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WORLD-WIDE FLUCTUATIONS OF SARDINE AND ANCHOVY STOCKS: THE REGIME PROBLEM

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Summed differences between the highest and lowest catches of two clupeoid taxa, sardines *Sardinops* spp. and *Sardina pilchardus* and anchovies *Engraulis* spp., in five regions where they co-occur are in excess of 29 million tons. Both taxa show large expansions and contractions of range with changes in abundance. Populations of sardines also shift alongshore, possibly in response to climate change. At time-scales of several decades, fluctuations in catches of sardines and anchovies are seemingly dominated by long-term environmental variations which cause large and prolonged changes in abundance and give rise to "regimes" of sardine or anchovy. These long-term fluctuations are probably associated with persistent environmental changes of oceanic to global scale, there being coherence of trends in various sardine stocks on an oceanic scale and similarities between these changes and global, hemispheric and oceanic indices of the environment.

Gesommeerde verskille tussen die hoogste en laagste vangs van twee klupeoïede taxa, sardyne *Sardinops* spp. en *Sardina pilchardus* en ansjovisse *Engraulis* spp., in vyf streke waar hul saam voorkom, oorskry 29 miljoen ton. Albei taxa vertoon groot uitbreidings en inkrimpings van verspreidingsgebied gepaardgaande met wisselings in talrykheid. Sardynbevolkings verskuif ook kuslangs, moontlik in reaksie op klimaatverandering. Op 'n tydskaal van etlike dekades word die skommelings van die sardyn- en ansjovisvangs blykbaar oorheers deur langtermynse omgewingsvariasies wat groot en langdurige veranderings in talrykheid veroorsaak en aanleiding gee tot "regimes" van sardyn of ansjovis. Hierdie langtermynse skommelinge hou waarskynlik verband met volgehoue omgewingsveranderings op 'n oseaan- tot wêreldskaal, want daar is samehang in die tendensies van verskeie sardynstapels op 'n oseaanskaal en ooreenkomste tussen hierdie veranderings en wêreld-, halfrond- en oseaan-indekse van die omgewing.

Varying catches of clupeoids contribute a disproportionate share of the total variability of the world harvest of fish. Two of the most important clupeoid groups commercially caught are sardines (*Sardinops* spp. and *Sardina pilchardus*) and anchovies (*Engraulis* spp.), which tend, in certain areas, notably those where tropical and subpolar currents mix, to coexist (Parrish *et al.* 1983, Kondô 1988). They share the important distinction of being able to digest carbohydrates, and are therefore able to feed on both phyto- and zooplankton (e.g. King and Macleod 1976, Kawasaki and Omori 1988) and to achieve high levels of abundance. The two taxa tend not to spawn in areas of intense offshore transport, where reproductive products may be lost from the shelf area, or in areas of strong turbulent mixing of the upper water column, where food patches may be disrupted (Parrish *et al.* op. cit.).

Intensive fisheries on sardines and anchovies are conducted in five regions of the world: the western (Japan system) and eastern (California Current) boundary areas of the North Pacific, the eastern boundary (Humboldt Current) of the South Pacific, and both the northern (Canary Current) and southern (Benguela system) boundaries of the eastern Atlantic. Both also co-occur off Australia (Blackburn 1967), but because they are generally not harvested there and data are consequently sparse, the Australian populations are not considered in this paper.

Maximum and minimum landings of sardines and anchovies in each of the five regions of intensive fishing until 1986 are listed in Table I. The pooled variation in catches of the two taxa amounts to more than 29 million metric tons, a figure which should be contrasted with the world harvest of about 80 million tons of marine fish in 1986 (F.A.O. 1988). Fortunately, the maxima and minima for the two taxa are not in phase, so fluctuations in the world harvest are damped.

The various populations of sardines and anchovies

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Table I: Variability of sardine and anchovy catches for the main fishery areas until 1986. The difference is obtained by subtracting the lowest catches from the highest catches in the historical record

Current/System	Maximum ('000 tons)	Minimum ('000 tons)	Difference ('000 tons)
Sardine			
Japan	5 191	9	5 182
California	719	12	707
Humboldt	5 814	0	5 814
Canary	1 096	3	1 093
Benguela	1 508	62	1 446
Anchovy			
Japan	474	28	446
California	424	0	424
Humboldt	13 060	59	13 001
Canary	836	0	836
Benguela	612	93	519

share many attributes, from their biology to the manner in which they are exploited and by which catches from them are utilized (e.g. Glantz 1983, Parrish *et al.* 1983, Crawford 1987, Silvert and Crawford 1988). Of particular interest, in view of their impact on the world fish harvest and on national economies, are the prolonged "regimes" of high or low abundance of the species (e.g. Glantz op. cit.). These regimes are of great importance to decision-making, especially that related to issues having implications over decades. In this paper, information on the regimes is synthesized and some factors that may influence their occurrence is discussed. Emphasis is placed on long-term population changes of sardines that have been observed worldwide.

