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EKMAN TRANSPORT AND SARDINE YIELDS IN WESTERN IBERIA

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Abstratc

Sardine catches in the coastal waters of Portugal and western Galicia (ICES area IXa) are examined on a regional basis. Catch trends in the northern and southern parts of this area tend to be of opposite sign. Since Bakun indices calculated for the northern and southern limits of the region, and for a station in the centre, are all positively correlated, the links between upwelling and catch must be more entangled than previously surmised.

Evidence is summarized which indicates that several distinct stocks may exist in this area. It is suggested that if Ekman drift plays a role in larval recruitment, then the northerly as well as the easterly component must be taken into account.

Resumen

El transporte de Ekman y los rendimientos en el oeste de la península Ibérica.

Se analizan las capturas de sardina en las aguas costeras portuguesas y de las costas atlánticas de Galicia (Area IXa del ICES). La tendencia de las capturas en el area norte y sur de este area muestran signos opuestos. Los índices de Bakun conocidos para estaciones situadas al norte, centro y sur del area considerada muestran por el contrario todos ellos una correlación positiva. Es por ello que la relación entre afloramiento y las capturas de esta especie debe ser más compleja de lo que normalmente se supone.

Para dilucidar el tipo de relación existente se indican distintas evidencias de la posible existencia de varios stocks. Asimismo se sugiere que el transporte de Ekman afecta al reclutamiento de las larvas, siendo especialmente significativos los componentes Norte y Este de dicho transporte.

Introduction

The initial stimulus for this study was the sardine "crisis" experienced by Galician industry between 1947 and 1956. During those years, landings of sardines in Vigo and other Galician ports fell to about a tenth of their values a few years earlier when the normal annual catch was reckoned around 60.000 t. Captures in the Cantabrian Sea also fell to about the same extent. Although shorter crises, of a year or two, had occurred previously, records suggest that only once in the preceding 200 years did a scarcity of sardines persist for as long as a decade, sometime around 1876. So short of demand did available catches fall in the 1940's and 1950's that whole factories were uprooted from Galicia, and replanted in Malaga, Algeciras, and other cities in southern Spain. The crisis was thus an economic disaster for the region, much as similar sardine crises had been in France, between 1880 and 1888, and between 1903 and 1910.

The local press of those years of sardine scarcity provides a detailed picture of what took place, and in reading it, one gains the impression that the biological events were complex. Thus large shoals of juvenile sardines, parrocha, occurred frequently during most years of the crisis in one ría or another, and constantly led fishermen to anticipate a return to "normal" conditions, as long tradition dictated. But these appearances were fugitive, and disappointment returned. Shoals of adults sometimes appeared too, but often at unexpectedly great depths, and they were consequently inaccessible to the fishing methods then in use. But perhaps the most perplexing aspect of the crisis was the continuing success of Portuguese fishermen during those years, especially at Matosinhos, only 150 km to the south of Vigo. Portuguese sardine landings fell briefly in 1949, but were almost up to their accustomed levels again the following year, and continued to rise throughout the years of impoverishment in northern Spain.

Portuguese landings themselves provide a picture of regional change on a more detailed scale. Table I shows annual landings of sardine between 1958 and 1969. The coast was divided into 50 km sections and the landings for ports in each section added together. For this short series, catches in northern Portuguese ports (Viana, Leixoes, Aveiro) were at first above the 12 year mean for their respective sections. Between 1962 and 1967 or 1968 the same situation held in the more southerly sections (Nazaré, Peniche, Setúbal, Sines). Thus the overall pattern of change in sardine captures in western Iberia conceals a rich structure.

Table I.- Portuguese sardine landings on 50 km lengths of coastal from N to S, in 10 t.

