Pelagic Fish Stocks and Environmental Changes in the South-East Pacific

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ABSTRACT

Anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*) landings in the north of Chile and in Peru between 1950 and 1993 are analyzed. Abundance variations of both species are expressed as catch per unit effort (CPUE), and compared with VPA (Virtual Population Analysis) estimates. Environmental fluctuations are analyzed through historical series of the Southern Oscillation Index (SOI), sea surface temperatures (SST), and the upwelling and turbulence indices. A global production model is fitted to data from the anchovy fishery of the north of Chile and in Peru from 1957 to 1977. The model explains variations of CPUE as a function of fishing effort and of SST, included as a linear subfunction of carrying capacity (B_∞). A similar model for the sardine fishery is fitted to data from the north of Chile from 1975 to 1992. The latter includes CPUE, fishing effort, and SST as a quadratic subfunction of B_∞ as explanatory variables. It is concluded that both resources were intensively exploited and affected by environmental changes that impacted surplus production. Anchovy develops better in a relatively cold environment; meanwhile sardine shows a clear preference for warm periods, but not as extreme as the El Niño 1982-83.

RÉSUMÉ

Les évolutions des captures d'anchois (*Engraulis ringens*) et de sardine (*Sardinops sagax*) au nord du Chili et au Pérou sont analysées entre 1950 et 1993. Les variations d'abondance des deux espèces sont estimées en utilisant les captures par unité d'effort (CPUE) et comparées avec les estimations des VPA (Analyses Virtuelles des Populations). Les fluctuations environnementales sont analysées à partir des séries historiques de l'indice d'oscillation Sud, de la température de surface (SST), et des indices d'upwelling et de turbulence. Un modèle global est ajusté pour la pêcherie d'anchois au nord du Chili et au Pérou entre 1957 et 1977. Ce modèle explique les variations de CPUE en fonction de l'effort de pêche et de la SST introduite comme une fonction de la capacité biotique (B_∞). Un modèle similaire est appliqué pour la sardine pour le nord du Chili entre 1975 et 1992. Ce dernier inclut la CPUE, l'effort de pêche et la SST en tant que fonction quadratique de B_∞. Il est conclu que ces deux ressources furent intensivement exploitées et affectées par les changements environnementaux qui ont des effets négatifs sur la production. L'anchois se développe mieux dans un environnement relativement froid, tandis que la sardine montre une nette préférence pour des périodes chaudes, cependant qui ne soient pas aussi extrêmes que le El Niño 1982-83.

INTRODUCTION

In the Pacific Ocean, south of the equator and in close relationship with the center of high atmospheric pressures located between 20°-35°S and 90°-110°W, lies the south-east Pacific anticyclonic gyre. The eastern sector of this gyre is the Chile-Peru Current System, a northern extension of the West Wind Drift reaching the south American coast at around 40°S (Bernal and Ahumada, 1985).

Thus, the oceanographic regime of the region is determined by the combined action of: 1) the Humboldt current, carrying cold waters and low salinities from the subantartic region towards the north; 2) coastal upwellings generated by the predominantly south-southwest winds along the coast of Chile (with maxima in the spring-summer season), and south southeast winds in Peru (with maxima in winter); 3) the intrusion of subtropical waters of high temperature and salinity from the north towards the coast; and 4) below the surface, a southward flux of equatorial subsurface water of high salinity and low oxygen content, which plays an important role in the distribution of marine pelagic resources (Robles *et al.*, 1976; Guillén, 1983; Bernal *et al.*, 1983; Parrish *et al.*, 1983; Bernal, 1990).

The region is also affected by the El Niño events, which produces an anomalous warming of surface waters. These events occur at irregular intervals in conjunction with the Southern Oscillation, a large fluctuation of atmospheric pressure between the tropical southeast Pacific and the West Pacific (Wyrtki, 1975; Guillén, 1983; Ramage, 1986; Philander, 1990). The region is also affected by environmental changes associated with cold periods and longer warm periods (Cañon, 1986; Yáñez and Barbieri, 1988; Sharp and McLain, 1993).

This dynamic and variable system is however one of the most productive regions of the world ocean, though with a low diversity of pelagic species. These species however are very abundant and thus support important fisheries: which is particularily the case of anchovy (*Engraulis ringens*) and sardine (*Sardinops sagax*), exploited in Peru (Fig. 1a) and the north of Chile (Fig. 1b).

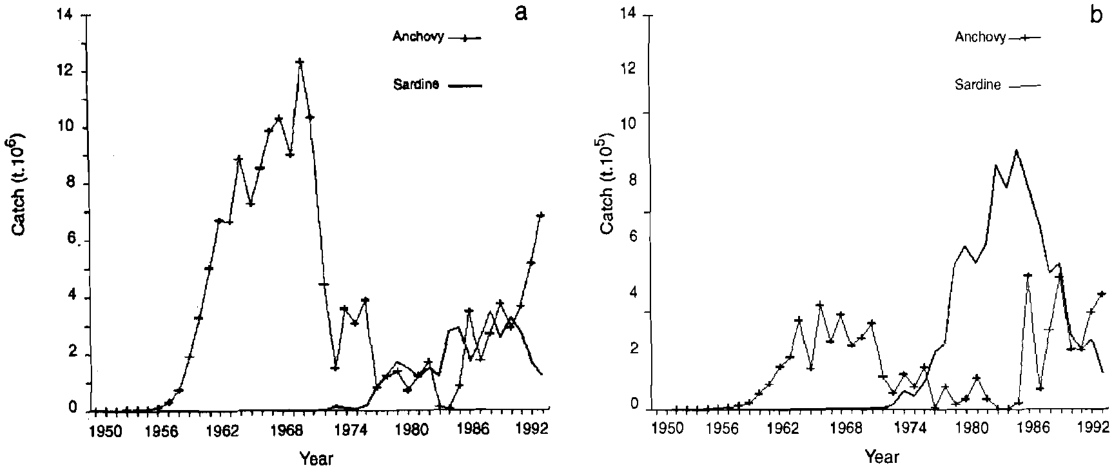

Fig. 1: Catch of major pelagic species in: a) Peru (IMARPE, 1950-94), and b) northern Chile (SAG, 1950-77; SERNAP, 1978-94).

