Estimating Sustainable Yield from Biomass and Harvest Rates: What Are the Appropriate Approaches for Tropical Species with High Values of M?

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ABSTRACT

Various methods have been proposed to calculate MSY from biomass estimates but the classical approach of Gulland (1971), MSY = 0.5 M B_o is still widely used, despite overwhelming theoretical and practical evidence pointing to its limited value, jprobably due to confusion as to available alternatives. A review of alternative methods is presented and their applicability to species with high values of M discussed. A simple method is presented on how to incorporate other ecological and life history parameters into the estimation of sustainable yield from biomass and harvest rates. The proposed method is then placed in the context of provding advice to fishery managers.

KEYWORDS: Biomass, mortality, production model, yield.

INTRODUCTION

The ineffectiveness of advice based on traditional fishery models to curtail mismanagement of fishery resources (Ludwig *et al.*, 1993) forces fishery scientists to reassess methods used to assess fish stocks. There is a special need to reassess methods designed to estimate sustainable yield on the basis of biomass and harvest rate data, because they are often applied to fast-growing tropical species for which they were not designed.

There are many fisheries in the developing world where research surveys are still the only source of data for the estimation of stock biomass and the maximum sustainable yield which the fishery may produce. The most common methods used for the estimation of MSY are derivations of Gulland's (1971) approximation, MSY = 0.5 M B_0. Scientists are not always aware of some of the assumptions of these methods, nor are they aware of recent methodological developments in this area of fisheries science. There is, therefore, a need to transmit and discuss such developments with our colleagues. Methods discussed in this paper include those developed exclusively for virgin stocks (Gulland, 1971; Beddington and Cooke, 1983) and those developed for exploited stocks which require additional information on harvest rates such as catch and fishing mortality (Cadima, in Troadec, 1977; Garcia *et al.*, 1989).

Appropriate natural mortality and fishing mortality values are required to apply the avove methods. Biological reference points can be used as estimators of F_{MSY} and a simple extreme value strategy may be used to deal with uncertainty in natural mortality rates. The biological reference points discussed in this paper are the fishing mortality which maximizes yield-per-recruit F_{max} , the closely related $F_{0.1}$, and the fishing mortality leading to maximum biological production F_{MBP} . [$F_{0.1}$ is a reference point for yield per recruit. It refers to a fishing mortality smaller than F_{max} and it is calculated at the pont where an increase in F increases yield-per-recruit by a tenth of the increase obtained when F is zero (the slope of the yield-per-recruit curve at $F_{0.1}$ is 1/10 of the slope at F=0). $F_{0.1}$ and F_{max} were calculated with program LFSA (Sparre, 1987).]

A simple method on how to constrain the value of F_{MSY} and $F_{0.1}$ to reduce the probablity of overfishing the spawning population is also presented. Finally a hypothetical example illustrates the effects on sustainable yield estimates of using the above mentioned biological reference points.

REVIEW OF MODELS FOR THE ESTIMATION OF SUSTAINABLE YIELD FROM BIOMASS DATA

Various authors have reviewed methods for the estimation of sustainable yield from exploited or unexploited stocks (*e.g.* Beddington and Cooke 1983, Caddy and Csirke, 1983; Garcia *et al* ., 1989). A brief summary of such reviews follows.

Gulland's approximation

Under the assumption that fishery production follows a Schaefer (1954) model and that F_{MSY} = M, Gulland (1971) proposed the following approximation,

$$MSY = 0.5\ M\ B_0 \qquad (1)$$

where MSY is the maximum sustainable yield, M is the instantaneous coefficient of natural mortality and B_0 is the virgin biomass. Gulland further developed the above equation by proposing,

$$MSY = x\ M\ B_0 \qquad (2)$$

where x is a constant that may be related to the growth and mortality characteristics of the stock.

Because equations (1) and (2) are derived from a Graham-Schaefer production model, MSY is assumed to be independent of age at recruitment, and recruitment is assumed to be unaffected by fishing at the level required to extract MSY. These approximations are also only applicable to unexploited stocks.

