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EVALUATION OF THE EFFECTS OF CLOSED AREAS ON FISH STOCKS

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ABSTRACT

There is increasing international interest in the use of closed areas or no-take-zones (NTZs) to protect fish stocks. Examples are given of the evaluation of European closed areas, as mathematical exercises and as empirical investigations. Models for the evaluation of closed areas are described. Generally the results show that it is beneficial to protect nursery areas. In contrast, protection of spawning areas is of limited use if the catch of fish is taken elsewhere. The results are compared with positive claims for the use of NTZs. It is argued that most benefits have been seen in reef fisheries. It is the different biology and management that gives the different results. A wider range of uses for NTZs is presented.

Keywords: Fisheries, reserves, no-take-zones, refuges, population model, plaice, cod, Bristol Channel.

INTRODUCTION

Fisheries scientists have an extensive experience in both the use of closed areas, as a management tool, and in the evaluation of the utility of closed areas. Figure 1 shows some of the areas in which fishing is restricted under EU Regulations. In this paper are described the use and evaluation of closed areas in fisheries on the European Shelf. Such evaluations are undertaken by specialist groups and the methodology is seldom exposed. Some models for the evaluation of the utility of closed areas are presented. The discussion highlights the importance of the prior evaluations, but also notes the limited nature of the class of problems addressed, and the sensitivity of the results to the other management measures that may be in place.

EXAMPLES OF EVALUATIONS

The Plaice Box

The Plaice Box is an area, of about 38,000 square km, off the Danish, German and Dutch coasts where trawling is restricted, to protect juvenile plaice (*Pleuronectes platessa*) and sole (*Solea solea*), Fig. 1. The Box was introduced in 1989, and its existence confirmed in the latest Regulation EC 850/98: for the conservation of fishery resources through technical measures for the protection of juveniles of marine organisms. As is common, the Box does not prohibit all fishing, and small local vessels are permitted to fish inside the Box.

ACFM undertook an evaluation of the utility of the Box in 1994 (Anon., 1994). It compared the long-term landings and spawning stock biomass (SSB) of plaice and sole, with different management options, relative to the then *status quo* of restrictions for the larger vessels in quarters 2 and 3 of the year. The results for plaice are summarised below.

Table 1: Percentage increase (%) in long-term landings & SSB relative to 1994 *status quo* Q2 and Q3 closures

MANAGEMENT OPTION	LANDINGS	SSB
	%	%
Remove box	- 8	- 9
Extend to Q4	+ 11	+ 14
Extend to all year	+ 14	+ 17
All year + no discarding fleets	+ 24	+ 29

It can be seen that if the Box was removed then long-term landings and SSB would decline by 8-9%, whereas if the prohibition was extended to all the year and to all vessels then landings and SSB would increase by 24-29%. The main reason for the impressive utility of the plaice Box is that discarding within the Box averaged 83%. Improvements in relative selectivity of the population would also have improved growth-overfishing.

The North Sea cod

The North Sea cod has been at, or near, historically low levels for about a decade. Fishing rates were such that SSB per recruit was reduced to less than 5% that at zero fishing. In 1993 the EU, through ICES and STECF, investigated the potential of closing large areas of the North Sea in order to protect the cod. Given our understanding of fish movements & fleet behaviour, the Working Group concluded that, closing areas, even as large as the one quarter of the North Sea, would do little or nothing to protect the widely dispersed and mobile fish, (Anon. 1993)

The Trevose spawning grounds

UK fishermen have been concerned about the state of fish stocks, and in 1993 the UK's National Federation of Fishermen's Organisations published "*Conservation, an alternative approach*" (NFFO, 1993), in which they advocated restricting fishing in certain areas. One such area was the Trevose spawning ground, off the north coast of Cornwall, England. It is a spawning ground for most of the important commercial fish in the Bristol Channel and in ICES divisions VIIf+g. A national evaluation was undertaken. To the disappointment of the fishermen, and similar to the results for the cod, it was found that prohibiting fishing on the spawning grounds, over spring, provided no benefits to cod, sole or plaice in terms of long-term catch or SSB.

