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Changes in catchability of cod, haddock, and whiting associated with the Scottish seine-net fleet

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The catchability coefficient, Q, of cod, haddock, and whiting associated with the Scottish seine-net fleet is examined. Cod and haddock show increasing catchability for the period 1963–1979. The rise in Q is related to the spatial distribution of the fleet as vessels increasingly fish in areas of higher fish abundance. Additionally, for haddock, catchability is related to year-class strength. The utility of catchability trends in the prediction of fishing mortality is discussed.

Introduction

Catch and effort data form the basis of much stock assessment work because they may be used to calculate abundance indices and to make short-term catch forecasts (e.g., Roff, 1983). It is frequently implicit in these calculations that fishing effort is linearly related to the instantaneous fishing mortality rate, F, which in turn assumes that the susceptibility of fish to capture, catchability, is constant.

There are many reasons to expect catchability to change, such as technological improvements in vessels or the imposition of conservation measures to protect stocks. The usefulness of catch and effort data from commercial vessels is therefore limited by the degree to which changes in catchability (if any) can be quantified and predicted. Recently attempts have been made to use commercial catch and effort data to estimate fishing mortalities in some North Sea demersal stocks (Armstrong and Cook, 1982; Sparre, 1982; Armstrong and Cook, 1983; Lewy, 1983). These methods have to a varying degree accounted for changes in catchability, but they all rely heavily on catch and effort data obtained from the Scottish seine-net fleet. The increasing use of such methods by assessment working groups (Anon., 1982, 1983a, 1984) merits some discussion of the underlying causes of catchability changes associated with this Scottish fleet in order to help understand the nature of the data being used in these assessments.

Source data

Landings by Scottish seiners have been sampled for age and length each month since 1963 on a sea-area basis. These areas, shown in Figure 1, are subdivisions of the ICES roundfish reporting areas. Effort data (hours fished) for the same month–area strata are also available. These data allow the estimation of catch in number per unit of effort for each age group of fish for any combination of area or time period. Estimates of total international catch at age and associated fishing mortality rates were obtained from the appropriate ICES working group report (Anon., 1983a).

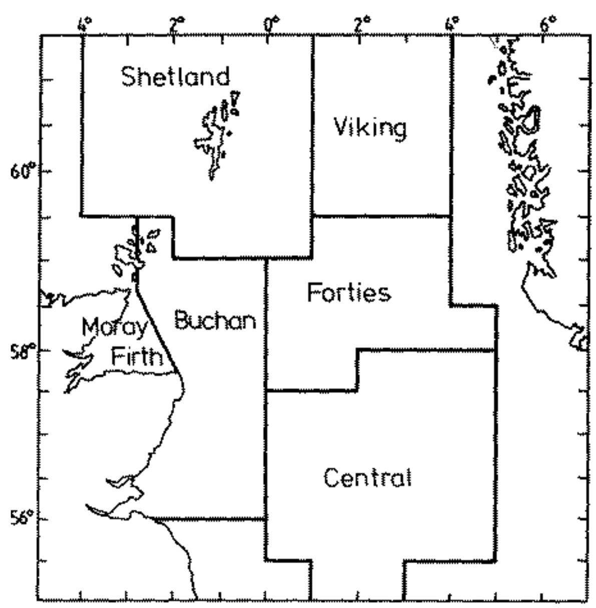

Figure 1. Scottish sampling areas referred to in the text.

Changes in catchability and effort

For simplicity the catchability coefficient for fleet i (Q_i) is assumed to be the proportionality constant in the relation:

$$F_i = Q_i\,E_i \qquad (1)$$

where F_i is the fleet fishing mortality rate and E_i is the fleet effort.

This definition of catchability incorporates all the factors responsible for generating the observed fishing mortality rate other than fishing effort *per se*. It therefore includes factors such as gear efficiency, and fleet and fish distributional changes, as well as the intrinsic susceptibility to capture of the fish in relation to the gear in question. It thus differs from the original definition of catchability used by Beverton and Holt (1957), which was limited to the last of these factors, i.e. the intrinsic susceptibility to capture.

