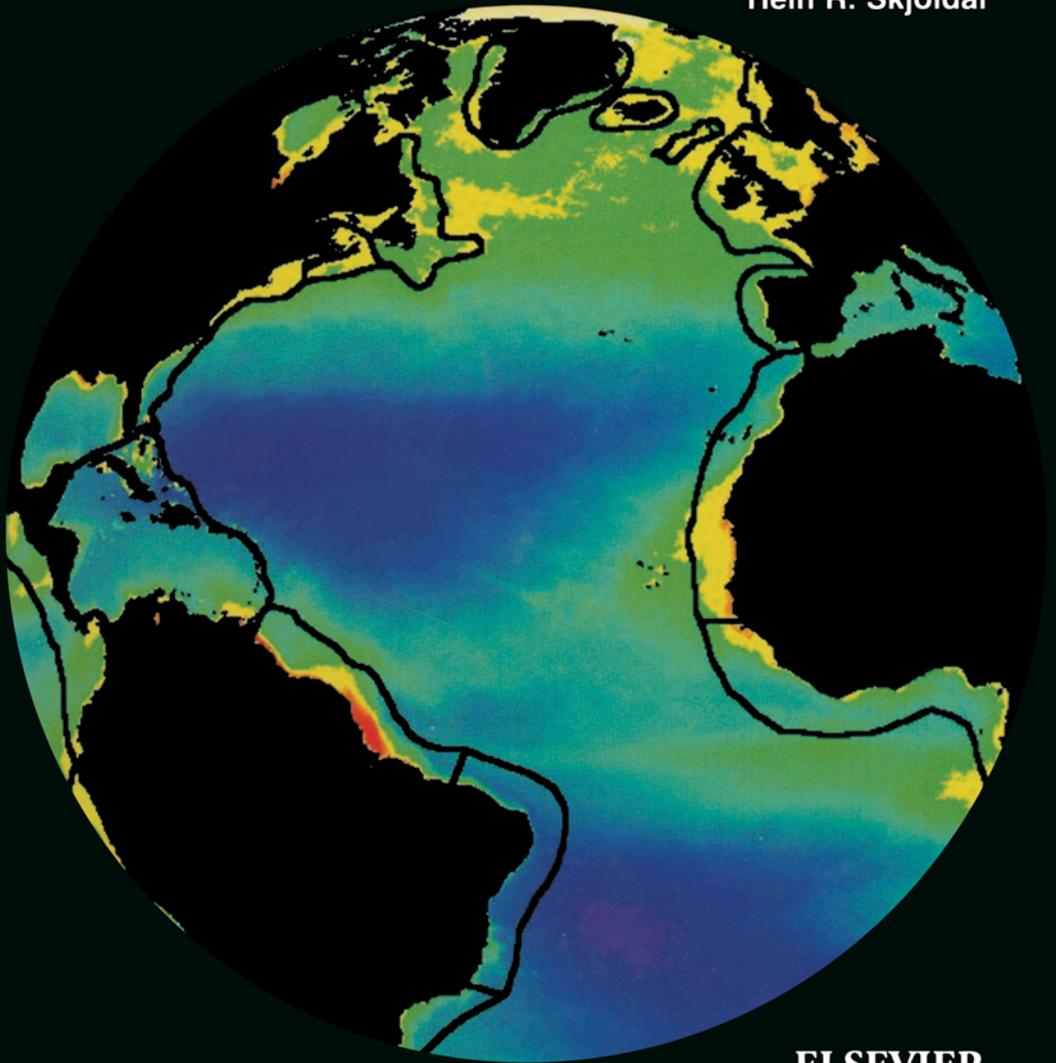


Large Marine Ecosystems of the North Atlantic

Changing States and Sustainability

Edited by
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ELSEVIER

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Iberian Sardine Fisheries: Trends and Crises

Tim Wyatt and Carmela Porteiro

FISHERIES GEOGRAPHY OF THE IBERIAN LME

The Iberian coastal ecosystem (LME 24) is relatively small in comparison with other such designated systems. It blends to the north with the Celtic-Biscay shelf (LME 23) across the Cap Breton Canyon, to the south with the Canary Current (LME 27) off northwest Africa, and with the Mediterranean Sea (LME 25) through the Straits of Gibraltar. The main geographical features are shown in Figure 11-1. They include: i) the north-facing Cantabrian shelf, which is quite narrow, mostly about 20 km wide but broader off Cabo de Peñas and Cabo Ortegal where it reaches a width of nearly 60 km; ii) the mostly west-facing shelf between Cabo Finisterre and Cabo de San Vicente, 30 to 50 km wide and incised by deep canyons; this coast trends mainly north to south but turns sharply eastwards at the important capes, Cabo de Roca and C. de Espichel; iii) the shelf of the Gulf of Cádiz which trends east from C. de San Vicente and gradually turns southeast towards the Straits of Gibraltar. Depths in the strait exceed 200 m so that the Spanish and Moroccan continental shelves are unconnected.