CHANGES IN RANGE AND ABUNDANCE

Both sardines and anchovies have exhibited large expansions and contractions of range concomitant with changes in abundance. This statement is illustrated for the sardine in each of the five regions considered, taking the geographical extent of catches or information derived from spawning surveys or both to approximate the range, and the catches themselves as an index of abundance. Although catch alone is acknowledged to be a crude measure of abundance, direct surveys have only recently started in most systems, so there are no comparative indices for periods of high and low abundance from this method. Off South Africa, for example, estimates of population size from direct surveys are only available from 1983 onwards (Hampton 1987). Nevertheless, the changes in catches have been so marked (Table I) that there can be little doubt that they reflect real changes in population size (e.g. Chikuni 1985).

The Japan system

In the Japanese fishery, catches of sardine during periods of low abundance have been restricted to the south-eastern coasts of Kyushu, Shikoku and Honshu, and spawning to even smaller areas (Fig. 1a). During periods of high abundance, catches have been made around most of Japan, as well as off Korea, the maritime provinces of Siberia, and Sakhalin Island, and spawning has extended well into the Sea of Japan (Fig. 1b).

Sardine catches peaked around 1935, when landings exceeded 1,5 million tons. From the 1940s, however, catches decreased rapidly, and only 9 000 tons were caught in 1965 (Fig. 1c). Of note is the fact that the catch decreased during World War II, primarily because boats were requisitioned for military purposes. When the fleet was rebuilt after the war, catches remained low until the mid 1970s. There is general agreement that an unfavourable environment, rather than excessive exploitation, was the main cause of the decline (e.g. Hayasi 1983, Chikuni 1985, Kawasaki and Omori 1988). Catches increased rapidly again after 1975 and, in less than a decade, annual landings attained unprecedented levels of over five million tons (Fig. 1c). This recent proliferation of the sardine resource has taken place in spite of intense exploitation, and it has been attributed to a favourable environment (Kondo 1980, Kondô 1988, Kawasaki 1983, Kawasaki and Omori op. cit.).

Catches of the Japanese anchovy attained maximum levels of more than 400 000 tons in the 1960s and early 1970s. Thereafter, they decreased gradually while sardine catches were increasing rapidly (Fig. 1c, Hayasi 1967, 1983).

The California Current

Sardine formed the bulk of the purse-seine catch in the California Current from the mid 1930s to the mid 1940s. During this period of high abundance, catches were made along a large portion of the North American west coast, from British Columbia to southern Baja California (Fig. 2b). In the late 1970s, a period of lesser abundance, catches were confined mostly to the west coast of Baja California and the Gulf of California (Fig. 2a, Molina *et al.* 1987, Centro Interdisciplinario de Ciencias Marinas

