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The stock of Atlanto-Iberian sardine: possible causes of variability[1]

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Fluctuations in the Iberian stock in the period 1980–1989 have been examined, taking into account what is known of the biology of the species, oceanic and atmospheric parameters, and the fishing effort directed at this stock. During this period, there have been significant changes in recruitment, which was good in 1983 and 1987 and poor in 1982, 1985, 1986, and 1988. Some links between recruitment anomalies and environmental parameters (surface temperatures, prevailing winds, sea level) have been identified. Variations in recruitment can be explained on the basis of fluctuations in "environmental windows" during the periods of spawning and larval drift. The success of spawning is controlled by the existence of a favourable environment during larval drift into areas with weak upwelling and abundant food.

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Introduction

The variability of recruitment in pelagic fish populations is an important problem in fisheries science. Traditional stock-recruitment models are based exclusively on the integration of biological interactions during the pre-recruit phase, but they ignore abiotic processes during recruitment, interspecific interactions, and the effects of climatic change on the habitat.

The mechanisms which govern large-scale spatial changes are not well understood, but in coastal systems, short and medium-term fluctuations in the abundance, distribution, and production of the ecosystem have been related to large and mesoscale variations in atmospheric processes which have an enormous influence on the upper ocean (Lasker, 1978).

On decadal time scales, environmental fluctuations cause variability which must be amplified by exploitation. Rational exploitation could smooth the natural fluctuations of the stock and attain an equilibrium between fishing and production; nevertheless, environmental fluctuations can cause large and prolonged changes in the mean size of the stock, i.e. prolonged periods of high or low biomass.

The sardine (*Sardina pilchardus*, Walb.) is the target of an important fishery on the Atlantic coast of the Iberian peninsula. Its capture and associated socio-economic infrastructure indicate that it may be one of the most ancient fisheries in this region.

The sardine belongs to a low trophic level. The biological characteristics show that its populations are well adapted to environmental fluctuations (Margalef, 1960). The northern and southern limits of the global distribution of the European sardine are well defined, in the north by the 10°C surface isotherm, and in the south by the 20°C isotherm. In the northern part (France, British Isles) its distribution overlaps that of the herring (*Clupea harengus*), and in the south (West Africa, eastern Mediterranean) with the alache (*Sardinella aurita*) (Wyatt, 1985).

On account of the broad distribution of this species, there are considerable variations in the life cycle characteristics, but here we refer only to studies of the sardine stock of the Atlantic waters of the Iberian peninsula. We assume for present purposes that there is a single stock distributed between France and Gibraltar.

Geographically this area lies at the northern limit of the east central Atlantic coastal upwelling system (Wooster *et al.*, 1976), which in these latitudes is seasonal (April to September) and relatively weak (Fraga, 1981; Blanton *et al.*, 1984; Fiuza, 1984).

[1]To the late Reuben Lasker and to Warren Wooster, wholehearted supporters since 1985 of the work by the Instituto Español de Oceanografía in recent years to further our knowledge of factors which affect the variability of recruitment in coastal pelagic fish.

Two regions can be distinguished in the Iberian peninsula from an oceanographic viewpoint, the Cantabrian Sea and the Atlantic, clearly differentiated and separated by a convergence which lies between Cape Ortegal and Cape Finisterre at the corner of the peninsula. Within each region it is possible to identify two slightly different sub-regions which may influence the behaviour of pelagic species (Fig. 1).

Two areas, eastern and western, can be distinguished on the Cantabrian shelf in the period March to October, a period important for the survival of larvae and pre-recruits (areas 1 and 2 in Fig. 1), with different dynamic and thermal features. Surface flow is to the east in the eastern area and can form gyres; the water here is warmer (mean temperature 2°C higher than elsewhere on the platform). Surface flow is to the west in the western area due to the predominance of northerly winds at this time, with zones of weaker circulation, and again a tendency to form gyres (Servain, 1976; Ibañez, 1984).