Meteorologically, this region is dominated between spring and autumn by the Azores High, which leads to a predominantly northerly airflow. The upper waters consist mainly of subpolar and subtropical branches of the Eastern North Atlantic Central Water (ENACW) which converge at the Galicia Front running NNW from Cape Finisterre (Fraga *et al.* 1982). Using sea surface temperature observations from merchant ships, Wooster *et al.* (1976) described the mean seasonal pattern of cold water anomalies from Cape Finisterre southwards, and noted that there was a good fit between this pattern and computed offshore Ekman transport values. They concluded that the temperature anomalies were due to upwelling driven by longshore wind stress, but noted that there was an unexplained phase difference between the wind stress and the temperature deficit, and that the cold anomalies extend farther offshore than expected on the basis of Ekman pumping. The cold plumes probably result from the upwelling associated barotropic instabilities, and there may be some secondary topographic trapping, especially off C. Roca and C. San Vicente where the plumes penetrate the ocean for 100 to 200 km (Coste *et al.* 1986). The general flow of the recently upwelled water is southwards near the shelf break as a summer coastal current. This flow reverses between late autumn and spring to form a poleward current (Frouin *et al.* 1990); these flow patterns have also been identified in the Cantabrian Sea and in the Gulf of Cádiz.

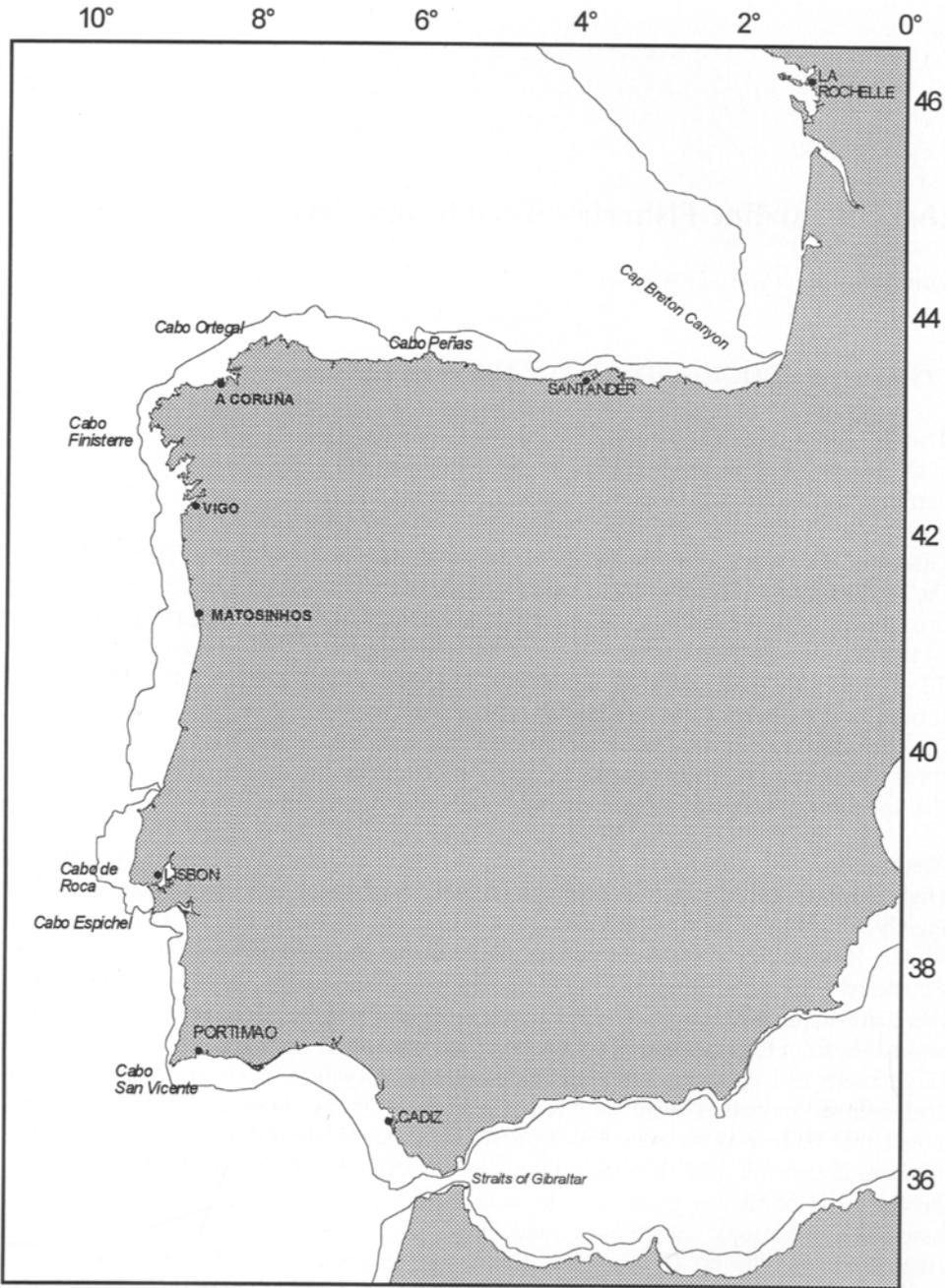


Figure 11-1. Main geographical features of the Iberian coastal ecosystem.