The partial mortality (F_i) caused by any fleet i is assumed also to be given by:

$$F_i = F_t\,C_i/C_t \qquad (2)$$

where C_t is the total catch, C_i is the catch by fleet i and F_t is the total fishing mortality rate. By substitution, the catchability coefficient may be written as:

$$Q_i = F_t\,C_i/C_t\,E_i. \qquad (3)$$

The catchability coefficient has been calculated in this way in Figures 2–4 for the Scottish seine-net fleet for cod, haddock, and whiting.

When plotted against time, catchability can be seen to have increased for both cod and haddock over the last two decades. The change in the catchability of haddock is much greater than that for cod, but both species show a more marked increase in young fish than old fish. It is noteworthy, however, that for whiting there is no clear trend with time. In explaining catchability changes it must be borne in mind that cod, haddock, and whiting are all part of essentially the same multispecies fishery. The obvious cause of increasing catchability, improving technological sophistication, appears therefore to be inadequate if we are to reconcile catchability trends for haddock and whiting. If the fishing power of vessels has increased then it is reasonable to expect comparable changes for all three species. This is clearly not so and indicates that some other factor or factors must be responsible. This is discussed below.

In recent years there have been an increasing number of restrictions placed on all North Sea fleets including the seine-net fleet. Minimum mesh sizes have been increased and TACs imposed. In particular there has been a substantial change of mesh size in the Norwegian sector of the North Sea, which is especially important to the Scottish fleet. These changes will tend to cause a decline in catchability such as that evident in recent years, notably in the case of haddock (Fig. 3). For this reason the following analysis is concerned primarily with the years 1963–1979, a period when the fleet may have been considered to be fishing "ad libitum".

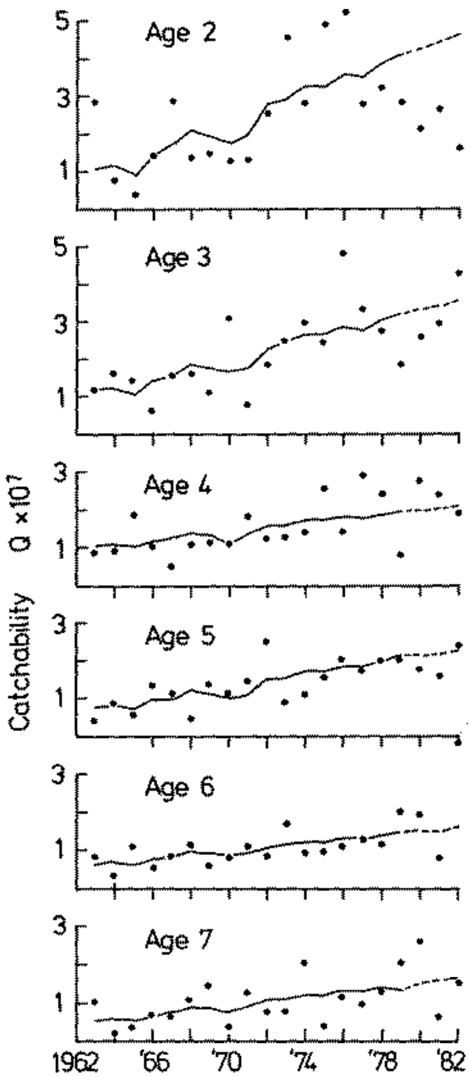

Figure 2. North Sea cod. Catchability, Q, plotted against time. Unbroken line shows predicted catchability from the fitted regressions in Table 4. Broken line shows the extrapolated regression values.

