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A COMMENT ON THE STOCK AND RECRUITMENT PROBLEM

by

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1 The continuing poor recruitment to the Georges Bank haddock stock in the ICNAF area, and to the adult Atlanto-Scandian herring stock in the NEAFC area, and the wide fluctuations in recruitment in the Arcto-Norwegian cod during this past decade have confirmed the opinion that small spawning stocks can only produce large year-classes if their eggs and larvae encounter exceptionally favourable circumstances. Reduction of the spawning stock progressively removes that surplus of offspring which in the unexploited stock cushions variation in recruitment and promotes stability against environmental fluctuation.

2 Whilst the dangers of attrition of the spawning stock have been recognized in general terms, the definition of a critical biomass of spawning stock remains a controversial subject. It is controversial because all observations relating recruitment to parent stock are associated with the high variance. This variance is real in the sense that improved precision in scientific observations is unlikely to cause a significant reduction in the variance and cannot, therefore, be expected to resolve the controversy. This means that for most stocks in the ICNAF area there is no prospect of an unequivocal definition of a 'critical biomass' of spawners within the next few years, and still less can we expect to understand density-independent (environmental) causes of variance to a degree that will admit prediction of recruitment.

3 Even so, the recent history of some stocks has shown that if the spawning stock does become too small, rapid recovery cannot be guaranteed even by stringent management measures. This situation could develop rapidly in any north Atlantic stock at the present time. In my view then, despite the scientific uncertainty, it has become essential that a 'critical biomass' be defined by the best means at our disposal.

4 There is a second reason for reaching such a definition: it follows from the criteria on which advice to ICNAF is currently based and which are to be discussed at the present meeting (Res. Doc. 72/26). In common usage the maximum

sustainable yield is the ultimate biological objective of management, being the efficient use of both the growth and recruitment potential of resources. The 'efficient' use depends on a compromise between the fishing mortality that will give the most efficient harvest of the growth potential of a year-class, and the fishing mortality that will maximize long-term recruitment. The first is known but the second is not; hence, although the maximum sustained yield of a resource can be described in terms of tonnage based on its historic yield, the level of fishing mortality to be associated with a future maximum sustained yield is not known.

5 However, the association between fishing mortality and age at first capture that will maximize the harvest of the growth potential, i.e. the maximum yield per recruit, is known and is designated F_{MSY}. This would generate the maximum sustained total yield if, and only if, there is no stock and recruitment relationship. F_{MSY} is unique but it has to be associated with a defined age at first capture, and there are subsidiary maxima (F_{MAX}) associated with each particular age at first capture, or, more generally, there is a pattern of fishing mortality with age.

6 The Mid-term Assessment Meeting has now recognized a further criterion, F_{OPT}. This is defined as the level of F where the marginal increase in total yield from one extra unit of effort is one-tenth of that in the lightly exploited stock (ICNAF Mid-term Assessment Report 1972, Figure 8). This is an arbitrary criterion expressing an economic expectation that a reduction in F to F_{OPT} will tend to improve the cost and earnings ratios in the fishery at a level where the catch will be satisfactorily close to its potential limit, and at which it is presumed the spawning stock will be adequate to sustain recruitment and hence yield.

7 There is an obvious and vital need to define these criteria clearly and simply, especially since F_{OPT} introduces a range of criteria which recognize explicitly the economic considerations. There may be other criteria besides costs and earnings ratios that could determine an economic optimum. For example, a management regime orientated to F_{OPT} may lead to disproportionately high profit margins for operators remaining in the fishery, and social costs to rehabilitate those that have been displaced. These aspects are considered elsewhere in the decision-making process. That they exist means that F_{OPT} should be complemented by a practicable upper limit, where the yield per recruit would be marginally higher than at F_{OPT} and where the spawning stock would be held close to the minimum needed to sustain recruitment. It can be argued therefore that advice to the Commissions should contain proposals for both minimum and maximum values of F, within which the economic criteria can be more fully assessed.

8 How then can we define a level of fishing mortality that will maintain the spawning stock close to a critical minimum level? We can say that, despite the controversy, population theory does indicate that F values associated with maxi-

issue is the four-dimensional relation between fishing mortality, catch, recruitment and spawning stock size. Seen in this light, conventional empirical two-dimensional relations between the latter two are of little help.

9 There is another way of approaching this complex. As a spawning stock is reduced the density-dependent component of egg and larval mortality will become smaller, whilst the density-independent component continues to fluctuate about a mean which, in the absence of environmental trend, can be expected to remain stable. At small spawning stock sizes, then, density-dependent mortality will tend to zero, and survival (recruitment per stock) will tend to a maximum defined by the density-independent component of mortality. By definition also, the maximum-sustained yield will be taken by that level of fishing mortality which is just sufficient to harvest all the potentially surplus adult stock (i.e. those which would produce eggs that would otherwise suffer density-dependent mortality). The appropriate level of fishing mortality, and, by implication, spawning stock, will be indicated by a maximum level of survival. Garrod (1972) found evidence of a maximum rate of survival in a number of stocks, and the approach may be useful here because it relates recruitment per spawning stock to a level of fishing mortality which, by definition, must maximize the long-term catch.