Seasonal patterns of phytoplankton pigment concentrations, based on Nimbus-7 satellite data, are described by Peliz and Fiúza (1999). Moderate to high concentrations occur in all coastal waters of the Iberian LME in winter, and extend well offshore beyond the shelf break; the highest offshore concentrations lie along the Galicia front, and these are present almost year round. During the upwelling season, pigment concentrations are lower than in winter and are confined to the inner shelf, except in the Gulf of Cádiz which is pigment-rich all year. The poleward current is very poor in pigments. These pigment patterns recur from year to year and appear to be strongly tied to the hydrodynamics (Peliz and Fiúza 1999).

IBERIAN SARDINE FISHERIES

Fish stocks collapse for two reasons, either because exploitation rates are too high, or because recruitment levels are inadequate to maintain the fishable stock. It is also recognized that overfishing can cause recruitment failure (Murphy 1966; Cushing 1971). To distinguish the relative importance of the natural and man-made components of change is a major challenge, especially now that many stocks are fully or over-exploited. For many fishery resources, overfishing is undoubtedly the major constraint at present on efficient economic exploitation, but if and when this problem is solved, the recruitment problem will remain, and, as several generations of biologists have emphasized, understanding recruitment processes must lie at the core of rational fisheries management.

It is generally agreed that the most significant event leading to variations in recruitment must be mortality during the early life of fish, during what is loosely called the larval phase, and that this mortality must be density dependent since fecundity is the result of natural selection. Density dependent survival depends on adequate feeding conditions, both to avoid starvation, and to escape size dependent predation. Sardine larvae found in the sea are therefore nearly always fit and healthy since those that fail to be so die of starvation or are eaten (Chícharo 1997, 1998). Climate *per se* is not the proximate factor which regulates density, but if changes in widely separated sardine stocks are synchronous, as Kawasaki and Omori (1988) and others have maintained, or are (in other species) precisely 180 degrees out of phase (Lluch-Belda *et al.* 1989) on these decadal time scales, then global-scale external forcing must be involved. Climate and tidal forcing are then the major candidates. Fecundity is high in many fish, but there are large variations in how high, and sardines are very much less fecund than cod for example, which may suggest that the former have better control over the density of their offspring than the latter.

Landings of pelagic fish like sardines undergo particularly high amplitude fluctuations in abundance, and there is evidence for large fluctuations in the abundance of some stocks even in the absence of exploitation (e.g., Soutar and Isaacs 1974; Holmgren-Urba and Baumgartner 1993). It has been established too that these fluctuations are accompanied by changes in other components of the ecosystems (Cushing 1984).

Generally, however, perceptions of the occurrence of fluctuations are based on fisheries records as distinct from real abundance estimates, and they may in principle therefore also be attributed to accessibility (as well as market forces). Without independent information, it is not possible to distinguish between the alternatives. Thus when we talk of the *abundance* of a stock, we should keep in mind that what may be meant is a combination of the abundance of the part of the stock available to the fishery, and a measure too of its economic value. In the case of the sardine stock to be examined here, there are no independent estimates of abundance prior to 1985, so that the perceived crisis of the 1940s and 1950s is based entirely on the market records.

Here we examine two sardine crises, particularly as recorded in the records of the Vigo fish market, and compare them with changes in sardine landings at other ports in the region. In earlier papers (Wyatt and Perez-Gándaras 1988, 1989), some of these records were compared with upwelling indices, and it was concluded that several distinct stocks contribute to the sardine fisheries of the region, and that each might respond independently to Ekman forcing. It was also suggested that changes in the geographical distribution of the different groups could partly account for the fluctuating fortunes of the fisheries in different parts of the region. A major redistribution of sardines (based on age classes) between the Cantabrian and western parts of the region is central to the hypothesis of Robles *et al.* (1992). Spring and winter spawning populations or races are also recognized in the central sector (Asturias) of the Cantabrian Sea (Villegas 1987), and Villegas and López-Areta (1988) note that multiannual trends in captures since the 1950s seem to occur independently in Asturias, Cantabria, and the Basque region.

NATURAL HISTORY OF SARDINES

Plankton surveys in European coastal waters have revealed that sardine eggs occur in high concentrations at or just beyond the edge of the continental shelf in the winter-spring months, and in lower numbers in summer-autumn at inshore locations. Such a pattern is described for the Bay of Biscay (Arbault and Lacroix 1977), and for the western Channel (Southward 1963, 1974; Demir and Southward 1974), where it is quite clear due to the breadth of the shelf. There are two peaks of sardine eggs farther south too, in March and November, off Matosinhos in Portugal (Ré 1981; Ré *et al.* 1990), in Ría de Vigo (Ferreiro and Labarta 1984), and off Santander (Oliver and Navarro 1952). But at these locations the shelf is narrow and it is less clear that the egg patches are produced at different distances from the coast. Sampling in the Cantabrian Sea (unpublished) between 1990 and 1995 has revealed that the autumn spawning peak in those years was weak in 1990 and absent for the next five years. It has been claimed that the autumn spawning fish are larger than those that spawn in spring (e.g., Oliver and Navarro 1952).