	Main ports								
Years	1	2	3	4	5	6	7	8	9
1958	0.1	20.4	4.6	7.6	3.0	0.2	1.3	4.6	1.4
1959	0.1	19.3	6.3	7.6	2.6	0.2	1.4	2.8	0.4
1960	0.1	19.9	5.8	7.1	3.7	0.1	0.8	3.3	1.2
1961	0.3	20.1	9.1	1.5	4.1	0.1	0.8	2.8	0.5
1962	0.3	15.5	6.8	9.1	3.9	0.1	1.1	4.4	1.7
1963	0.5	17.4	6.6	10.8	3.6	0.0	0.5	3.5	1.1
1964	1.3	21.8	7.3	14.2	9.2	0.1	1.0	4.0	0.3
1965	0.2	15.1	5.4	16.4	7.8	0.0	1.2	6.8	0.9
1966	0.2	11.8	4.7	16.8	9.9	0.0	1.2	4.9	1.3
1967	0.2	11.9	2.7	26.6	7.8	0.0	1.4	5.2	2.0
1968	0.1	7.3	2.0	16.2	4.1	0.0	0.5	2.9	1.1
1969	0.4	6.8	1.5	10.1	2.6	0.0	0.3	2.1	0.9

Main ports:
(1) Viana, (2) Leixoes, (3) Aveiro , (4) Figueira, (5) Peniche, (6) Ericeira, (7) V. Franca, (8) Setúbal, (9) Sines

Sea surface temperature data (Wooster *et al* , 1976) show that Iberian coastal waters lie at the northern limit of a system analogous to other eastern boundary currents. Upwelling is seasonal and takes place in the (northern) spring and summer. But unlike the poleward extension of analogous systems, the Iberian upwelling region is separated from the rest of the system off northwest Africa by the Gulf of Cadiz and the entrance to the Mediterranean, while to the north the coast makes an abrupt turn eastwards into the Bay of Biscay. Wooster *et al* (1986) showed that south of 37^{0} N (Cape San Vicente) there is a broad zone where mid-ocean/coastal temperature differences are small (their fig. 4) and where westward Ekman transport is negative or weak (their fig. 6).

Upwelling occurs too in the coastal zone of the Cantabrian Sea, at least as far east as Gijón, Though it has not so far attracted as much attention as that to the west of the peninsula. Upwelling to the north of Spain is different in character, involves a much deeper layer of water, and depends less on variations in local winds (Fraga *et al.* , 1985).

There are two different though nor irreconciliable views of how upwelling may influence the abundance of pelagic fish. On the one hand, increased upwelling rates can lead to more production, better survival and growth of fish larvae, hence to a positive link between upwelling rates and year class strength. There may be limits to the benefits of increased upwelling in this sense, based on the increased dispersion of larval food (Lasker, 1981), or on changes in the kind of food produced (Wyatt, 1980), but these limits are probably not reached in the Iberian system where upwelling rates are quite low (Dickson *et al.*, 1986). On the other hand, increased upwelling, or increased offshore Ekman transport, may directly reduce larval survival and subsequent recruitment by dispersing the larvae to areas whence they cannot return (Bailey, 1981).

In the case of the Iberian sardine, both positive (Fiuza *et el.*, 1982) and negative (Dickson *et al.*, 1988) links with upwelling indices have been identified. Westerly Ekmán transport was the common index in these two studies. It can be argued that if there is a negative correlation between westerly transport and survival, in view of the geographical features already referred to, northerly transport too in the northern part of the peninsula, and southerly transport in the southern part should also lead to poorer survival, since these directions at the geographical extremes of the peninsula are both offshore (fig. 1). In fig. 1 a, there is a net northerly residual, and larvae spawned in the northern part of the region fail to recruit to the coastal population. In fig. 1 b, there is a net southerly residual and larvae in the south are at a relative disadvantage. Larvae spawned on the central part of the coast might not be affected by either trend.

