# An Overview of Objectives for Fisheries Management

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## Abstract

A brief description of modern aims and targets for fisheries management that have been used recently is given. This covers MSY, $F_{max}$, $F_{msy}$, $F_{0.1}$, spawning stock maintenance, buffer stock maintenance, *status quo* F, $F_{med}$, $F_{low}$, $F_{high}$, and constant escapement. A selection of examples from managed fisheries is given.

## Introduction

Larkin (1977) and Gulland (1977, 1984) have discussed some of the limitations of the concept of maximum sustainable yield (MSY) as a fisheries management objective. Since these reviews, a number of mathematical targets have been described in order to address problems other than straightforward yield maximization. Some of the more simple and accessible of these targets, particularly those that have a proven record in stock management, are discussed here. If one is going to recommend some sort of management advice, it is essential to have a declared policy aim, i.e., the objective, and some clearly-defined target against which one can compare the present condition. This target should be a marker of the 'optimum' which one has defined for the fishery and describes the condition towards which one is trying to take the fishery by managing it. Current progress in fisheries management can then be assessed by comparing what is the actual situation with reference to the chosen target and advice issued on what to do in order to lead the fishery closer to the target.

Unfortunately, many of the targets in current use have been described in publications with limited circulation and may not all be readily available to readers of Fishbyte. In an attempt to redress this situation, some of the objectives that have been used in recent years are described here, together with the models used to calculate the targets. Some of their advantages and disadvantages are discussed, with some emphasis to tropical fisheries.

## A. To Maximize Yield

Most obviously, one may choose to attempt to maximize the long-term MSY. This is a useful concept as it is simple and straightforward and can be easily explained to the political and industrial sectors. It has been used throughout the world in many fisheries and has become largely accepted as the usual objective. A disadvantage, however, is that MSY, in the tropics, often occurs at such high levels of effort and relatively low catches per unit of effort that the fisheries tend to be unprofitable. MSY and its approximation can be calculated using either surplus-production or age-structured models. The MSY concept has perhaps been overused and has been applied in inappropriate situations. Four targets are commonly used:

*A.1. MSY from surplus-production models.* This is the well-known MSY from models such as those of Schaefer (1957), Fox (1970), Caddy and Csirke (1983), etc. The models are simple and undemanding of data and have the advantage of implicitly including a stock-recruitment relationship. A problem with most of these - except the Caddy and Csirke model - is that it is difficult to define the fishing mortality at which MSY is obtained ($F_{msy}$). Although the fishing effort of MSY ($f_{msy}$) can be estimated, this is not always useful as a management tool, because catchability can vary widely.

*A.2. MSY from age-structured models.* It is possible to include an explicit stock-recruitment relationship in a conventional age-based stock assessment in order to calculate an MSY. This approach, based on a "self-regenerating model", is very demanding of data and in fact has rarely been used in the past.

*A.3. $F_{max}$.* This is the fishing mortality (F) at which maximum yield per recruit is obtained. $F_{max}$ is often confused with $F_{msy}$ but it is a different quantity. It is an approximation to MSY-based age-structured models, but on the assumption that there is no reduction in recruitment at levels of biomass corresponding to $F_{max}$. It is based on maximizing yield in weight per recruit entering the fishery. $F_{max}$ can be calculated using the Beverton and Holt (1957) yield-per-recruit equation, or using age-structured forecast models (Thompson and Bell 1934). The use of $F_{max}$ is justifiable in cases where there is no demonstrable decrease in recruitment at low stock sizes. The principal weakness of the use of this target is that no account is taken of declines in recruitment associated with declines in stock size. A further disadvantage is that in some stocks the yield-per-recruit curve is asymptotic and there is no estimate of $F_{max}$.[a]

In cases where the stock relationship is flat-topped over a wide range of parental stock sizes, as in many demersal fish, use of $F_{max}$ as an approximation to $F_{msy}$ is acceptable. In the case of pelagic fish, use of $F_{max}$ may lead to serious error as no account of recruitment overfishing is taken.

*A.4. $F_{0.1}$ ("F nought point one")* is another approximation to MSY from age-structured models, but one which seeks to take approximate account of expected stock-recruitment effects and, it is argued, economic parameters (Gulland and Boerema 1973). $F_{0.1}$ is the F for 10% of maximum rate of catch increase with respect to F: it is often approximated by using the F for 10% of the maximum rate of yield-per-recruit increase with respect to F. At the start of a fishery, fishing mortality F is low, and an increase in F brings increased catches. At higher F, the curve flattens out and at maximum yield per recruit no increase in yield can be achieved by increasing F further, while recruitment is reduced. This is why the $F_{0.1}$ target, which lies at lower effort levels than $F_{max}$ allows improved profitability in the fishery and is relatively safe with respect to recruitment effects. A criticism of this approach is that it does not explicitly take into account the shape of any underlying stock-recruitment relationship, and that the economic factors; however, it is a very useful measure. A detailed description of this target is given by Gulland (1984).

## Management Action for MSY Fishing

There are various approaches to regulating a fishery for MSY. Most simply, one may regulate catches to equal the expected MSY, but this is risky and best avoided. Stochastic variation in a stock from which the calculated MSY is repeatedly extracted will tend to produce declines in stock size (Beddington and May 1977) as happened in the California sardine fishery (MacCall 1979) unless a stochastic yield model is used (Murawski and Idoine 1989). This is because overly high landings in one year can cause a stock decrease which is worsened in the following years until the stock is reduced to a very low level. Error in the initial MSY estimate will have a similar effect. At constant catch but declining stock size, F increases rapidly and so hastens the decline. A better way is to regulate nominal effort, f, to the level at which it is expected that MSY will be landed ($f_{msy}$), but this suffers from the disadvantage that nominal effort due to "learning effects" does not always hold a constant relation to real effort and to fishing mortality. The preferred approach is to regulate F in the fishery to the F at which it is expected that MSY will be landed. Note that, according to the actual target chosen, this F may be $F_{msy}$, $F_{max}$ or $F_{0.1}$. This latter approach cannot be used if simple surplus-production models are used to estimate MSY as these are usually used to estimate $f_{msy}$ - the model of Caddy and Csirke (1983) is an exception.