There may be two races of European sardine in much of its range in the Atlantic, with spring and autumn spawning seasons. In the Galician rías, juvenile sardines (*parrocha*) become the target of a fishery when about six months old. This fishery has two peaks in

the year, in spring and autumn (Andreu 1969). The spring caught parrocha might then be equated with the autumn spawning and the autumn parrocha with the spring spawning fish. Southward (1963) came to the same conclusion for sardines in the Western Channel. The view that there are two (or more) kinds of sardine in Galician waters has wide currency among fishermen, who are recorded as believing that one group spawns in the open coastal waters and the other within the rías (Bernárdez 1926). Fishermen along the French Atlantic coast traditionally distinguished *rogue* sardine which approached from the west in spring or summer, successively later at more northerly fishing stations, and never found in spawning condition, from *derive* sardines which could be fished in all months of the year, and which were found to be ripe at a certain season (Wyatt 1983). Thus spring and autumn spawning fish are spatially segregated during their reproductive seasons. It is probable that the larvae that result from the inshore and offshore spawning areas remain segregated during the drift phase, as has been demonstrated for herring larvae in the North Sea (Heath 1990). The nursery grounds of sardines have not been discovered on the Atlantic coasts of either Portugal or Spain, but in the Mediterranean are close inshore near sandy beaches, where juvenile sardine were commonly caught in beach seine fisheries.

The existence of sympatric (or parapatric) spring and autumn spawning sardines in the western Channel, Galicia, and elsewhere is additional to the classical racial separations of sardines based on morphological criteria (see e.g. Furnestin 1945; Larrañeta 1968). Both sympatric and allopatric evolution of the European sardine may have resulted from the combination of temperature changes and rising sea levels that followed the end of the last Ice Age (Wyatt *et al.* 1991). As in herring, the variability of morphological and genetic patterns may be uncoupled. Genetic differentiation between inshore and offshore marine populations in the Atlantic has been described too in bottlenose dolphins (Hoelzel *et al.* 1988) and in petrels as well as in fish.

Long-term records of sardine egg abundance are only available for the Plymouth area, but may be taken to indicate the kinds of change that can be expected throughout the range of the species. Records for the Plymouth area begin in 1924. The general trends are summarized by Southward (1974). From 1924 to 1934, spring-summer spawned eggs (April to July) were rather scarce, but from 1935 to 1961 they became very abundant. Beginning about 1950, a second peak in spawning intensity was discernible from September to November. The quantities of eggs produced in the two spawning seasons appear to vary independently.

SARDINE FLUCTUATIONS IN IBERIAN WATERS

Fluctuations in the abundance of sardines have provoked speculations concerning their causes for at least two hundred years in Galicia, just as in other coastal regions of Europe where this fish has formed an essential component of the economy and culture of the local inhabitants. The same is true for other species such as the herring and the cod in more northerly regions. Much of this effort may have been barren, but without it

and the publications to which it has given rise, we would know less about the long-term history of these fluctuations. This history is not only of interest in itself, but must eventually comprise an essential component of any durable understanding of the causes of these changes in abundance. Fishing communities have always reckoned with changes in catches from day to day and from year to year, but the changes are sometimes so dramatic that in the cases when there are catastrophic declines in catch over very short periods of time, one or a few years and accompanied by severe economic disruption, the word “crisis” or some equivalent is employed to describe them and to distinguish them from the lower amplitude fluctuations which the experiences of fishermen classify as normal.

Excluding the present crisis, five periods in which sardines catches were *perceived* to be notably poor in Galician waters have been recorded in the last 150 years, although the earlier ones are poorly documented. These were from 1876 to 1895, 1924 (or perhaps earlier) to 1925, 1941 to 1942, 1946 to 1957, and since the late 1980s. We say *perceived* because one could argue that, with the exception of a few years, the Galician sardine fishery has been in an almost permanent state of crisis since the early 1940s. There were of course variations in catches at other times, but in the years listed here sardines were taken in such small quantities as to generate widespread concern and economic hardship. These periods range from two to nearly twenty years in duration, which suggests that a single generic cause may not be adequate to account for all of them. A puzzling feature of the crisis which began in the 1940s was that catches were low for only two years at Matosinhos in Portugal, about 100 km to the south of Vigo (Figure 11-2).