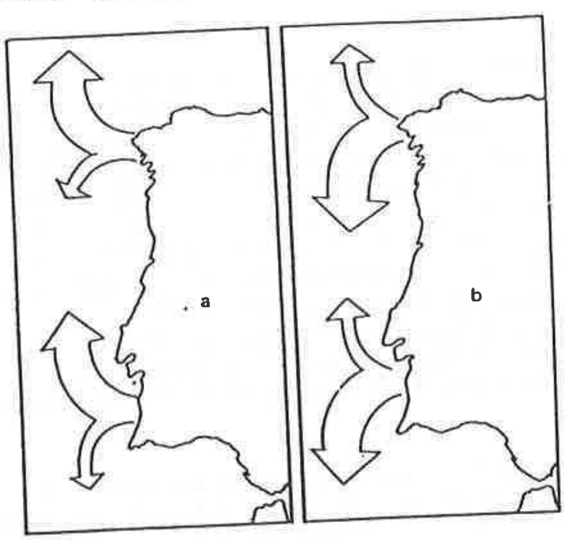

Fig. 1. Sketch of western Iberian peninsula. Note that both northerly (a) and southerly (b) components of Ekman drift, as well as westerly, may disperse larvae offshore.

This hypothesis depends to a large extent on the relation between the timing of spawning and the duration of the upwelling season. The spawning seasons and areas of the sardine in this region are not well known, but available information indicates that spawning generally takes place with greatest intensity in autumn (October to December) and spring (March to May). Eggs and larvae are much less abundant in January (but see below) and February and in the summer (June to September). In areas where sampling has been adequate, there are two peaks in egg abundance. This information is summarized in table II.

Table II.- Spawning seasons of sardine in Portugal and northern Spain.

Area	Autumn peak	Spring peak	Reference
Faro	?	May	Ré 1979
Peniche	December	April	Ré 1984
Sines	October	March	Ré 1984
Vigo	November	March	Ferreiro,Labarta 1984
C. Ortegal	?	March/April	Arbault, Lacroix 1973 Franco, Solá 1985
Santander/Bilbao	?	March/April	Arbault, Lacroix 1973 Solá, Franco 1985

The spawning areas identified in the studies listed in table II are shown in Fig. 2. Unpublished Portuguese results have revealed high egg concentrations about 60 km off Matosinhos during a January cruise (Ré, pers. com., 18.IX.86), and this area has also been tentatively indicated in the figure.

Spawning thus occurs mainly in the months when upwelling is quiescent, but important amounts of spawning occur in March and April as the upwelling season begins. It is the eggs and larvae of these months which would be a risk in terms of Bailey's (1981) hypothesis. In terms of the modified form of this hypothesis proposed here, one can suspect that spring spawning off western Galicia would be at risk were northerly drift predominant, and that off Sines under the opposite circumstances. Spring spawning off Peniche might not be at risk at all from this cause.

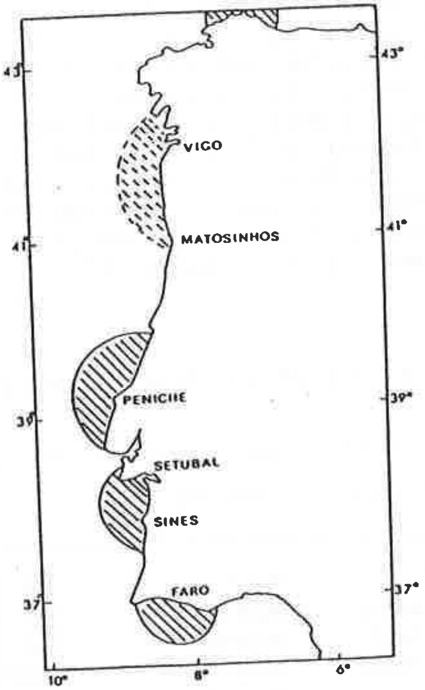

Fig. 2. Spawning areas of sardine in western Iberian coastal waters. cf table II.