The effect of effort distribution

A major change in recent years in the seine-net fleet is in its spatial distribution. Figure 5 shows the proportion of total effort expended in each of the six North Sea areas illustrated in Figure 1. It can be seen that in earlier years fishing was predominantly inshore in Moray Firth

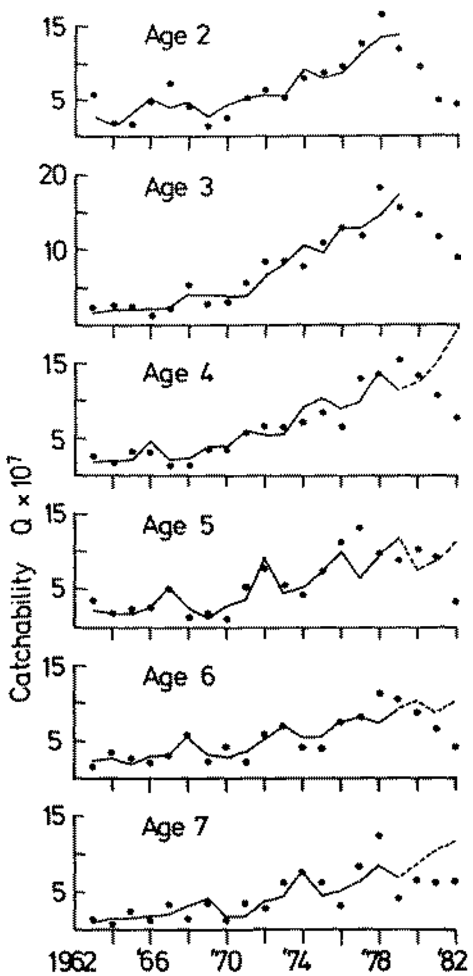

Figure 3. North Sea haddock. Catchability, Q, plotted against time. Unbroken line shows predicted catchability from the fitted regressions in Table 5. Broken line shows the extrapolated regression values where sufficient data are available.

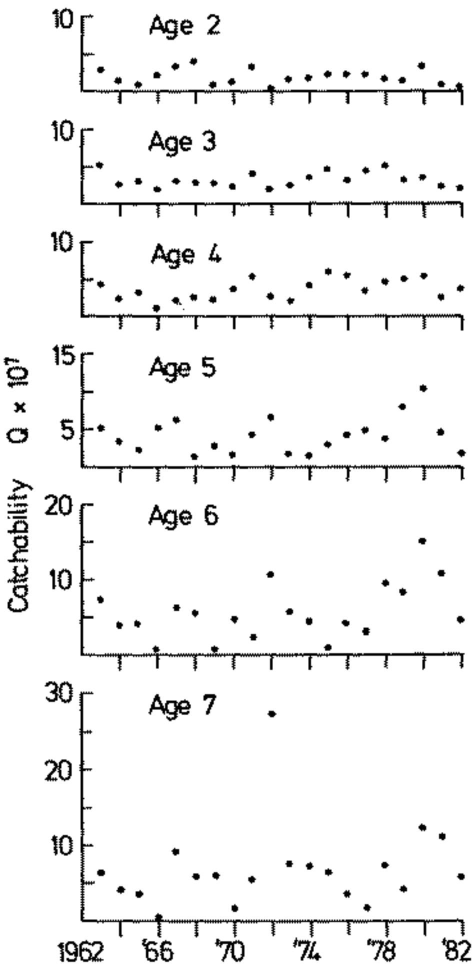

Figure 4. North Sea whiting. Scatter plots of catchability, Q, against time.

and Buchan, the more recent distribution is in the offshore areas of Viking, Forties, and Central. The change is substantial. In the early 1960s over 40 % of effort was spent in Buchan, whereas this has now dropped to less than 15 %. Conversely, effort in Forties has risen from less than 5 % to over 15 % in recent years. The movement of vessels has occurred presumably because catch rates are higher in these areas. Thus it seems reasonable to propose that the rise in catchability is related to the movement of vessels to areas of higher fish abundance.