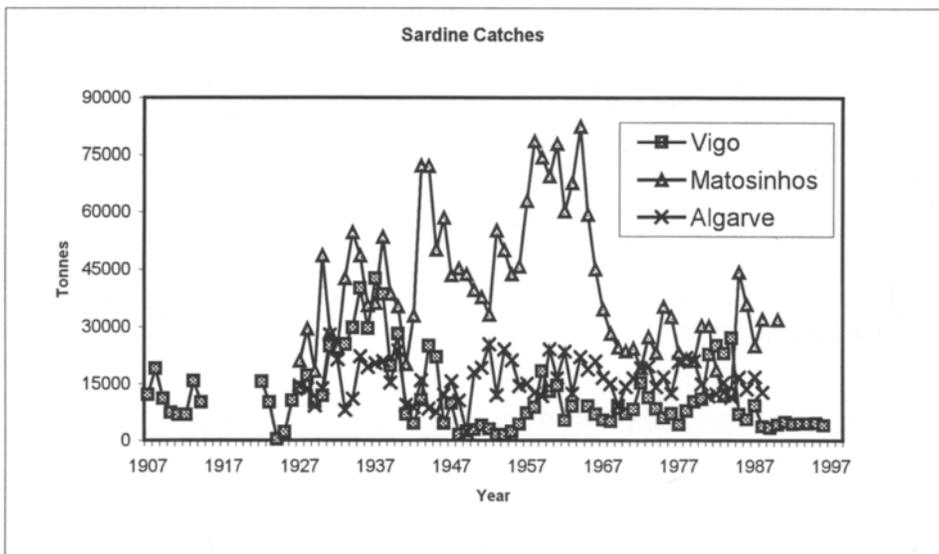


Figure 11-2. Sardine catches, 1907-1997.

Thus the spatial scale on which we need to examine these trends to understand the underlying ecology are more fine-grained than those which are used for management purposes.

The sardine crisis of 1942 to 1957

Sardine landings in Vigo and neighbouring Galician ports reached their highest levels of this century in the 1930s. The bimonthly trade journal *Industrias Pesqueras* provides a detailed view of the fortunes of this fishery. In the 1930s, editorials routinely described Vigo as the premier sardine port of the world (although catches were generally higher in Matosinhos!), referred to the fish as “our bread, our love, our prosperity” (15th January, 1938). As the fishery failed, and year succeeded year without any signs that the sardine would return, the phrase “another year without sardine” was repeated like a refrain.

We should bear in mind that while the sardine has probably changed its habits very little since the 1930s, fishing practices have evolved rapidly. In the 1940s and 1950s, the Portuguese fleet was technologically more advanced than the Galician, and had more powerful vessels equipped with echosounders and radiotelephones. After three years' experience with echolocation, the Portuguese abandoned night fishing and dispensed with the traditional reliance on surface manifestations of the shoals during the darks of the moon (*ardora*). The number of so-called American seines employed, which had been the main nets used in the 1930s, gradually fell, and they had disappeared by the end of the 1950s. This trend was compensated by a rapid increase in the number of *traineros* until 1955, and these were maintained until 1970.

Previously, it had been traditional to pay out the nets as Venus was setting. At this moment the sardines (and anchovies) were thought to be provoked to change the direction of their movements (*motivo*). The shoals were reckoned to enter the rias *en masse* after San Xoan, and especially in early September (*Golpes de Santos*) and in late December (*Golpes de Nadal*). Most of these signs had their equivalents among herring fishermen in the North Sea and elsewhere. Much of this tradition is now forgotten, and indeed has never been transmitted to the younger generations of fishermen who rely much more heavily on technological developments. Thus in the 1950s in Portugal, and somewhat later in Galicia, a fishing culture which may have had its roots in the Palaeolithic started to die.

HYPOTHESES TO EXPLAIN SARDINE CRISES IN GALICIA

Overfishing

Overexploitation was widely agreed by industrialists at the time to be a major reason for the collapse of the Galician sardine fishery in 1947 (various articles in *Industrias Pesqueras*). The scientific community did not agree. Sardine fishing at that time was

almost entirely limited to the interiors of the rías, where the presence of sardines was regarded as casual. The main concentrations of fish were known to remain outside the rías. Andreu (1956) argued that fishing methods were quite primitive, and that the reduction of the fleet and the regulations against winter fishing imposed after 1953 did not lead to any increases in yields. This view was supported by Anadón (1954), who failed to find any relation between the abundance of juveniles and adults, but did establish that there had been a real reduction in abundance. The idea that the crisis could be overcome by protecting the sardine during the spawning season was also discounted, since spawning was thought to continue for eight or nine months of the year (Andreu 1955), while landings had in any case always been very low during the time of maximum sexual activity. The spawning areas had not then been identified, but spawning was known not to take place on the traditional fishing grounds. These arguments were summarized by Margalef and Andreu (1958), who commented that the precocity and high fecundity of the sardine were sufficient guarantees for adequate reproduction.

Changes in distribution

The very marked contrast between the Galician crisis and the continued abundance of sardines in the Matosinhos fishery little more than 100 km to the south suggested that there had been a shift in the distribution of the main concentrations of fish. Meristic studies, however, indicated that the Spanish and Portuguese fish were probably racially distinct (Andreu 1955), and the fact that landings peaked at the same time in both Matosinhos and Vigo was also used to argue against a displacement over this distance. Paradoxically, Andreu seems to have been unaware that sardine spawned in Galician waters, and followed de Buen (1928) in supposing that all sardines in the sector between the Miño and the French border derived from spawning areas in the Cantabrian Sea or off Setúbal in central Portugal.

