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INTERMIXTURE OF THE NORTH SEA AND WESTERN MACKEREL STOCKS DETERMINED BY ANALYSES OF NORWEGIAN TAGGING DATA

by

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Summary

Mackerel spawning in the North Sea and southwest of Ireland are considered to be two stocks and both are assessed each year by ICES. The distribution areas of the two stocks overlap, therefore the fishery exploits a mixture of them. Every year since 1970 a large scale Norwegian tagging program has relased tags in two areas, one southwest of Ireland and one in the North Sea. The results of the experiment has been used both to describe migration patterns and to allocate catches to the stocks.

In later years questions have been raised on how to interpret the tagging data, since the assumption of tagging on "pure" stocks remains untested. The present paper investigates if tagged fish from the two spawning areas mix completely , mix partly with overflow between the two groups or if they keep completely separate.

The main conclusions are :

Mackerel from the two spawning areas do not mix completely, and a possible hypothesis of one mackerel stock must be rejected. Western and North Sea mackerel have a different distribution pattern, but the areas overlap. The intermixture in an area, measured as the relative proportion of mackerel present from each stock, decreases as the distance from the area of origin increases. There is a trend in the period 1970-1985 for tagged individuals from the two stocks to mix more completely in recent years. This may be caused by an overflow of fish from the Western to the North Sea area. A model of population pressure is proposed that is a function of the two spawning stock biomasses. The overflow computed by the model corresponds well with data from the tag returns.

Introduction

Assessments of mackerel (Scomber scombrus) in the northeast Atlantic are made for two stocks: The North Sea stock and the Western stock (Anon. 1985). The spawning areas of the stocks are geographically separated and some biological characteristics differ, but the distribution areas of the adults overlap. The fishery, therefore exploits a mixture of the two stocks in certain areas, particularly in the northern North Sea and in the Norwegian Sea during the summer.

The exploitation of mixed stocks constitutes a special problem for assessments, as discussed by the ICES Mackerel Working Group at various meetings in recent years. In general, the Group made use of tagging data to relate catches of mixed origin to each of the two mackerel stocks. It is, however, becoming increasingly difficult to interpret the data (Anon. 1986),and further analyses seem needed in order to evaluate the assessments.

The present paper discusses the two-stock concept and intermixture of stocks on the basis of analyses of data from Norwegian tagging experiments 1970-1985.

Stocks and migration

Hamre (1980) and Lockwood and Shepherd (1984) have outlined the biology of the mackerel in the northeast Atlantic. Two separate spawning stocks are recognized, the North Sea stock which spawns in the central and northern North Sea in June-July and the Western stock which spawns along the outer shelf area west of Britain, France and Ireland during March-July. The North Sea stock overwinters in the Norwegian Trench and to the west of the Shetlands and Orkneys while the Western stock overwinters in the Celtic Sea area northwards. Both stocks migrate northwards in summer and are found distributed over a wide area from the Bay of Biscay to the Norwegian Sea.

Figure 1 gives a schematic representation of the shifts in distribution by season for both the North Sea stock and the Western stock. The figure is based on similar representations given by the ICES Mackerel Working Group (Anon. 1981). Figure 1 shows a generalized picture, intended to represent the "average" of the period 1970-1985.

After spawning, during June-July, Western stock mackerel migrate northwards along the continental slope into the Norwegian Sea and the northern North Sea, with a return migration, possibly across the northern part of the North Sea, in September-October. Likely migration routes are indicated by Rankine and Walsh (1982) and the Working Group (Anon. 1986). North Sea mackerel also migrate north after spawning, expanding the area of distribution to cover most of the central and northern North Sea and the Skagerrak during late summer. In October part of the stock migrate westward to the west of Shetland to overwinter, while some descend into the Norwegian Trench in the North Sea.