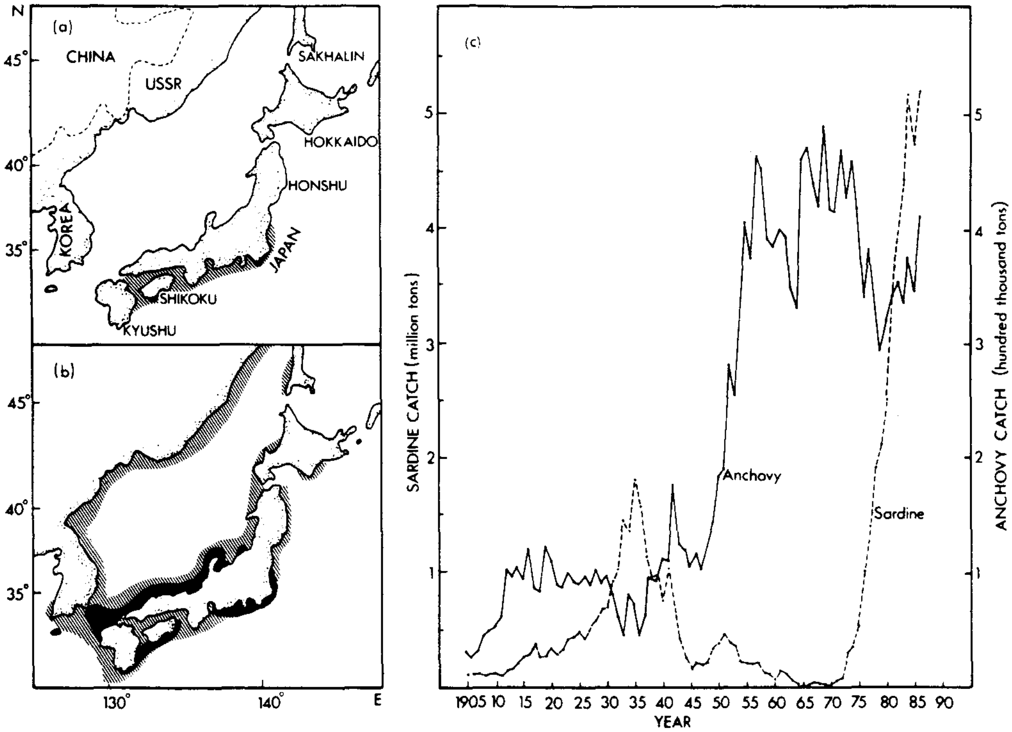

Fig. 1: Information pertaining to the Japanese sardine fishery (updated from Nakai 1959, Kawasaki and Omori 1988, and using information in Chikuni 1985, F.A.O. 1988) — fishing (hatched) and spawning (black) grounds during periods of (a) low and (b) high abundance, and (c) trends in the annual catches of sardine (dashed line) and anchovy (solid line)

[CICIMAR] unpublished data).

Sardine catches in the California Current peaked at over 700 000 tons in 1936, but they decreased rapidly between the mid 1940s and the early 1950s (Fig. 2c). Except for a small resurgence in 1958, they remained low until the mid 1970s, when catches off Baja California began to increase. From 1965 through 1985, the annual sardine catch off the United States state of California was <1 000 tons, and this was mostly a by-catch in the hauls of other species. In 1975 it was only 3 tons. Between 1966 and 1985 there was a moratorium on directed fishing for sardine off California (Troadec *et al.* 1980), but it was lifted in 1986 because estimates of biomass off California then exceeded the minimum (20 000 tons) above which fishing could again be allowed (Radovich 1982, Grant 1987). That year the total catch of sardines in the Gulf of California approached 300 000.

The decline of the Californian sardine, initiated in the 1940s, was evident first in the north and only later in the south. Ultimately, no sardine fisheries remained except off south-western Baja California and in the Gulf of California, the southern and near-tropical limits of the resource's distribution (Ramirez-Granados 1958, Radovich 1982, Pedrin-O. and Ancheita-Avalos 1976, Molina *et al.* 1987). In this southern region, sardine catches increased after 1975 (Molina *et al.* op. cit., CICIMAR unpublished data).

Anchovy catches off California and Baja California peaked between the mid 1970s and the early 1980s, over 340 000 tons being taken in 1981 (Fig. 2c). They then decreased substantially to slightly over 100 000 tons in the mid 1980s (Grant 1987, Cota-V. 1986, García-F. *et al.* 1986).

The Humboldt Current

Between 1963 and 1972, a period of low abundance of sardine in the Humboldt Current, the species

