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INFLUENCE OF HYDROGRAPHICAL AND METEOROLOGICAL FACTORS ON CATCH AND RECRUITMENT STRENGTH OF THE SPRAT STOCK IN WESTERN NORWAY

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INTRODUCTION

The Norwegian fishery for sprat (*Clupea sprattus* L.) takes place mainly in the Oslofjord and in the fjords of western Norway south of Stad. The season lasts from May to October and by far the greatest part of the catch is taken by purse-seiners and utilized in the canning-industry. During the last ten years the average annual yield has been about 9000 tons.

Various authors have demonstrated relationships between hydrographical factors and recruitment or catch of sprat. Based on observations over five years, HELLAND-HANSEN and NANSEN (1909) found that a comparatively small area of coastal water, measured on a vertical section seaward from western Norway, co-occured with small catches of sprat the same year. They also found a correspondence between the dimensions of the area of coastal water in this vertical section and the rainfall in southern Norway and northern Germany the preceding year. MOLANDER (1939, 1943, and 1952) gives several examples of how sprat catches and strength of recruitment depend on hydrographical and meteorological conditions. Along the Swedish west coast easterly and northerly winds caused diminishing catches while southerly and westerly winds were favourable. Years with relatively weak predominant winds had the richest year-classes of sprat. For the sprat stock both along the west coast of Sweden and along the east coast of England, VELEY (1951) found that predominant and strong offshore winds were correlated with relatively poor year-classes.

The present investigation is confined to the West-Norwegian part of the sprat stock. SUND (1911) assumed that this sprat mainly originated from spawning grounds in the Skagerak and that the larvae were brought by the coastal current to the fishing area. This view has been supported by BJERKAN (1923 and 1926), even though analysis of vertebrae counts

(DANNEVIG 1951), egg and larvae investigations (DANNEVIG 1954, GUNDERSEN 1954), and examination of length composition of the catches (BJERKAN 1950 and 1958) indicated that local spawning in the fjords of western Norway might be of some importance for the recruitment.

The coastal current carries water of low salinity, here called Skagerak water, from the Skagerak westward and northward along the coast of southern Norway. If SUND's assumption is correct, the recruitment to the sprat stock will be largely dependent on the coastal current. The water transport, the direction, and the speed of the current will be among the most important factors influencing the drift of the sprat larvae. If the hydrographical conditions of the coastal current explicitly affect the recruitment to the stock in western Norway, it supports the view that spawning in the fjords may be of minor importance.

In order to compare hydrographical conditions of the coastal current and the recruitment to the sprat stock, an attempt has been made to express numerically : Variations in quantity of Skagerak water from year to year, and variations in strength of recruitment.

Variations in the strength of recruitment could be revealed by determining the abundance of sprat larvae in the coastal current each year. However, the available material is restricted, and an attempt has been made to express recruitment strength by means of sprat catch statistics. It is probable that the annual sprat catches from western Norway can be used assuming that the quantity of a year's catch reflects the recruitment strength the year before.

The calculated hydrographical parameter will to some extent be influenced by meteorological factors such as wind. It is known that northerly winds on the coast of western Norway transport the surface layers of the coastal water away from land (HELLAND-HANSEN and NANSEN 1909, EGGVIN 1940). In view of this, wind observations have been compared with the calculated average thickness of the Skagerak water.

BJERKAN (1958) states that the northward drift of the sprat larvae is related to the force of the coastal current at the end of the summer, and that this is what causes the fishing districts to shift from year to year. It seems likely that not only the force but also the direction of the coastal current and the wind effects are determining factors in the destination of the larvae. Since few current measurements are available, wind observations have been used to investigate the influence of northerly winds upon the distribution of the catches within the fishing area in western Norway.

Table 1. The mean depths of the $34^0/_{00}$ isohaline in the summer months at Utsira and the sprat catches in western Norway. Mean depth in metres, catch in 1000 "skjepper".

