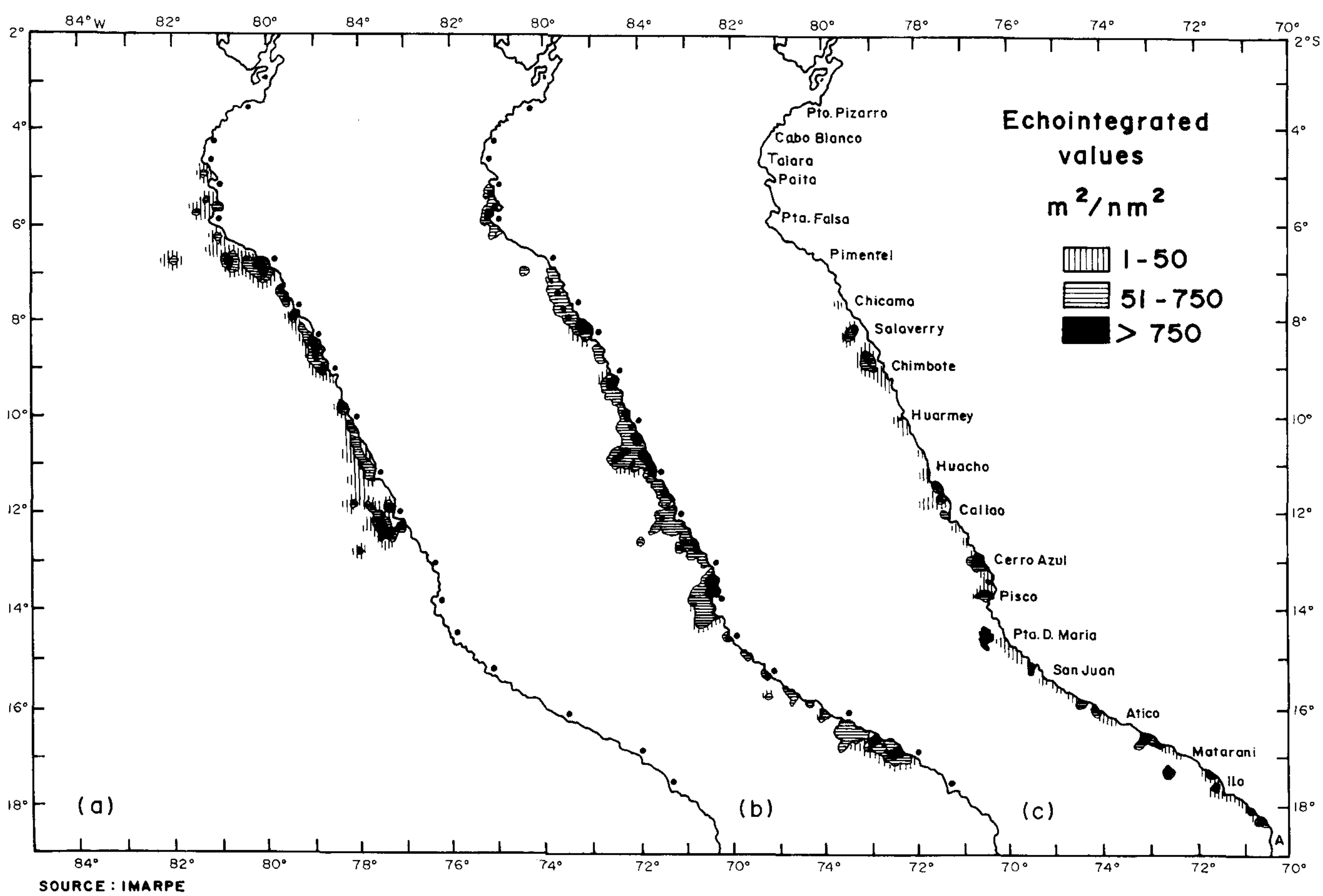

Figure 20. Distribution of anchovy, *Engraulis ringens*: *a*, R/V *Humboldt* cruise 9704 (4–23 April 1997); *b*, R/V *Humboldt* 9709-10 (1 September–11 October 1997); *c*, R/V *Humboldt* 9803-05 (20 March–7 May 1998).

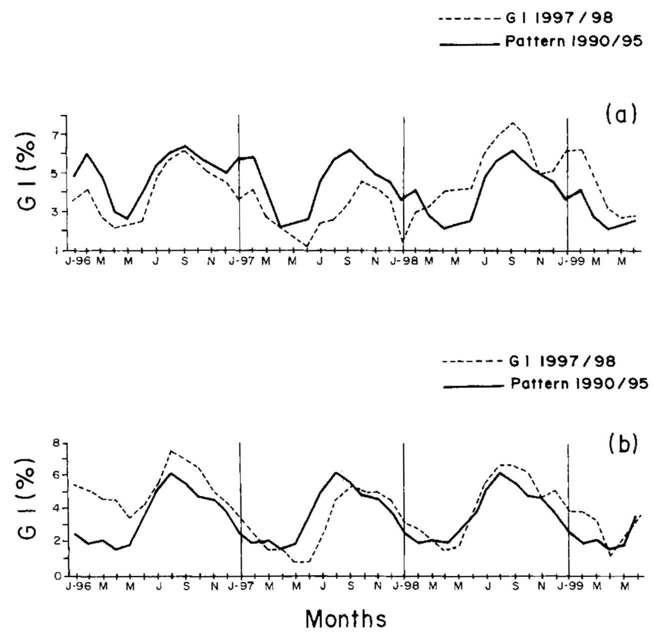

Figure 21. Gonadosomatic index (GI) of anchovy: *a*, north and central Peruvian region (3°24'–15°59'S); *b*, south Peruvian region (16°–18°21'S). Adapted from Mori et al. 1999.

1997, sardine were distributed between Pimentel and Huacho; the greatest concentrations were north of 10°S, associated with ESW, which were close to the coast off Salaverry (fig. 22a). The estimated biomass was 2.5 million t (fig. 19). Vertically, sardine reached 60 m depth. This species was very scarce in September and October 1997 (9709-10), but was detected between 6° and 12°S at 5–100 m depth, associated with the SSW, <35.2 ppt (fig. 22b). Biomass at this time was 1.1 million t (Ñiquén et al. 1998).

In March to May 1998 (9803-05), sardine were detected near the coast, with a discontinuous distribution between Salaverry and Matarani (17°40'S) in subtropical waters very close to the coast (35.7 ppt) and off Chimbote-Salaverry at depths from 4 to 60 m (fig. 22c). Biomass was 2.1 million t (Castillo et al. 1998). Sardine remained present along the coast from May to June 1998 between Cerro Azul and Callao; the lowest concentration was found between Salaverry-Chimbote and the Pimentel area, associated with the high-salinity waters >35.2 ppt moving away from the coast (>21°C).