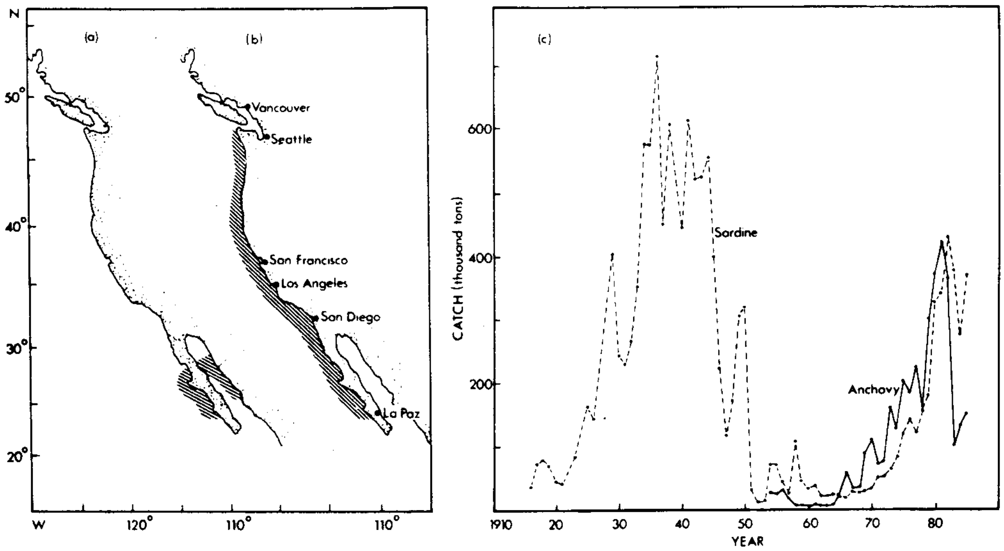

Fig. 2: Information pertaining to the sardine fishery of the California Current (catch data from Anon. 1961, Aasen 1967, Messersmith 1965, F.A.O. 1959–1984, F.A.O. 1988) — distribution during periods of (a) low and (b) high abundance, and (c) trends in annual catches of sardine (dashed line) and anchovy (solid line)

spawned off Chile only north of 27°S (Fig. 3a). Nine years later, when the population had grown considerably, substantial spawning was recorded in the Talcahuano region as far south as 40°S (Fig. 3b). Serra (1983) noted that no sardine were sampled in catches offloaded at Talcahuano in the late 1960s, and that several authors had indicated that the sardine's range did not extend south of Coquimbo (30°S) during the late 1950s and early 1960s. Off Peru, at the northern limit of the species' range, sardine were found as far north as 5°S in 1972, although at low density. A decade later, they extended to at least 3°S (the northern boundary of Peru), and considerable concentrations were to be found along the entire Peruvian coast (Zuta *et al.* 1983). In the mid 1960s, there was little spawning by sardines off Peru but, by the late 1970s and early 1980s, it was much heavier (Santander and De Castillo 1977, Muck *et al.* 1987).

The anchovy fishery off the west coast of South America started in the 1950s. It grew rapidly and catches peaked at more than 13 million tons in 1970, but it then declined even faster (Fig. 3c). In terms of yield, the decline was the most drastic in any fishery known to date (Yáñez-R. 1983, Zuta *et al.* 1983).

Sardine catches were low when the anchovy was abundant, but almost six million tons were taken in 1985 (F.A.O. 1988), the highest yield achieved to date by any of the world's sardine fisheries. It is clear also that sardine catches increased rapidly after the collapse of the anchovy resource.

The Canary Current

Off Morocco, sardines have been intensively exploited, but anchovy catches have been comparatively small. Both species have been fished extensively off the coasts of western and southern Europe. The near equatorial limits of sardines in the Canary Current are off Senegal, but extensions into the subarctic area include most of the region off western Europe (Garcia 1982, Belvèze and Erzini 1983, Riedel 1959, F.A.O. 1959–1984). In the English Channel near Plymouth, sardine eggs were abundant from the mid 1930s until about 1970, but not for periods of some 15 years on either side of this (Cushing 1982, Southward and Boalch 1988). Along the African coast, there was a considerable southward expansion of the sardine's range between 1966 and the mid 1970s, from Morocco to Senegal (Garcia op. cit.), with a subsequent retreat to the north (Gulland and Garcia 1984, Crawford and Shannon 1988, Fig. 4a, b). The expansion and contraction of the southern