The west Atlantic coast (areas 3 and 4 in Fig. 1) is subject to seasonal upwelling and surface currents parallel to the coast in the direction of the dominant winds, with a marked northerly component (Cabanas *et al.*, 1988; Coste *et al.*, 1986; Fiuza, 1984). It should be noted that in the northern part (area 3, very sinuous, indented by rias) there is a convergent zone close to Cape Finisterre which affects the exchange of water between the Cantabrian platform and the Atlantic, and deflects some offshore (McClain *et al.*, 1986).

The reproduction and feeding periods of the sardine seem to be adapted to the conditions of each area, and although sardines are found in all areas, they tend to be distributed by age classes (Porteiro *et al.*, 1986). The 0-group fish (recruits) are found mainly on the west coast of the Iberian peninsula between Cape Ortegal and Cape Roca, the zone of maximum upwelling at the time when the recruits reach this area (Dias *et al.*, 1983; Pastor *et al.*, 1986; Dias *et al.*, 1989). The 1-group fish occur mainly in the southern part of the area occupied by the stock, in Portuguese waters. Fish of five years and older are found in the Cantabrian Sea (Pastor *et al.*, 1986; Porteiro *et al.*, 1990).

The Iberian sardine has two spawning areas, off the Portuguese coast in winter (Cunha and Figueiredo, 1988) and in the Cantabrian Sea in spring (García *et al.*, 1988). On the north Portuguese coast, maximum spawning takes place in December at temperatures between 14°C and 16°C (Ré *et al.*, 1990). In the Cantabrian Sea, spawning takes place between October and July, with maximum intensity in April and May, and a smaller peak in November and December, the maxima occur at temperatures between 12.5°C and 15°C (Chesney and Alonso, 1988; Solá *et al.*, 1990).

Analysis of sardine stock trends during the period 1976 to 1989 (Pestana, 1989) shows that in the short term the yield depends on the recruitment indices, as is characteristic of short-lived pelagic species (Ulltang, 1980).

In this work, an attempt is made to qualitatively relate the variability of certain environmental factors to the variations observed in recruitment, and thus to changes in sardine stock abundance.

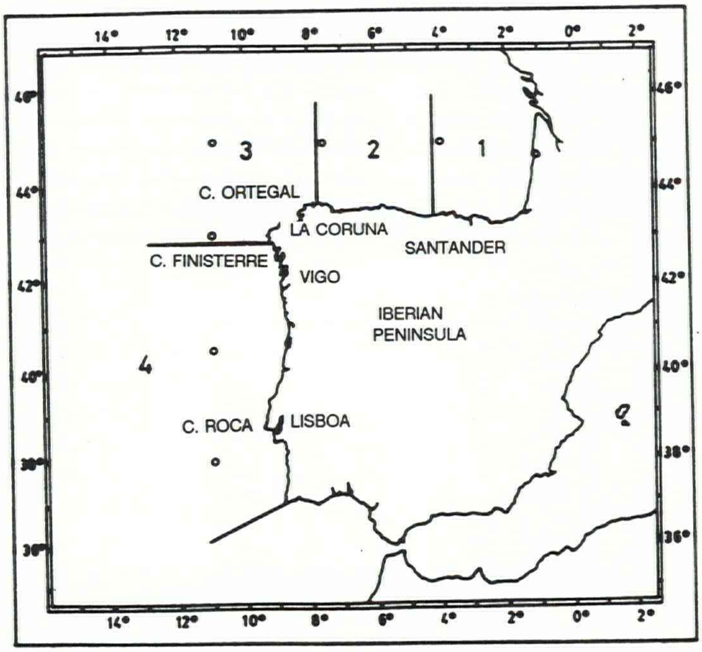

Figure 1. Situation map, with indications of zones and points where upwelling indices are calculated.

Table 1. Recruitment, landing of juveniles, upwelling index.

Year	Recruitment (*)	Upwelling index (**)	Landing juveniles (*)
1980	26 784	188	388
1981	17 709	337	329
1982	12 466	193	2
1983	35 468	13	1 179
1984	14 990	456	157
1985	11 530	118	21
1986	9 506	470	11
1987	18 547	241	788
1988	9 943	245	9
1989	9 272	379	95

* millions of individuals.
** m^3/s km.