Changes in reproductive success

Data for the years 1925 to 1952 from Marín (Ría de Pontevedra) analysed by Anadón (1954) revealed decadal scale changes in the relative contributions to the catches of spring and autumn progeny, principally due to a long-term decline in the abundance of juveniles derived from the spring spawning. Anadón's arguments were extremely astute, and although by and large they have not been dismissed to any extent, neither have they been considered in detail in more recent efforts to interpret sardine fluctuations. Anadón wished to calculate mortality rates of the Galician sardine from the data available, and to do so it was necessary to make several assumptions. These were a) that the population was either stationary, or that its movements were local and regular; b) that fish of different ages were not spatially segregated in the target stock; c) that fishing effort impinged equally on all age classes, and d) that fishing did not significantly affect mortality. He discussed each point in turn.

At the time Anadón wrote, it was fashionable to estimate mean vertebral numbers in fish to define racial distinctions between stocks from different areas. It was already recognized that the mean vertebral count of a fish contained signals of both the genetic origin of the individual and of the environmental conditions, mainly temperature, during a critical phase during early morphogenesis. Ruivo (1950) had implied that the mean vertebral number of a group of fish could be used to determine the geographical origin of the sample, and Anadón made this hypothesis explicit. He argued that if two or more generations of sardine appeared successively in the same region, it would be very likely that each group would have a distinct mean vertebral count, and that they would therefore appear to be mixtures of fish of distinct origin. Literature data indicated that this might be so for various local sardine fisheries on the Atlantic coasts of France and Spain and in the Mediterranean.

He then suggested that if mean vertebral numbers remained constant at a given locality over periods of several years, and were different from the means at adjacent localities, the populations must be relatively stationary. He cited data that indicated that the sardines in northern Portugal were distinct from those of Vigo, and that those of Vigo, Ferrol, and Gijón were all different from each other. Anadón therefore concluded that the sardine has different local spawning areas in each coastal zone, that the annual migrations must be short, and that the routes of these migrations could not be parallel to the coasts of Portugal and Galicia.

The second and third assumptions, that age classes are neither spatially separated nor differentially captured, were based on the fishermen's experience a) that sardines are never taken in depths beyond the 100 m isobath (and in Galicia this means never further from the coast than 2 to 6.5 miles), even though the same nets were used in greater depths to capture anchovy, b) the unselective nature of the gear (*cercos*, which reached depths of 85-100 m, and hence could reach all age classes even if they were vertically segregated), and c) the absence of sardines from the stomachs of albacore and bonito which reach the outer shelf but are not caught inshore.

The landing data at Marín available to Anadón (1954) were recorded as either juveniles (*parrocha*) or adults. The exact size of *parrocha* is a little uncertain, but usually about 9 to 15 cm in Galicia, so includes fish from 6 to 12 months old. The numbers of these young fish reach maximum abundance (*arribazones*) in the landings twice each year, in spring and autumn. Knowledge of the growth rate of the Galician sardine and the time of spawning allowed Anadón to relate these peaks to eggs produced in autumn and spring respectively. It was believed then that spawning occurred continuously from spring to autumn, and Anadón therefore presumed that the two peaks were due to the reduced capture rates of the winter months (as a result of the fish being more dispersed), and not to the possibility that there were two peaks in spawning.

A closer examination of the Marín data (his Table II and Figure 4) may suggest that the two peaks identified by Anadón (1954) were identified by intuition rather than rigour. The autumn *parrocha* peak is a strong feature, but the spring peak is quite ephemeral

and only clearly recognizable in about seven years of the 28-year series; also in some years the two peaks cannot easily be distinguished (e.g. 1931, 1932). Furthermore, the timing of *parrocha maxima* is quite variable. Much of this variability can be attributed to the fact that *parrocha* varies in length from 9 to 15 cm and thus in age over several months.

We can identify the following general trends in the Marín time series. From 1924 to 1928 *parrocha* landings were very small, perhaps indicating that recruitment failed almost completely in those years. From 1929 to 1947, nineteen years altogether, the autumn *parrocha* fishery was generally good in most years (but poor in 1935, 1938, 1940, and 1946), and in three years exceptionally good (1944, 1945, 1947); it is during this period that the spring peak can be identified. Finally, from 1948 to 1952 there was a return to the very poor *parrocha* fishery of the 1920s.

Changes in oceanographic conditions

A climatic hypothesis was favoured by Margalef (1956), who associated the sardine crisis with changes in the phytoplankton composition and with changes in patterns of water exchange between the *rías* and the open sea. He linked good sardine fishing with presence in the plankton of the diatom *Melosira (Paralia) sulcata*, and poor fishing with *Thalassiosira rotula* "invasions". *M. sulcata* is predominantly benthic, but is found in the water column either during relatively intense upwelling or during strong vertical mixing in winter, while *T. rotula* is a planktonic species associated with upwelling pulses in spring. Margalef proposed that during years favorable to the fishery, i.e., when the sardine shoals were abundant inside the *rías*, the surface water flow into the *rías* was frequent and provided them easy access, especially in autumn. These conditions he thought would favour the entry of the fish and hence their accessibility to the fishermen. During unfavorable years, the flow of surface water into the *rías* would be reduced, and the entry of sardines discouraged. These good and bad years were associated respectively with high and low rainfall, particularly in autumn and winter. Thus Margalef did not at that time explicitly invoke reduced productivity as the ultimate cause of the sardine crisis, nor suggest that recruitment variability was critical.