Beddington and Cooke model

Beddington and Cooke (1983) proposed a modification of Gulland's generalised model in which they recognise the importance of distinguishing biomass estimates referring to the total virgin stock biomass B_0, from those referring to the virgin recruited biomass B_0',

$$MSY = c_1 B_0 = c_2 B'_0 \qquad (3)$$

The above authors provided values of the constants c_1 and c_2 in a table for given values of the age at recruitment, the natural mortality rate, and the Von Bertalanffy growth parameter K. Because the underlying model used by Beddington and Cooke (1983) in their calculations is of the same form of a Beverton and Holt (1957) yield model these values were derived under the assumption that recruitment is independent of stock biomass. Unfortunately also, these authors provide estimates of c_1 and c_2 for a limited number of M (0.2, 0.4, 0.6) and K (0.2 and 0.4) values representing only slow growing and low mortality species. This model is only applicable to unexploited stocks.

Cadima's approximation

Cadima (in Troadec, 1977) proposed an estimator for exploited stocks where the instantaneous coefficient of total mortality Z or the catch Y is known,

$$MSY = 0.5\, Z\, B \text{ or } MSY = 0.5\,(Y + M\, B) \qquad (4)$$

where B is the biomass under exploitation.

Garcia et al . (1989) showed, however, that this method has serious flaws because it is only unbiased in two situations: when the stock is virgin (a trivial case because then Cadima's formula is equal to Gulland's), or when the stock is fished at around the MSY level (which would only make it useful in a few, unidentifiable, cases).

Other models

In an attempt to correct the problems raised by Cadima's approximation, Garcia *et al.* (1989) presented two alternative formulations, one based on the Schaeffer (1954) production model,

$$MSY = \frac{F_{MSY} B}{2F_{MSY} B - Y} \qquad (4)$$

the other on Fox's (1970) production model,

$$MSY = F_{MSY}\, B\, e^{\left(\frac{Y}{F_{MSY} B} - 1\right)} \qquad (6)$$

Both equations are directly derived from production model formulations, and thus provide unbiased estimates of MSY regardless of the state of exploitation of the fishery. They rely, however, on the same assumptions regarding age at recruitment and the effect of fishing at MSY levels as any other model based on production models. Although making a statistical choice between these two functions is difficult even when a time series of effort and catch is available, an informed choice can be made depending on the life history of the stock, with short lived species being more often associated with the second form of the Garcia *et al.* (1989) model (equation 6).

If the fishery follows a Schaefer model, equation (6) will underestimate MSY regardless of the state of exploitation. This underestimation, however, will only be very large if the stock is either very lightly or very heavily exploited. If the stock follows a Fox model, however, equation (5) will overestimate MSY regardless of the state of exploitation. The overestimation will be small for underexploited stocks but may be very large if the stock is overexploited (here the terms under- and overexploited refer to fisheries where fishing mortality is below or above F_{MSY} respectively). Thus equation (6) will generally produce more conservative MSY estimates than equation (5). In overexploited fisheries equation (5) may create dangerously false expectations about the value of MSY.

THE ESTIMATION OF SUSTAINABLE FISHING MORTALITY RATES

The two models proposed by Garcia et al. (1989) do not make any assumptions about the status of exploitation nor about the value of F_{MSY}. However, the user of the model is forced to look for an appropriate estimate of F to substitute instead of F_{MSY} in formulas (5) and (6).

Making the wrong estimate of F_{MSY}, however, will also bias the estimation of MSY. If F_{MSY} is overestimated equations (5) and (6) will overestimate MSY for underexploited fisheries and underestimate it for overexploited fisheries. The opposite will occur if F_{MSY} is underestimated. These biases are potentially very high when F_{MSY} is inferred from Z_{MSY} and M because of the high uncertainty of most M estimates. That is why it is better to use some other biological reference point, other than Z_{MSY} or M as estimators of F_{MSY}. From now on we will refer to F_{SY}, the fishing mortality rate at a high sustainable yield, as any of the biological reference points which can be used instead of F_{MSY} in equations (5) and (6).