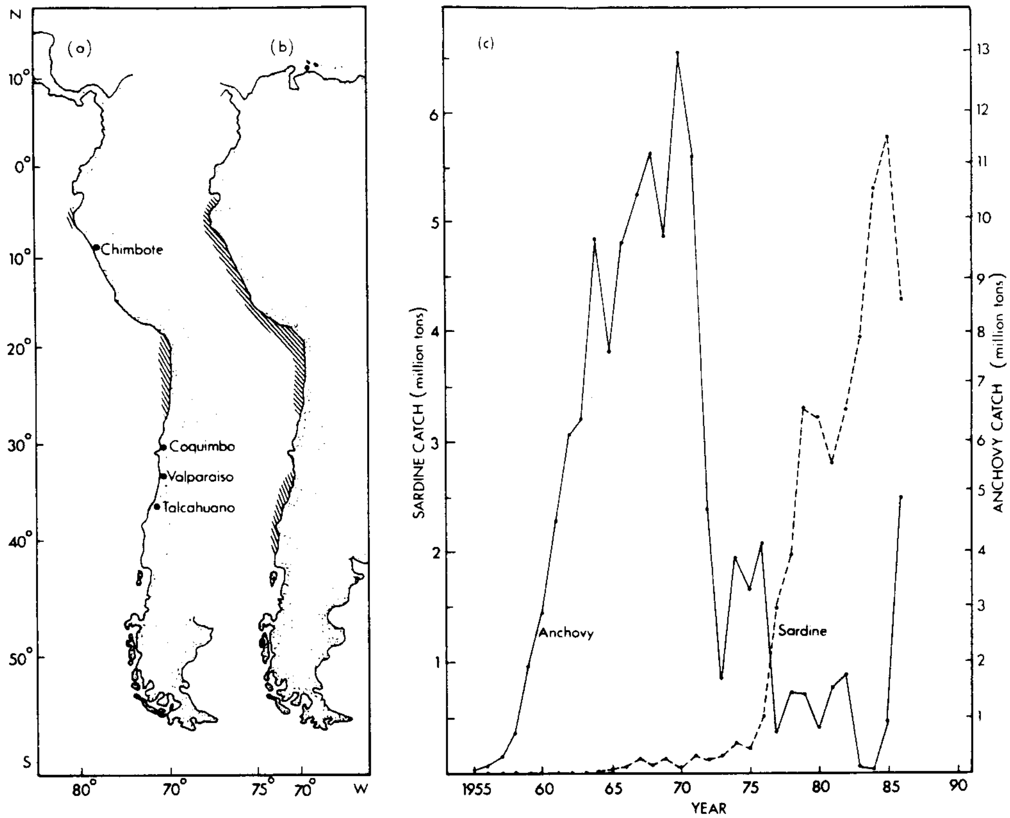

Fig. 3: Information pertaining to the sardine fishery of the Humboldt Current — spawning grounds during periods of (a) low and (b) high abundance (from information in Serra 1983, Santander and De Castillo 1977), and (c) trends in annual catches of sardine (dashed line) and anchovy (solid line)

limits corresponded with an estimated increase and decrease in the abundance of sardine there (Belvèze and Erzini op. cit.). The southward expansion also coincided with intensification of upwelling off Mauritania and Senegal (Binet 1988).

Catches of sardine in the Canary Current remained at moderate levels until the mid 1960s. They then climbed rapidly as the species extended its range southwards, and subsequently decreased with the species' retreat to the north (Fig. 4c).

The Benguela system

Purse-seiners exploit sardine (where it is locally known as pilchard) and anchovy in the Benguela system off both Namibia and South Africa. The results of tagging surveys and other information have indicated that relatively discrete stocks of both species exist north and south of an area of intense upwelling near Lüderitz, where the water is turbulent and cold (Crawford *et al.* 1988). During periods of reduced abundance, spawning has been restricted to the northern and south-eastern areas, but in years when the sardine has been plentiful, intensive spawning has also taken place nearer the centre of the system (Fig. 5a, b). Further, in years of apparently high biomass, catches have ranged considerably farther north off South Africa and south off Namibia than when biomass has been low (Crawford *et al.* 1987).

Purse-seine fisheries for sardine were initiated after World War II, and catches increased until 1968 (Armstrong and Thomas 1989). They then collapsed, stocks being at a very low level in the 1980s (Fig. 5c). Anchovy were not exploited before the mid 1960s,

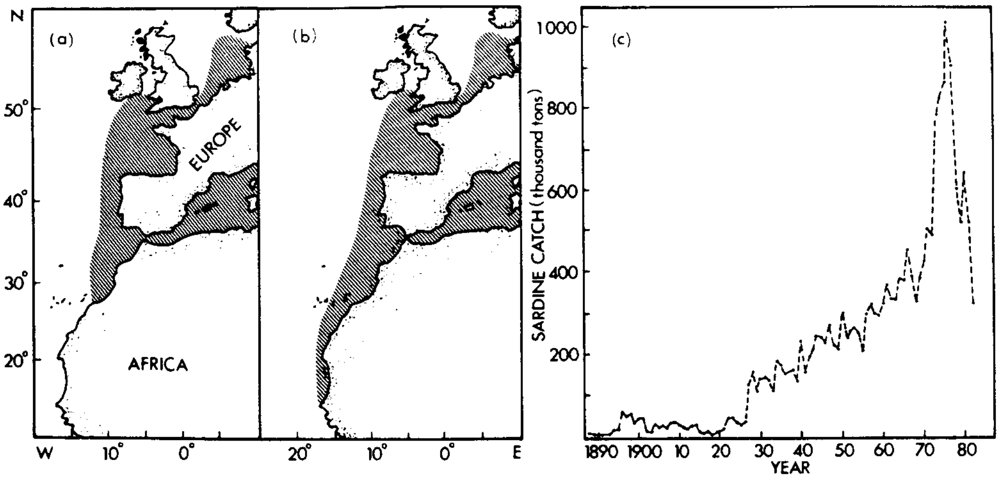

Fig. 4: Information pertaining to the sardine fishery of the Canary Current — distribution during periods of (a) low and (b) high abundance (from information in Garcia 1982), and (c) trends in annual catches of sardine

when small-meshed purse-seines were first permitted in the fishery. Thereafter, catches of anchovy increased concomitant with the decrease in sardine catches (Crawford *et al.* 1983, 1987).