Anticipating the later discussion, the reason for the lack of benefits in the latter two examples is that the fisheries are managed by TACs. If the fish are not caught in one locality then, and given the known migration and movements, the same fish will be caught in another locality.

THE EVALUATION MODELS

Approaches to modelling restricted areas have been presented in various places, but most of the work within ICES has been presented as Working Group reports, and these often lack the mathematical detail necessary to fully comprehend the analyses (eg. Anon., 1994). Horwood

et al. (in press) presented models for the evaluation of closed areas, conditional on the type and amount of biological and fishery data typical of the European waters. The following briefly introduces some of the models.

A rule of thumb

We can consider the relative sensitivity of an equilibrium biomass (B), of the mature component of the population, to proportional changes in adult (Z_a) and juvenile (Z_j) mortality. It can be shown that the relative sensitivity of mature biomass to unit changes in adult relative to juvenile mortality, $(dB/dZ_a + dB/dZ_j)$, is $(td.Z_a)^{-1}$ where td is the time from recruitment to knife-edge age at maturity.

When the sensitivity is unity the spawning biomass benefits equally by an incremental decrease in either Z_a or Z_j . For higher values, the greater proportional benefits accrue from a decrease in the adult mortality and *vice versa*. If we take $td=2$ years then, for adult mortality rates Z_a below $0.5y^{-1}$, a greater benefit to the spawning biomass will be achieved by a reduction in adult mortality rather than juvenile mortality. For many stocks $td.Z_a > 1$, indicating that the mature stocks would benefit more from a proportional protection of juveniles.

A model with some spatial catch data

Key information, of any evaluation of a spatial restriction on fishing, is knowledge of the biological character (eg age-composition) of the fish caught in an area, and of the fish caught in any other area into which effort is displaced. Even if we could accurately predict the behaviour of fishermen, seldom, even in our relatively data-rich region, do we have biological data on small enough space scales. We have to make assumptions.

Horwood *et al.* assumed that typical fishery data would include the total and fishing mortality rates at age in the population (Z_a, F_a), the total international catch weight (C_Σ) and that of a potentially restricted fleet inside of, (CIT_Σ), and outside of (COT_Σ) the box. It was assumed that the total catches, by age, of the target, (CT_a), and total, (C_a), fleets are known, but cannot be allocated by area. Under these conditions, further assumptions are needed to evaluate the effects of a closure; in particular the "relative availability" of the fish by age, to the target fleet, in the box (A_a). For example, if the box is a spawning ground then immature fish will be scarce and an estimate of the "relative availability" could be the proportion mature at age.

The assumption allows an estimate of the catch at age from the target fleet in the box. A second assumption is that effort can be related to catch and catch rate, if known, and reallocated accordingly. We need to estimate the partial fishing mortality of the target fleet operating in the box (FIT_a), and then calculate the effects on the equilibrium yield (Y_e) and spawning biomass (B_e) per recruit.

Defining $Y_e(F) = \sum_a F_a \cdot \phi_a$, it can be shown that $FIT_a = ((CIT_\Sigma / C_\Sigma) \cdot Y_e \cdot A_a / \sum_a A_a \cdot \phi_a)$ which implies knowledge of FOT_a . We can now calculate a revised $Y_e(F)$, and $B_e(F)$ with $F_a = F_a - FIT_a$ to give yield and biomass recruit if the fishing of the target fleet in the box was stopped and not redeployed. Fishing effort is likely to be redeployed. If effort, of the target fleet in and out of the box, is unknown, we can assume that the relative effort is related to the catch and catch rates (CR), such that the new total fishing mortality at age becomes,

$$\hat{F}_a = F_a - FIT_a + FOT_a (CIT_\Sigma / COT_\Sigma) (CR_o / CR_i), \text{ and we can calculate } Y_e(\hat{F}_a) \text{ and } B_e(\hat{F}_a).$$

Such a model was applied to evaluate the benefits of closing the Trevose spawning ground.