Questions raised

As outlined above, Figure 1 represents a generally

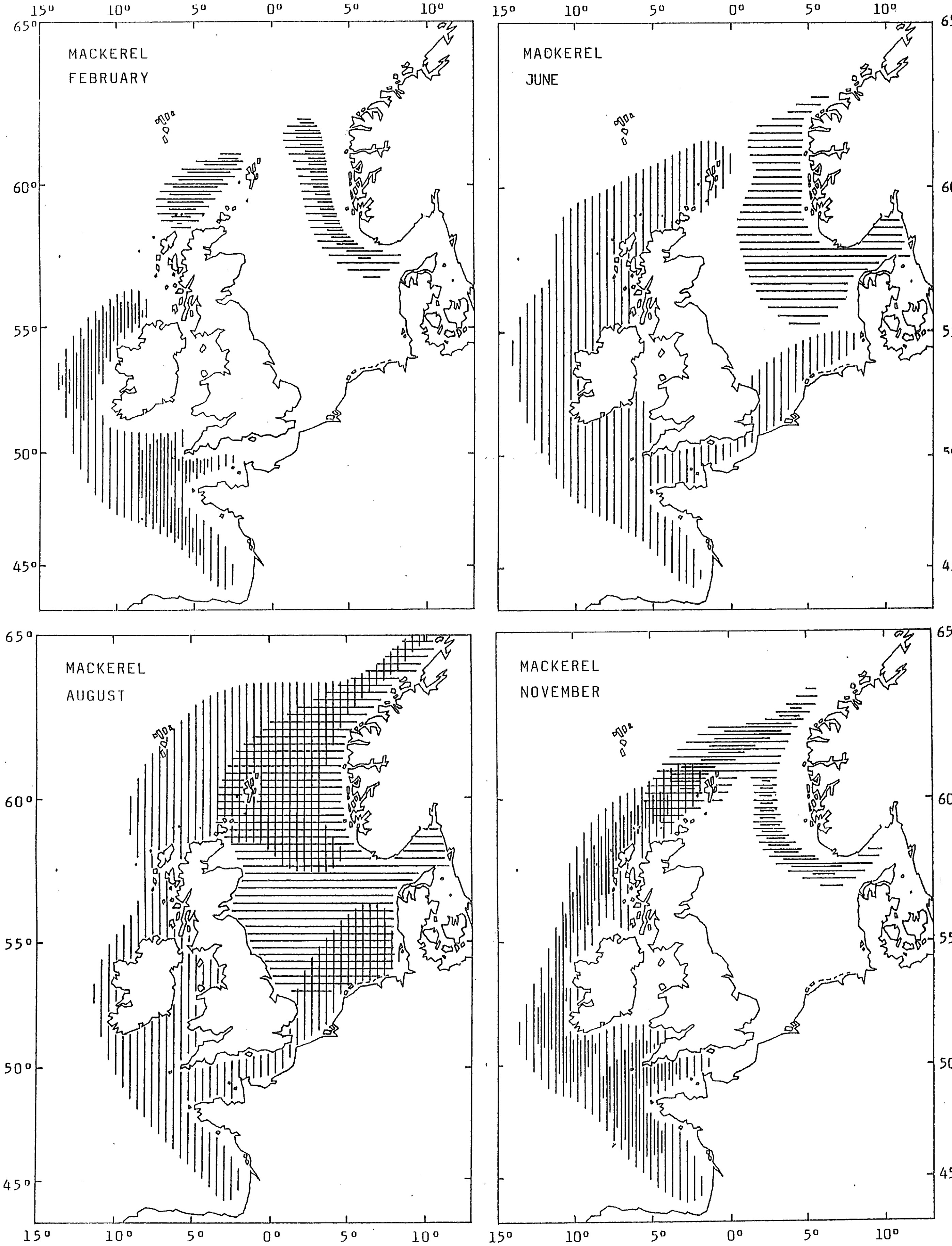

Figure 1. Seasonal distribution of mackerel of the North Sea stock (horizontally hatched) and the Western stock (vertically hatched)

recognized interpretation of distribution and migration of the North Sea and Western mackerel stocks. The distribution areas of the two stocks overlap in part for about half the year. Mackerel in such mixing areas cannot easily be identified as belonging to one or the other stock. For assessment purposes, mixing ratios have been estimated from the relative proportion of recovered tags originating from the two main release areas (see below), assumed to represent Western and North Sea stock respectively (Anon. 1985).