Whilst it is difficult to prove that fish are more abundant offshore, it can be shown that the catch per unit effort by seiners has been consistently higher in offshore

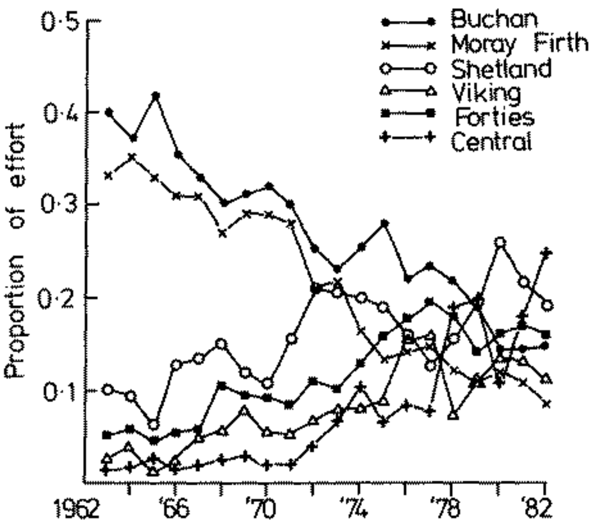

Figure 5. Proportion of total hours' fishing by Scottish seine-net vessels spent in six areas, plotted against time.

Table 1. Overall ranks of c.p.u.e. in each sea area for each age group of cod, haddock, and whiting. Kendall's coefficient of concordance, W, has been calculated to show that the rankings for each year do not differ significantly.

		Inshore		Offshore					
	Age	Moray Firth	Buchan	Forties	Central	Shetland	Viking	W	Probability
Cod	2	4	5	3	1	6	2	0·4922	<0·01
	3	4	6	3	2	5	1	0·5341	<0·01
	4	4	6	1	3	5	2	0·6440	<0·01
	5+6+7	5	6	1	3	4	2	0·7532	<0·01
Haddock	2	6	5	1	2	4	3	0·4574	<0·01
	3	6	5	1	4	3	2	0·7480	<0·01
	4	6	5	3	4	2	1	0·7026	<0·01
	5+6+7	6	5	2	4	3	1	0·7197	<0·01
Whiting	2	6	2	3	4	1	5	0·4197	<0·01
	3	6	2	4	5	1	3	0·5271	<0·01
	4	6	3	5	4	1	2	0·6774	<0·01
	5+6+7	6	3	5	4	1	2	0·6934	<0·01

areas over the past twenty years. This can be done by ranking the c.p.u.e. in each area for each year. Using Kendall's W it can be shown that the rankings for each year do not differ significantly from each another and that the offshore areas rank highest (Table 1). If c.p.u.e. is an acceptable measure of population size then this means fish have been more abundant offshore for at least the period under investigation.

The ranking procedure demonstrates that area catch rates differ in a consistent way. It does not, however, quantify the disparity between areas. Unfortunately catch per unit effort is modified by the effect of discarding fish at sea (see Jermyn and Robb, 1981). The discarding effect is different in each area (Jermyn and Robb, unpublished data), thus the true relative magnitude of the catch rates is difficult to assess for the range of years considered. Table 2 shows the mean catch per unit effort in inshore and offshore areas. For older fish, which are least susceptible to discarding, the difference in catch rates is large enough to explain the change in Q, but for younger fish no unequivocal statement can be made. As expected in the case of whiting, the catch rates inshore and offshore are very similar, and this is consistent with the apparent lack of change in Q with time (cf. Fig. 4).

Table 2. Mean catch per unit effort (no./h) for Scottish seiners for each age group of cod, haddock, and whiting for inshore and offshore areas.

	Age	Inshore	Offshore
Cod	2	14·9	37·9
	3	4·6	11·5
	4	1·2	3·4
	5+6+7	0·6	2·3
Haddock	2	84·1	130·8
	3	65·4	151·6
	4	26·2	74·7
	5+6+7	9·6	40·8
Whiting	2	44·6	46·3
	3	51·1	58·6
	4	24·1	38·9
	5+6+7	12·8	16·7

This analysis suggests that the increase in Q with time can be explained at least in part by the movement of vessels to areas of higher fish abundance. Since the offshore movement of vessels has been continuous and occurs simultaneously with the change in Q it would not be difficult to relate the two quantitatively. A first approach might be to perform a multiple regression of Q against the independent variates of proportion of effort in each area. This results in a high correlation, but because the independent variates are obviously highly correlated themselves, each successive independent variate in the regression does not really contribute any new information. Clearly the change in effort in each area is measuring the same thing – the movement offshore – so there is redundancy in the variates.