DISCUSSION

Approximately parallel trends in sardine abun-

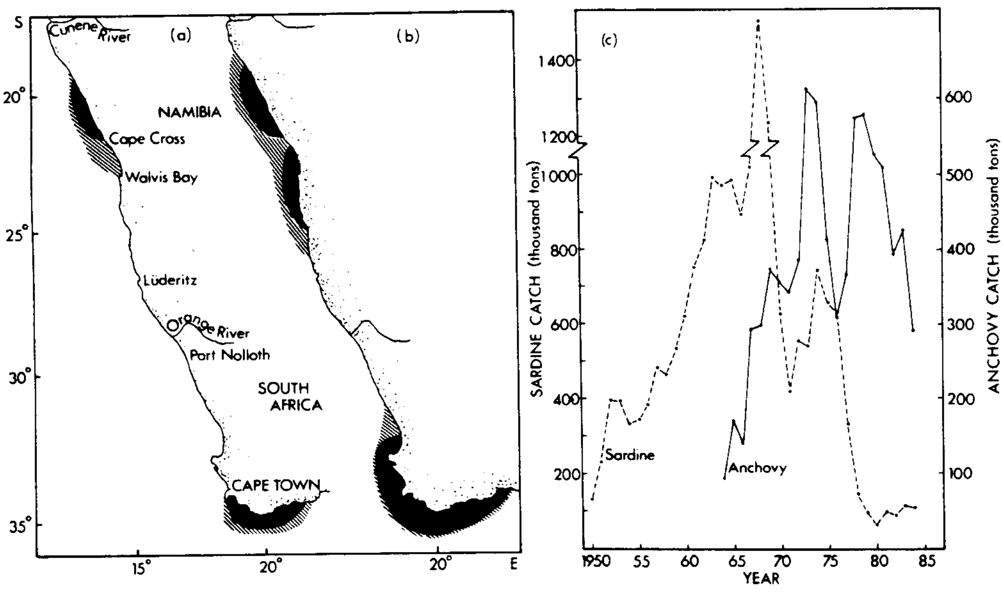

Fig. 5: Information pertaining to the sardine fishery of the Benguela system (based on information in Crawford *et al.* 1987) — major fishing (hatched) and spawning (black) grounds during periods of (a) low and (b) high abundance, and (c) trends in annual catches of sardine (dashed line) and anchovy (solid line)

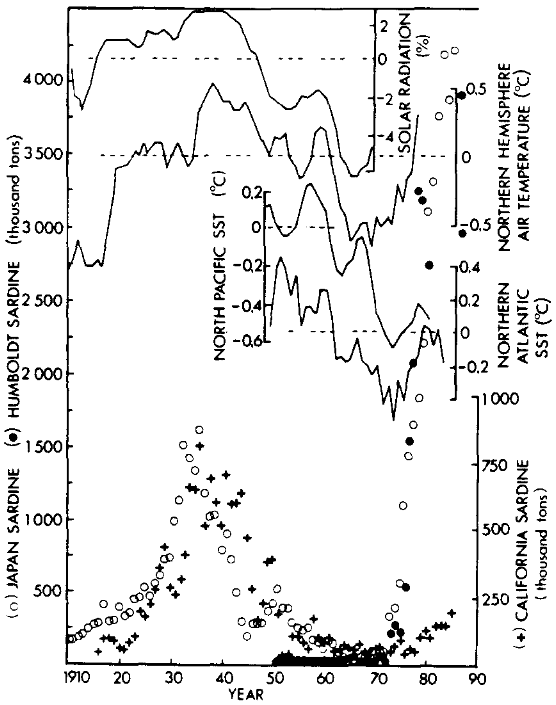

Fig. 6: Trends in anomalies of direct solar radiation (Miles 1978), air temperature for the northern hemisphere (from information in Raper *et al.* [1983] smoothed by five-year running means) and sea surface temperature for the North Pacific and North Atlantic (by courtesy D. Cayan, Scripps Institution of Oceanography, pers. comm.) compared with catches of sardine in the Japan (open circles), California (crosses) and Humboldt (dots) systems (updated from Kawasaki and Omori 1988)

dance in the Pacific Ocean have been documented by several authors (Kawasaki 1983, Kawasaki and Omori 1988). Catches off Japan and in the California Current were large in the 1930s and early 1940s, and then small until they began increasing again in both regions during the 1970s. Catches of sardine in the Humboldt Current were small until 1975, after which they also increased spectacularly. There was no fishing for sardine off Peru and Chile in the 1930s and 1940s, but in the early 1940s, the range of the sardine off Chile extended almost as far south as during the present period of high abundance (Serra 1983). It is therefore quite likely that sardine was also abundant in the Humboldt Current in the early 1940s.