Maximum Biological Production

Caddy and Csirke (1983) developed another biological reference point in place of F_{MSY}: the fishing mortality rate F_{MBP} leading to the Maximum Biological Production of the stock. F_{MBP} is defined as:

$$F_{MBP} = 0.5\ (r - M) \tag{7}$$

where r is a parameter of Graham's (1935) production model which defines the convexity of the parabola, and is related to the value of x in equation (2) by

$$r = \frac{M}{x} \tag{8}$$

F_{MBP} has useful properties for a developing fishery, because it is difficult to produce excessive fishing mortality by using it as a biological reference point. Caddy and Csirke (1983) suggest that at the point of maximum biological production there is less risk of ecological perturbation because the stock is at its maximum productive capacity (Figure 1). This suggestion is also consistent with the theory that a virgin stock would be dominated by old fish with low conversion efficiency. As these authors point out this may be specially

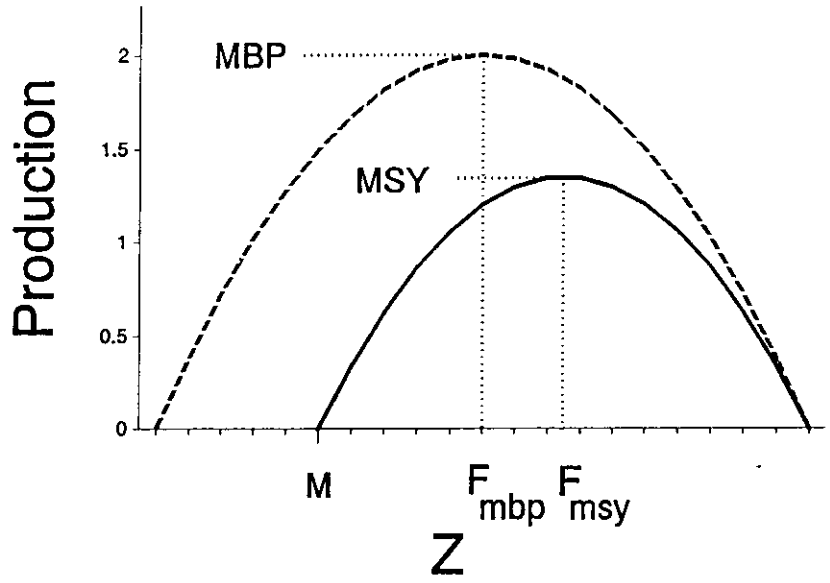

Figure 1. Biological (dashed line) and fishery (solid line) production curves as derived from the model of Caddy and Csirke (1983).

significant for fisheries where many species contribute to the catch. In such cases large changes in abundance caused by fishing beyond MBP may alter the ecology of the fish community and affect stable fishery production of other species. Using F_{MBP} as a biological reference point for fishery development is therefore more conservative than using F_{MSY}.

TheRelationship between M and F_{MSY}

Caddy and Csirke (1983) presented data from eleven stocks where M and F_{MSY} had been estimated, and showed that the factor x in equation (2) could range from 0.18 to 2.12. This is the equivalent to F_{MSY} ranging from a third to five times the value of M, and these data certainly suggest that $M = F_{MSY}$ is not a common situation. Table 1 presents other estimates which fall within this range. Unfortunately both data sets suggest that both short and long lived species may be associated with both high and low x values. This contrasts with the theoretical and empirical results from several authors. For instance, on the basis of theoretical inference, Beddington and Cooke (1983) proposed that x is in general smaller than 0.5 and decreases as M increases, and Garcia and Le Reste (1981) suggested that x for tropical penaeids is smaller than 0.5 (between 0.32 and 0.44). These later values agree with an empirical estimate for x of 0.335 obtained by a review of production model assessments in several penaeid stocks (Garcia, 1985).

Table 1. Instantaneous coefficients of natural mortality ***M*** and of fishing mortality which produces the maximum sustainable yield F_{MSY} for several stocks of fish selected from recent literature. (a): Zhang *et al*. (1991), (b): Zhang and Sullivan (1988), (c): NPFMC (1992), and (d): Correa Ivo and Batista de Sousa (1988 [These authors did not provide estimates of M or F_{MSY}, but their data on yearly catches and total mortalities were fitted to Csirke and Caddy's (1983) production model to obtain these two parameters).