EMPIRICAL EVALUATIONS

The models above permit an *a priori* evaluation. Few examples exist of empirical *a posteriori* evaluations. One such case is that of the Mackerel Box (Fig. 1), which was established in 1981, off southern England and Ireland, to protect the relatively high concentrations of juvenile mackerel found in the area. Table 2 shows the relative selectivity (as $F(\text{age})/F(4-8)$) for the period 1972-1980 compared with the, post-Box, period of 1982-1996. After the introduction of the Box, the relative mortality on 0, 1, and 2-year old mackerel reduced by 83%, 60% and 20% respectively.

Table 2: Fishing mortality at age, relative to that for $F(4-8)$, for Western mackerel for the period 1972-1980 compared with 1982-1996.

	1972-1980	1982-1996	% REDUCTION
AGE 0	0.023	0.004	83
AGE 1	0.277	0.111	60
AGE 2	0.503	0.404	20

More generally, the OECD (Anon., 1997) recently reviewed the benefits to fisheries of 52 restricted areas. It found that in 32 cases stocks declined or had major oscillations. Only in 16 cases had stocks either increased or stayed the same.

To give some appreciation of how difficult are empirical studies, consider the North Sea plaice Box. Potential benefits are relatively large, of the order 20%. It is not possible to monitor SSB directly, and increased landings can be at the expense of the stock. Benefits will most directly be judged through apparent increased recruitment. Let us assume that Log-recruitment is normally distributed, and independent from year to year; the variance of plaice log-recruitment is about 0.15 (sd 0.39). Under these conditions, it would take over 30 years before we had a 90% probability of recognising a 20% improvement in recruitment with 5% statistical significance. A similar statistic for a 15% improvement would be about 60 years!

DISCUSSION

The use of closed areas, or "No-Take-Zones" (NTZs), has been the subject of much international debate (eg. Anon. 1990; Ballantine 1991; Roberts & Polunin 1993; Rowley 1994; Gubbay 1996; Pullen, 1996; Russ & Alcalá 1996; McGlade *et al.* 1997; Roberts 1997; Schmidt 1997; Walters *et al.* 1997; Watson 1997; Crosby, 1998). There have been significant claims for the benefits of NTZs such as: spawning biomasses can double or quadruple over 2-10 years; increased catches; increased diversity; enhanced habitat; benefits demonstrated by field studies; and all delivered with closures of the order of 10-20%.

It is therefore no surprise that fishing interests and conservation organisations are looking towards NTZs as an answer to the pressing problems of growth and recruitment overfishing. However, the studies above show that quantitative analyses of European stocks, managed under TACs, will not in general deliver such benefits.

From the above we can see that, in general, restricting fishing on nursery grounds will give benefits to the stock, and especially so if there is significant discarding of small fish. Protecting spawning grounds, where the stock is managed by a TAC, is likely to divert effort

and dissipate any benefits. In fact, more fish may well be killed because of the displacement onto smaller fish. Why then the claims above?

Most of the positive benefits have been observed in reef fisheries. These are characterised by, if any, an effort management. The adult fish are relatively immobile but their spawning products can be widely dispersed. The NTZs act as a source for other adjacent areas. This is not the biology implicitly modelled in the examples above. The differences can thus be put down to differences in biology and other management measures, and one must conclude that the benefits from reef fisheries do not directly translate to marine temperate fisheries managed by TACs.

Nevertheless, there are examples where NTZs must be an obvious management tool. There are vulnerable species, caught as by-catch and which are not, and cannot be, fully protected by TACs. Rays are such an example. NTZs may be an important tool in giving protection to such species. There are areas vulnerable to fishing, such as those housing delicate slow-growing forms such as corals. If we want these areas protected it is difficult to imagine that anything else other than a NTZ will work. Indeed we may need something stronger than a NTZ - perhaps a No-Impact-Zone. There are species that behave like reef-species, being essentially sedentary, dispersing their progeny, and being vulnerable to over-exploitation; scallops might be such an example. It is possible to imagine a management system wherein key areas of scallops are protected, in order to seed adjacent areas - just like the reef fisheries. Finally, if we want to study the dynamic behaviour of fish benthic habitats, we will need to monitor the natural changes that occur in the sea-bed over decades. NTZs or no-impact-zones would be essential for this purpose.