The validity of this method has been questioned, since the assumption of tagging on "pure" stocks remain untested. Observed shifts in area of main Western stock fisheries (Anon. 1985, Fig. 2.1) and similarities in age composition of samples over wide areas may call in question the two-stock concept. In principle, any of the following situations seem conceivable:

a) Mackerel originating from each of the two separate spawning areas undergo complete mixing, i.e. only one stock exists.

b) Mackerel of the two stocks have discrete areas of distribution with no mixing, i.e. two completely separated stocks.

c) Mackerel of the two stocks mix, with or without overflow from one to the other, or interchange between stocks.

The tag release and recapture data were used to provide estimates of stock mixing by the calculation of relative proportions of "Western" tags to "North Sea" tags in various geographical areas. With these proportions as a basis, attempts were made to answer questions of stock separation or intermixture.

Tagging data

Mackerel were fished by hook-and-line, placed in tanks on deck and removed by chamois lined dip nets for measurement of length and tagging. Individually numbered stainless steel tags, 15 x 4 x 1 mm, were injected by a special "pump" ventrally along the inner side of the body wall, anterior to anus. The mackerel were then immediately released.

Taggings have taken place off Ireland in May, before peak spawning in may/june (Lockwood et.al., 1981), and off south-west Norway in July- August just after spawning every year since 1970. A total of 330 000 mackerel have been tagged.

Tagging survival was estimated to 65-70 % as average for all length groups and releases in the North Sea (Hamre 1980). Variations in survival were observed, but for the purpose of the present analysis a constant survival was assumed and no corrections applied.

Tags were recovered by magnets installed in processing machinery at reduction plants and since 1980 also in limited number by electronic tag detectors at selected fish receiving plants. Tag recoveries could be related to catches by areas and time periods of the mackerel fishery. The quantity processed and the efficiency of the magnets varied greatly during the period, but variations are irrelevant to the analysis below, due to the calculation method applied.

Figure 2 shows the two areas of release of tagged mackerel off southwest Ireland and off southern Norway together with seven identified areas of tag recapture.

Tag recaptures were classified by area and season determined by established statistical areas for catch reporting and by well defined seasonal fisheries. In this way, the following recapture classes were used (Figure 2):

1. Between latitudes $54^0$00'N and $56^0$30'N, off northwestern Ireland, Irish fisheries, mainly November-December and January-March.

2. Between latitudes $56^0$30'N and $58^0$45'N, Scottish fisheries in the Minch area, August-October.

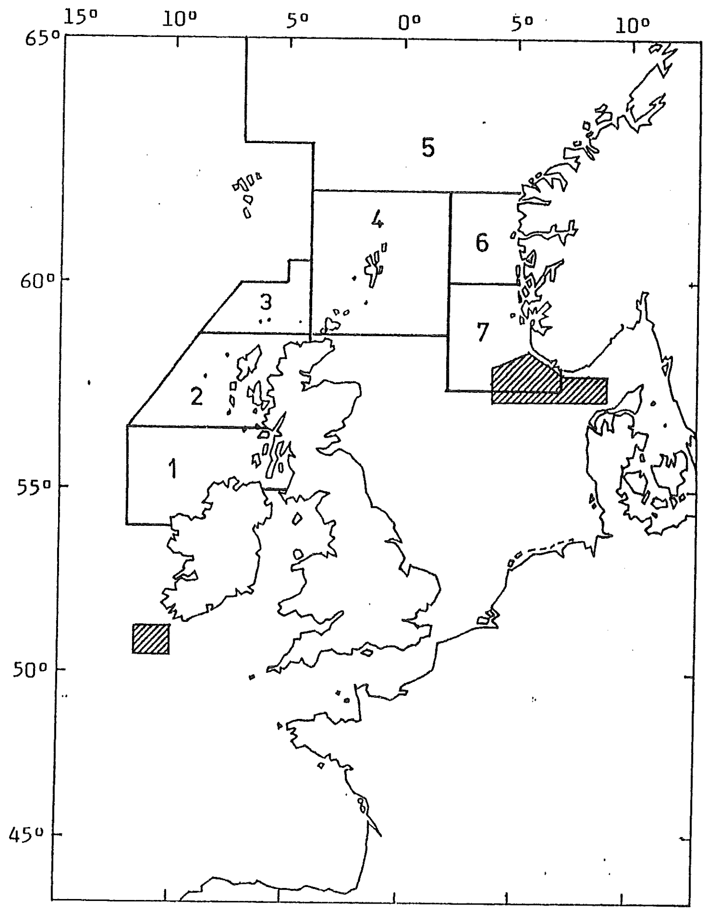

Figure 2. Areas of releases (hatched) and recaptures (1-7) of tagged mackerel.