Species	F_{MSY}	**Reference**	***M***	**Reference**
Yellowfin Sole	0.2	(a)	0.2	(b)
Alaska Plaice	0.34	(a)	0.2	(b)
Sablefish	0.29	(c)	0.10	(c)
Pacific cod	0.12	(c)	0.27	(c)
Slope Rockfish	0.05	(c)	0.06	(c)
Brazilian Snapper	0.45	(d)	0.4	(d)

It is obvious, as suggested by Caddy and Csirke (1983), that there may be great benefit, in reviewing published estimates of M and F_{MSY} from the literature to see whether simple rules can describe the relationship between these two parameters. Caddy and Csirke (1983) note that r may be low for species that are low in the food chain, and suffer high predatory stress, and which therefore cannot be expected to contribute too much surplus production towards a fishery catch without this leading to collapse of their populations and that of their predators. Looking at the data provided by Caddy and Csirke (1983) and the dat pesented in Table 1, however, it seems that defining such rules may be a more complex matter than these authors had hoped for.

Francis (1974) and Deriso (1982) reported that the relationship between F_{MSY} and M, is defined by the parameters of the spawner-recruit relationship. Even if true, unfortunately these parameters are generally not known. Deriso (1983) also proposed that the fishing mortality that maximises yield per recruit F_{max} in a fishery can be used as an estimate of the upper limit of F_{MSY}. This in fact is equivalent to Gulland's suggestion that an estimate of x in equation (2) can be obtained from the Beverton and Holt (1966) tables of yield-per-recruit. More recently Clark (1991) has similarly shown that, on the basis of a yield model which incorporates a stock-recruitment relationship, safe groundfish exploitation rates should be set at a level that ensures maintenance of 35% of the virgin spawning biomass per recruit. According to Clark, in most cases, a fishing mortality equal to $F_{0.1}$ will ensure such levels of spawning biomass per recruit.

Observations that in some fisheries F_{MSY} is larger than M are not in disagreement with the theories of Francis (1973), Deriso (1982) and Beddington and Cooke (1983). In fact such fisheries are probably characterised by having asymptotic yield-per-recruit and sustainable yield curves (MSY and yield-per-recruit become insensitive to F as F increases). This is certainly the case for those fisheries where recruitment is largely independent of stock size and where most of the landings are made up of the recruits of a single year class. It is also characteristic of fisheries for apical predators, where M is very low. Clark (1991) reports that fisheries where recruitment and maturity schedules do not coincide will require exploitation rates corresponding to fishing mortalities significantly different from $F_{0.1}$.

ARE YIELD ESTIMATES SUSTAINABLE?

Most methods mentioned above assume there is no strong effect on recruitment by fishing at the level proposed by the various biological reference points. It is important to get a feel for whether this is a reasonable hypothesis or not especially in cases where the proposed F target is high (*e.g.* for a small pelagic fish, an $F = M = 1.0$ implies only 13% stock survival per year). A rough idea of the effects of fishing mortality on the spawning stock is obtainable if there is knowledge of the size at 50% maturity, L_m and first capture, L_c. Estimates of these two parameters can be obtained during a biomass survey.

Consider a stock where the average length of fish in the catch is $\bar{L}$. If $\bar{L} > L_m$, on average, an individual fish will have reached maturity (and hopefully spawned once) before it is caught. Therefore the stock is more likely to be able to sustain itself than if $\bar{L} < L_m$. Beverton and Holt developed an expression that relates total mortality and average size in the catch,

$$Z = \frac{(L - \bar{L})\,K}{(\bar{L} - L_c)} \tag{9}$$

where K and L are the Von Bertalanffy growth parameters. If we incorporate the inequality $\bar{L} > L_m$ in equation (9), then

$$Z^* < \frac{(L - L_m)\,K}{(L_m - L_c)} \tag{10}$$

gives an upper limit for Z. Obviously if $L_m < L_c$ there is no need of applying the above equations, because on average a fish will mature before it is caught. This upper limit Z^* can be used in two ways. First it can lead to the estimation of an upper limit F^* which could be used as a biological reference point or at least checked against some of the other biological reference points presented above. Second it can be used to monitor a fishery as it develops, if Z is estimated periodically. This latter approach has the advantage that it does not require knowledge of M. Given how difficult it is to estimate M and given the likelihood

Table 2. Fishing mortality at a sustainable yield F_{SY} and sustainable yields *SY* obtained by "guessing" the value of F_{SY} by different methods and by using the methods proposed by Garcia *et al.* (1989). Data are from an hypothetical sardine example in the text.