For all the examples, and uses, it is however possible to quantify the effects of proposed closed areas. Such results will be sensitive to the behaviour of fish and fishermen, and to the other management systems in place. Undoubtedly one will encounter the problem of poor spatial resolution of fisheries data, but even so approximate evaluations can and should be made.

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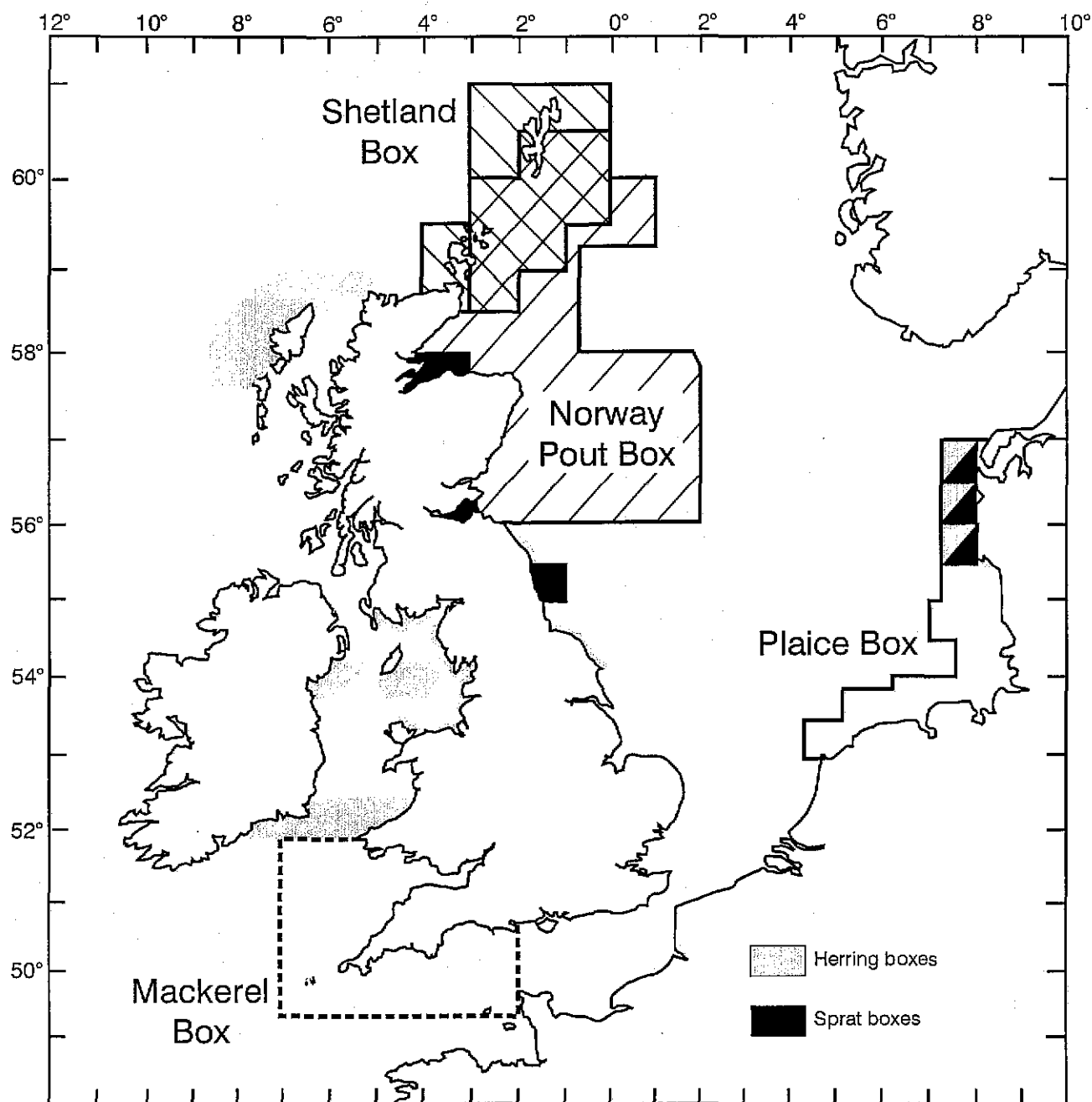