In the next assessment of the sardine resource (9805-06), with the normalization of oceanographic condi-

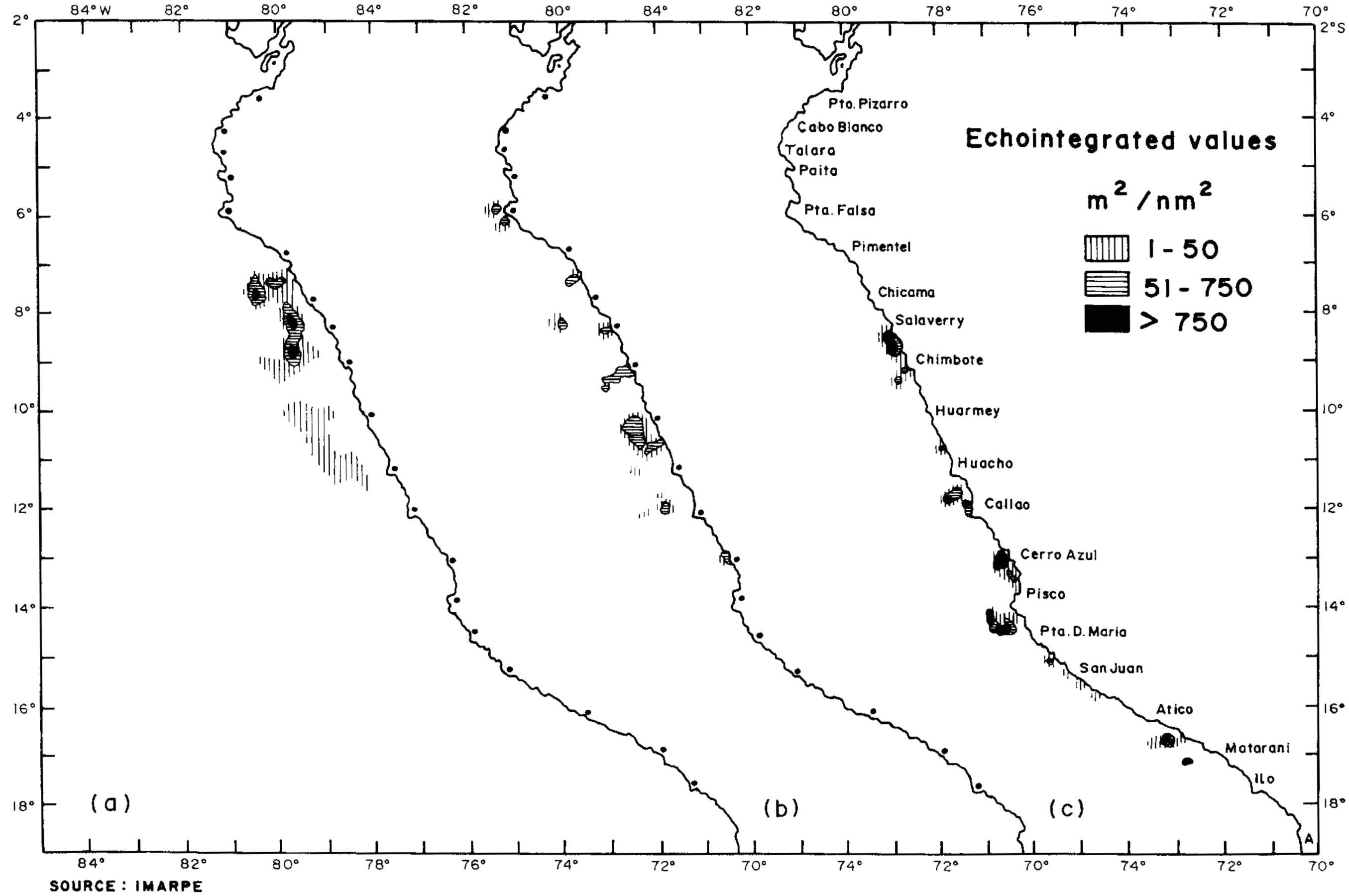

Figure 22. Distribution of sardine, *Sardinops sagax sagax*: *a*, R/V *Humboldt* cruise 9704 (4–23 April 1997); *b*, R/V *Humboldt* 9709-10 (1 September–11 October 1997); *c*, R/V *Humboldt* 9803-05 (20 March–7 May 1998).

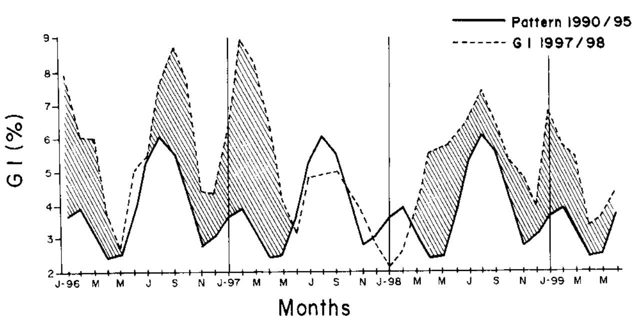

Figure 23. Gonadosomatic index (GI) of sardine 1995–99. Adapted from Mori et al. 1999.

tions, the biomass was very similar to that of autumm 1998, but with a retreat to the north (13°S).

Summer spawning in 1997 was more successful than normal, and the process was quite prolonged. In autumn, the gonads had immature and maturing stages. During winter 1997, a high percentage of sardine captured on the central coast were spawning or partially spawned. This species continued spawning in winter 1998 (cold, post–El Niño conditions), as shown by high gonadosomatic indexes (fig. 23).

***Trachurus picturatus murphyi*, southern jack mackerel.** In September–October 1997 (9709-10) jack mackerel were distributed between Salaverry and Callao, at temperatures <23° (fig. 24a), with the greater concentrations in the central zone between Huarmey and Callao. Dispersed concentrations were found between Pisco and San Juan, with colder waters (around 19°C). In the north and especially near Paita, jack mackerel were found jointly with hake in depths of 150 to 250 m, associated with the waters of SECC, which started moving southward when El Niño began. The biomass was 1.2 million t in April, and 1.9 million t in October 1997 (Gutierrez 1997; Gutierrez et al. 1998).

During autumn 1998 (9803-05) jack mackerel showed a disjunct distribution north of 7°S (17°–21°C and 34.8–35.0 ppt) near the coast (associated with ESW), and also in the south between San Juan and Ilo (SSW; 20°C, 35.2 ppt), and the biomass was smaller (Castillo