	F_{SY}		*SY*	
M	**Method**	**Estimate**	**Schaeffer**	**Fox**
0.58		0.58	3,200	2,500
0.88	$F = F_{MSY} = M$	0.88	4,600	3,600
1.79		1.79	9,200	7,000
0.58		0.62	3,400	2,700
0.88	$F = F_{max}$	1.04	5,500	4,200
1.79		4.30	21,700	16,200
0.58		0.37	2,100	1,800
0.88	$F = F_{0.1}$	0.56	3,100	2,500
1.79		1.37	7,100	5,400

that M and F may be related (M may change as the fishery develops and the ecology of the area is changed by fishing), it seems that monitoring Z would be less uncertain than trying to monitor F.

The theory behind this last equation relates to the concept of sustainable exploitation rates on fisheries where the recruitment and maturity schedules do not coincide (Clark, 1991). This author showed that if recruitment to the fishery takes place much later than maturation, the maximum sustainable F can be significantly higher than $F_{0.1}$ without dangerously reducing the spawning biomass. Conversely he also showed, that if fish mature much later than they recruit a truly sustainable F may be much smaller than $F_{0.1}$. Equation (10) provides, in the absence of information on the stock-recruitment relationship, a simple way to check the effects of fishing on the spawning stock.

Equation (10) can also be used to establish the minimum size at first capture require to support a fishery where $\bar{L} > L_m$. To do so it is enough to incorporate the inequality $M < Z^*$ in the above equation and solve for L_c.

$$L_c > L_m - \frac{(L \ - L_m)\ K}{M} \qquad (11)$$

Note that this equation is only defined if

$$\frac{L}{L_m} > \frac{M}{K} + 1$$

Table 3. Fishing mortality F_{MBP} and corresponding yield Y_{MBP} at maximum biological production estimated from the model of Caddy and Csirke (1983), for various values of the parameter *r*. Data are from an hypothetical sardine example in the text.

		F_{MBP}	Y_{MBP}	
M	***r***	**Estimate**	**Schaeffer**	**Fox**
0.58	1.0	0.21	1,400	1,200
0.88		0.06	1,800	1,200
1.79		-	-	-
0.58	2.0	0.71	3,800	3,000
0.88		0.56	3,100	2,500
1.79		0.10	1,000	1,000
0.58	3.0	1.21	6,300	4,800
0.88		1.06	5,600	4,300
1.79		0.60	3,300	2,600

Table 4. Fishing mortality at a sustainable yield F_{SY} and sustainable yields *SY* obtained by using the methods proposed by Garcia *et al*. (1989), and by equating F_{SY} to $F_{0.1}$ and constraining it by F^*. Data are from hypothetical examples in the text. (a) In this case the value of $M > Z^*$. This implies that natural mortality alone will reduce the average size of an animal in its exploitable phase below the average size at maturity.

			SY	
Life history type	***M***	F_{SY}	**Schaeffer**	**Fox**
Shrimp	1.28	1.40	7,300	5,500
	1.94	0.71	3,800	3,000
	3.97	(a)	-	-
Grouper	0.17	0.10	1,000	1,000
	0.26	0.14	1,100	1,100
	0.53	(a)	-	-
Sardine	0.58	0.31	1,800	1,600
	0.88	0.47	2,600	2,100
	1.79	0.61	3,300	2,600

APPLYING SY ESTIMATORS TO SURVEY DATA: AN EXAMPLE

Consider a tropical fishery for a sardine-like fish, where biomass is estimated at 10,000 t, the annual catch at 1,000 t, the length at first capture at 9 cm, the L at 30 cm, and the annual K at 0.4; all estimates from length frequency data.

Commonly M will not be known and will have to be estimated empirically. Pauly's (1980) equation can be used, and for a temperature of 22° C gives an estimated M of 0.88. According to Gulland and Rosenberg (1992) a rough estimate of confidence limits for this value would be from 0.58 to 1.79.