10 The estimation of survival begins from the expectation that in an unexploited stock the number of fish surviving to spawn is determined by natural mortality. Presuming that the unexploited stock is stable, the survival of eggs will, on average, provide replacement of the recruitment. This establishes a reference level of survival from spawners to recruits, a replacement norm equal to unity, $\log_e = 0.00$. As the stock is fished, the spawning stock is reduced by a proportion expressed by ΣF between recruitment and spawning. If replacement is to be maintained against this pressure, survival must increase by the reciprocal of the degree of depletion. For example, if the potential spawning stock is reduced by one-half ($\Sigma F = \log_e 0.5 = -0.7$) then survival must double (increase in survival $= \log_e 2 = +0.7$) irrespective of the natural mortality. The 'inverse' of the cumulative fishing mortality measured between an exploited parental stock and its offspring is a first component of increased survival. The second component expresses the success of replacement. This is measured as the number of 3-year-old recruits in a new year-class as a ratio of the average number of 3-year-olds in the year-classes that comprised the stock which spawned the new generation. Thus

$$\log_e (\text{increase in survival}) = \begin{array}{l}\Sigma F \text{ between recruit-} \\ \text{ment and a median} \\ \text{age of spawning}\end{array} + \log_e \frac{\text{recruits to year-class } x}{\begin{array}{l}\text{average recruits to year-} \\ \text{class of the parental} \\ \text{stock in year } x\end{array}} .$$

This total survival would be equivalent to the total fishing mortality that a stock could withstand and still replace itself in the long term (i.e. when the second term in the equation is $\log_e = 0.00$).

Table 1 summarizes estimates of survival for a number of stocks for which long-term series of data are available. These are taken from Table 5 of Garrod (1972), separating the results for the gadoid stocks as being indicative of levels of survival that roundfish might maintain; i.e. they indicate the scale of fishing mortality from first recruitment to spawning which these stocks could offset without any risk to the size of a filial generation. Survival would, of course, fluctuate: this is indicated by the standard deviation. It is perhaps significant that this measure of year-to-year variability in survival shows a degree of consistency for all the gadoids cited except North Sea haddock. The mean survival of these stocks, $\log_e S$, is 2.38 ± 0.84, to give an indicative margin. From this it can be argued that the cumulative fishing mortality should not exceed $\Sigma F = 2.38$, at which the spawning stock will be reduced to 10% of its original potential by numbers; reduction to about 20% of the potential ($\Sigma F = 2.38 - 0.84$) would give a margin of safety, but reduction of a spawning stock to 5% of its potential ($\Sigma F = 2.38 + 0.84$) could expose the stock to a high risk.

11 This judgement is based only upon the observed performance of these stocks and makes no assumptions concerning the shape of a stock and recruitment curve; it can be shown that they will tolerate this scale of reduction which at the same time provides a yield per recruit close to the maximum. As yet biologists cannot predict what may happen at higher levels of depletion: recruitment may suffer, it may not. But certainly there will be no gain in yield. In my view, then, the level of fishing mortality that will reduce a spawning stock to 20% of its potential at mean age of first spawning is the maximum permissible level.

12 Transformation of this cumulative depletion into coefficients of annual mortality depends upon the age pattern of recruitment and maturity of the stock concerned. For Arcto-Norwegian cod in 1970/71, for example, the cumulative fishing mortality from first capture at 3 years old through to mean age of first spawning was $\Sigma F = 1.81$, and the annual fishing mortality of the fully recruited age groups was 0.50 at the 1971 pattern and intensity of fishing. On the suggested criterion, ΣF should not exceed 1.6, or annual $F = 0.45$. For species or stocks with a shorter exploited life-history before spawning, the annual fishing mortality could be higher without the total margin of permissible depletion being exceeded.

13 The regulation of fishing mortality to the cumulative level suggested would ensure replacement and a sustained average level of recruitment in a stock which has not already been depleted below the implied critical level. If that scale of depletion has occurred, regulation to this level will not provide for recovery; that will depend on the chance occurrence (and protection) of the occasional strong year-class. More stringent management measures would be necessary to ensure a lasting recovery and, in theory, the more stringent the measures, the more rapidly the stock would recover.

14 The study of survival can therefore indicate levels beyond which fishing mortality should not rise without an unnecessary (unrewarding) increase in risk to the stock. In this paper, such a level is indicated for Arctic gadoid stocks; this may be refined. An appropriate level for clupeids may well be different but might be approached in the same way.

REFERENCE

GARROD, D. J., 1972. The variations of replacement and survival in some fish stocks. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer, Vol. 164 (in press).

Table 1 Statistical characteristics of estimates of survival ($\log_e S$)

	n	Mean	Standard deviation	Max
GADOID STOCKS				
Arcto-Norwegian cod	23	1.52	0.76	3.27
Iceland cod	23	0.53	0.76	1.68
West Greenland cod	27	0.36	0.80	2.21
Arcto-Norwegian haddock	14	2.18	0.63	3.35
North Sea haddock	26	3.73	1.31	5.94
Georges Bank haddock	28	1.90	0.60	3.16
Average		2.38	0.84	
OTHERS				
Pacific halibut	19	0.73	0.53	1.38
Hokkaido-Sakhalin herring	38	0.43	1.40	3.29
California sardine	23	1.67	0.79	2.71