Variability is an inherent feature of these resources. This variability is generally associated with both the intensity of exploitation and changes in environmental conditions (Csirke and Sharp, 1983; Cañon, 1986; Yáñez, 1989). This variability, well analyzed may become a source of information for a better understanding of the dynamics of the above mentioned species (Bernal, 1990).

Quinn *et al.* (1978) estimated that certain features of the Southern Oscillation can be used as precursors of El Niño events. Michelchen (1985) suggested that the interannual variations of coastal upwellings in West Africa are related to the variability of the Southern Oscillation. Binet (1988) discussed the possible role of an intensification of the westerly winds in the distribution changes of pelagic fishes of West Africa. Bakun (1992) suggested that an intensification of the winds causing upwelling may be due to greenhouse effects.

Parrish and MacCall (1978) analyzed the horse mackerel fishery off California, and incorporated oceanographic variables into the stock-recruitment models, thus explaining 75% of total variance. Mendelssohn and Cury (1987) analyzed the catch per unit effort (CPUE) of small pelagic fishes Côte-d'Ivoire (1966-82), as a function of the sea surface temperature (SST) collected by merchant ships, which explained 43% of the variance. Cury and Roy (1989) indicated that there exists an 'optimum environmental window' for the success of the pelagic resources recruitment in upwelling areas. Patterson *et al.* (1993) analyzed the collapse of the horse mackerel in the Eastern Central Pacific. They found that catchability varied with environmental conditions and stock size. Fréon (1988), analyzing the small pelagic fisheries of West Africa, proposed the incorporation of environmental variables in global production models. Later, an interactive software was developed for this purpose (Fréon *et al.*, 1993).

Mendelssohn (1989) fitted an additive non-linear model using the parental biomass and Trujillo's transport in Peru, thus explaining 75% of the variance of recruitment of anchovy in Peru. Muck (1989) analyzed biomass changes, individual growth, dominance of species, feeding strategies and oceanographic parameters off Peru. He concluded that overfishing and high temperatures affected the anchovy which led to increases of sardine, jack mackerel and horse mackerel, among other species. Muck *et al.* (1989) showed that the anchovy's area of distribution is biomass and SST related. Yáñez (1991) showed that the decrease of anchovy CPUE from 1957 to 77 could be explained by fishing effort and SST; whereas the change in the CPUE of sardine from 1973 to 88 was explained by fishing effort and Bakun's upwelling index (1973). Yáñez *et al.* (1994) showed that the distribution of anchovy and sardine in time and space in the north of Chile varied along with intra and interannual changes of SST as measured by NOAA satellites.

This brief review establishes — if needed be — the need to consider environmental variables when assessing the pelagic fish stocks of upwelling systems. Thus, we move on to describe these environmental variables.

1. ENVIRONMENTAL FLUCTUATIONS

Time series of environmental changes are analyzed, these include sea surface temperatures (SST) from 1950 to 1990 off Peru (4°-18°S), from the COADS dataset (Mendelssohn and Roy, this vol.); SST of tidal gauges of Arica (18°28'S) (1951-93), and Antofagasta (23°40'S) (1950-93); magnitude and direction of the wind from the meteorological station of Antofagasta (1950-93), used to obtain an upwelling index (Bakun, 1973) and a turbulence index (Elsberry and Garwood, 1978); and atmospheric pressures of Darwin (12°26'S-130°52'E) and Tahiti (17°33'S-149°20'W) (1950-93), used to estimate the Southern Oscillation index (SOI) (Ropelewski and Jones, 1987). Monthly anomalies were computed for each of the series and smoothed by 13 month centered moving average procedures. The monthly anomalies were also integrated to generate a series of accumulated values, taking into account their monthly signs.

The relationship of the Chile-Peru environmental system with changes of the ocean-atmosphere system is of a global nature. In fact, the SOI shows aperiodical decreasing trends associated to the occurrence of the El Niño events (Fig. 2a); since 1976 negative anomalies prevailed, due to a long term weakening of the South-East Pacific anticyclone (Fig. 2b). It should be noticed that after the 1987 El Niño event, the SOI recovered its positive values, then diminished again when the El Niño of 1992-93 developed.

Associated with such SOI variations, the monthly mean SST off Peru showed positive anomalies during the El Niño events (Fig. 3a); after the 1950-75 period, a clear dominance of positive anomalies settled in at least until 1990 (Fig. 3b). Along the coast of the north of Chile, monthly mean SST also shows the effects of El Niño events: there is a predominance of negative anomalies from 1950 to 1975, followed by a warm period, and a cooling trend in the last period under study (Fig. 4, 5).