Given the value of length at first capture, the natural mortality rate, and the Von Bertalanffy parameters, we can estimate the fishing mortality which maximises yield-per-recruit, F_{max} and the $F_{0.1}$. For the values of M estimated above the values of F_{max} are, 0.62, 1.04, and 4.30 and the values of $F_{0.1}$ are 0.37, 0.56 and 1.37. These values can now be used to calculate sustainable yield (SY) from equations (5) and (6). Estimated SYs (Table 2) range by more than one order of magnitude (1,800 - 21,700). Considering that the confidence limits for M may be optimistic (Gulland and Rosenberg, 1992) there is a fair chance that by choosing an average MSY of 4,600 (obtained from the best estimate of M and assuming F_{MSY} = M), we may overestimate or underestimate SY by a factor of three. Clearly such large uncertainty in the estimate of SY will lead to problems in formulating advice to fishery managers.

Out of the three methods used to obtain estimates of F_{SY} the one that is less affected by the uncertainty in the value of M is Gulland's assumption that F_{MSY} = M. Using F_{max} from yield per recruit leads to the widest range of SY values as a function of M. The most conservative estimates of SY are obtained by using $F_{0.1}$. The conservative character of the $F_{0.1}$ biological reference point had already been established in earlier studies but it had not been clarified that any variance associated with the estimate of M is amplified in the estimation of yield.

Alternatively one may want to calculate the yield at maximum biological production as suggested by Caddy and Csirke (1983). Again, depending on the values of M and r, we obtain a large range of predicted yields (Table 3) which vary by a factor of six (1,000 - 6,300 t). Note however that most estimates are relatively conservative, and, as reported by Caddy and Csirke (1983), approximate estimates are obtained by using $F_{0.1}$. The main problem with this method is in guessing the value of r, which is analogous to guessing the value of F_{MSY}. In fact the value of r really determines how conservative this method is compared to the others above: the lower the r the more conservative.

Now assume that the estimated length at maturity from the survey was 12 cm. From equation (10) above we can calculate a Z^* which would ensure fish, on average, reach maturity before they are caught. The value of Z^* obtained is 2.4, which combined with estimates of M of 0.58, 0.88 and 1.79 gives estimates of F^* of 1.82, 1.52 and 0.61 respectively. It is now possible to compare these values of F^* with those of F_{MSY}, $F_{0.1}$ and F_{max} estimated above for the corresponding M.

This suggests that:

if M is either 0.58 or 0.88, and
$$F \rightarrow \begin{array}{c} M \\ F_{0.1} \\ F_{max} \end{array} \text{ then } \bar{L} > L_m$$

the average size of fish in the catch will be above the length at first maturity. However,

if M = 1.79, and
$$F \rightarrow \begin{array}{c} M \\ F_{0.1} \\ F_{max} \end{array} \text{ then } \bar{L} < L_m$$

the average size of fish in the catch will drop below the size at first maturity. It is therefore advisable to use F^* as a constraint for any target of F set from M, $F_{0.1}$ or F_{max}. Table 4 shows yield calculations obtained by using $F_{0.1}$ as an F biological reference point constrained by the value of F^*. Note that the value of F suggested for M = 1.79 is 0.61, which is very close to F_{MBP} (Table 3). According to these results the level of sustainable yield is between 1,600 and 3,300 t. By this method we seem to obtain a narrower range of values within the lower range of yield estimates than any of the previous approaches.

The same calculations can be made for another two life history types, a grouper-like fish (L = 130 cm, K = 0.12, L_m = 50 cm and L_c = 30 cm) and a tropical shrimp (L = 15 cm, K = 1.0, L_m = 9 cm and L_c = 7 cm). Using these parameters in equation 10 the estimates of Z^* for these two life history types are respectively 0.48 and 3.0. Results of calculations of sustainable yield values show that the expected sustainable yield for a shrimp stock would be from 3,000 to 7,200 t and for a grouper stock from 1,000 to 1,100 t (Table 4). It is interesting to note that for both the grouper and shrimp examples if M is high, equation (10) results in a Z^* smaller than the corresponding M. For these two examples there is a chance that even in the absence of fishing the average size of fish in the exploitable phase is smaller than the size at first maturity. It follows that any fishery with such low sizes at first capture would run the risk of recruitment overfishing. To reduce this risk, according to equation (11), length at first capture would have to be larger than 32 cm for the grouper and larger than 7.5 cm for the shrimp.