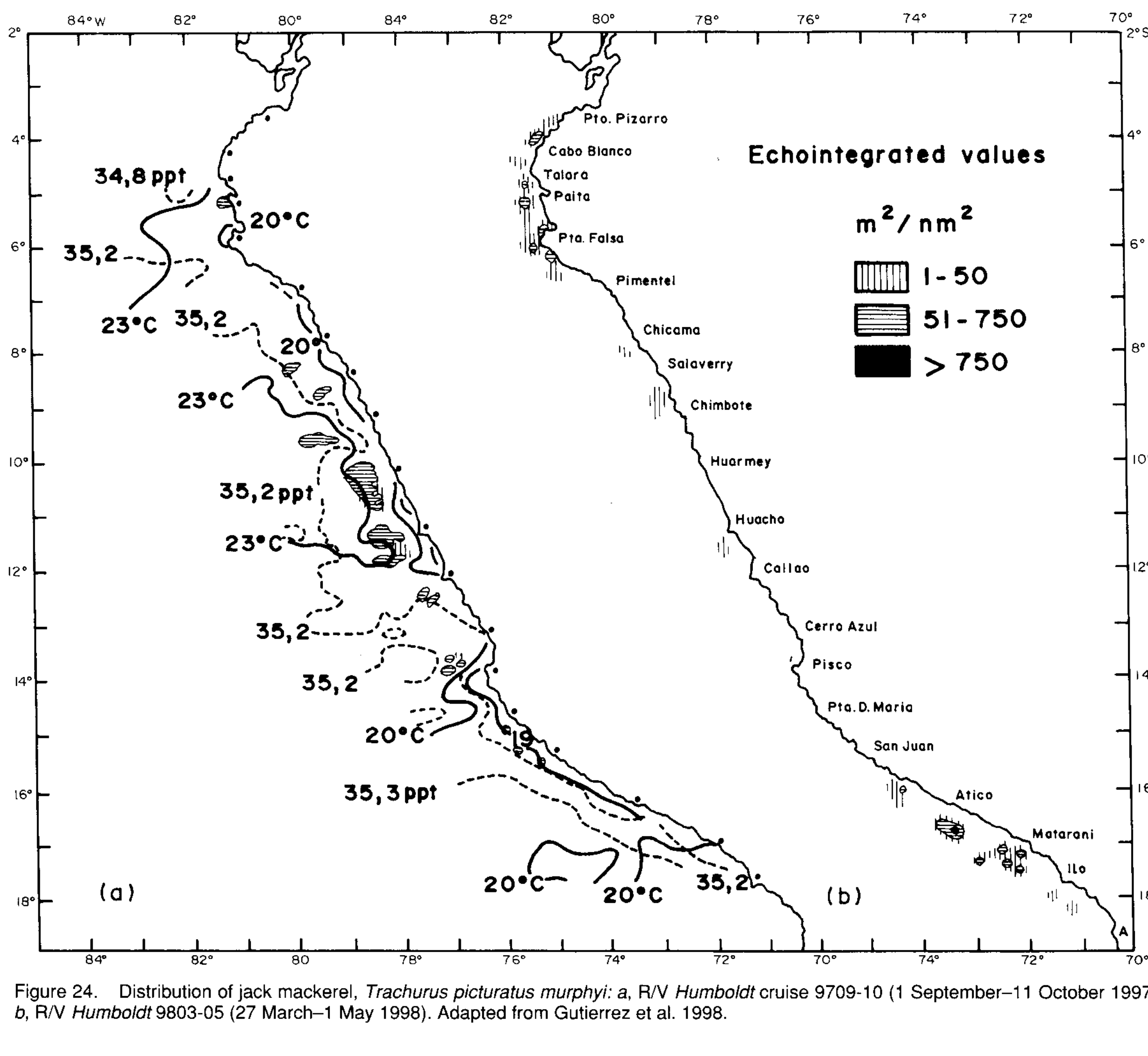

Figure 24. Distribution of jack mackerel, *Trachurus picturatus murphyi*: *a*, R/V *Humboldt* cruise 9709-10 (1 September–11 October 1997); *b*, R/V *Humboldt* 9803-05 (27 March–1 May 1998). Adapted from Gutierrez et al. 1998.

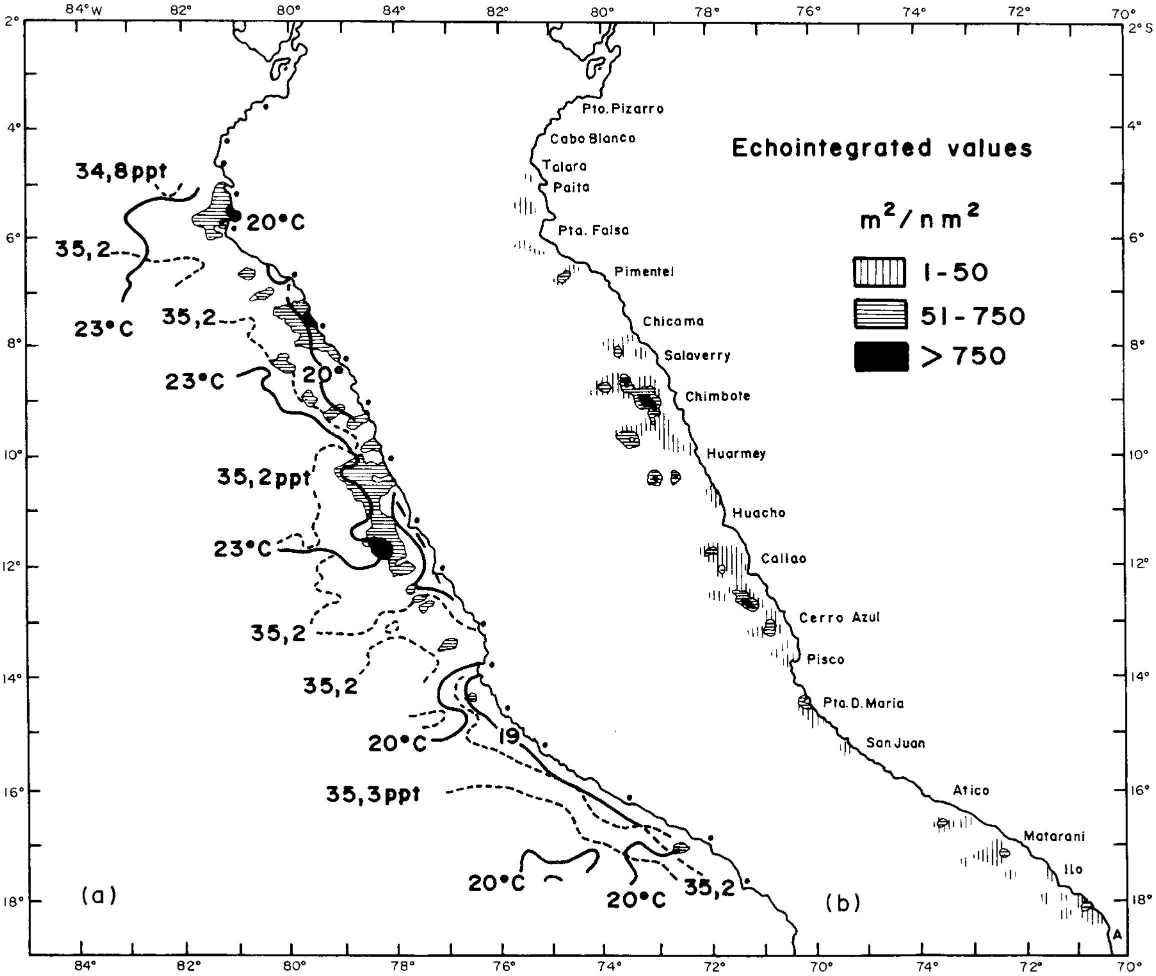

Figure 25. Distribution of chub mackerel, *Scomber japonicus*: *a*, R/V *Humboldt* cruise 9709-10 (1 September–11 October 1997); *b*, R/V *Humboldt* 9803-05 (27 March–1 May 1998). Adapted from Gutierrez et al. 1998.

et al. 1998). This distribution of jack mackerel remained equally poor in winter (fig. 24b).

***Scomber japonicus*, chub mackerel.** The response of chub mackerel to El Niño was similar to that of sardine and jack mackerel, shifting to the south (Ñiquén et al. 1998). The biomass of this species varied from 1.1 to 2.5 million t from April to October 1997 (9704, 9709-10), corresponding to the beginning and development of El Niño.

In September–October (9709-10) the chub mackerel was distributed from Paita to Pucusana (12°28'S), but with greater indices of abundance on the central coast of Peru, associated with SSW (fig. 25a). Vertically, this species was found between 5 and 110 m. Between summer and autumn 1998 (9803-05), as ESW retreated, the chub mackerel was found all along the Peruvian coast, but very scarcely (fig. 25b); its distribution was mainly between Pacasmayo (7°24'S) and Cerro Azul (13°S), with the greatest concentration between Salaverry and Chimbote in SSW.