Year	Mean depth d	Catch c
1942	41.6	—
43	41.1	488
44	31.1	346
45	42.0	319
46	45.9	592
47	29.9	327
48	38.1	213
49	30.7	393
50	38.1	208
51	36.4	336
52	35.9	213
53	46.8	392
54	40.7	390
55	31.2	166
56	46.8	104
57	37.7	438
58	50.7	144
59	35.9	441
60	32.9	379
61	54.1	240
62	38.5	549
63	39.8	804
64	39.8	539
65	—	308
	$\bar{d} = 39.38$ $s_d = 6.385$	$\bar{c} = 362.1$ $s_c = 163.46$

MATERIAL

Since 1942 the Institute of Marine Research has collected data, usually every fortnight, at a fixed oceanographic station five nautical miles southwest of Utsira Island (59°15' N, 4°47' E). Dr. JENS EGGVIN has kindly made salinity isopleth diagrams from this station available. The area on the Utsira isopleth diagrams enclosed by the surfaceline and the $34^0/_{00}$ isohaline depth between the dates 1 May and 30 September was measured with a planimeter. From the values obtained the mean depth of the $34^0/_{00}$ isohaline each year was calculated (Table 1). This expresses the average thickness of the Skagerak water in the summer months.

In Table 1 is given the sprat catches in western Norway in "skjepper", (one "skjeppe" is equivalent to 17 kg and is the Norwegian standard unit of sprat measurement).

The wind data used have been collected at the meteorological station on Utsira Island (59°18' N, 4°53' E) and reported in JAHRBUCH DES NORWEGISCHEN METEOROLOGISCHEN INSTITUTS 1942—1944 (1944—1945) and NORSK METEOROLOGISK ÅRBOK 1945—1964 (1946—1965). The wind observations of each year have been transformed into a wind-vector. The wind-vector comprises the products based on monthly mean wind forces and the number of cases with wind from north, summed over the months May, June, July, August, and September. The wind forces are given according to the Beaufort scale. The wind directions for the years up to and including 1948 are given in the eight general directions, later in the scale 01—36 reduced to the nearest direction divisible by three. This means that the wind-vectors for the period 1942—1948 cover a sector of 45° around north and for 1949—1964 a sector of 30°.

RESULTS

In Fig. 1 the mean depth of the $34^0/_{00}$ isohaline one year is compared with the the sprat catch in western Norway the following year for the period 1942—1965. Years having relatively great mean depths are as a rule followed by years giving large catches of sprat.

The relationship demonstrated in Fig. 1 has been correlated statistically for the 23 years with interdependent sets of data, *c* and *d* (Table 1). Calculation of the correlation coefficient gave $r_{c,d} = 0.4713$, $(P \approx 0.02)$.

The result indicates that there is a certain linear correlation between the two factors, which means that good catches seem to be conditioned by a thick layer of Skagerak water the previous year. But the value of the coefficient shows clearly that the interdependence is restricted.

From the residual variance $s_c'^2 = s_c^2\,(1-r^2_{c,d}) = s_c^2 \cdot 0.77$ it may be seen that a great part of the variance of the catch is caused by other factors than those expressed in the mean depth of the $34^0/_{00}$ isohaline. Only about 22 % of the variance may be explained as due to changes in the thickness of the Skagerak water near Utsira.