An appropriate technique to use to resolve this difficulty is principal-component analysis (e.g., see Morrison, 1978). This technique has the advantage of finding new pseudovariates (which are linear combinations of the original variates) that are uncorrelated. Also each new pseudovariate accounts for a successively smaller proportion of the total variance. Thus the first principal component will account for the greatest proportion of the total variance in the original variates. The result of this analysis is given in Table 3 where it is evident from the eigenvalues that over 80 % of the total variance is contained in the first principal component. The eigenvector associated with this component is a contrast between the offshore and inshore areas. This can be seen from the elements of the eigenvector. For the offshore

Table 3. Eigenvalues and eigenvectors from principal-component analysis of proportion of effort data.

Component	Eigenvalue	Eigenvector					
		Shetland	Viking	Moray Firth	Buchan	Forties	Central
1.	0·02321	0·2631	0·2408	−0·5863	−0·5241	0·2939	0·4099
2.	0·00164	0·4841	0·2827	0·0876	−0·2814	0·0811	−0·7696
3.	0·00124	0·5862	−0·4623	0·2301	−0·2528	−0·5061	0·2642
4.	0·00047	0·3474	−0·4292	−0·5765	0·5553	0·1583	−0·1904
5.	0·00013	0·1616	0·6297	−0·2281	0·3645	−0·6171	0·1087
6.	0·00005	0·4539	0·2603	0·4671	0·3756	0·4951	0·3492

areas these elements are all positive, while for the inshore areas the values are all negative. The first principal-component score therefore forms a convenient "offshoreness" index to correlate with Q. Figure 6 shows Q plotted against this index for cod and haddock

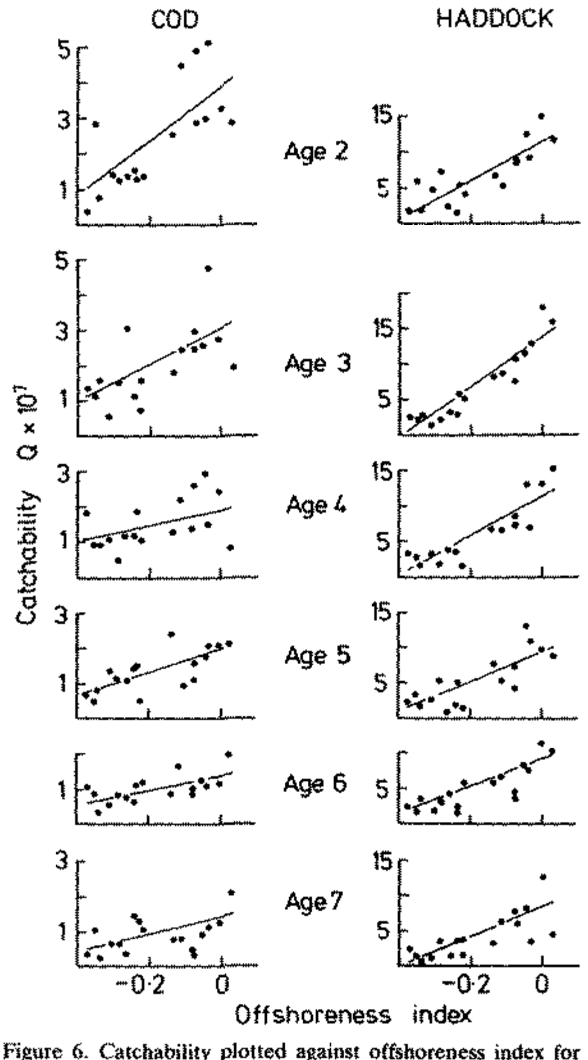

Figure 6. Catchability plotted against offshoreness index for cod and haddock, for ages 2–7. Coefficients of fitted regressions are given in Table 4.

Table 4. Regressions of catchability, Q, against offshoreness index for cod and haddock.