3. North of $58^0 45'$N and west 4^0W, mainly Norwegian fisheries, October-December and January-March.

4. Between latitudes $58^0 45'$N and $62^0 00'$N and longitudes 4^0W and 2^0E, Norwegian fishery in the Shetland area July- September.

5. North of $62^0 00'$N, Norwegian fishery, July-September.

6. Between latitudes $60^0 00'$N and $62^0 00'$N east of 2^0E, Norwegian fisheries , July-October.

7. Between latitudes $57^0 30'$N and $60^0 00'$N and longitudes 2^0E and 7^0E, Norwegian fisheries, August-October.

The number of tag returns by area varied among years (Table 1), mainly due to shifts in the fisheries and catch quota regulations.

As mentioned in the previous section, it is assumed that mackerel tagged at the two main areas of release (Figure 2) are representative members of the respective stocks. Taggings have taken place in May just before the peak spawning for the Western area and in July-August just after spawning for the North Sea area. Tagging earlier in the North Sea proved unsuccessful due to a very low catch rate by hook-and-line. Because of the timing of the North Sea taggings, it cannot be ruled out that some of the mackerel tagged in the tagging area off southern Norway were Western stock fish which had migrated as far as into the North Sea. For the present analysis no attempts were made to correct for any error or distortion this may make.

Results

Random mixing between areas ?

For each of the 7 recapture classes defined above for the period 1970-1985 recaptured tags were inspected to see if they were of Western or North sea origin. The number of tags in each category is given in Table 1. The tags recaptured in the year of release are excluded to ensure that the fish observed have completely mixed into the population. For the situation described the binominal sampling model is pertinent and a 2x7 contingency table is set up for each of the years.

An interesting approach is to see if the tags from the two releases are randomly or non-randomly present in the defined recapture classes. If the tags are distributed randomly this might indicate that there is no clear boundaries between the stocks.

To test whether the tags recaptured in year k from the two series of releases are randomly present in the recapture classes or not a test variable T_k is defined which is a function of the $2xg_k$ contingency table for that year. The variable g_k is the number of recapture classes where tags were returned, i.e. observed, that year. T_k is assymptotically chi-squared with $(g_k-1)\cdot(2-1)$ degrees of freedom (Kendall and Stuart, 1969).

The values of T_k are given in Table 1 together with the number of degrees of freedom f_k and the probability q_k that the tags are non-randomly present in the recapture classes. Equal probability of recapture is assumed for all tagged fish present in a recapture class and year.

For each of the years 1972-1979 the recaptured tags from the two series of releases are distributed non-randomly across the recapture classes at the 2.5 % level. In the period 1980-1985 only one year shows the same result. Consequently there is a tendency of more random mixing of the two series of releases in the later years.

Since T_k is regarded to have a chi-squared distribution the sum of T_k for all years is also chi-squared with the number of degrees of freedom equal the sum of f_k 's. The value of this variable is shown in the bottom line of Table 1 together with the number of degrees of freedom and its q-value. It is seen that the tags recaptured in the whole period are distributed across recapture classes an years non-randomly at the 2.5 % level.

Geographical distribution of tags.

To inspect the nature of the non-random distribution across the recapture classes a new variable x_{jk} is defined, which is the relative proportion of recaptured tags of western origin in class j in year k.

Table 1. Number of tags returned from releases off southwest Ireland and in the North Sea in 7 recapture classes for the years 1971-1985. The chi-squared test variable T_k with its number of degrees of freedom f_k and the corresponding probability q_k that the tags are non-randomly distributed across recapture classes in year k.