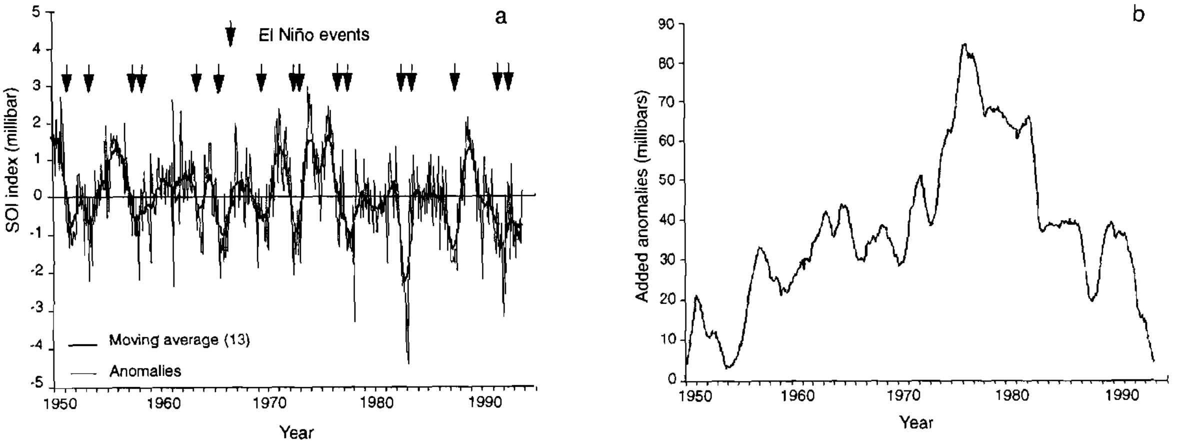

Fig. 2: Monthly mean Southern Oscillation Index (SOI) from 1950 to 1993: a) anomalies, and b) added anomalies.

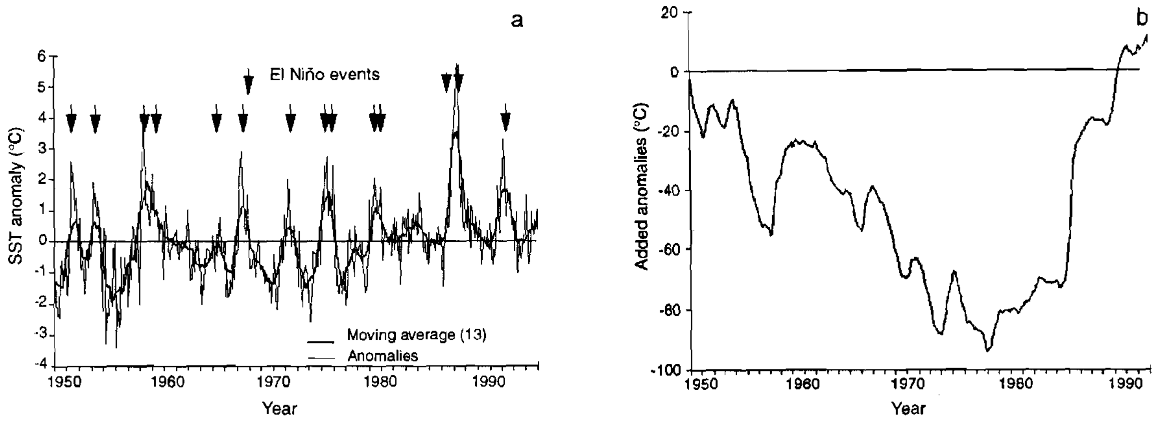

Fig. 3: Monthly mean sea surface temperature off Peru (1950-90): a) anomalies, and b) added anomalies.

The monthly anomalies of the upwelling index at the meteorological station of Antofagasta showed a predominance of negative values from 1950 to 1975; later on, the anomalies became mainly positive, with a tendency to decrease from the mid 1980s (Fig. 6a). The anomalies of the turbulence index follows the same trend, as an effect of the S-SW predominant winds (Fig. 6b). Bakun (1990) showed similar trends for wind stress along the coast of California, the Iberian Peninsula, Morocco and Peru, from 1950 to 86. This author suggests the existence of a mechanism through which the greenhouse effect would strengthen the upwellings by intensifying wind strength along the coast.

Thus, there appear to be a positive relationship between SST trends and the wind indexes. It is likely that the observed warming trend starting in 1976, may have been caused by an invasion of subtropical waters from the north and coastward, associated with the long term weakening of the Pacific anticyclone. The intrusion of these waters would have caused a

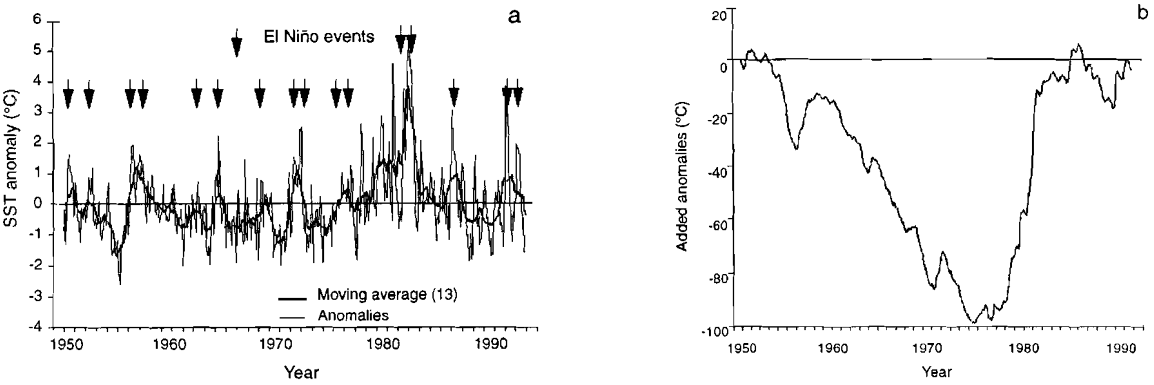

Fig. 4: Monthly mean sea surface temperature at Arica coastal station (1951-93): a) anomalies, and b) added anomalies.