Methods and Results

The hypothesis sketched in fig. 1 is explored here using calculations of Ekman transport kindly supplied by A. Bakun. Monthly values of the easterly and northerly components are available for the period from 1946 to 1984. The values used are referred to Cabo Finisterre (43^0 N, 9^0 30' W) and Cabo de Roca (39^0 N, 9^0 30' W). The catch data are taken from ICES and Portuguese sources. These time series have been examined using elementary statistical techniques.

The long term average patterns of Ekman transport for the 39 year period are shown in fig. 3. Westerly transport at Roca is greater than at Finisterre, and northerly movement is weaker, but in general the two are positively linked in most months.

Table III. Correlation coefficients between easterly (E) and northerly (N) components of Ekman transport at Finisterre (FIN) and Roca (ROC), for the period 1946 to 1984 (d.f.= 37)

x	y	months	r	t	P<
ROC, N	FIN, N	XII, I, II	0.838	9.346	0.001
		III, IV, V	0.694	5.871	0.001
		VI, VII, VIII	0.183	1.130	n.s
		IX, X, XI	0.834	9.197	0.001
ROC, E	FIN, E	XII, I, II	0.897	12.378	0.001
		III, IV, V	0.472	3.266	0.005
		VI, VII, VIII	-0.079	0.481	n.s
		IX, X, XI	0.600	4.561	0.001

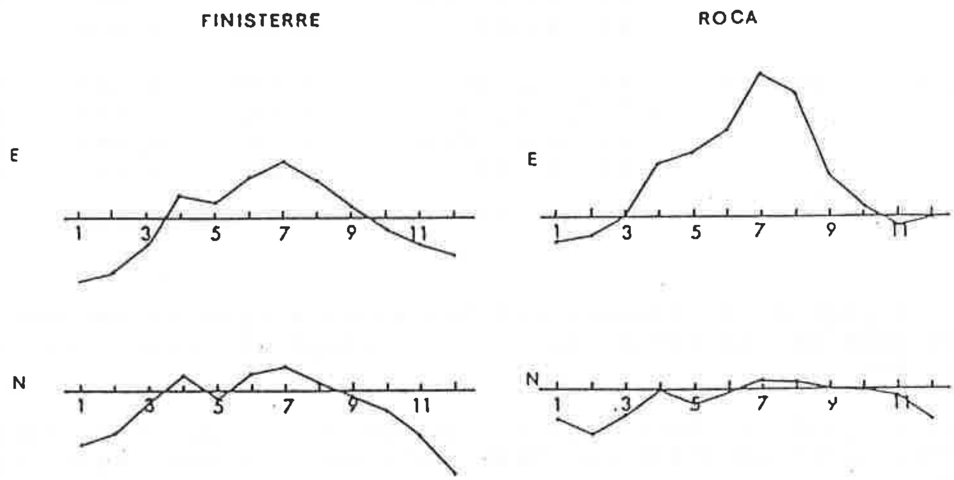

Fig. 3. Long term (1946 to 1984) monthly patterns of Ekman drift at Cabo Finisterre (43⁰N. 9⁰30' W) and Cabo de Roca (30⁰ N. 9⁰30'W).

Correlation coefficients between the easterly and northerly components of transport at the two stations are summarized in table III. For each pair of variables, the coefficients are higher and more highly significant during the autumn and winter quarters (September to November, December to February) than in spring (March to May). In summer they are not significant. The northerly and easterly components at Finisterre are highly correlated all year, but this is only true of the winter quarter at Roca (Table IV), and then weakly.