***Merluccius gayi peruanus*, hake.** Hake extended their range to 12°S, which allowed the blackfin gurnad to move northward with good results, especially between Cabo Blanco and Paita.

In summer 1997, hake were strongly concentrated north of 6°S, due to a strong retraction of the SECC, which significantly reduced the distribution area of this species (Espino 1999), as in the cold year of 1995. During the first peak of El Niño (9705-06) this demersal species widened its area of distribution, together with the displacement of the SECC to the south, and even had a pelagic behavior extending to Callao (fig. 26a) during May and June 1997 (Castillo et al. 1997).

During May–June 1997 the main areas of higher concentration were in Callao-Huarmey, Salaverry-Chimbote, Paita-Pimentel, and north of 4°S, mainly along the border of the shelf, where the axis of the SECC, with temperatures of 13°–20°C and 34.9–35.0 ppt of salinity, was apparently located (Vásquez 1997).

After January 1998, this species started to repopulate

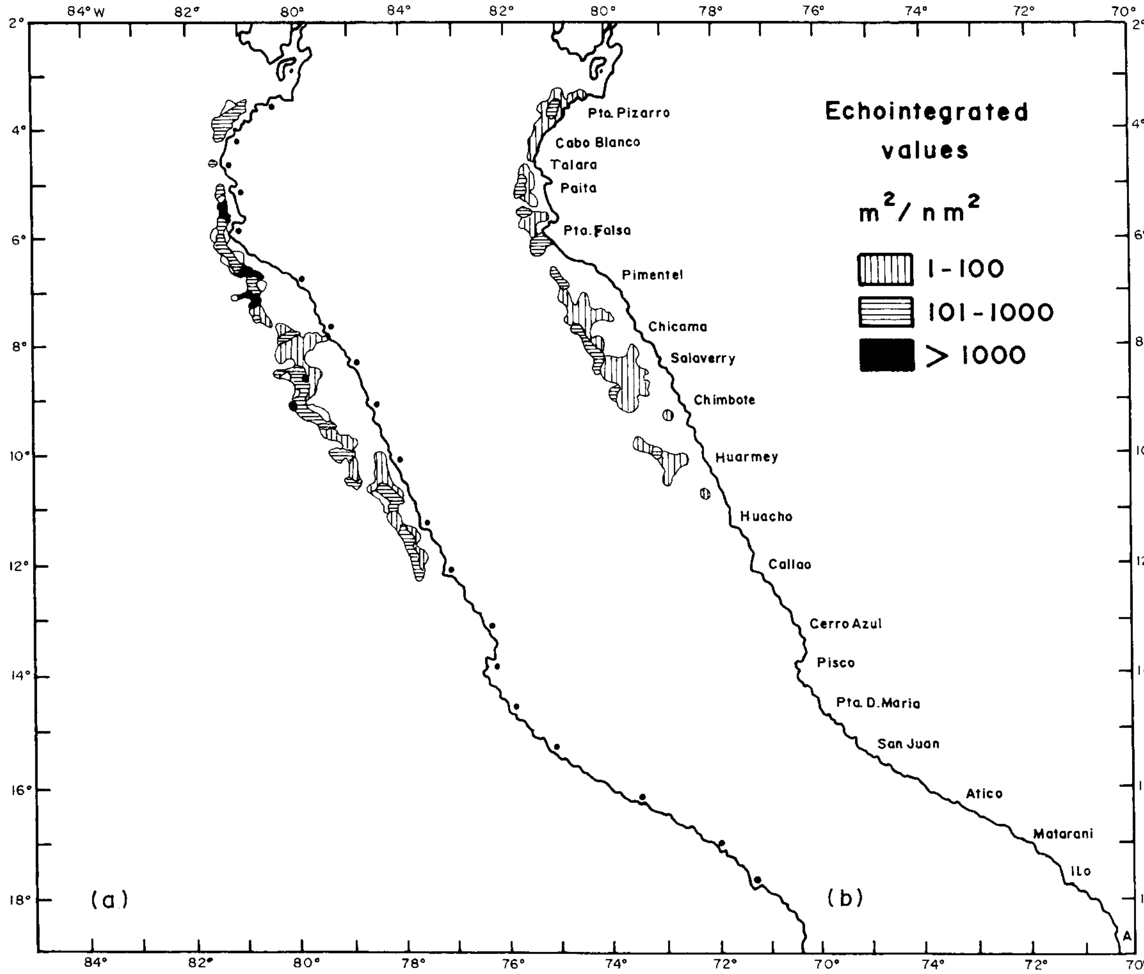

Figure 26. Distribution of hake, *Merluccius gayi peruanus: a,* R/V *Humboldt* cruise 9705-06 (15 May–8 June 1997); *b,* R/V *J. Olaya* cruise 9806-07 (27 June–13 July 1998). Adapted from Castillo et al. 1997; Samamé and Fernandez (1998).

its usual areas of distribution, and in June there was more density between 6° and 8°S (fig. 26b) and between 100 and 200 fathoms, while south from 9°S, trawls were poor or negative (Samamé and Fernandez 1998).

Other Fish

***Anchoa nasus*, samasa.** During El Niño this species was abundant in winter 1997, with a biomass of 1.5 million t (Gutierrez et al. 1998), sharing its vertical distribution with the anchovy between 3 and 50 m and in mixed coastal and subtropical waters (fig. 27a). In the first half of 1998 (fig. 27b) it was found near the coast from Máncora to the south of Ilo (Castillo et al. 1998), with a greater presence between Pimentel and Pisco and denser concentrations off Salaverry; it was also observed on cruise 9803-05, when its greatest concentration was in the northern region (7°–9°S), with a calculated biomass of 2.09 million t (Gutierrez 1998).

From June to September 1998 there was a greater availability of samasa, but only in the north zone of the Peruvian coast, as the resource retreated to its natural habitat associated with the ESW.

***Myctophidae*, lanternfishes, and others** Diversity of this group of oceanic fishes was remarkable during El Niño 1997–98, and included many fishes typical of the Panamanian province. The most conspicuous was *Diogenichthys laternatus*, which was found along the Peruvian coast from the beginning of the sea warming, and which, together with other species, became more frequent as the thermal anomalies intensified.

***Bregmaceros bathymaster*, unicorn cod.** This species is normally restricted to the Gulf of Panama. During El Niño 1982–83 it was recorded with the incursion of TSW along the Peruvian coast, constituting an important diet item for pelagic resources such as chub mackerel and jack mackerel and for demersals such as hake (Sánchez et al. 1985). According to the ERFEN report (1998) this species was present since autumm 1998, together with other pelagic resources of the SSW, including bullet tuna, *Auxis rochei*; yellowfin tuna, *Thunnus albacares*;