THE PRESENT SARDINE CRISIS

Stock evaluations since 1976 have shown that there has been a reduction in spawning stock biomass since the mid 1980s. Also, surveys in the Cantabrian region indicate that spawning there has been very low. During the 1980s, the fishery was mainly sustained by the '83 and '87 year classes. The moderate '91 year class was the last and the fishery is now very poor.

Data from the present crisis has provoked another explanation for the changing yields based on analogies with the Norwegian spring spawning herring and the Pacific sardine.

In this view, reductions in the size of the stock lead to behavioral changes; some parts of the traditional feeding and spawning areas are abandoned, and the fish then confine themselves to reduced areas closer to the coast, in what can be called core areas or refuges. For the Iberian sardine, the main core area is the northern Portuguese shelf, and when the stock is concentrated there, the spawning areas in the Cantabrian Sea are not visited. Changes in the upwelling regime drive this model as in the hypotheses already mentioned. An increase in the strength and frequency of the northerly wind component during summer is thought to favour larval dispersion, which transports them away from the recruitment areas and increases mortality. It is not possible with data currently available to distinguish between this model and one based on the varying success of independent stocklets, but a crucial component of this view is the extent to which the shoals migrate.

OTHER CHANGES IN THE IBERIAN LME

Two other notable changes have taken place in Iberian seas over the decades considered here. Neither of them is linked in any obvious way with fluctuations in the sardine fishery. The first is a rather marked change in the abundance of certain dinoflagellate species, and the second the expansion from small beginnings in the 1950s of a blue mussel farming industry. From about the beginning of this century until the 1950s, red tides were a more or less annual occurrence in the Rías Bajas; these were almost always due to the dinoflagellate *Gonyaulax*, and sometimes the ciliate *Mesodinium*. But since the 1970s, *Gonyaulax* has not been reported to form blooms in the Rías Bajas, and instead there have been occasional blooms of toxic dinoflagellates, *Alexandrium tamarense* and *A. minutum*, and *Gymnodinium catenatum*. It is not clear whether a similar trend has taken place in Portuguese waters. These changes in the phytoplankton of the region have been seen as part of a worldwide increase in the frequency and intensity of harmful algal blooms, called the “global spreading hypothesis” (Wyatt 1995), and attributed to various causes including eutrophication and ballast water transport.

Species of *Alexandrium* are almost certainly autochthonous in these waters, and rare toxic events (PSP) which are probably attributable to them are known since at least 1946 in Portugal. The vectors to humans are shellfish. We are not aware that any systematic search of historical medical records for PSP has been made in either Portugal or Spain, but by 1976 when the first major toxic event in Spain took place, mussel cultivation on rafts had already been practiced for about twenty years. It is therefore possible that there has been a genuine increase in the frequency or magnitude of toxic *Alexandrium* outbreaks. It is possible too that *Gymnodinium catenatum* has been introduced to this region, but it too may have been a cryptic species prior to its becoming a pest. Suggestions for source range from Morocco to Argentina (Wyatt 1992), but the taxonomic status is not yet fully resolved. There may have been other changes in the phytoplankton composition which have escaped attention since they are

not of significance to human health. Unfortunately, there have been no follow-up studies in the region of the diatoms which Margalef used as indicator species.

The second major change in the Rías Bajas is the introduction of raft cultivation of blue mussels, as just mentioned. This industry started slowly in the 1950s, and now produces about 200,000 tons annually. It is thought that in the main raft area, Ría de Arosa, the standing stock of mussels is near or above the ideal carrying capacity, and that mussels alone could consume the entire annual production of phytoplankton. Cabanas *et al.* (1979) provided budgetary estimates for a mussel raft in Ría de Arosa over a 20-day period. Samples upstream and downstream of the raft indicated that about 60% of the chlorophyll in the water column was removed during passage through the mussel ropes. The daily "fallout" of organic matter from the raft amounted to 190 kg of dry sediment daily. This last number, multiplied by the number of rafts in Arosa, amounts to around 175,000 tons annually and has led to speculation that it may lead to changes in the species diversity of the ría. Whether or not the growth of mussel farming in the rías is linked to the changes in the phytoplankton already mentioned remains an open question.

DISCUSSION

It is tempting to suppose that fluctuations in sardine abundance are ecologically equivalent to those of other pelagic species such as herring, but information on the age structure of the two species indicates that parallels are not exact. For example, in the case of the Atlanto-Scandian herring, it is well known that the success of the fishery over many decades has depended on a very small number of large year classes. This possibility is due of course to the longevity of this herring. The shorter-lived European sardine needs a higher frequency of years with good recruitment if it is to support a successful fishery. In the northern part of the sardine's range, in Cornwall and Ireland, the fishery has always been seasonal and intermittent, and declines in catches have nearly always been attributed to movements of the shoals beyond the range of the vessels. But in Spain and Portugal, the sardine fishery is prosecuted throughout the year, weather permitting. Nor is it clear to what extent the Pacific sardine provides a model for the European sardine, since those stocks seem to have distinct patterns of genetic differentiation from the European sardine (Hedgecock 1991).