Year (k)	Series of release	Recapture class 1	2	3	4	5	6	7	T_k	f_k	q_k
1971	Western	0	0	1	15	0	0	1			
	North Sea	0	0	2	96	0	3	29	4.2	3	0.750
1972	Western	1	0	1	19	0	10	7			
	North Sea	0	3	3	95	0	156	108	21.8	5	0.999
1973	Western	0	4	4	126	0	6	63			
	North Sea	0	8	5	361	0	58	814	102.6	4	0.999
1974	Western	0	6	23	83	0	68	43			
	North Sea	0	4	374	230	0	217	675	149.8	4	0.999
1975	Western	0	13	1	103	0	166	8			
	North Sea	0	10	13	110	1	1043	24	160.9	5	0.999
1976	Western	0	47	1	66	0	156	4			
	North Sea	0	32	0	131	0	674	47	87.9	4	0.999
1977	Western	4	51	0	15	0	12	134			
	North Sea	1	22	0	87	8	95	732	151.4	5	0.999
1978	Western	12	88	0	40	0	0	6			
	North Sea	5	42	0	132	1	11	58	102.7	5	0.999
1979	Western	14	35	106	79	0	2	5			
	North Sea	14	47	247	103	0	4	16	15.2	5	0.990
1980	Western	6	55	0	0	0	0	5			
	North Sea	7	65	2	0	0	0	2	3.5	3	0.520
1981	Western	24	137	11	0	7	1	0			
	North Sea	23	68	21	0	3	1	2	17.8	5	0.995
1982	Western	20	34	3	0	37	0	1			
	North Sea	9	20	7	0	9	0	2	11.9	4	0.975
1983	Western	13	29	11	0	17	0	0			
	North Sea	6	22	28	0	18	1	1	12.8	5	0.975
1984	Western	0	54	30	4	59	1	1			
	North Sea	0	68	39	3	69	0	4	3.1	5	0.475
1985	Western	0	37	52	1	103	8	2			
	North Sea	0	51	56	0	103	3	5	6.4	5	0.740
						Whole period:			852.0	67	0.999

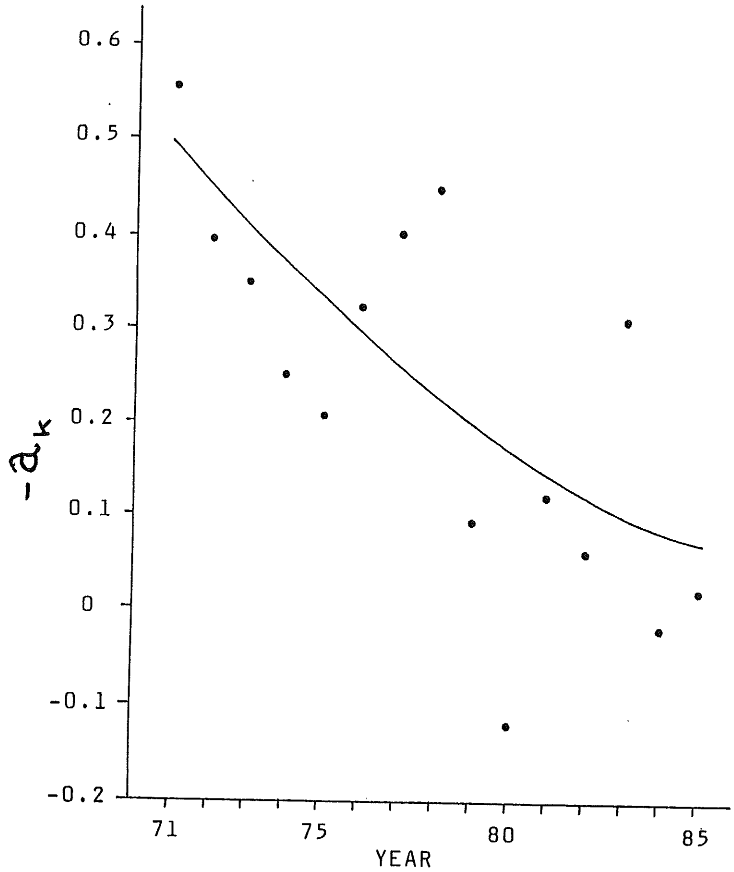

Figure 3. Values of the coefficient of seperation, $-a_k$ (•) and the polynominal regression line between $-a_k$ and time (———) for the years 1971-1985.