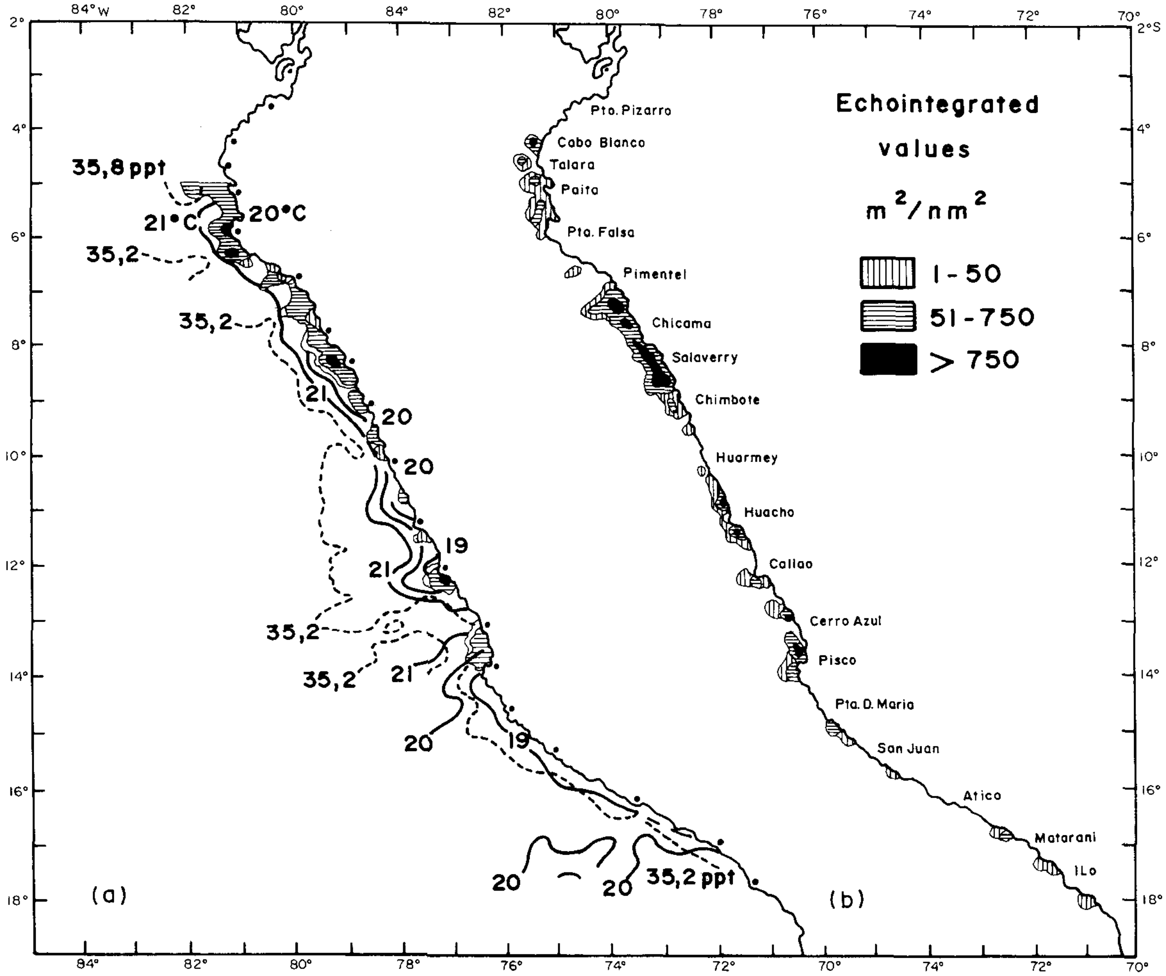

Figure 27. Distribution of the samasa, *Anchoa nasus: a,* R/V *Humboldt* cruise 9709-10 (1 September–11 October 1997); *b,* R/V *J. Olaya* cruise 9803-05 (20 March–7 May 1998). Adapted from Castillo et al. 1998; Gutierrez et al. 1998.

mahi mahi, *Coryphaena hippurus*; blue shark, *Prionace glauca*; sierra, *Scomberomorus maculatus*; and cutlassfish, *Trachiurus nitens*. During El Niño these species were constantly present in the northern and central regions.

Marine Mammals

During ENSO, cetaceans (whales and dolphins) migrated southward in search of cold waters and food to fulfill their energetic needs (Arntz and Fahrbach 1996; Bello et al. 1998). In October 1997 *Tursiops truncatus*, *Delphinus capensis*, *Lagenorhynchus obscurus*, *Globicephala* sp., *Megaptera novaeangliae*, *Balaenaptera* sp., and *Delphinus delphis* were reported.

Between March and May 1998, dolphins like *Tursiops truncatus* and the common dolphin, *Delphinus delphis*, were seen frequently along the Peruvian coastline. The tropical dolphin *Stenella* sp. was also observed. The higher concentrations of minor cetaceans were found near Salaverry, between Huacho and Callao and between Mollendo and Ilo. Dolphins appeared at a wide range of temperatures, tending toward the south, in relation to the distribution of anchovy and sardine (Sánchez et al. 1998).

Seabirds

As has been reported for previous El Niño events, El Niño 1997–98 brought a reduced abundance and a redistribution of piscivorous bird species typical of the Peruvian marine ecosystem—mainly guanay, boobies, and pelicans—that were forced to modify their distribution according to the availability of anchovy.

Observations of marine birds carried out during cruises 9803-05 and 9808-09 showed differences in relative abundance. In the first cruise the camanay, *Sula nebouxii*; the pardelas, *Puffinus* spp.; and the albatross of Galápagos, *Diomedea irrorata*, were abundant. Also observed were tropical species such as *S. nebouxii* and *S. leucogoster*, which was recorded for the first time at 6°S, the most austral record of that species. The guano birds were more abundant during the second cruise (Jahnke et al. 1998), when oceanographic conditions were normalized.

LANDINGS OF THE MAIN FISH RESOURCES

El Niño decreased landings of the main pelagic species by 74%, mainly because of a reduced anchovy catch (ERFEN 1998; fig. 28).

In summer 1998, the anchovy in the central and southern regions were mainly adults. In winter 1998, the main modal size of anchovy was 5.5 to 6 cm total length, with a secondary mode of recruits between 8 and 8.5 cm. The smallest specimens, aged 4 to 6 months, came from spawnings in autumn of 1998. The estimates of recruits for 1998 were very positive, in that they reached a high percentage of the total biomass; thus a quick recovery of the stock for the biological year 1998–99 is expected (Ñiquén et al. 1998).

Sardine catches increased slightly at the end of November 1997, with daily capacity of 20,000 t. The ports of Chicama and Chimbote were the most important. Nevertheless, in December a decrease was observed in association with thermal anomalies in the northern zone. The total length range of sardine at the end of the first peak of El Niño, in winter 1997, was from 2 to 30 cm, with modes at 4, 10, 12, and 27 cm (9709-10).

The sardine population at the end of El Niño 1997–98 (9808-09) comprised predominantly juveniles (3–23 cm total length, with a main mode at 6 cm and a secondary mode at 21 cm) of approximately 2 years of age, from the spawning period between winter and spring 1996 (Ñiquén et al. 1998).

Jack mackerel landings increased from January to October 1997, stabilizing in the last two months at over 50,000 t per month. At the end of winter 1997, jack mackerel had three groups of modes of prerecruit sizes between 6 and 14 cm and recruits smaller than 26 cm. The group of smaller sizes was found within 20 nmi of the coast. In summer 1998, jack mackerel (as expected) had a distribution of larger sizes on the north coast to 6°S, while to the south, the size structure had modes from 21 to 36 cm.

Mackerel landings were not impressive between January and July 1997. Nevertheless, between August and September they increased significantly, from 36,000 to 49,000 t. In relation to 1996, landings increased more than 300%. At the end of summer 1998 this species presented a structure of bimodal sizes from 12 to 33 cm long (to the tail fork; Chipollini et al. 1998). In autumn and winter its size structure encompassed juveniles and adults between 5 and 33 cm; the juvenile specimens were distributed nearer the coast than usual.