Table IV. Correlation coefficients between the two components (E and N) of Ekman transport at Finisterre (FIN) and Roca (ROC) respectively (d.f.= 37) of Table III.

x	y	months	r	t	p<
FIN, E	FIN, N	XII, I, II	0.638	5.033	0.001
		III, IV, V	0.540	3.901	0.001
		VI, VII, VIII	0.755	7.008	0.001
		IX, X, XI	0.700	5.959	0.001
ROC, E	ROC, E	XII, I, II	0.578	4.307	0.001
		III, IV, V	0.381	2.503	0.05
		VI, VII, VIII	0.145	0,982	n.s.
		IX, X, XI	0.449	3,057	0.01

A plot of Portuguese catches against Spanish catches in IXa shows that we can recognise several groups of years, as follows (fig. 4):

Group A, 1946 - 1956: Spanish catches were low, while Portuguese catches declined (1946 to 1949) and then increased again (1949 to 1956).

Group B, 1957 - 1967: both Spanish and Portuguese catches were relatively high.

Group C, 1968 - 1978: Portuguese catches fell to moderate levels while Spanish catches continued for several years at their earlier levels (1968 to 1972) and then fell suddenly (1973) and remained there until 1978.

Group D, 1979 - 1984: Spanish catches rose very quickly to their highest levels for the period while Portuguese catches changed little.

Thus the years of most marked change in catches were 1967 - 1968, 1972 - 1973, and 1978 - 1979.

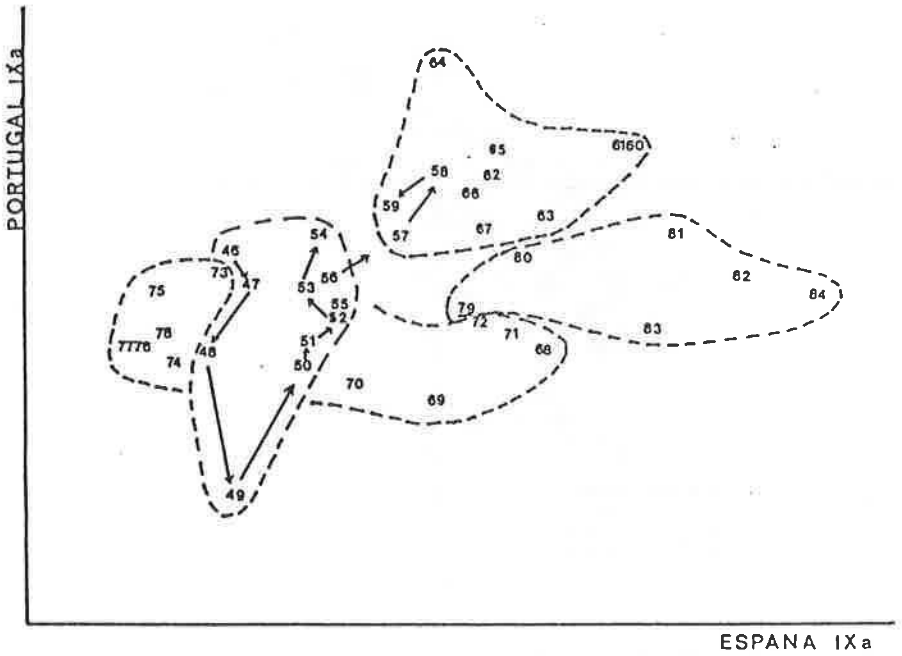

Fig. 4. Plot of Portuguese sardine landings against Spanish landings from area IXa. Figures indicate years.

The catch data shows several significant autocorrelative signals. Both Spanish and Portuguese catches in area IXa are very highly autocorrelated whit time lags of 1 to 3 years, and with time lags of 10 to 12 years. The last result confirms that of Moura & dos Santos (1984), who found a strong link between Portuguese sardine abundance and solar activity.

Plots similar to fig. 4 of Ekman transport values cannot be grouped into sequences of years. An example is given in fig. 5. But they do emphasize the high interannual variability, and in some cases the long term trend recognised by Dickson et al (1988). In the Oporto data there is no detectable autocorrelation in any of these transport time series.