Table 2. The observed ratios of western tags x_{jk} and computed variables (a_k, r_k, $-\hat{a}_k$) based on tag returns from western and North Sea releases in the period 1971-1985. Biomasses in million tonnes for the Western (B_1) and North Sea (B_2) mackerel stocks (Anon. 1985) and estimated overflow (O_k) in arbitrary units from B_1 to B_2. Missing values are indicated by a hyphen.

Year	x_{jk} 1	2	3	4	5	6	7	a_k	r_k	$-\hat{a}_k$	B_1	B_2	O_k
1971	-	-	2.65	1.08	-	0.00	0.27	-0.58	.89	0.047	5.6	1.4	17.64
1972	3.90	0.00	0.98	0.65	-	0.23	0.24	-0.39	.62	0.045	5.5	1.4	16.81
1973	-	1.38	1.84	1.08	-	0.39	0.30	-0.34	.65	0.043	5.4	1.4	16.00
1974	-	2.45	0.24	1.08	-	0.98	0.25	-0.25	.59	0.040	5.3	1.2	16.81
1975	-	2.30	0.28	1.85	0.00	0.55	1.01	-0.21	.44	0.038	4.9	1.1	14.44
1976	-	1.34	2.28	0.77	-	0.43	0.18	-0.32	.80	0.036	4.4	0.9	12.25
1977	2.51	2.19	-	0.46	0.00	0.35	0.49	-0.40	.87	0.034	4.3	0.7	12.96
1978	2.41	2.48	-	0.78	0.00	0.00	0.32	-0.45	.91	0.031	4.1	0.5	12.96
1979	1.34	1.16	0.81	1.16	-	0.89	0.65	-0.09	.80	0.029	3.7	0.4	10.89
1980	1.13	1.13	0.00	-	-	-	1.74	+0.12	.44	0.027	3.2	0.33	8.24
1981	1.13	1.48	0.75	-	1.54	1.10	0.00	-0.12	.50	0.024	3.0	0.28	7.40
1982	1.25	1.15	0.55	-	1.45	-	0.60	-0.06	.35	0.022	2.9	0.26	6.97
1983	2.00	1.69	0.83	-	1.45	0.00	0.00	-0.31	.86	0.020	2.7	0.23	6.10
1984	-	0.85	0.83	1.10	0.89	1.93	0.39	+0.02	.08	0.018	2.0	0.18	3.31
1985	-	0.74	0.85	1.76	0.88	1.26	0.51	-0.02	.10	0.015	1.9	0.20	2.89

$$x_{jk} = \frac{\dfrac{n_{1jk}}{\sum_i n_{ijk}}}{\dfrac{\sum_j \dfrac{n_{1jk}}{\sum_i n_{ijk}}}{g_k}} \qquad (1)$$

Where :

- i = 1 (Western releases), 2 (North Sea releases)
- j = 1...7 is the index of recapture class
- k = index of the year
- n_{ijk} = number of tags recaptured from the release series i in class j in year k
- g_k = number of recapture classes with one or more recaptured tags in year k

Note that the expression beneath the fraction line is included merely to normalize the numbers around the mean for that year. In this way results can be more easily compared between years. Intuitively it is recognized that the stock members of fish tagged in the two series of releases are well separated if the relative proportion of tags of western origin gradually decreases from recapture class 1 to class 7. This is equivalent to saying that if a straight line is fitted to the values of x_{jk} in year k using the index j as the x-axis in the regression, a steep slope of the regression line indicates two well separated groups of tags in that year. The slope of the regression lines a_k ,which could be called a coefficient of separation, and the coefficients of correlation r_k are shown in Table 2. The values of a_k are also plotted in Figure 3 (The sign of a_k is reversed in the Figure). There is a tendency in later years that a_k approaches zero i.e. the two series of releases seems to be more randomly mixed.

A second degree polynominal is fitted to the values of $-a_k$ giving a correlation coefficient of 0.72. The polynominal is given in equation (2) and Figure 3.

$$-\hat{a}_k = 9.609 - 0.21k + 0.00115k^2 \quad , \quad k = 71....85 \qquad (2)$$

The overflow concept.