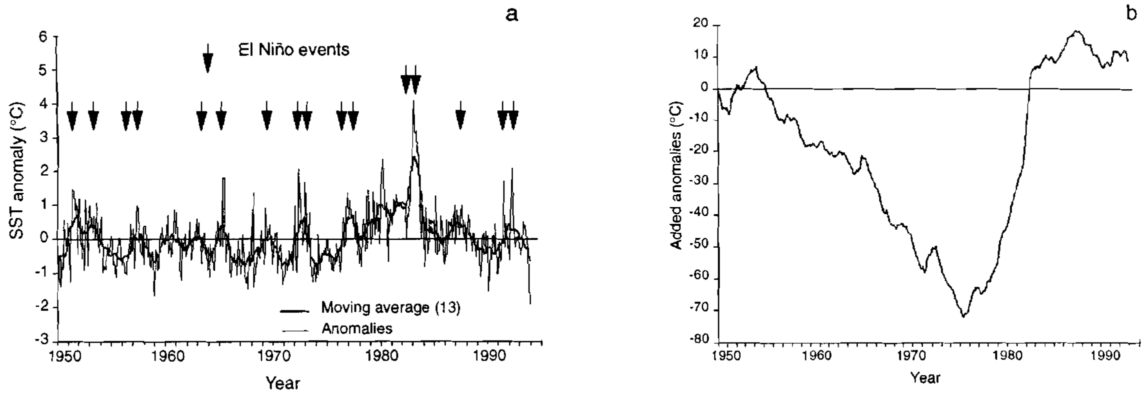

Fig. 5: Monthly mean sea surface temperature at Antofagasta coastal station (1950-93): a) anomalies, and b) added anomalies.

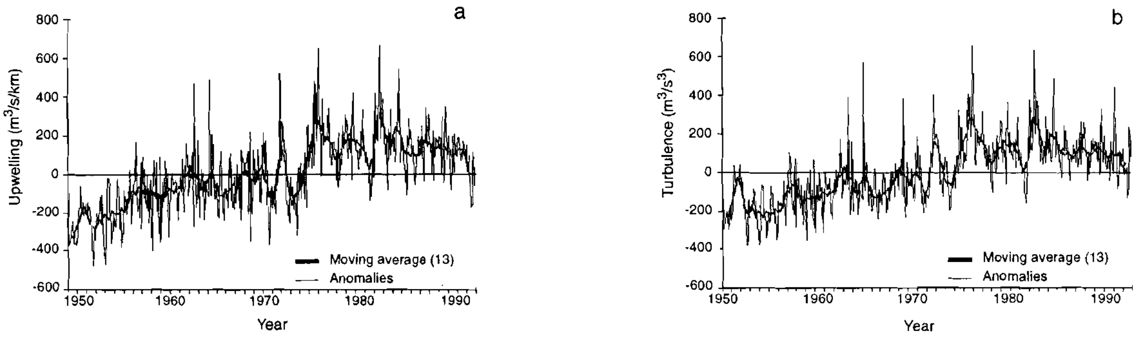

Fig. 6: Monthly mean anomalies at Antofagasta coastal station (1950-93) of: a) upwelling index; b) turbulence index.

deepening of the thermocline; thus, the upwelling would not bring cold waters to the surface, but warm and nutrient-poor waters (Guillén, 1983; Ramage, 1986).

Cañón (1986) indicated that this effect become strongest during the extraordinary strong El Niño event of 1982-83: the subtropical layer of water reached a thickness of 150-200 m, over a large and extensive region.

The seasonal variations of the Pacific convergence zones are influenced by variations in intensity and position of the subtropical anticyclones (Rutllant, 1985). In general, during the Southern Hemisphere winter the Pacific anticyclone is well developed, and the south Pacific convergence reaches its most westerly position, crossing 20°S at 175°W. In summer, it crosses the 20°S at 145°W, and is located to the equator. The interannual variations of the SOI show a behaviour similar to that of the seasonal variation.

It is therefore deduced that the predominance of SOI negative anomalies since 1976 may be associated with a long term eastward displacement of the climatic action centers, in particular areas of pressures. This would explain the increase of winds favourable to upwellings in the north of Chile and in Peru. On the contrary, in the area of Talcahuano (37°S), decrease of SOI is observed after 1975, which may be associated with a period of anticyclonal weakness (Yáñez *et al.*, 1992).

2. PELAGIC FISHERIES AND ENVIRONMENTAL CHANGES

2.1. The anchovy fishery

IMARPE (1970) indicated that the anchovy fishery extends almost along the entire Peruvian coast, and penetrates waters of the northernmost extreme of Chile, without any clear discontinuity to suggest the presence of isolated and independent populations. Thus, for the analysis of the relationships between the catch, the CPUE and the fishing effort (f), a single anchovy population was assumed.

Still, the possibility that several unit stocks existed was not dismissed (Serra, 1983; Pauly and Tsukayama, 1987), including the hypothesis of a great number of local subpopulations (Mathisen, 1989).