Catches of sardines in the three regions of the Pacific are shown in Figure 6 together with indices of direct solar radiation (Miles 1978), air temperature for the northern hemisphere (Raper *et al.* 1983) and sea surface temperature for the North Pacific and North Atlantic (D. Cayan, Scripps Institution of Oceanography, pers. comm.). There is some similarity between the various time-series, maxima and minima occurring during the same general periods. Maxima are evident during the 1930s and 1940s and minima during the 1960s or early 1970s. Since then, each series has shown an upward trend. This approximate similarity is in spite of limitations inherent in the environmental data series. Insolation reaching the surface is influenced by cloud-cover and varies considerably from region to region, thereby complicating computation of a global mean and anomaly. Trends in air and sea surface temperature over large regions are also difficult to determine because the distribution of data is uneven.

Sardine abundance in the Atlantic Ocean is not in phase with that in the Pacific, and there is no apparent relationship between catches from the Canary Current as a whole and the mean sea surface temperature anomaly of the North Atlantic. However, near the United Kingdom, at the cool northern extremity of the sardine's range, there is some similarity between trends in catches and in sea surface temperature (Fig. 7). The period when sardine eggs were abundant in the English Channel coincided with above average sea temperatures there (Southward and Boalch 1988).

Sardines in each of the regions considered have shown a remarkable propensity to extend their range during periods of high abundance. In some of the regions, this has also held true for anchovy (e.g. MacCall 1984). Anchovy populations have tended to expand and contract about a fixed geographic centre (e.g. Fig. 8a, b), whereas sardines have tended to shift their geographic centre as well (e.g. Fig. 2a, b), often alongshore in response to climatic change.

The ranges of the sardine populations in the four eastern boundary currents have extended into cooler regions during warm periods. The Benguela system is unusual as an eastern boundary upwelling system in that it is bounded at both northern and south-eastern extremities by relatively warm water (Shannon 1985). Therefore, expansion into cooler regions has implied colonization of areas near the centre of the system. In the Humboldt, Canary and California currents as well as off Japan, range extensions into cooler regions have been polewards. In addition to its periodic colonization of cooler waters, the sardine of the Canary Current has expanded into a warmer southern area. There has also been an equatorward extension of the sardine's range in the South-East Pacific.

Sardines are more migratory than anchovies, and in some areas become increasingly so with age (see Murphy 1966). During periods of increasing abundance, sardines often expand their spawning areas

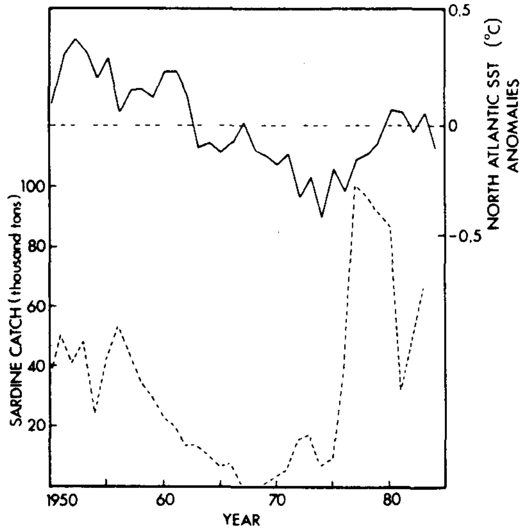

Fig. 7: An index of sea surface temperature anomaly for the North Atlantic (by courtesy D. Cayan, Scripps Institution of Oceanography, pers. comm.) compared with sardine catches off England

upstream (e.g. Fig. 3a, b), thereby facilitating the advection of larvae to productive areas. El Niño events in the South-East Pacific and Benguela Niños in the South-East Atlantic may result in large, but temporary, shifts in the distribution of sardines, and they may therefore play an important role in the recolonization of upstream areas. As well as expanding their spawning range, sardines also extend their feeding range towards areas of high food productivity, whether upstream or downstream.

When their abundance is low, sardines contract into a few relatively fixed locations, and migratory behaviour is greatly reduced, though this may be caused partly by a shortened lifespan resulting from increased rates of mortality (e.g. Crawford 1981). In effect, at low levels of abundance, the geographic strategy of sardines becomes similar to that of anchovies.