Methods

Sardine stocks are assessed by the ICES working group using virtual population analysis, calibrated by acoustic surveys and the catch per unit effort of the fishery. From the age-class distribution the abundance of 0-group fish is obtained, which corresponds to recruitment (Table 1) (Anon., 1990).

The monthly captures of juveniles (length range 8–12 cm) landed in southern Galician ports (Table 2 and Fig. 2) are correlated ($r = 0.8$) with the VPA recruitment estimates. By assuming that juveniles are caught six months after hatching (based on studies of the daily growth rings of the otoliths, (Alvarez and Butler, 1989)), it is possible to determine the most successful spawning period each year (Table 3).

Two series used to examine the environmental variability during this period are the upwelling indices calculated from the wind stress on the sea surface (Bakun, 1973), and mean sea level in the port of Vigo (Lavín and García, 1991). The upwelling indices ($-Mx$, Ekman mass transport in the x-axis) gives us an idea of surface transport due to the wind. Upwelling provides nutrient-rich water to the euphotic zone. Sea level is also related to the wind and other coastal oceanographic phenomena.

The daily upwelling indices along the coast are estimates using the geostrophic winds (Lavin *et al.*, 1991). It can be seen from the 1988 series that the station at 43°N, 11°W was representative of the whole area. Correlation analyses give $r>0.8$ with each of the other stations (Fig. 1). Table 1 gives the mean upwelling indices during the active period of upwelling (April to September) for the representative station.

From the wind data, we can extract the periods of five consecutive days when wind speeds were less than 6 m/s; these periods, called "Environmental Windows", are periods when turbulence and food availability as larval growth limiting factors in upwelling areas are minimized; and may be one of the keys to recruitment success (Cury and Roy, 1989). Table 4 lists the monthly presence (+) or absence (0) of such periods.

Results and discussion

The correlations between recruitment and the upwelling index for April to September (active upwelling season) and March to May (spawning season) are similar ($-0.5 < r < -0.6$) for the period 1976 to 1989 (Cabanas *et al.*, 1989) and for the period 1980 to 1989. Although they are not significant, upwelling appears to influence annual recruitment. But this index cannot on its own be considered a good forecast of recruitment. In part forecasting may not be possible without separating the pre-recruit phase into at least two stages, the larval drift stage when transport plays an important role, and the post-larval stage when survival depends on the abundance and availability of food.

Previous studies have tried to find the causes of sardine fluctuations in this upwelling area by comparing them with the position and strength of the Azores anticyclone. Dickson *et al.* (1985) found a negative correlation between the upwelling indices and sardine landings in area IXa for the period 1950 to 1984, and concluded that an increase in the intensity of northerly winds increased turbulence and Ekman transport, and reduced production at all levels in the food chain. Fiuza *et al.* (1982) found a positive correlation between the

Table 2. Landing of juveniles in the Galician zone (t).

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Jan	559	761	223	0	170	0	0	0	17	23
Feb	17	145	112	0	1 802	0	0	0	136	1
Mar	119	33	2	0	454	0	0	0	35	0
Apr	33	61	0	0	1 788	0	0	0	23	0
May	107	1	0	0	1 488	0	0	0	24	0
Jun	136	0	0	0	861	0	0	117	0	0
Jul	40	0	0	2	899	0	0	1 258	0	46
Aug	259	4	0	87	1 138	0	16	1 689	0	252
Sep	1 306	238	17	1 335	0	19	3	3 115	0	607
Oct	1 067	980	0	3 279	0	118	10	1 456	0	196
Nov	968	2 660	5	2 768	0	121	0	1 970	117	69
Dec	958	252	0	1 290	0	18	0	527	1	1

Table 3. Percentage of stock contribution according to birthdate.