In any case, anchovy catches off Peru and in the north of Chile have the same trend (Fig. 1a, b), with fluctuations associated with El Niño events and the environmental changes previously mentioned (Fig. 2 and 6). The largest landing of the northern zone of Chile in the latest years, compared to historical levels, is due to the technological development of the fleet (Caballero *et al.*, 1992). The CPUE estimated here, combining the CPUE of the north of Chile (1957-77) (Yáñez and Barbieri, 1988) and that of Peru (1961-70) (IMARPE, 1972), follows the same trend as the Peruvian anchovy biomass (Fig. 7) estimated by Pauly *et al.* (1987) by means of a length-structured version of VPA, the same method is also used in Mendoza *et al.* (this vol.).

The anchovy catch series used by Yáñez (1991), were here reanalyzed with the CLIMPROD program of Fréon *et al.* (1993). The linear relationship between $CPUE_i$ and the f_i, i.e., contemporary effort (f_i) had a coefficient of determination of $R^2 =$ 79%, increasing to 82% when a weighted fishing effort (fr_i) is recalculated to account for the two age classes which contribute to the catches (Fox, 1975), thus explaining the strong relationship between the decreasing index of abundance and fishing effort which increased from 1957 to 1977.

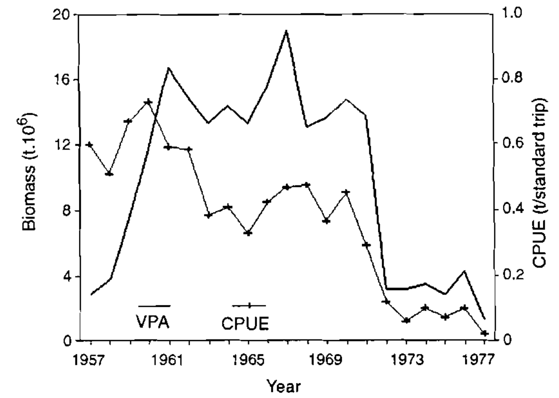

Fig. 7: Anchovy CPUE off southern Peru-northern Chile region, and biomass off northern-Central Peru, estimated by length-structured VPA.

A second explanatory variable was then considered: SST of Arica, in form of the mean of the second semester of year i-1 and the first semester of year i ($SSTA_i$). The fitted model much reduced the differences between the estimated and the observed values (R^2=91%):

$$CPUE_i = 3{,}5727 - 0{,}1609 \,.\, SSTA_i - 1{,}69 \,.\, 10\text{-}8 * fr_i \qquad \text{(see Fig. 8a)}$$

$$C_i = CPUEi \,.\, fr_i \qquad \text{(see Fig. 8b)}$$

This model, similar to the one fitted with $SSTA_i$ data off Peru, does not suffer from multicolinearity problems between the explanatory variables, nor shows trends in its residuals; it was validated by the jackknife method (R^2=87%). The partial correlation coefficients are: -0,95 between the $CPUE_i$ and fr_i; -0,61 between the $CPUE_i$ and $SSTA_i$; and -0,65 between fr_i and $SSTA_i$. The simple linear regression between fr_i and $SSTA_i$ has a R^2=9%.

The anchovy is typically a neritic species (60-80 n. miles off the coast; 50 m depth); it spawns very near the coast, is recruited at 6-9 months and participates significantly in the catches until it reaches 2 years (IMARPE, 1970 and 1972; Serra *et al.*, 1979; Serra, 1983; Santander and Flores, 1983). Bernal *et al.* (1983), and Santander and Flores (1983) showed that anchovy spawning declines during warm years. During warm periods, the upwelling continues but the upwelled waters are warm and low in nutrients, thus resulting in a decreasing abundance of phyto- and zooplankton (Guillén, 1983; Chávez *et al.*, 1989).

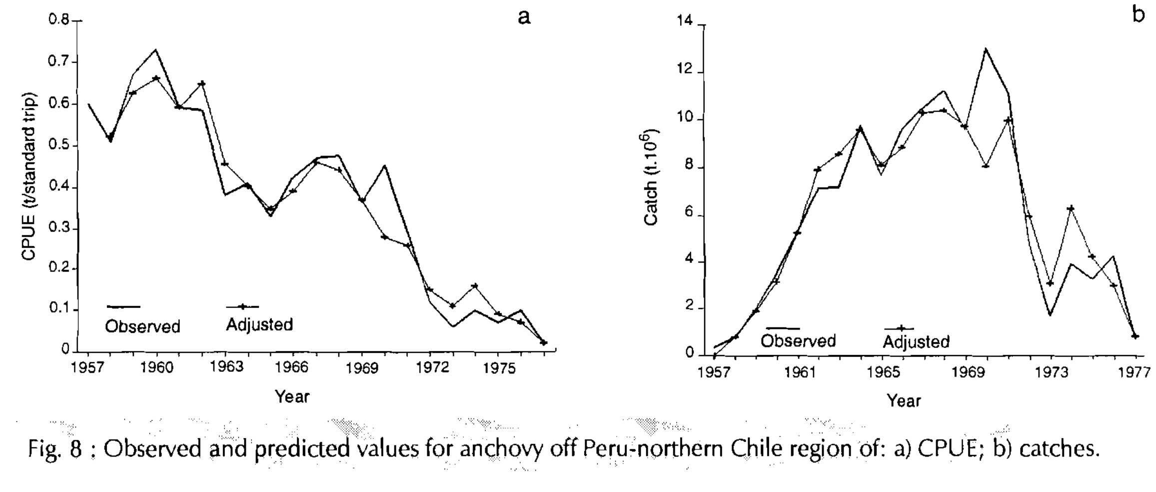

Fig. 8 : Observed and predicted values for anchovy off Peru-northern Chile region of: a) CPUE; b) catches.