Hake landings from January to the first week of September 1998 were 62,000 t—less than in the same period of 1997 (108,000 t). In the second semester of 1998 the landings increased progressively, with a high percentage of juveniles. This increase was due to an increased number of trawling boats in the area of Paita and to the availability of the resource (fig. 29).

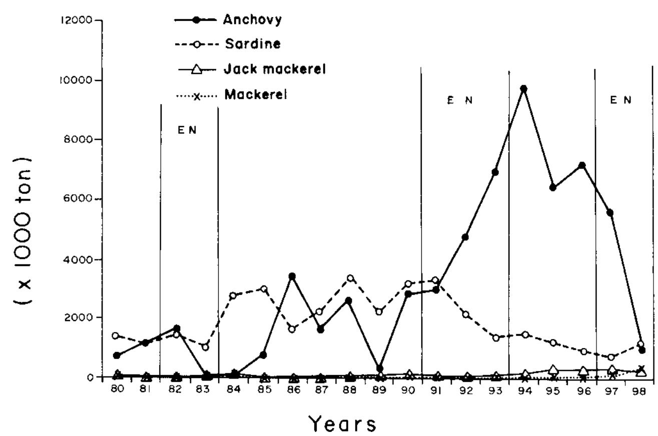

Figure 28. Landings of the main pelagic resources, 1980–98. Adapted from Bouchon and Ñiquén 1999.

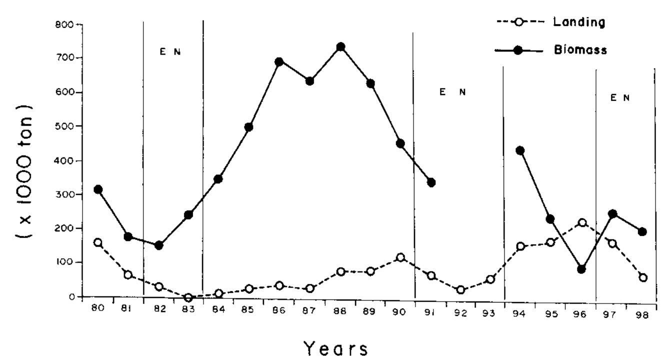

Figure 29. Landings and biomass of Peruvian hake, 1980–98.

At the beginning of 1998, in the second peak of El Niño, there was a recruitment mode at 25 cm, as recruits entered the fishery. In the second semester of 1998, with the reestablishment of normal environmental conditions, the mode increased (43 cm) in the zone of Paita. Smaller sizes (juveniles of 25 cm) were found south of this area.

DISCUSSION

In the three last decades the El Niño events of highest impact in Peru were in 1972–73, 1982–83, and 1997–98. The last is considered exceptional and was better observed than the two others (Hansen 1989; Halpern 1996; Leetma 1999) because it was prognosticated. Many countries were able to take mitigation measures (even though the forecast was not quite accurate for the first phase). As noted earlier, however, we have little information about primary production off Peru.

El Niño 1997–98 was preceded by a period of moderate cold (1995–96) and followed by a cold, post–El Niño period that started in 1998. The cooling trend continued in 1999 with an atypical distribution of the anchovy *Engraulis ringens*, while the sardine's distribution was restricted to the northern region.

During the evolution of the extraordinary 1997–98 event, there were two peaks in the SST anomalies: the first in July 1997 (anomalies of 6°C) and the second around January 1998 (anomalies of 9°). Defined by anomalies higher than 1°, it can be said that the event lasted 13 or 16 months, fewer in the south than in the north, with a period of relaxation in October 1997. Associated with the thermal anomalies of the first peak, very poor volumes of plankton and an abundance of dinoflagellates and small copepods endemic to warm waters were observed. This situation was also present during El Niño 1982–83, when the diatoms were not present (Chavez 1987) and warm-water dinoflagellates appeared in the coastal environment. Those species, endemic to warm waters, had an indicator value at the beginning of the anomalies in the Peruvian coast, but afterwards their presence did not represent a clear response to the environmental conditions.

The patterns of nitrate observed during 1997–98 were most altered from normal in December 1997, when the deepening of the oxycline and nutricline was notably intensified (1 ml/L iso-oxygen depths greater than 250 m, and concentrations of 5 μg-at/L of nitrate at 100 m). The chemical conditions in the sea surface in 1997–98 were similar to those of El Niño 1982–83, but the nutricline and oxycline were deeper in that year (Chavez et al. 1983). All nutrients showed similar patterns of distribution, except in summer 1998 (9802-03), when the silicate concentrations near the coast were high north of Paita (5–20 μg-at/L) due to continental influence, because rains intensified the river discharge. A higher local photosynthetic activity was detected in the volumes of plankton recorded by Delgado and Fernandez (1998) for that cruise. This situation was similar to that found in February of 1972 and 1983 by Guillén and Calienes (1981), and by Guillén (1985) in the same area.

During the first phase of the advance of low-salinity equatorial waters, the anchovy were near the coast. The decrease in biomass from 9.5 million t in January 1997 to 1.2 million t after El Niño 1997–98 was similar to the depression caused by environmental perturbations of the 1982–83 ENSO (Jordan 1983).

The distribution of sardine in the first months of the event was associated with the ESW and SSW. The same situation occurred in El Niño 1982–83, when the sardine were more highly concentrated in the coastal zone due to the position of SSW, as well as having come from the equator with the advance of ESW (Tsukayama and Santander 1987). Like the anchovy, this species also migrated to the south, as was observed during El Niño 1982–83 (ERFEN 1984). In the intermediate phase of thermal relaxation, sardine were very scarce and associated with SSW south of 12°S.

On the other hand, the success of the endemic species' spawning in the upwelling zone was affected by the perturbation of the environment. Anchovy during El Niño 1997–98 had, according to the gonadosomatic indexes, a low intensity and change in time of spawning. In the second peak (summer 1998) spawning was above normal, and reached a peak in September of that year (cold, post–El Niño period). These variations in the reproductive process were reflected in a decreased population, and had consequences in recruitment, but the strategy used by some species was to stay near the coast, as during El Niño 1982–83 (Barber and Chavez 1986), and also to move to the depths and to migrate southward. Adequate management of the resource allowed the anchovy population to recover promptly.

The gonadosomatic indexes of sardine indicated the effect of the cold year (1996), and spawning was good in the summer of 1997. In the second peak of the warming of El Niño 1997–98, a phase shift in time was observed, but spawning was good in the post–El Niño phase, and sardine recruitment improved during 1998 and even 1999.

The habitat of jack mackerel and chub mackerel, which are more oceanic species, is in SSW, so the two species are found far from the coast. With the coastward penetration of these waters (SSW, ESW), the distributions were near the coast in El Niño 1997–98, and in the north zone they deepened with the SECC. This pattern was present in the events of 1972–73 (Chavez 1987) and in 1982–83 (Tsukayama and Santander 1987).

Another species which significantly increased its distribution and biomass was the samasa, or anchoa, the greatest biomass being around 2.09 million t during September–October 1997, diminishing substantially to 214,000 t in the post–El Niño period (cruise 9808-09; Castillo et al. 1998). The catch of samasa was very significant during the event, although this species in normal years occurs only on the north coast, typical of the Panamanian province.