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Jan	–	–	–	–	2	–	–	4	–	–
Feb	–	–	–	–	3	–	–	5	–	1
Mar	1	1	–	4	–	–	–	8	–	1
Apr	6	3	–	8	–	–	–	4	–	1
May	3	6	–	7	–	1	–	5	–	–
Jun	1	1	–	3	–	–	–	1	–	–
Jul	2	–	–	1	–	–	–	–	–	–
Aug	–	–	–	5	–	–	–	–	–	–
Sep	–	–	–	1	–	–	–	–	–	–
Oct	–	–	–	5	–	–	–	–	–	–
Nov	–	–	–	4	–	–	–	–	–	–
Dec	–	–	–	2	–	–	–	–	–	–
	13	11	0	40	5	1	0	27	0	3

monthly percentage of the total Portuguese landings (1939 to 1974) and upwelling indices three months earlier. Wyatt and Pérez-Gándaras (1986) also found a positive correlation between annual captures and dominant winds on the western shelf of the Iberian peninsula.

Table 3 shows that the period March to May is the most important part of the spawning season in terms of production of recruits. It can also be seen that there are periods when spawning produces few recruits, perhaps because the environmental conditions are unfavourable for larval survival. So any attempt to explain relations between environmental conditions and recruitment must take account of both upwelling indices and the environmental window concept.

From observations summarized in Tables 3 and 4 on successful spawnings and environmental windows, it can be deduced that in the months with a high survival of brood there was always an environmental window. Tables 3 and 4 show that in the period April to July, when there are no windows (0), the production of recruits is very small or fails completely. On the other hand, the more successful spawnings correspond to years with "Environmental Windows" in the months following the spawning, indicating periods of low turbulence and weak upwelling on the west coast.

In the first stage the coastal current must aid the transport of larvae from the spawning zone (Cantabrian Sea) to the pre-recruit zone in the West (Galicia). In this period (April to June) the circulation changes from the winter to the spring–summer pattern, with a change in the direction of the surface current. Depending on the timing of the change and on the velocity of the current, the brood from the Cantabrian Sea will either be transported to the West Galician coast where there is abundant food associated with coastal upwelling, or it will be dispersed off Cape Finisterre towards the open sea where many larvae die of starvation. But some larvae survive this obstacle, and reach the nursery area on the Atlantic coast, an upwelling zone, where food is abundant.

In 1983 and 1987, sea level on the west coast (Vigo) was significantly higher than during the rest of the decade, while in 1981, 1982, and 1986 sea level was lower than normal. The 1983 year class was the strongest on record, and the 1987 year class was also relatively strong. The 1988, 1989 year classes were the poorest in the decade (Fig. 3a).

Recruitment was poor in 1982, 1985, 1986, and 1988, perhaps due to dispersal of the eggs or transport to the open sea during periods of larval abundance, coinciding with the absence of environmental windows. Recruitment was very good in 1983 and 1987, years with en-

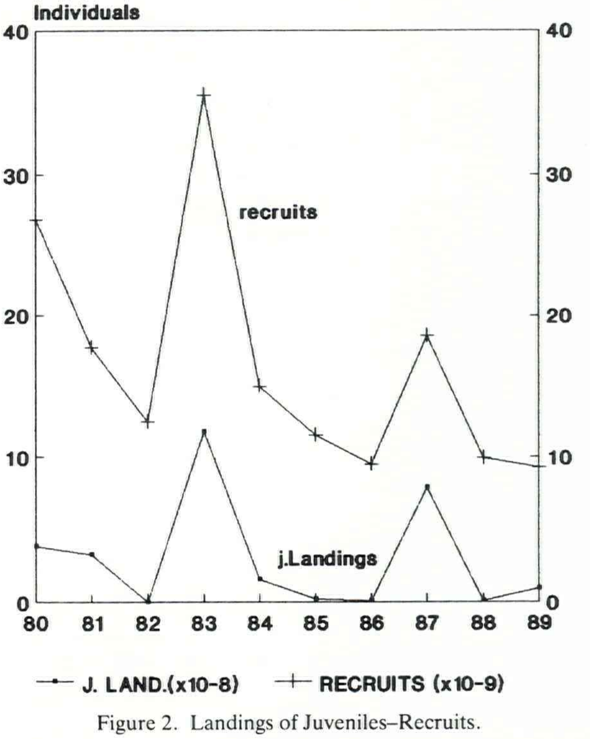

Figure 2. Landings of Juveniles–Recruits.