Since during El Niño events, the winds that generate the upwelling do not decrease, but intensifies (Romero and Garrido, 1985; Bakun, 1987), the increased turbulence thus generated disperses eggs and larvae, disrupts the spatial distribution of food in patches, and thus affects recruitment (Bakun, 1984). Mendelssohn (1989) showed that a large parental biomass and a moderate level of transport produces the best recruitment. Chavez *et al.* (1989) indicated that, in warm periods, primary production decreases and that changes of plankton composition occur, which affect the survival of anchovy larvae and their recruitment levels. Loeb and Rojas (1988) indicated that starting with the 1972-73 El Niño, there was a succession of years of poor anchovy larval survival off Peru and Chile.

It can therefore be suggested that during the period analyzed (1957-77), the anchovy, while intensively exploited, was also affected by warm periods that modified the production system itselft (Fig. 9). The fitted model considers that the environmental influence impacts the abundance of the resource,notwistanding changes in catchability. Csirke (1989) found that the catchability coefficient (g) is inversely related with the size of the population. He also showed that, after 1972, Peruvian anchovy fluctuations appeared to be constained by a much reduced carrying capacity. Yáñez *et al.* (1994) showed that during warm years, a high degree of concentration of the resource occurs near the coast, also affecting its latitudinal distribution; Santander and Flores (1983) indicated that the same happens to the spawning areas. The long warm period visible since 1976 is thus associated with the increasing abundance of sardines, a predator of anchovy eggs (Santander and Flores, 1983).

It is likely that the noticeable abundance of eggs and larvae observed since 1985 (Loeb and Rojas, 1988; Castillo *et al.*, 1994), as well as the extraordinary increase of catches in recent years (Fig. 1), are related to cooling trend, visible in spite of the El Niño events of 1987 and 1991-92 (Fig. 4 and 5).

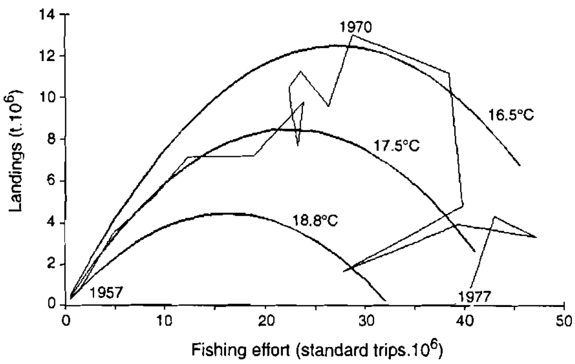

Fig. 9: Relationships between anchovy catches, fishing effort and three levels of SST along the Peru-northern Chile coast.

2.2. The sardine fishery

In the late 1960s the sardine experienced an increase in abundance and expended geographical distribution in the south-east Pacific (Serra and Tsukayama, 1988). This became obvious in the northern zone of Chile after the El Niño event of 1972-73, and even more clearly from 1976 on, (Drago, 1984; Yáñez, 1989; Cubillos and Fuenzalida, 1990).

De Buen (1960) considers that it is the subspecies *Sardinops sagax musica* which inhabits coasts of Chile while *S. sagax sagax* occurs off Peru and around the Galapagos islands. Chirichigno *et al.* (1982) indicated that the latter is limited to the FAO fishing areas 77C (1°39'N and 5°S), 87A (5°-6°S), 87B (6°-18°S) and 87C (18°-37°S); the former occurs only in fishing area 87C (18°-37°S). There is a need to identify with greater precision the distribution limits of both subspecies. There is also the possibility of the existence of two subpopulations, apparent when abundance levels were low. Now, due to their high abundance the two subgroups become mixed over their distribution area (Serra and Tsukayama, 1988).

During the 1964-73 period, the anchovy in Chile had two very well-defined spawning areas, one in the northern zone (18°21'-24°S), the other off Talcahuano (35°-38°S); meanwhile the sardine spawning area was restricted to the first one of these, with a mean density of eggs equal to about 16% of the estimated egg density of anchovy (Serra, 1983; Bernal *et al.*, 1983). Contrary to what happened to the anchovy, during the warm years associated with the El Niño events of 1965, 1969 and 1972-73, sardine showed positive anomalies in its spawning intensity, independently of anchovy's egg abundance (Bernal *et al.*, 1983).

From the standpoint of population dynamics and population genetics, an interesting working hypothesis is to assume that when anchovy dominated the pelagic ecosystem of Chile and Peru, the sardine populations were restricted within two separate refuge zones, one to the north of Chile and the other to the north of Peru, thus effectively limiting genetic drift among the two subpopulations (Bernal *et al.*, 1983).

After the decrease of anchovy (Fig. 7), sardine in Chile increased their area of distribution even establishing a spawning center in the area of Talcahuano (Serra, 1983). This expansion of sardine occurred after the El Niño of 1972-73, reflecting a replacement of the epipelagic dominant filtering fish in the ecosystem (Bernal *et al.*, 1983).

With the El Niño of 1972-73, a large increase in the spawning and larvae distribution of the sardine was observed in Peru, spreading out to the whole coast and concentrating outside 35 n. miles, apparently avoiding the coastal spawning area of the anchovy (Santander and Flores, 1983). From this year until 1982, sardine spawning area expended with until 1979. Moreover, the higher concentrations are getting closer to the coast (10-20 n. miles), close to those of anchovies. Sardine decreased since 1980/82, with slight increases when there is a warming such as that of 1982-83.