DISCUSSION

We may question whether it is possible to use any of the above methods to provide a safe yield target for fishery development or/and management. The most obvious weakness of all these methods is that they assume a stock in steady state and that recruitment is determined by intrinsic characteristics of the stock. For most stocks these assumptions will not be fulfilled. These methods however, should be judged by their capacity for providing useful advice, not by their ability to fully replace proper stock assessments.

We have to remember that our perception of the proper use of biological reference points in fisheries development and management has changed since Gulland proposed his original formulation in the 1950's. At that time, fisheries were still in an expanding phase in the developing world, and the only biological information available were some isolated estimates of biomass from research vessel surveys of virgin stocks and some very uncertain guesses of the likely natural mortality rate of the species.

This new perception about the use of biological reference points for the estimation of sustainable yield has five important implications:

1. Using MSY or F_{MSY} as fishery development strategies causes significant problems and, other alternatives which have been proposed based on biological reference points like $F_{0.1}$, F_{MBP}, F^*, etc., come closer to both ecological and economic optima.
2. These more conservative development strategies can still lead to a fishing effort pulse.
3. Any development strategy that attempts a single 'leap' from an unexploited or underexploited situation to any of the above biological reference points makes a number of assumptions that are probably not justifiable, namely that a single estimate of yield is accurate and sufficient to guide the fishery through to full exploitation.
4. Environmental factors may lead to major fluctuations in recruitment and biomass from year to year. If harvest levels are fixed at a high proportion of the available yield, overfishing in poor recruitment years may lead to irreversible stock decline.
5. Even if the biological reference point is reached, the ecological context that the stock finds itself in relation to its predators, prey and competitors may be considerably changed from the lightly fished condition, depending on the resilience of the stocks in the face of fishing. Our still limited experience with multispecies fisheries over the last few decades suggests that the assumption of continued ecological stability is almost certainly untenable.

Although it is useful to have an idea of the potential of a fishery, for the above reasons it is now standard advice from FAO, that development should be approached in a staged fashion. In addition, monitoring of a variety of population variables can be used to refine the initial yield estimate, and help establish the appropriate fleet size for the sustainable use of the resource. It is clear then that the sustainable yield predictions we have been discussing are only very approximate, and should not be used as the main support for immediate fleet build up.

Then, do these biological reference points have other uses? We believe they do, especially when there are not enough resources for a routine yearly assessment of the size and status of all stocks. This alternate use of biological reference points in fishery management depends on the concept of the 'feedback loop', and we make an analogy between a managed fishery and a thermostat for regulating the temperature of a room. Just as the thermostat registers overheating by turning off the current, so a fishery manager in theory could react in a prompt way by reducing credit and/or access when one or preferably sever ogical reference pointsindicate that the stock is in trouble (Caddy, 1986).

What could be the biological reference points for such a system? Including economic indicators (which generally must be defined specifically for each fishery), fishery managers might agree in advance with the fisheries industry to react automatically when some or all of the following biological indicators flash warning signals:

- when Z rises above ZMBP or Z^*;
- when falls below L_m; or when the proportion of mature fish in the catch falls below some preset minimum;
- when annual recruitment is poor.

Evidently, some preliminary analysis is needed to provide realistic values for the biological reference point. The system would also require an unbiased monitoring program for the biological reference points chosen and a prompt and predetermined response from managers when preset values are exceeded.

For a fishery where little is known and where advice on the level of yield that can be extracted is required, there seem to be no alternatives to the use of the above methods. It has to be recognised however, that this sort of advice is generally used for development at the medium to long term. Therefore regardless of the fact that more data may be produced in the near future the initial advise should be conservative rather than optimistic. It is much easier to increase a development target after a few years, than later have to reduce it. It is also less risky from a biological and ecological point of view to set a conservative level of exploitation, and approach fisheries development with caution.

Given that conservative targets for fishing mortality should be preferred we have proposed here a method to develop sustainable yield estimates from biomass surveys. Such a strategy will produce a range of conservative estimates of sustainable yield which can be used to provide robust advice to fishery managers. It is however imperative that such advice be qualified by:

- Making fishery managers aware of the very serious shortcomings of the methods and data used to produce this advice, and
- Recommending that a proper resource assessment study be set up to reassess the above mentioned sustainable yield estimates.

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