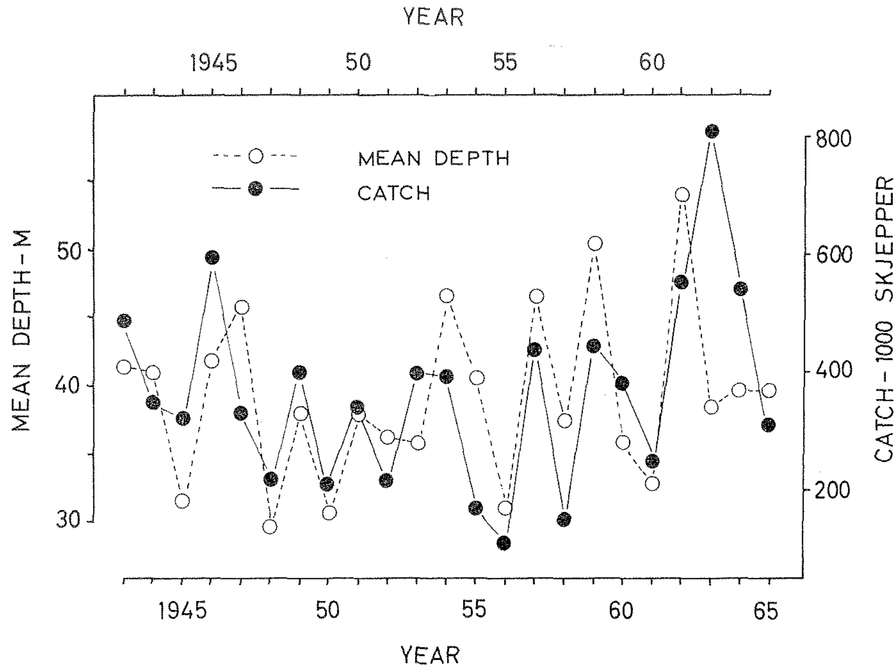

Fig. 1. The mean depth of the $34^{0}/_{00}$ isohaline at Utsira in the summer months compared with sprat catch in western Norway the subsequent year.

In Fig. 2 the thickness of the Skagerak water is compared with the calculated wind-vectors of northerly wind the same year. The figure indicates a restricted relationship between the mean depth of the $34\,^{0}/_{00}$ isohaline and the wind-vector, showing that small wind-vectors give great thickness and conversely. Consequently, in view of Fig. 1, northerly wind may be a primary factor in determining the recruitment strength by influencing directly the transport of sprat larvae. However, a comparison of wind-vectors and catch gives a lower correlation than that obtained between the thickness of Skagerak water and catch.

In Fig. 3 the wind-vectors are compared with the sprat catch in Rogaland which is the southernmost county within the fishing area in western Norway. The annual catch in Rogaland is expressed as a percentage of the total catch in western Norway and the wind-vectors of one year are compared with the catch percentage the subsequent year.

The comparison indicates that when weak northerly winds predominate during summer a greater part of the total sprat catch will be taken in Rogaland the following year.

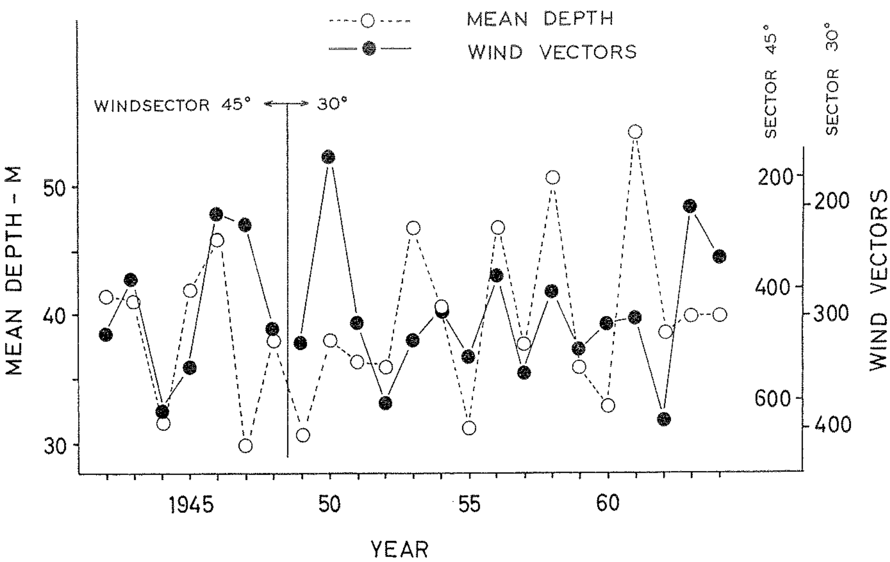

Fig. 2. The mean depth of the $34^{0}/_{00}$ isohaline at Utsira in the summer months compared with wind-vectors of northerly winds. The wind-vectors for the period 1942—1948 cover a sector of 45° around north and for the period 1949—1964 a sector of 30°.