Guillén et al. (1985) showed that the layer of 2–1 ml/L O_2 was between 100 and 150 m deep off Callao in February 1983. That layer was between 100 and 250 m in December 1997 in the same area, and deeper in Paita—between 150 and 280 m in July and December. In average conditions (1981) this layer is found at 30–50 m. This anomaly has great importance when related to the demersal species, especially hake. Hake shifted to 12°S during the first phase of the event (Castillo et al. 1997); probably in the second peak of the event, when the low oxygen layer was deepest, the species migrated to great depths with more favorable environmental conditions.

The developmental details of El Niño 1997–98 off the Peruvian coast were not forecast adequately to allow an environmental evaluation during the main warming peak of the event, so it is not possible to precisely describe its effects on the different resources of the Peruvian marine ecosytem. However, during the event the main fishery resources were intensively evaluated in order to determine such factors as vertical and latitudinal distributions, abundance variations, and reproductive behavior.

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LITERATURE CITED

Arntz, W., and E. Fahrbach. 1996. El Niño, Experimento climático de la naturaleza. Primera ed. Mexico: Fondo de Cultura Económica, 312 pp.

Ayón, P., and K. Aronés. 1997. Comunidades de zooplancton e ictioplancton frente a la costa norte-centro del Perú. Crucero BIC/*Humboldt* 9705-06. Inf. Inst. Mar Perú 128:70–79.

Ayón, P., and M. Girón. 1997. Composición y distribución del zooplancton e ictioplancton frente a la costa peruana durante febrero–abril 1997. Inf. Inst. Mar Perú 127:56–71.

Ayón, P., and R. Quesquén. 1998. El ictioplancton frente al litoral peruano a fines del otoño 1998, BIC *José Olaya Balandra* 9805-06 de Tacna a Mancora. Inf. Inst. Mar Perú 137:57–65.

Ayón, P., S. Sánchez, M. Girón, P. Villanueva, and E. Delgado. 1996. Composición y distribución del plancton en el litoral peruano en el verano de 1996. Inf. Inst. Mar Perú 122:69–78.

Ayón, P., M. Giron, K. Aronés, and R. Quesquén. 1998. Composición, abundancia y distribución del ictioplancton frente a la costa del Perú en otoño 1998. Crucero BIC *Humboldt* 9803-05 de Tumbes a Tacna. Inf. Inst. Mar Perú 135:121–133.

Barber, R., and F. Chavez. 1986. Ocean variability in relation to living resources during the 1982–83 El Niño. Nature 319(6051):279–285.

Bello, R., M. Arias-Schreiber, and R. Sánchez. 1998. Distribución y abundancia relativa de cetaceos durante el crucero BIC *Humboldt* 9709-10, de Matarani a Paita. Inf. Inst. Mar Perú 130:78–85.

Bouchon, M., and M. Ñiquén. 1999. Estadísticas de la pesquería pelágica de la costa Peruana. Inf. Interno. Inst. Mar Perú.

Calienes, R., and O. Guillén. 1981. Masas de agua y producción primaria en el Perú. Bol. Inst. Mar Perú, Vol. Extraordinario ICANE:155–163.

Calienes, R., O. Guillén, N. Lostaunau. 1985. Variabilidad especio-temporal de clorofila, producción primaria y nutrientes frente a la costa peruana. Bol. Inst. Mar Perú, Proyecto OEA/IMARPE 10(1):1–44.

Carrit, D., and J. Carpenter. 1966. Comparison and evaluation of currently employed modification of the Winkler method for determining dissolved oxygen in sea water. J. Mar Res. 24:286–318.

Castillo, R., F. Ganoza, A. Aliaga, M. Gutierrez, and R. Guevara. 1997. Distribución, concentración y biomasa de la merluza peruana en otoño de 1997 con el método hidroacústico Crucero BIC *Humboldt* 9705-06. Inf. Inst. Mar Perú 128:12–24.

Castillo, R., M. Gutierrez, S. Peraltilla, and N. Herrera. 1998. Biomasa de recursos pesqueros a finales del invierno 1998. Crucero BIC *Humboldt* y BIC *Jose Olaya* 9808-09 de Paita a Tacna. Inf. Inst. Mar Perú 141:91–102.

Chang, F., E. Delgado, and P. Villanueva. 1997. Características del fitoplancton en el crucero oceanográfico 9706-9706-07. Informe Interno DGIO, Inst. Mar Perú.

Chavez, F. 1987. El Niño y la Oscilación del Sur. Investigación y Ciencia. Scientific American (Spanish ed.) 128:46–55.

Chavez, F., R. Barber, and F. Vasquez. 1983. Progression of the 1982–83 El Niño off Northern Peru. Trop. Ocean-Atmos. Newsl. Oct. 1983.

Chipollini, A., A. Echevarria, and G. Cárdenas. 1998. Aspectos biológicos pesqueros de los principales recursos pelágicos entre marzo y mayo 1998. Crucero BIC *Humboldt* 9803-05 de Tumbes a Tacna. Inf. Inst. Mar Perú 135:103–113.

Delgado, E., and C. Fernández. 1998. Comunidades del fitoplancton durante el Monitoreo Oceanográfico para la Predicción del Fenómeno El Niño, MOPFEN 9802-03. Informe Interno DGIO, Inst. Mar Perú.

Delgado, E., and P. Villanueva. 1998a. Estructura comunitaria del fitoplancton durante el Cr. BIC/*Humboldt* 9709-10 de Matarani a Paita. Inf. Inst. Mar Perú 130:53–64.

———. 1998b. La comunidad fitoplanctónica en el litoral peruano durante marzo a mayo 1998. Crucero BIC/*Humboldt* 9803-05 de Tumbes a Tacna. Inf. Inst. Mar Perú 135:114–120.

ERFEN. Estudio Regional Fenómeno El Niño. 1984. Condiciones bioceanográficas y meteorológicas frente a la costa peruana, de enero a septiembre de 1983. IMARPE, SENAMHI, DHNM, IGP. Bol. 10:2–8.

———. 1998. Resumen de las condiciones actuales: oceanográficas, meterorológicas y biológico-pesquera del mar peruano e impactos agroclimáticos registrados de octubre 1997 hasta octubre de 1998. Informe Técnico del Comité Multisectorial para el Estudio Nacional del fenómeno El Niño IMARPE, SENAMHI, DHN, IGP, INDECI Noviembre, Callao, Perú.

Espino, M. 1999. El Niño 1997–1998: su impacto sobre los recursos pesqueros y sus pesquerías. *En* Forum el fenómeno El Niño 1997–1998. Evolución, pronóstico mitigación. Informe final. IMARPE/MIPE/PNUD, pp. 112–129.

Flores, G., J. Cordova, J. Ledesma, and N. Carrasco. 1998. Condiciones hidroqímicas del mar peruano a fines de Otoño 1998 Cr. BIC/*José Olaya* 9805-06, Tacna a Máncora. Inf. Inst. Mar Perú 137:90–104.

Flores, G., J. Ledesma, and J. Solís. 1998. Condiciones hidroquímicas del mar peruano durante el invierno 1998. Inf. Inst. Mar Perú 141:176–186.

García, W. 1998. Monitoreo oceanográfico para la predicción del fenómeno El Niño—MOPFEN BAP/*Carrasco* 9802-03 (12 febrero–18 de marzo, 1998). Informe Interno DOF, Inst. Mar Perú.

Girón, M. 1998. Zooplancton e ictioplancton durante el crucero BIC *Humboldt* 9709-10 de Matarani a Paita. Inf. Inst. Mar Perú 130:70–77.