Present ichthyoplankton abundance levels of pelagic species in the north of Chile, confirms the persistence of the change in the specific composition detected since 1985, characterized by the strong dominance of the anchovy over the sardine and jack mackerel (Castillo *et al.*, 1994).

In the northern zone of Chile the increase of sardine abundance until 1980-82 (Serra, 1991), and of its catches until 1985 (Fig. 1b), are associated with a long term warm trend (Fig. 4 and 5). This trend period should have favoured the increase of spawning intensity and recruitment levels produced three years later, thus yielding a Ricker (1954) type stock-recruitment relationship and a dome-shaped relationship between recruitment and SST (Yáñez, 1989). An increment of the abundance of 5-8 year old individuals would have then been produced, which are most represented in the catches of the expansion phase of the fisheries (Serra and Tsukayama, 1988; Martinez *et al.*, 1986).

It is also likely that, up to a certain limit, fishing activity would have not affected the growth of stock abundance, due to exploitation rate remaining below the natural rate of increase of the resource (Yáñez, 1991). However, sardine abundances tend to diminish after the El Niño of 1982-83 (Fig. 10), when the environment begins to show a cooling trend (Fig. 4 and 5).

The sardine fishery of the north of Chile for the years was analyzed using the CLIMPROD program. The following variables were considered: annual catches (C_i; t) (Fig. 1b), annual fishing effort (f_i) estimated as standard trips with catch (vcpst) (Yáñez, 1991; Yáñez *et al.*, 1993), and annual mean SST, recorded at the tidal gauge station of Antofagasta (SST_i).

The calculated $CPUE_i$ (t/vcpst), follows almost the same trend as the sardine stock biomass (B_i 3+) estimated by Barría and Serra (1993) by means of VPA (Fig. 10; R^2=91%). A weighted fishing effort (fr_i) was recalculated by considering the significant participation of the 3-4 years classes in the catches. The close relationship between $CPUE_i$ and $SSTP_i$ ((R^2=80%) is established, viz. $CPUE_i = - 5469 + 598\ SSTP_i - 16.22\ (SSTP_i)^2$, where $SSTP_i$ is the mean SST from spawning to recruitment at 3-4 years of age.

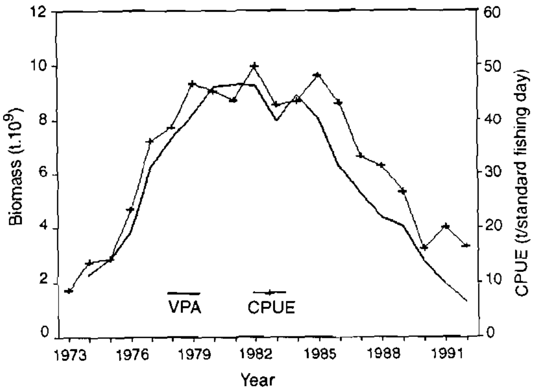

Fig.10: Sardine CPUE and biomass (estimated by VPA) off northern Chile.

By additionally considering the weighted effort (fr_i), the following quadratic lineal model is adjusted (R^2=92%):

$$CPUE_i = - 5282 + 570\ SSTP_i - 15.15\ (SSTP_i)^2 - 8.03 \cdot 10^{-4}\ fr_i \qquad \text{(see Fig. 11a)}$$

$$C_i = CPUE_i \cdot fr_i \qquad \text{(see Fig. 11b)}$$

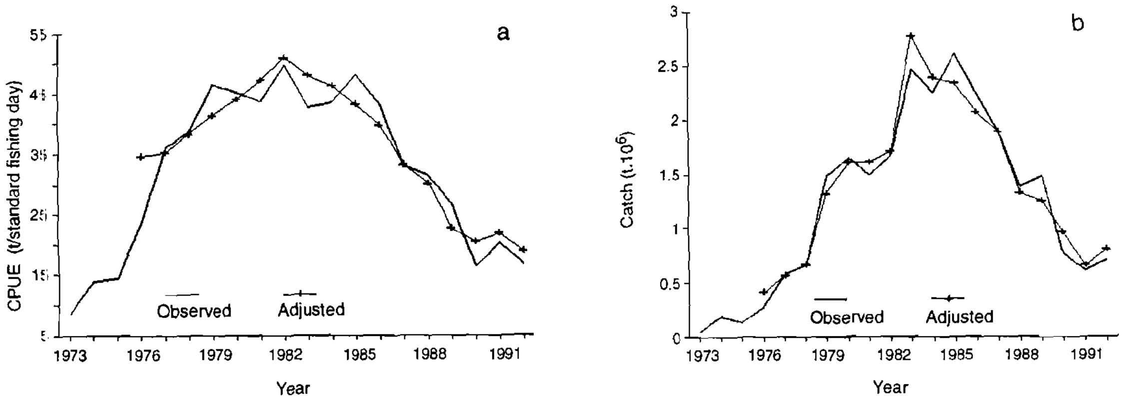

Fig 11: Observed and predicted values for sardine off northern Chile: a) CPUE; b) catch.

It can be thus deduced that environmental changes modify conditions for surplus production by the sardine stock off northern Chile (Fig. 12). Warm conditions would be favourable (as long as they are not as extreme as those observed during the El Niño event of 1982-83), while cold conditions would be unfavourable.

From 1974 to 1983, the 5+ year groups represented on the average 89% of the annual catch (Serra and Tsukayama, 1988). Since 1985, a sustained decrease of the older age groups begins, while individuals of 7 years or more disappeared; at the same time a strong increase in the catches of 2 and 3 year old individuals was observed (Martínez *et al.*, 1993). Thus, the mean age at first capture now roughly corresponds to the first maturity, of 4.2 years (Martínez *et al.*, 1986; Yáñez, 1989).