	Age	Slope	Intercept	Coefficient of determination
Cod	2	8·08	3·90	0·537
	3	5·37	3·05	0·417
	4	2·21	1·85	0·181
	5	3·33	1·95	0·536
	6	1·04	1·35	0·305
	7	2·29	1·37	0·305
Haddock	2	26·02	11·39	0·665
	3	37·21	13·85	0·880
	4	29·02	11·46	0·761
	5	22·54	9·49	0·654
	6	18·15	8·27	0·695
	7	16·92	7·42	0·494

from 1963 to 1979, and Table 4 gives the regression equations.

In Figure 2 the fitted values of Q obtained from this "offshoreness model" are plotted for cod, and there is satisfactory agreement. The model has been extrapolated for the years 1980–1982 in Figure 2, and again the predicted values continue the observed trend. The exception is the two-year-olds. Here the observed trend in recent years is downward while the predicted trend is upward. This is probably the result of changes in mesh-size regulations as discussed below.

The correlations are generally better for haddock, perhaps not surprisingly, as this is the primary target species for this fleet. However it is known that year-class fluctuations affect fishing mortalities for this species (Cook, 1974), and the effect needs to be included in the model. This is described in the next section.

The effect of year-class strength in haddock

Cook (1984) noted that in the North Sea haddock fishery there were detectably higher fishing mortalities on age groups of fish constituting a high biomass. Armstrong and Cook (1983) found that there was a relationship between year-class strength and the residual

Table 5. Analysis of variance tables for haddock catchability. X1 = offshoreness index. X2 = log year-class-strength index.

Age	Source	d.f.	F	Slope	Intercept	Coefficient of determination
2	Regression	2	17·392		3·20	0·713
	X1	1	27·163	4·06		
	X2	1	5·632	−0·40		
3	Regression	2	63·435		2·50	0·901
	X1	1	126·279	5·90		
	X2	1	1·202	0·12		
4	Regression	2	39·256		1·65	0·849
	X1	1	70·671	4·92		
	X2	1	10·645	0·42		
5	Regression	2	21·951		1·09	0·758
	X1	1	28·629	4·13		
	X2	1	9·879	0·55		
6	Regression	2	25·206		1·59	0·783
	X1	1	36·897	3·28		
	X2	1	4·303	0·25		
7	Regression	2	13·928		1·20	0·666
	X1	1	18·722	4·02		
	X2	1	3·496	0·38		

variation in Q after allowing for changes in effort distribution. There is some reason, therefore, to expect year-class strength in haddock to contribute to changes in Q. This was examined as follows.

An index of year-class strength was calculated from the Scottish research-vessel series as described in the Appendix. A multiple regression of log Q against the offshoreness index and log year-class-strength index was then calculated for each age group. This model was chosen simply because it yields the highest coefficient of determination. The results of this analysis are shown in Table 5. For ages 4–7 there is a significant positive effect of year-class strength on Q which is consistent with earlier findings. Interestingly, the results for younger fish are rather different. In the case of two-year-olds the year-class effect is significantly negative. This may appear to be in contradiction to the results for older fish, but in fact it is probably a characteristic of the same process. Directed fishing for older fish of abundant year classes (hence elevating Q) would be worth while. To do the same when an abundant year class is recruiting as young fish would, however, be pointless, because the catch would then contain large numbers of small fish which are either uneconomic or illegal to land. Abundant year classes at this age are best avoided, as the trend in Q reflects. At age 3 there is no significant effect attributable to year-class strength since this represents an intermediate stage between avoidance and directed fishing.

Figure 3 shows the fitted values from the above model and it can be compared with the observed values. The model describes the data points up to 1979 well. However, if it is extrapolated it diverges significantly from the data (Fig. 3). The downward trend in Q is most marked in younger fish, though all ages 2–7 show the decline. It seems likely that mesh changes are the major factor because catchability for cod (a larger fish) does not seem to be affected except for the youngest fish, while for haddock a larger range of ages shows declining catchability. This change in trend prevents successful extrapolation of the model. The almost complete lack of data on selectivity of demersal seine prevents any attempt, at present, to include such an effect in the model.