If we take the modulus of Ekman transport as a measure of energy input, then we can plot energy on catches. Fig. 6 shows an example in which all four series of values for April have been summed y = (Fin, N) + (Fin, E) + (Roca, N) + (Roca, S) and plotted against the total catch in area IXa one year later. A reasonably clear pattern is recognisable in this figure, and in that for the quarter containing April, but less clearly at other times of the year. The line I1 of the figure might be taken to represent an index of carrying capacity.

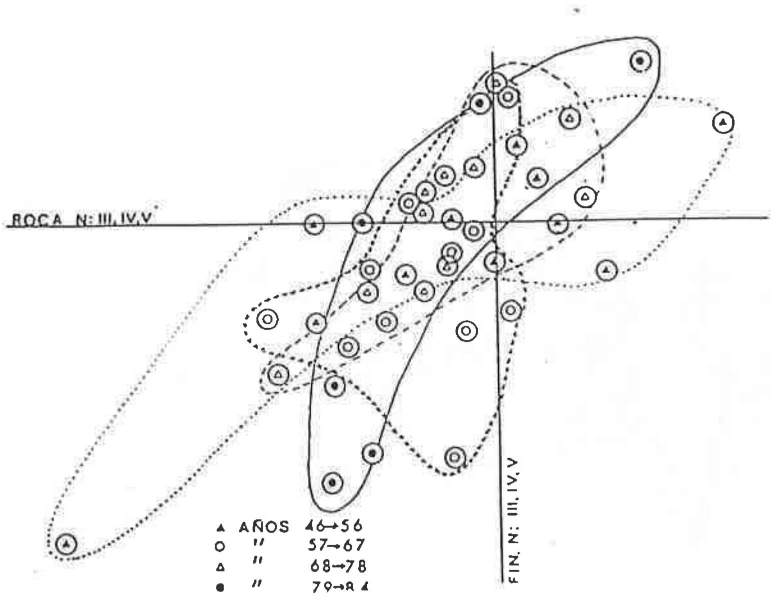

Fig. 5. Plot of Ekman transport at Cabo Finisterre against Cabo de Roca. Grouping of years as in fig. 4.

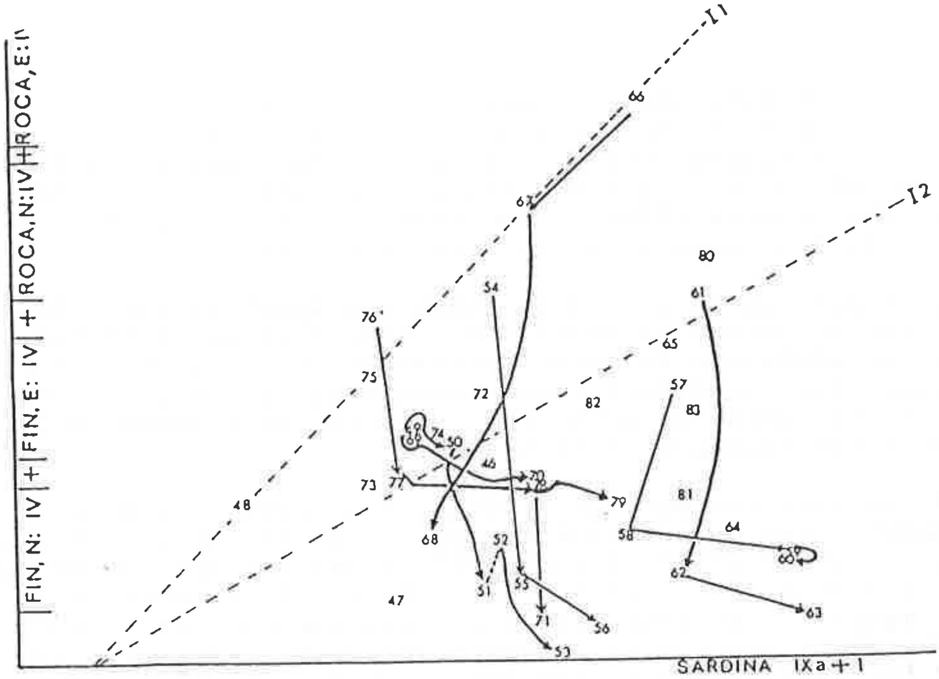

Fig. 6. Modulus of Ekman transport plotted on area IXa sardine landing one year later. For explanation of lines I1 and I2, see text.