Figure 1: Major closed areas in European waters

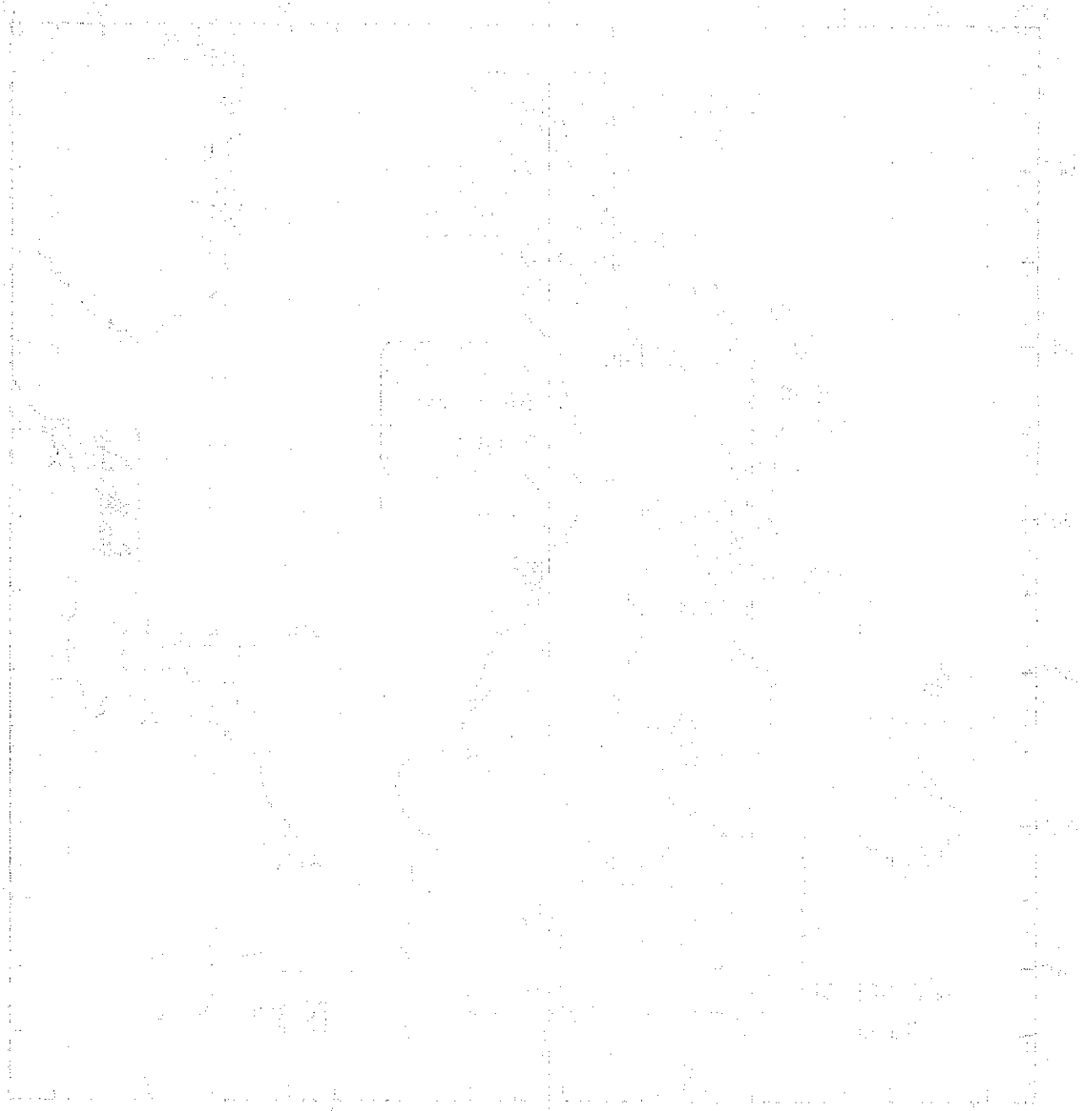


Figure 1. [Illegible text]