The use of catchability trends in stock assessments

Given that the major causes of changes in catchability over the last two decades have been identified it should in principle be possible to predict Q with knowledge of the fleet distribution and year-class strength. If Q can be predicted then it is possible to calculate the fishing mortality rate from effort data, and this would solve many of the difficulties facing assessment scientists in evaluating current mortality rates and stock sizes. This was the basic principle in the methods of Armstrong and Cook (1982, 1983) and Lewy (1983), where trends in Q coupled to virtual population analysis (VPA) were used to estimate current fishing mortalities and stock sizes. Indeed the so-called "rho method", (Armstrong and Cook, 1982) has become a standard method used by the North Sea Roundfish Working Group (Anon., 1982, 1983a, 1984). The true value of these methods however depends on two conditions:

(1) It must be realistic to extrapolate the observed trends in Q.

(2) The variance of the predicted values of F must be no greater than the total variance in the observed values of F.

There is increasing evidence, at least in the case of haddock, that the trend observed in Q up to about 1979 cannot be extrapolated using the models currently fitted to the data (see Fig. 3). All these models predict increasing Q beyond 1979 either because a time trend is extrapolated (Armstrong and Cook, 1982; Lewy, 1983) or because the offshoreness index is still increasing (Armstrong and Cook, 1983). Recent changes in Q for haddock indicate a substantial fall for reasons already mentioned, and these effects need to be built into the model before Q can be successfully predicted.

The question of the precision of the predicted F is also difficult to answer because of the problem of estimating the variance of the prediction. It is a feature of the North Sea demersal fisheries that fishing mortality rates show low variance. This puts considerable demands on any predictive method to satisfy condition (2), and at present no method can be shown to be satisfactory in this regard. Such tests that have been carried out on these methods indicate that the variance of the predicted Fs is greater than that of the observed Fs (Armstrong and Cook, 1982, 1983). The problem of assessing the accuracy of these and other so-called "tuning methods" is further discussed by Pope and Shepherd (1983; this volume, p. 129) and Anon. (1983b).

Conclusions

The catchability of cod and haddock associated with the Scottish seine-net fleet has undergone a continuous increase during the period 1963 to 1979. The single most important factor underlying these changes appears to be the redistribution of fishing effort in the North Sea to offshore areas. In the case of haddock there is an additional year-class effect contributing to catchability changes.

Although there have been technological improvements in the seine-net fleet, many of these changes have increased the efficiency of shooting and hauling the gear rather than affecting the fishing power of the net itself. This would increase the efficiency of a vessel, without affecting the value of Q and, considering its distribution, could explain why the catchability of whiting does not seem to have changed.

In the years since 1979 there is some evidence that catchability has declined, particularly for haddock. This decrease cannot be explained by effort distribution of year-class strength and is most probably caused by mesh-size increases. Total allowable catches (TACs), though aimed more at reducing fishing mortality at all ages by reducing effort, are also liable to cause changes in catchability. This is because TACs are set separately for each major species in the mixed demersal fishery and allow vessels the limited possibility of redirecting effort in the most rewarding way amongst target species. There is evidence that effort can be redirected amongst ages of fish within a species (Cook, 1984) so there is no reason why such redirection could not also occur across species. If redirection does occur then, for the same effort, this effect would be manifest as a change in Q for each species.

References

Anon. 1982. Report of the North Sea Roundfish Working Group. ICES CM 1982/Assess:8, 145 pp. (mimeo).

Anon. 1983a. Report of the North Sea Roundfish Working Group. ICES CM 1983/Assess:18, 125 pp. (mimeo).

Anon. 1983b. Report of the Working Group on Methods of Fish Stock Management. ICES CM 1983/Assess:17, 73 pp. (mimeo).

Anon. 1984. Report of the North Sea Roundfish Working Group. ICES CM 1984/Assess:10, 138 pp. (mimeo).

Armstrong, D. W., and Cook, R. M. 1982. A proposal for the use of catch per unit effort data for the assessment of terminal F in VPA. ICES CM 1982/G:53, 4 pp. (mimeo).

Armstrong, D. W., and Cook, R. M. 1983. A proposal for the use of catch per unit effort data for assessing terminal F in VPA. ICES CM 1983/D:15, 7 pp. (mimeo).