In many years, we see that the catch is high when the carrying capacity is low. Only a few years in each of the groups A to D previously identified fall near the line. The time trajectory here seems to cycle in a predominantly vertical direction towards and away from either the line I1, or the lower line I2. Thus we can recognise years of "high input" which fall near the line and "pasive" years, the rest.

The annual patterns of Ekman transport within these groups of years have been examined and are shown in fig. 7. Note that the figure shows anomalies. The years of "recovery" have been omitted from the figure for clarity. We draw attention to the following features of these curves. Years of "high input" are characterized by an early, strong, and persistent upwelling season, which continues until July. Years of "medium input" are characterized by the absence or upwelling in May and June, and by a late upwelling peak in July and August, which is specially prominent in the Roca, N time series. This group also exhibits upwelling in winter, specially in January. The main features of the "passive" years are that upwelling is weak and sporadic, or fails to occur, for most of the year, and reaches a small peak in September or October.

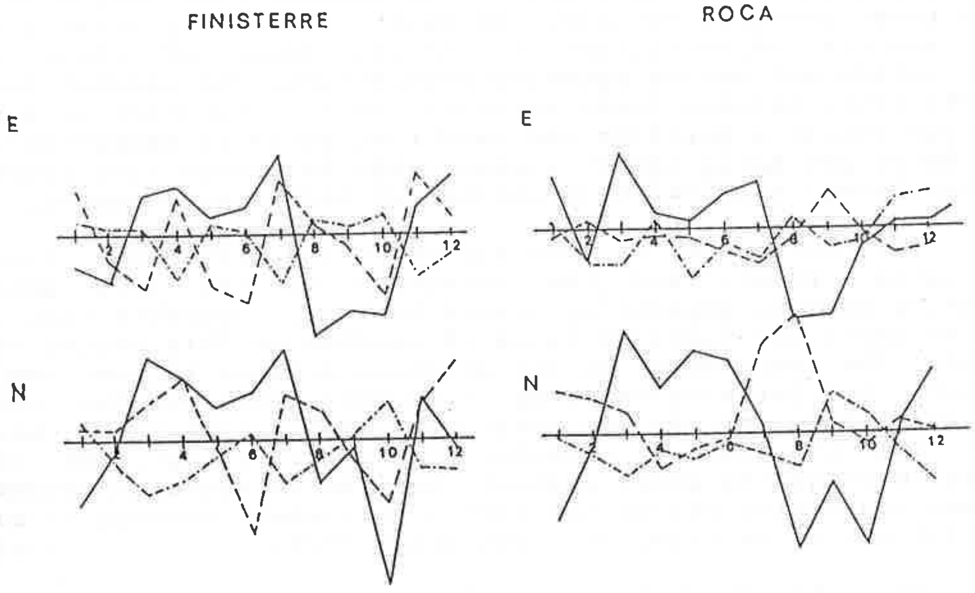

Fig. 7. Mean monthly patterns of Ekman transport for groups of years identified in fig. 4; ——— years 1946 to 1956; ----- years 1957 to 1967; ·-·-·- years 1968 to 1978.

The shorter time series (1958 to 1969) already introduced to illustrate regional trends in Portugal was divided into northern (Miño to Aveiro) and Southern (Nazaré to Sines) parts, and compared with monthly and quarterly Ekman transport values for Roca, N. The only month in which a significant correlation emerged was July ($p < 0.001$, $r= -0.857$) for the southern part. The equivalent figure for July and the northern part is not significant ($p < 0.05$), but the trend is positive. Thus there is a north-south shift in the distribution of catches in accordance with the hypothesis suggested in Fig. 2; the shift refers to adults, not to larvae, and only operates in July. But the strong autocorrelations of the catches with time lags of 1 to 3 years suggest that it could refer to the larval phase.