Why is it so that the two series of releases seems to be more and more intermingled ? A possible answer could be that mackerel from the relatively strong Western stock flows into the areas of the weak North Sea stock. To quantify an overflow as a function of the two biomasses an analogous physical model is proposed.

A vessel is divided vertically by a permeable membrane and a liquid is filled to a different level in the two parts of the vessel (see Figure 4). There is no flow through the membrane below the level where there is liquid on both sides of it. The differential flow dQ over the element dy of the membrane is supposed to be pressure dependent :

$$dQ = \alpha(H_1 - y)dy \qquad (3)$$

Where α is some constant y is the height from the bottom of the vessel to the element dy and H_1 the liquid level in the left part of the vessel. To get Q, the total flow from H_1 to H_2 , (3) is integrated from H_2 to H_1. This yields :

$$Q = \frac{\alpha}{2} (H_1^2 - 2H_1 H_2 + H_2^2) \qquad (4)$$

The biomass of the Western stock ,B_1, and the biomass of the North Sea stock ,B_2, are now regarded analogous to H_1 and H_2 respectively. The estimated overflow from the Western to the North sea area in year k, O_k , in arbitrary units is:

$$O_k = (B_1^2 - 2B_1 B_2 + B_2^2) \qquad (5)$$

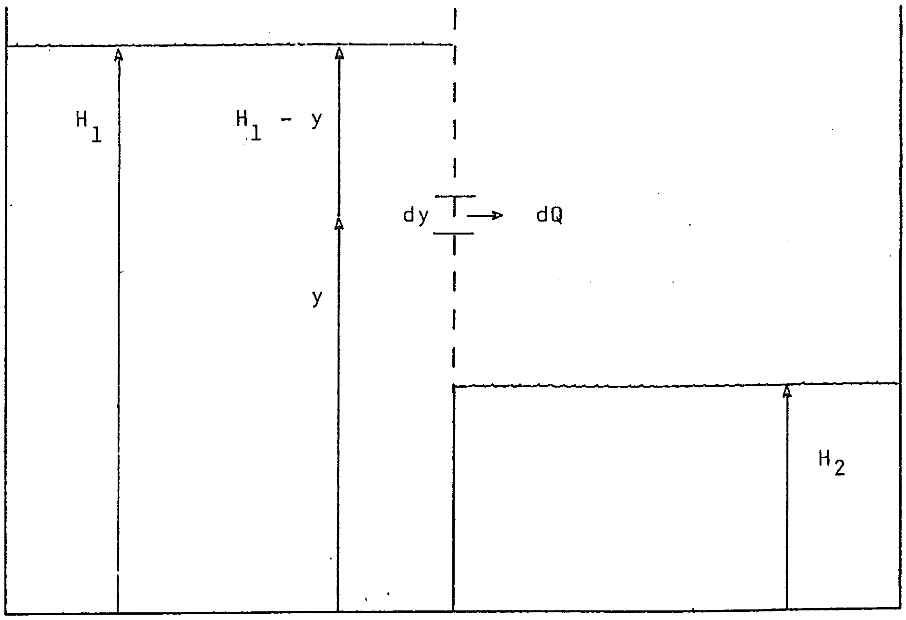

Figure 4. Analogous physical model of population pressure between two closely related stock.