Beverton, R. J. H., and Holt, S. J. 1957. On the dynamics of exploited fish populations. Fish. invest. Ser. 2 (19). HMSO, London. 533 pp.

Cook, R. M. 1984. Evidence for directed fishing effort in North Sea cod and haddock stocks. J. Cons. int. Explor. Mer, 41: 199–204.

Jermyn, A. S., and Robb, A. P. 1981. Review of the cod, haddock and whiting discarded at sea by Scottish fishing vessels for the period 1975–1980. ICES CM 1981/G:47, 4 pp. (mimeo).

Lewy, P. 1983. Determination of terminal fishing mortality rate based on catch and effort data. Unpublished MS.

Morrison, D. F. 1978. Multivariate statistical methods, McGraw-Hill, Tokyo. 415 pp.

Pope, J. G., and Shepherd, J. G. 1983. A comparison of the performance of various methods for tuning VPAs using effort data. ICES CM 1983/G:9, 17 pp. (mimeo).

Roff, D. 1983. Analysis of catch and effort data: a comparison of three methods. Can. J. Fish. aquat. sci., 40: 1496–1506.

Sparre, P. 1982. A comment to the North Sea Roundfish Working Group. ICES CM 1982/G:48, 6 pp. (mimeo).

Appendix

Derivation of a year-class-strength index for haddock

Scottish research vessels have carried out trawling surveys of the North Sea for many years. The surveys provide catch-per-unit-effort indices of abundance for haddock of ages 1 to 5 as described by Jones and Hislop (1978). These abundance indices were used to calculate a year-class index.

Each year class is sampled up to five times by successive surveys (i.e. once at each age 1–5). The year-class-strength index was therefore calculated by taking the average abundance over the five values. In order to ensure equal weighting to each of the samples the abundance of each group was first scaled to the value of the 1967 year class at that age. This was necessary to allow for missing values. A simple mean of the scaled values was then taken for each year class. Table 1A shows the values used.

Table 1A. Abundance indices for haddock from Scottish research-vessel surveys scaled to the 1967 year class.

Year class	Age 1	2	3	4	5	Mean
1956 ...	0·004	0·004	–	0·023	0·069	0·025
1957 ...	0·003	–	0·020	0·027	0·077	0·030
1958 ...	0·057	0·044	0·063	0·179	0·246	0·118
1959 ...	0·018	0·014	0·025	0·061	0·077	0·039
1960 ...	0·016	0·004	0·111	0·043	0·162	0·067
1961 ...	0·078	0·104	0·079	0·136	0·231	0·126
1962 ...	0·600	0·518	1·230	3·250	1·538	1·427
1963 ...	0·001	0·003	0·018	0·009	0·085	0·023
1964 ...	0·004	0·002	0·003	0·014	0·008	0·006
1965 ...	0·005	0·004	0·004	0·025	0·016	0·053
1966 ...	0·153	0·019	0·143	0·159	0·038	0·103
1967 ...	1·000	1·000	1·000	1·000	1·000	1·000
1968 ...	0·055	0·039	0·037	0·052	0·023	0·041
1969 ...	0·049	0·011	0·017	0·014	0·069	0·032
1970 ...	0·150	0·716	0·067	0·277	0·217	0·157
1971 ...	0·130	0·060	0·594	0·318	–	0·275
1972 ...	0·023	0·065	0·032	–	0·073	0·048
1973 ...	0·113	0·096	–	0·156	0·082	0·112
1974 ...	0·157	–	0·212	0·179	0·215	0·191
1975 ...	–	0·014	0·008	0·036	–	0·019
1976 ...	0·029	0·019	0·038	–	–	0·029
1977 ...	0·584	0·031	–	–	–	0·045
1978 ...	0·094	–	–	–	–	0·094

– = no data

This index was devised because no abundance-at-age index was available for fish aged 6 and 7 and because there are occasional years when no survey was carried out. By simply using year-class strength as an independent variable the analysis could be extended to all groups and years.

Reference

Jones, R., and Hislop, J. R. G. 1978. Changes in North Sea haddock and whiting. Rapp. P.-v. Réun. Cons. int. Explor. Mer, 172: 58–71.