Discussion

The result summarized above suggest that sardine catches, and presumably therefore sardine abundance, depend for two or there consecutive years on the amount of total Ekman transport during the spawning period in particular years. This character may be of two different kinds, strong and persistent transport in spring, beginning in late February or early March, or late summer transport. There are no years in the present time series in which both these features occurred. We might intuitively therefore link the success of recruitment to the coincidence of these events with autumn and spring spawning populations, and suggest that the relationship between their strength and the abundance of sardines in area IXa is a positive one, and that suitably energetic events in March and April are on average able to create conditions for better larval survival than similar events in late summer.

The existence of two different and favorable types of upwelling regime, and the existence of two well separated spawning seasons apparently linked to them, suggests that there are at least two distinct races of sardine in this region (Wyatt, 1985). The separation of the spawning seasons is confirmed by a fishery for juvenile sardines in Galicia which has two peaks in the year (Fig. 8). We can quite confidently link these two peaks with the two spawning seasons. The relative magnitude of the peaks in different years suggest that the relative importance of autumn and spring broods has been a persistent feature of sardine populations in Galicia, at least since 1925.

In years which produce relatively good year classes, the easterly anomalies (fig. 8) are positive, hence onshore, for both the spring and autumn spawning windows. This explains the results of Wooster to which we have already referred. But so are the northerly events, which suggests that neither Bailey's hypothesis, nor its modification outlined above, are supported in the present case. In short, the year class strength of sardines in area IX a seems to be positively correlated with the energy input at critical times of the year.

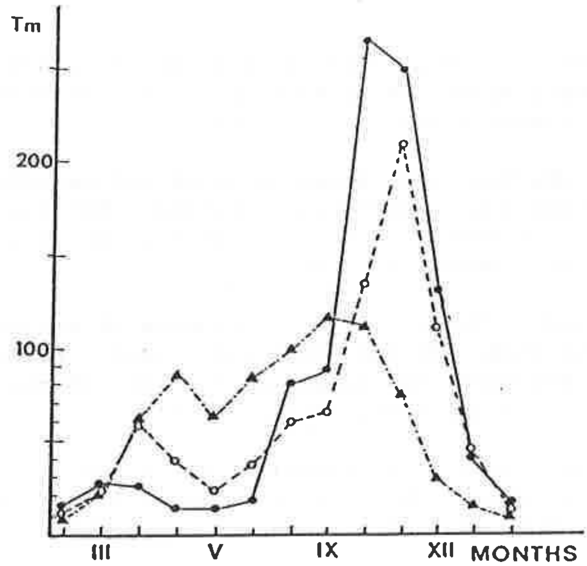

Fig. 8. Mean monthly landings of juvenile sardine (parrocha) for different groups of years, in Marín; 1925 to 1934; o-o-o-o 1935 to 1944; -.-.- 1945 to 1952.

The Galician "crisis" of 1947 to 1956 (years in group A) was thus due to low energy input for both spring and autumn spawning races of sardine. During those years, Ekman transport at Finisterre and Roca was weak and intermittent.

The beginning of the recovery was provided by a good autumn generation in 1957, which sustained the fishery until 1961. Good autumn generations in 1961 and 1965 kept catches high. There were then two excellent and consecutive spring broods (1966 and 1967) poor or moderate broods in 1969 and 1972 to 1974 (autumn) and 1975 and 1976 (spring), and then moderate to good autumn broods again in 1980 and 1982. While Anadon's data (fig. 9) suggest that the spring population was more important between 1925 and 1952, this analysis suggests that autumn broods have been more important in sustaining the fishery since then.

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