It seems, therefore, that one consequence of intensively harvesting expanding or declining sardine stocks would be to reduce the lifespan and often, as a result, the migration range. A formerly self-perpetuating stock may well then collapse, thus prematurely shifting the population into a low-abundance mode.

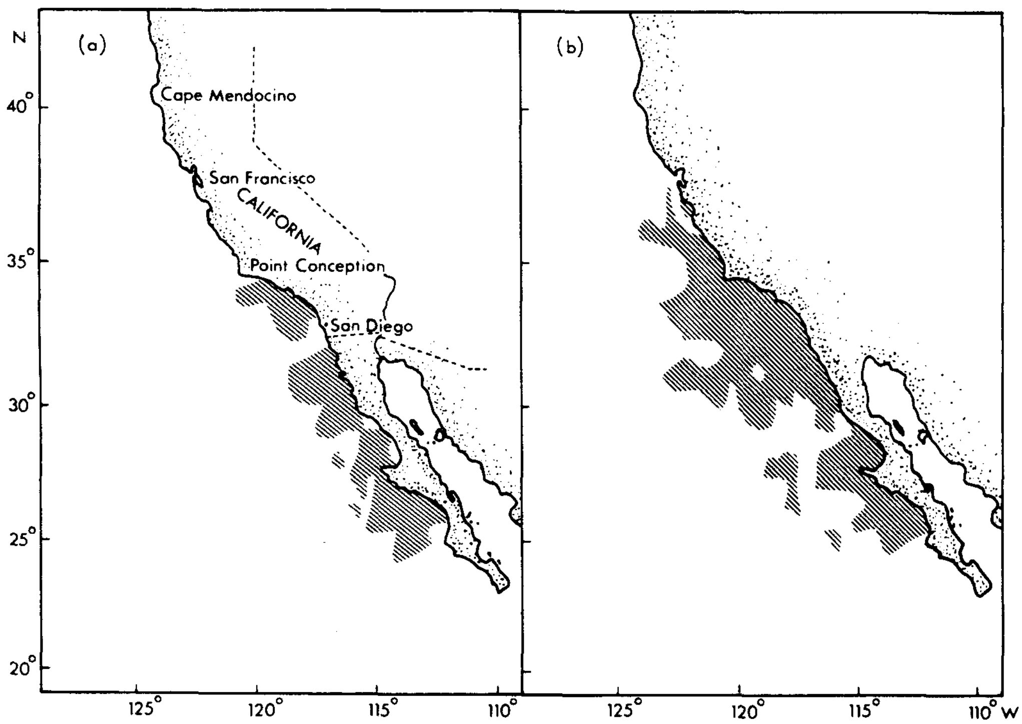

Fig. 8: Geographic distribution of anchovy larvae during periods of (a) low and (b) high abundance (after MacCall 1984)

This type of collapse has been experienced off both California and southern Africa (Murphy 1966, Crawford 1981). The Japanese sardine may be somewhat more resistant to overfishing, because advection of larvae and juveniles ensures that younger fish also participate in the geographic expansion of the species (e.g. Kondô 1988).

Short-term variability of sardine and anchovy populations, on time-scales of a few years, is undoubtedly influenced by environmental fluctuations (e.g. Shannon *et al.* 1988), and such variability tends to be amplified by exploitation. Fishery management can reduce fluctuations at intermediate time-scales by balancing harvests against stock productivity. However, longer-term fluctuations of sardine and anchovy resources seemingly again become unavoidably dominated by environmental variations which can cause large and prolonged changes in average stock productivity, giving rise to persistent regimes of high or low abundance of the species.

The mechanisms which initiate, sustain, and terminate outbursts of sardine or anchovy populations are not yet clear. If populations in widely separated areas are linked, as suggested by the coherence in trends of various sardine stocks on an oceanic scale (Fig. 6), the mechanisms must operate over similarly large spatial scales.

Long-term decisions, such as those pertaining to the scheduling of fleet replacement or the construction of processing plants, would be greatly facilitated by improved knowledge of the mechanisms underlying long-term fluctuations in sardine and anchovy populations or of the circumstances in which they occur. As short-term management of these populations is increasingly being based on measurement rather than prediction (e.g. Hampton 1987), a move away from the traditional "recruitment problem" to address the "regime problem" may prove to be a useful change in emphasis. As analysis of the regime problem would take less cognizance of ephemeral life stages and environments and more of long-term and large-scale averages and processes, it could well be more accessible to investigation than an analysis of the recruitment problem.

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