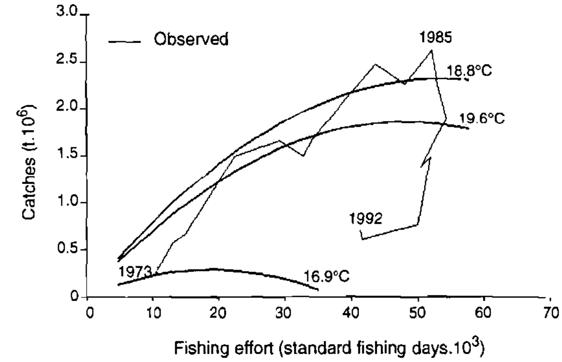

Fig. 12: Relationships between catches, fishing effort and three values of sea surface temperature for sardine off northern Chile.

The parental stock increase led to a density-dependent relationship such as in Ricker (1954). Surprisingly after the successful recruitment of 1984, associated with the maximum parental biomass observed in 1981, recruitment linearly diminishes with the adult stock (Fig. 13). This decrease coincides with the occurrence of the strong El Niño event of 1982-83 and the sub sequent cooling trend of the environment (Fig. 4 and 5). This implies a temperature-dependent relationship, which can be seen observed by relating recruitment to mean SST of years i, i-1 and i-2 (Fig. 14). In this case, the environment affects natural mortality and individual growth during the previous period to recruitment (Fréon, 1988).

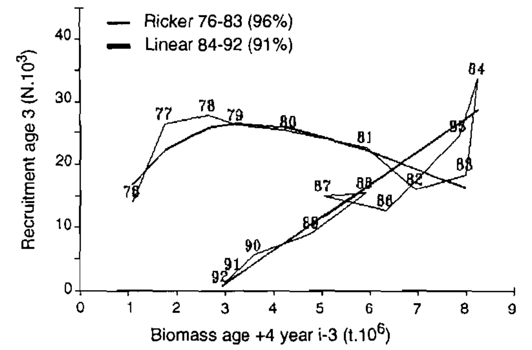

Fig. 13: Stock-recruitment relationships for sardine off northern Chile (%= variance explained by plot).

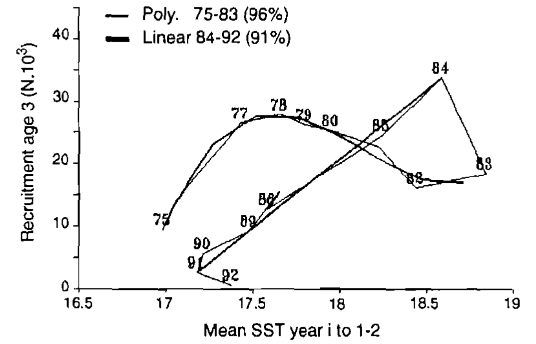

Fig. 14: SST-recruitment relationships for sardine off northern Chile (%= variance explained by plot).

Changes of the thermal structure as observed with the NOAA satellites also affect the sardine distribution in the north of Chile (Yáñez *et al.*, 1993 and 1994). The sardine concentrated near the coast during the warm periods, as happened in 1987-92. During periods such as the 1988-91, with cooler characteristics, sardine spread out in the zone, even over the 200 n. miles off the coast, particularly between 18°-19°S.

CONCLUSION

Anchovy was intensively exploited during the period 1957-77, and also affected by El Niño events, which diminishes its competitor's abundance and catches. Thereafter the fishery did not recover due to a long term warm period and to the increase of predator species such as the jack mackerel, horse-mackerel and of sardine.

In effect, with a very reduced abundance of anchovy during a significant period of time (1973-85) and favoured by the environmental change observed from the mid 1970s, sardine increased its distribution and abundance, becoming the dominant species in the system. At the same time an intensive exploitation developed which, together with the strong El Niño of 1982-83 and the cooling trend observed later, induced a decrease of sardine abundance. This led to the collapse of the fishery in northern Chile, which decreased from 2.6 million t in 1985 to 0.2 million t in 1994.

Nevertheless, after 1985, anchovy catches increased noticeably, well beyond the historical levels in Chile (1 million t in 1966; 2.7 million t in 1994) (SERNAP, 1994), and approaching such levels in Peru (12 million t in 1970; 10 million t in 1994) (IMARPE, 1994).

For both fisheries, models were fitted considering fishing effort and an environmental variable (SST) as affecting the abundance of these resources. In the case of anchovy, SST appears as additional variable in the adjusted model while for sardine it is a key parameter. However the fits indicated that environmental variations modified the production models of both species (Fig. 9 and 12). Anchovy favours cooler environmental conditions, while the sardine prefer warmer conditions.

Contrary to conventional models, these models generate different MSY level for different environmental settings (Fig. 15).

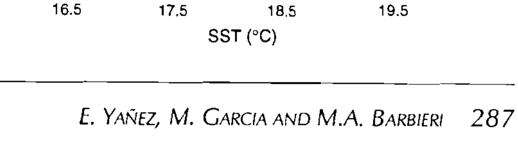

Fig. 15: MSY as a function of SST for anchovy in Peru and northern Chile, and for sardine in northern Chile.

In spite of their limitations, applications of this type allows a better understanding, and sometimes forecast of the fisheries trends (Fréon and Yáñez, 1995). According to Csirke (1984), fisheries management should be prescriptive and preventive instead of being only reactive. Models including parameters such as SST — whose changes can be predicted — may thus help for fisheries management.

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