Current views on the regulation of fish recruitment in eastern boundary current ecosystems are based on the studies of Lasker and his colleagues (e.g. Lasker 1975, 1978), Bakun (1985), Cury and Roy (1989), and others. Bakun (1996) provides a synthesis of these ideas, and builds on them a model that he calls *ocean triads*. The essential elements of the triad are enrichment due to upwelling, concentration of the larval food brought about by convergences, and mesoscale circulation patterns that help to maintain larval retention. When the temporal sequence of these sometimes conflicting oceanographic processes is optimal, larval survival and subsequent recruitment are maximized. It has generally been taken for granted that within limits, increased upwelling rates raise productivity, and the extra planktonic food becomes

available to the feeding larvae. But in Lasker's hypothesis and in the ocean triad model, this only happens if the plankton is subsequently concentrated at fronts or other convergences. Larval feeding success can therefore vary even though productivity does not. But fluctuations in upwelling rates do lead to changes in primary production, and to changes in species composition and phytoplankton size distribution (Wyatt 1980), so that there are four extreme possibilities determined by the oceanography, as follows:

productivity	convergence	recruitment
high	effective	good
high	ineffective	bad
low	effective	moderate
low	ineffective	bad

Within upwelling systems, suitable spawning sites are near the areas where upwelling is strongest but not coincident with them; this leads to a decrease in dispersive loss rates (Parrish *et al.* 1981). Shelter from the more dynamic divergence of core upwelling areas can be provided, for example, by capes (Roy 1997) or topographically trapped eddies (Navarro-Perez and Barton 1997). The distribution of sardine eggs and larvae in Galician waters seems to indicate that capes are especially important, and we can assume that this is generally true (Bakun 1996). We can surmise that topographic features and circulation patterns constrain the natural history of each putative stocklet, and thus the stock structure of the region as a whole. The same principle has been established for the herring in the North Sea (Heath 1990).

Fish are normally faithful to their spawning sites, and thus in the absence of vagrancy (i.e., failure to return to the natal site at the spawning season) must be reproductively isolated from fish at other spawning sites. Even if vagrancy occurs, genetic exchange may be reduced or absent due to variations in the times at which the different groups reach maturity. Existence of this pattern of local demes means that the variability of a stock as a whole is damped. Small climate shifts that lead to negative trends in one deme can be balanced by positive trends in another deme. Then crises generated by the influence of larger climatic shifts might cause lowered recruitment to all or most demes simultaneously. The French sardine crises of the late 19th and early 20th centuries provide an example of the latter. Modellers search for simplicity by looking for transcendent principals, and strip away the messy complexity that obscures them, perhaps stigmatizing it as noise. In some fisheries management, this process of simplification has perhaps been pursued too far. If the smaller scales, which may be the correct ones within which to interpret sardine population dynamics, are not resolved, then the larger scale "maps" which we use for management will contain large errors.

Sherman (1998) groups the sources of variability in LMEs under three categories, climate shifts, exploitation, and pollution. The third is not of major importance in the context of the Iberian LME, except in a few local regions. Climate, and in this case we think mainly in terms of upwelling, has certainly played the primary role in the regulation of productivity and resource abundance historically. But the impact of

exploitation is now challenging climate as a significant source of variability in this region as in so many other parts of the ocean, and some stocks are depressed below the levels at which yields can be optimized.

It is well known that major changes in fish abundance are accompanied by equally radical changes in other trophic levels. We mentioned above that Margalef identified marked changes in the phytoplankton composition in Galician waters during the 1950s sardine crisis there, and that he associated *Thalassiosira rotula* abundance with poor yields. There are no reports to indicate whether this diatom became less abundant when the fishery recovered after 1957, but there have been significant changes in phytoplankton composition in recent decades.

As a test-bed for exploring and developing the ideas of *ecosystem management* (Christensen *et al.* 1996), or for the more ambitious project of *ecosystem rebuilding* (Pitcher and Pauly 1998), the Iberian LME offers several advantages. It is one of the smallest LMEs of the fifty or so that have so far been designated, sufficiently small that the entire system can be surveyed with the national resources already available on an annual or better frequency. It is bordered by only two nations, Spain and Portugal, which already collaborate effectively in various fisheries contexts. Both are members of the European Union, and can therefore lay claim to substantial resources in addition to those available nationally. Thus the geographical, political and financial barriers to acquiring the background information necessary to convert ecosystem management from a paradigm to a practical affair are less severe here than in many other LMEs. Spain, which has the largest distant water fleet of any European country, is also gradually being excluded from several of its traditional extraterritorial fisheries, and needs to turn more attention to exploiting local resources in a more rational way, with long-term sustainability as a priority goal, in the spirit of Agenda 21 (Earth Summit).

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