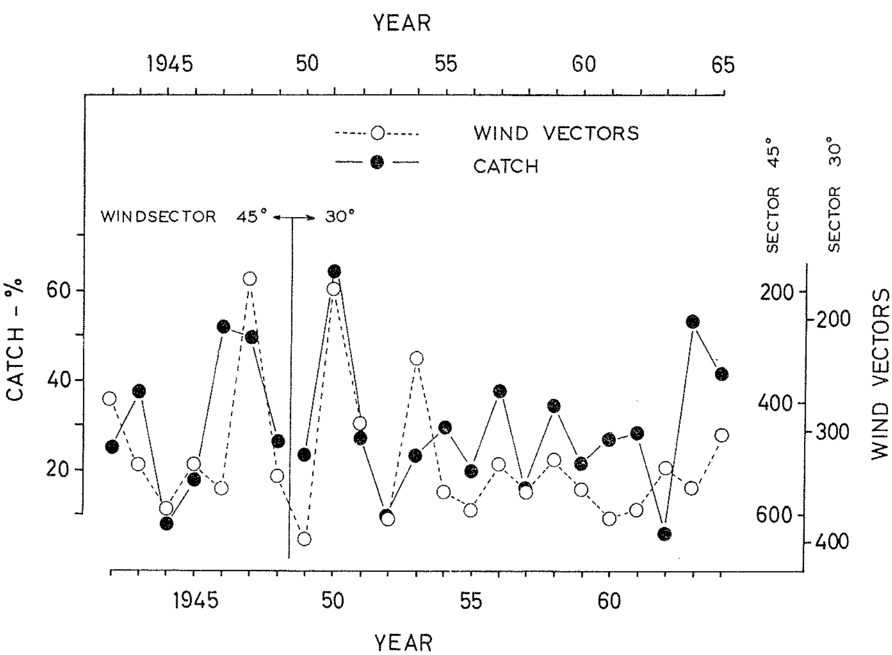

Fig. 3. Wind-vectors of northerly winds compared with sprat catch in Rogaland county the subsequent year as percentage of total sprat catch in western Norway. The wind-vectors for the period 1942—1948 cover a sector of 45° around north and for the period 1949—1964 a sector of 30°.

DISCUSSION

The fixed oceanographic station near Utsira has a position well suited for the investigation. The observations are taken within the coastal current between the two principal sprat fishing districts in western Norway, the Hardangerfjord area and the Ryfylkefjords; the depth here is more than 200 m. The observations from the station do not give information about the direction and speed of the coastal current and tell little about the horizontal extent of the Skagerak water. Variations in the thickness of Skagerak water, however, are clearly demonstrated from the observations.

Salinities below $34^0/_{00}$ are characteristic for Skagerak water (LAEVASTU 1963). This is also the limit for the *coastal water* as used by HELLAND-HANSEN and NANSEN (1909), and they point out that the variations in vertical and horizontal extent are best demonstrated by choosing this limiting value.

The period 1 May - 30 September covers the time when sprat larvae are likely to appear along the coast of western Norway, assuming recruitment from spawning areas in the Skagerak and the Kattegat with spawning optimum in May and June (HÖGLUND 1938, LINDQUIST 1961).

Outside western Norway very few sprat larvae have been found (LJØEN 1962). Later investigations (present author, unpublished) gave evidence that sprat larvae of more than 20 mm length avoid the plankton nets used. Further east in the coastal current the larvae are smaller and data from plankton net surveys are more reliable. DANNEVIG (1956) investigated the outer Norwegian coastal waters in the Skagerak south of Ferder and between Larvik and Kristiansand taking vertical hauls from 50 m to the surface with a one metre plankton net. His data give the following averages :

1950	13.4	sprat larvae per haul
1951	2.1	— » —
1952	4.6	— » —
1953	46.7	— » —
1954	42.5	— » —

There seems to be no relationship between the average number of larvae per haul one year and the catch of sprat in western Norway the following year. For example, the number of larvae in 1953 was ten times that in 1952, but the corresponding catches of sprat in 1954 and 1953 were almost similar.

The assumption that the sprat catch directly reflects recruitment strength is based on particular facts regarding the sprat fishery. Between 1920 and 1930 more than 95 % of the sprat catch consisted of one year old sprat, after 1930 two year old sprat have been found more frequently

(BJERKAN 1950). Yet it may be assumed that the fishery in the years 1943 to 1965, which are covered by this investigation, has mostly been concentrated on single year-classes. Samples taken from sprat catches during the last decade show length compositions which support this view (GUNDERSEN, personal communication).