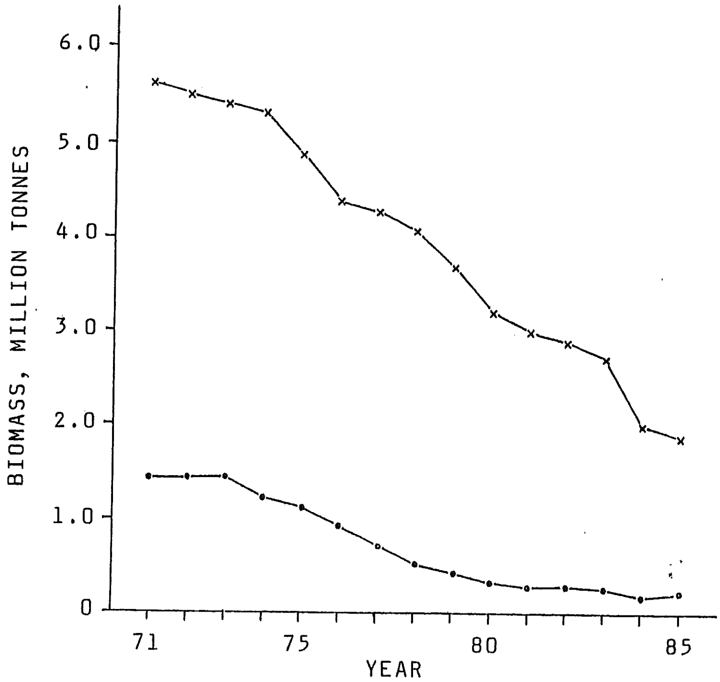

Figure 5. The spawning stock biomass of the Western (x——x) and North Sea (●——●) mackerel stocks.

The resulting values of O_k are given in Table 2. The biomasses of the Western and North Sea mackerel stocks, as given by Anon. 1985, are shown in Table 2 and Figure 5.

Overflow and tag returns.

It is assumed that if B_1 and B_2 had been constant for the years 1970 to 1985 and tags were released in both areas each year the values of a_k would also been constant in that period. The rate of decline in the value of a_k from year to year is hypothisized to be a function of a permanent overflow in the same years. Estimates of the rate of decline, $\dot{a}_k$, as a function of time k of a_k is computed from equation (2), the values of this derivative is given in Table 2. The linear regression between the derivative and the overflow had a correlation coefficient of 0.98.

$$\hat{\dot{a}}_k = 0.002 O_k + 0.009 \qquad (6)$$

This might indicate that an overflow has taken place in the time period 1970-1985 from the Western to the North Sea area.

Discussion and conclusions

The calculated parameters used to evaluate stock mixing are likely to be encumbered by errors, both of random and systematic nature. In previous sections it was pointed out that variations in tagging survival and possible tagging of Western fish in the North Sea may influence the results. It should also be mentioned that the estimated biomass of the stocks (Table 2 and Figure 4) is to some extent influenced by tagging results (Anon. 1986). Hence, the correlation between size of stocks and measure of overflow is determined on data not completely independent.

Accepting the assumptions and shortcomings it seems reasonable to draw some general conclusions from the analysis:

Mackerel from the two spawning areas do not mix completely, and a possible hypothesis of one, single mackerel stock must be rejected. Western and North Sea mackerel are not found in a random composition within the total mackerel distribution area, and it seems that the basic concept of two unit stocks must be regarded as valid.

Mackerel, however, from the North Sea and the Western stock occur in a mixture over most of the area. The intermixture, measured as the relative proportion of mackerel from a particular stock, decreases as the distance from the area of origin increases. The probability of recapture in areas distant from the origin increases in the period 1970-1985.

These trends, revealed by the analysis, can be explained by a gradual admixture or overflow of mackerel from the Western area to the North Sea during the period investigated. It is suggested that the overflow is related to population pressure expressed as difference in size between the Western and the North Sea stock. A physical diffusion model was used to describe the rate of overflow in relation to changes in stock size differences. The quantitative analysis support the view of an overflow to the North Sea stock which is correlated with the size difference between the Western and the North Sea stocks during the period 1971-1985.

The findings reported here are in general agreement with other observations. Hamre (1980) noted an influx of mackerel to the North Sea from the west, e.g. the 1971 yearclass which seemed to "recruit" to the North Sea spawners in 1976. In the assessments of the North Sea stock given by the ICES Mackerel WG in the 1980s there seems to have been a general tendency to predict lower stock sizes than those estimated by later assessments. A possible overflow may in part explain this tendency.

Records of tags recovered at electronic detectors giving exact recapture position show that mackerel tagged off Ireland in May are found in July-August the same year not only in the Norwegian Sea but some tags are also found in the northeastern North Sea (ICES sub-division IVa East). It is unfortunate that there is no commercial fishery of mackerel in the central North Sea at the time of spawning, and therefore no possibility to check the tag ratios of the North Sea spawners.

At this stage it has not been possible to quantify the indicated admixture of Western fish to the North Sea stock. It appears necessary to investigate this further, and in addition identify if such a possible overflow is restricted to strong yearclasses only, and whether it takes place through the English Channel or via the northern North Sea.

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