Table 4. Environmental windows (5 days consecutively of wind speed less than 6 m/s).

	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
Jan	0	+	+	+	0	0	+	+	0	+
Feb	0	+	0	+	+	+	0	+	+	+
Mar	+	0	+	+	+	+	0	+	0	+
Apr	+	+	0	+	+	0	0	+	+	0
May	+	+	+	+	0	+	+	+	+	+
Jun	+	+	+	+	+	0	0	+	0	0
Jul	+	+	+	+	+	+	0	+	+	+
Aug	+	+	+	+	+	+	+	+	+	+
Sep	+	+	+	+	+	+	+	+	+	0
Oct	0	+	0	+	+	+	+	+	+	0
Nov	0	+	+	+	0	0	0	0	0	0
Dec	0	+	+	+	+	0	+	0	+	0

+: presence of Environmental Windows.
0: absence of Environmental Windows.

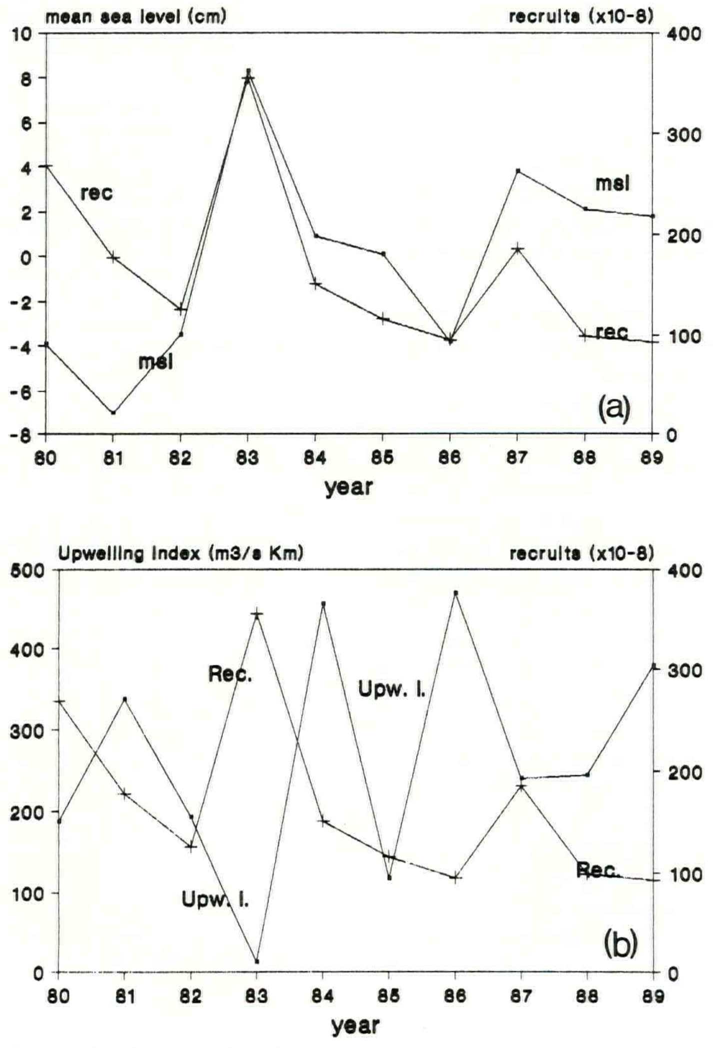

Figure 3. a. Mean sea level anomaly (Vigo) and recruitment. b. Upwelling index and recruitment.

vironmental windows throughout the larval phase. During this decade, the stock has varied within its normal limits, considering the cyclical oscillations of pelagic stocks, and is now in a period of low recruitment.

No clear trends have been identified during this decade in environmental parameters (upwelling index, temperature, sea level) which have remained within normal limits (Fig. 3). Only during 1983 were significant climatic anomalies noted; the upwelling season was reduced to half (to three months), and sea level was higher throughout the year than during the rest of the series.

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