Guillén, O. 1985. Chemical characteristics and productivity off Peru during El Niño 1982–83. Symposium on vertical motion in the equatorial upper ocean and its effects upon living resources and the atmosphere. Paris, France.

Guillén, O., and R. Calienes. 1981. Biological productivity and El Niño. *In* Resource management and environmental uncertainty, lessons from coastal upwelling fisheries, M. Glantz and J. Thompson, eds. New York: John Wiley & Sons Inc. Interscience Pub., pp. 255–282.

Guillén, O., N. Lostaunau, and M. Jacinto. 1985. Características del fenómeno El Niño 1982–83. Bol. Inst. Mar Perú, Volumen extraordinario El Niño, su impacto en la fauna marina, pp. 11–21.

Gutierrez, M. 1997. Distribución, concentración y biomasa de los principales recursos pelágicos peruanos a principios de otoño de 1997. Crucero BIC *Humboldt* 9704, Callao-Paita. Inf. Inst. Mar Perú 127:1–92.

———. 1998. Resumen ejecutivo acerca de la distribución, biomasa y aspectos biológicos de los principales recursos pelágicos durante el otoño 1998. Crucero BIC/*Humboldt* 9803-05 de Tumbes a Tacna. Inf. Inst. Mar Perú 135:1–7.

Gutierrez, M., L. Vásquez, R. Castillo, T. Dioses, J. Mori, and M. Perea. 1998. Distribución, concentración y biomasa de los principales recursos pelágicos a finales del invierno e inicios de primavera 1997. Crucero BIC *Humboldt* 9709-10 de Matarani a Paita. Inf. Inst. Mar Perú 130:13–44.

Guzmán, S., P. Ayón, and R. Quesquén. 1998. Composición, distribución y abundancia del ictioplancton. Crucero BIC *Humboldt* y BIC *Jose Olaya* 9808-09. Inf. Inst. Mar Perú 141:72–84.

Halpern, D. 1996. Visiting TOGA's past. Bull. Am. Meteorol. Soc. 77(2):233–242.

Hansen, D. 1989. Physical aspects of the El Niño event of 1982–1983. *In* Global ecological consequences of the 1982–83 El Niño Southern Oscillation, P. W. Glynn, ed.

Jahnke, J., L. Ayala, and C. Mendoza. 1998. Abundancia relativa y distribución de aves marinas frente a la costa peruana y su relación con la abundancia de anchoveta. Crucero BIC/*Humboldt* 9808-09 de Piura a Lima. Inf. Inst. Mar Perú 141:85–95.

Jordán, R. 1983. Variabilidad de los recursos pelágicos en el Pacífico sudeste. FAO. Informe de Pesca 291(2):113–130.

Leetma, A. 1999. The 1997/98 El Niño/La Niña. *In* Proceedings of the international CLIVAR conference, Paris, France, 2–4 December 1998, WCRP-108, Jeure. ICSU-WMO-UNESCO.

Mori, J., A. Perea, and B. Buitrón. 1999. Cambios en la estrategia reproductiva de la anchoveta (*Engraulis ringens*) durante el evento El Niño 1997–98. Resumen del Congreso Latinoamerico de Ciencias del Mar, Trujillo, Perú.

Morón, O. 1998. Condiciones oceanográficas durante el crucero BIC *Jose Olaya Balandra* 9805-06 de Tacna a Mancora. Inf. Inst. Mar Perú 137:80–89.

Morón, O., and R. Marquina. 1997. Aspectos oceanográficos del mar peruano desde Callao a Paita. Crucero BIC *Humboldt* 9704. Inf. Inst. Mar Perú 127:31–39.

Morón O., N. Dominguez, and P. Chapillequén. 1998. Características oceanográficas durante el crucero pelágico BIC *Humboldt* y BIC *Jose Olaya Balandra*, 9808-09 de Paita a Los Palos (Tacna). Inf. Inst. Mar Perú 141:96–113.

Ñiquén, M., A. Echevarría C., R. Tafur, M. Bouchon, R. Dávalos, J. Quiñones, S. Cahun, and D. Valdez. 1998. Situación de los principales recursos pelágicos en el mar peruano durante el periodo postNiño 1997–98. Inf. Inst. Mar Perú 141:13–29.

NOAA. 1997. Climate diagnostics bull. 1–12, January–December 1997. National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

———. 1998. Climate diagnostics bull. 1–12. January–December 1998. National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Pizarro, L. 1997a. Crucero oceanográfico BIC/*Humboldt* 9706-07 (19 junio–17 julio, 1997). Informe interno DOF, Inst. Mar Perú.

———. 1997b. Crucero oceanográfico BAP/*Carrasco* 9711-12 (27 noviembre–22 diciembre 1997). Informe interno DOF, Inst. Mar Perú.

Samamé, M., and F. Fernandez. 1998. Resultados generales del crucero de estimación de la biomasa de merluza en el área de Pto. Pizarro-Huarmey. Crucero BIC/*José Olaya* 9806-07. Inf. Inst. Mar Perú 138:7–18.

Sánchez de Benites, G., J. Vélez, and A. Chipollini. 1985. Un pez panameño en aguas peruanas: *Bregmaceros bathymaster* durante El Niño 1982–83. Boletin de Lima 38:92–96.

Sánchez, R., M. Arias-Schereiber, and K. Onton. 1998. Avistamientos de cetaveos en el mar peruano y su relación con los principales recursos pelágicos. Crucero BIC *Humboldt* 9803-05 de Tumbes a Tacna. Inf. Inst. Mar Perú 135:163–179.

Sánchez, S., P. Villanueva, M. Menacho, and F. Chang. 1997. Composición y distribución del fitoplancton en el mar peruano febrero–abril 1997. Inf. Inst. Mar Perú 127:56–71.

Strickland, J., and T. Parsons. 1972. A practical handbook of seawater analysis. Bull. Fish. Res. Board Can. 167 (2d ed.), 310 pp.

Tsukayama, I., and H. Santander. 1987. Cambios bióticos y efectos sobre los recursos pesqueros y las pesquerías en Perú. Rev. Com. Perm. Pacífico Sur 16:97–166.

Vásquez, L. 1997. Condiciones oceanográficas del mar peruano desde Callao a Tacna. Crucero BIC/*SNP-1* 9702-03. Inf. Inst. Mar Perú 127:24–30.

Vásquez, L., and E. Tello. 1998. Condiciones oceanográficas durante el crucero BIC *Humboldt* 9803-05 de evaluación hidroacustica de recursos pelágicos desde Tumbes a Tacna. Inf. Inst. Mar Perú 135:20–33.

Villanueva, P., E. Delgado, and C. Fernandez. 1998. Biomasa planctónica como alimento disponible durante el crucero BIC/*Humboldt* y BIC/*José Olaya* 9808-09 de Paita a Los Palos (Tacna). Inf. Inst. Mar Perú 141:49–54.

Zuta, S., and J. Otiniano. 1998. Avances del Proyecto ECCIP: estudio de los cambios climáticos y su impacto en el Perú. Rev. Inv. Fis. FCF-UNMSM 1(2):1–40.

Zuta, S., T. Rivera, and A. Bustamante. 1978. Hydrologic aspects of the main upwelling areas off Peru. *In* Upwelling ecosystems, R. Boje and M. Tomczak, eds. Berlin: Springer-Verlag, pp. 235–257.