Table 1 illustrates considerable variations in annual yield of the West-Norwegian sprat fishery. Several factors may influence the catches.

The abundance is probably directly dependant on the strength of recruitment the year before, because the fishery is mainly restricted to only one year-class. This gives the pronounced annual variations in the sprat fishery.

The availability does not change much from year to year, and this factor has a small influence on the catch. The sprat fishery takes place in inshore waters nearly independent of wind and weather conditions.

The effort in the fishery cannot be expressed by exact data as participation, fishing period, equipment, etc. are not specified in available statistics. Sild- og Brislingsalslaget, Bergen, which is the sales organization of the sprat fishermen, claims that about 300 purse-seiners take part in the fishery every year. The number has varied little, and was the same even during World War II. During the years covered by this investigation, the efficiency of the sprat fishery has increased due to better boats, synthetic fibre seines, echo sounders, sonar and fishery by artificial light. The number of land-seines has decreased and participation is lower to-day than 20 years ago. However, the average annual yield for the whole country has changed very little. For the decades after 1911 it has been:

1911—1920	582 000 skjepper
1921—1930	604 100 »
1931—1940	483 000 »
1941—1950	483 100 »
1951—1960	492 900 »

This indicates that the increased effiency has not affected the catch.

An evaluation of the factors influencing the catch indicates that abundance is the decisive factor, and that the abundance in turn is mainly determined by the strength of recruitment the year preceding the fishing season.

Weak northerly winds during summer seem to be favourable to the sprat catches the following year in the southernmost district within the fishing area (Fig. 3). According to EGGVIN (1940), coastal water masses transported out from land by prevailing winds and pressed northward are later again found near land. This may explain the distribution of the sprat fry and thereby the catch, taking into consideration that the fry is limited to these upper water layers.

Based on the various comparisons the following explanations seem plausible: Years having a weak water transport and much northerly wind in the summer will show a restricted thickness of Skagerak water on the isopleth diagrams. The upper water layers are shifted out from land and the $34^0/_{00}$ isohaline is "lifted". In years when the coastal current carries much water and there is less northerly wind, the thickness of the Skagerak water will be relatively great. Large water transport will increase the chances for transport of sprat larvae from the spawning area in the Skagerak and the Kattegat to western Norway. If the surface layers where the larvae stay are transported seawards, it is possible that under such conditions larvae will not be available to maintain the stock in western Norway. Conversely, a powerful coastal current and weak northerly wind in the summer should favour the influx of larvae and thus increase the sprat catch the following year.

HELLAND-HANSEN and NANSEN (1909) concluded that a great volume of coastal water gives a good catch of sprat the *same* year (see p. 63). This does not agree with the present investigation. A correlation analysis between the thickness of Skagerak water and the catch from the same year indicates no relationship.

CONCLUSIONS

The results from the various comparisons between hydrographical data and catch and catch distribution indicate that the yield of the sprat fishery in a particular year is influenced by current and wind conditions during the preceding year. These relationships suggest that such abiotic factors play a relatively significant part in determining the recruitment strength compared to presumptive important biotic factors, such as success in spawning, food, predators etc.

The indicated relationships support the view that the sprat in western Norway originate from spawning grounds in the Skagerak and the Kattegat.

The correlations are too weak to form the basis for any forecast of the sprat catch.

SUMMARY

The dependence of recruitment strength on hydrographical conditions has been studied, *i. e.*, possible relationship between the transport of sprat larvae from the Skagerak to the stock in western Norway and the thickness

of Skagerak water in the coastal current. The material consists of data from 23 years of hydrographical observations and catch statistics. A correlation analysis gave the correlation coefficient $r = 0.4713$ ($P \approx 0.02$). which means that good catches seem to be conditioned by a great thickness of Skagerak water the previous year.

The validity of the material is discussed, especially the use of catch statistics as numerical expression of recruitment strength.

An analysis of the influence of prevailing winds on the hydrographical conditions and on the catch distribution has been carried out. Weak northerly winds during summer seem to give the southernmost county in western Norway a greater proportion of the total sprat catch the following year.

The results of this investigation indicate that the majority of the sprat in western Norway originate from spawning in the Skagerak and the Kattegat.

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