## B. To Improve Catch Stability

In the event that a stock is reduced to allow size, the catches that can be taken depend largely on the strength of the recruiting year-class. As this can be highly variable, this means that catches will be very variable between years. This is undesirable for a fishing industry which will make better economic use of capacity if catches are stable. Stability can be achieved if there exists a 'buffer stock' which allows the effects of poor or good recruitment to be smoothed out over a number of years.

***B.1. Buffer stock maintenance.*** The size of a buffer stock that needs to be maintained will usually be based on empirical judgement. This will need to account for the recruitment and the lifespan of a cohort in the particular stock, although methods do exist that allow calculation of the balance between immediate gain and future risk. An increase in stability may incur a penalty in reduced long-term catches.

## C. To Avoid a Recruitment Collapse

Particularly in the case of shoaling pelagic fish, managing a stock to avoid a recruitment collapse is a constant worry. Often, good data on stock-recruitment relationships are only available after a collapse has occurred, so a number of strategies have been developed as rough guidelines to prevent a collapse occurring, even in the absence of a reliable stock-recruit relationship. One approach is based directly on maintaining a certain stock size, whilst the other is based on regulating fishing mortality in the stock. The aim of both is to ensure that recruitment success is not adversely affected by fishing (see Mathews, this issue).

***C.1. Spawning stock maintenance (SSM).*** This is in practice very similar to the buffer stock maintenance, but with a different object. Some authors use the terms "constant escapement" or "fixed escapement" (Hall et al. 1988), but here "escapement" is given another

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[a] Editor's note: The apparent asymptotic shape of such curves is due to the knife-edge assumption; when a logistic or another appropriate selection curve is used, all Y/R curves become peaked and/or Fmax is shifted towards lower values of F (see Pauly and Soriano 1986).

meaning, explained below. In stocks where recruitment failure has been seen to occur at low stock sizes, it is obviously prudent to avoid letting the stock size fall to low levels.

An immediate and obvious concern with this approach is the manner of selecting the stock biomass which is to be conserved. C/f and total catch (c) will depend on the value actually chosen. Typically, stock levels will be chosen as the lowest historical level at which no negative effects on recruitment or stock stability have been observed. Observations on a number of stocks suggest that recruitment begins to be adversely affected if the spawning stock biomass decreases below 20-40% of the spawning stock biomass with no fishing (Beddington and Cooke 1983; Goodyear 1989; Mathews, this issue) and this is suitable value to use if no other data are available. Another example is the 'CUTOFF' strategy (Stocker, in Hall et al. 1988).

A disadvantage of this approach is that in stocks which have highly-variable recruitment, an approach in which a total allowable catch (TAC) is set so as to leave a constant spawning biomass, leads to large interannual fluctuations in TAC and so reduces catch stability. A constant-F strategy tends to improve catch stability, albeit at the expense of a slightly increased risk of recruitment being affected.

*C.2. Fishing mortality for low, medium and high risk of stock depletion:* $F_{low}$, $F_{high}$, $F_{med}$. The fishing mortalities that are likely to result in adverse effects on recruitment with a given probability can be estimated and these targets can be used in directing fisheries management. These methods take into account likely stock-recruitment relationships in order to estimate the level of F at which there is, respectively, a low, medium or high probability [actually 10%, 50% and 90%] that the stock will not be able to maintain its size through recruitment. These measures are particularly useful when dealing with pelagic stocks, where a constant management worry is the possibility of falling into a stock-recruitment dependence and rapid collapse of the fishery (see Seisay, this issue). The $F_{med}$ criterion has been criticized as being excessively conservative, and in addition the method suffers the disadvantage that in some cases all three reference points cannot be calculated. In cases where dependence of recruits on stock cannot be calculated it can be argued that there is no sound basis for using these targets (Sissenwine and Shepherd 1987). However, some may consider that when an explicit relationship can be calculated, the stock will already have collapsed. Calculation of these reference points requires, among other data, a reasonably long time-series of data on stock size and recruitment.

*C.3. Constant escapement.* Most fish spawn every year throughout their life, once a certain age of first maturity has been reached. Some, however, spawn once only at the end of their life. In this case, the analogue to the spawning stock maintenance strategy described above is a "constant escapement" target. In formulating this, one must calculate the proportion or amount of fish that is to be left alive to spawn at the end of their life. Two special situations require this type of management: one is for squid, the other is for salmonids. A 40% escapement has been suggested as a suitable value for the farms (Caddy 1983; Rosenberg et al. 1990).

## Management Action to Prevent a Recruitment Collapse

Management measures to maintain spawning stock size include managing F by limiting effort or catches, or by defining closed areas or closed seasons, or by managing the exploitation pattern by regulating mesh sizes. If a spawning stock maintenance approach has been chosen, catch quotas can be set according to the stock biomass. A good example of this is the law that the California Legislature passed in 1972 to manage the mackerel fishery, with a target of maintaining a buffer stock of 20 million pounds of spawning fish. This law provides a series of catch quotas as a function of stock size (Table 1). This approach is intuitively attractive but estimates can be calculated every year. California enacted legislation covering the determination of stock size to complement this legislation.

Alternatively, annual quotas can be set or effort can be regulated in order to regulate F to one of the target values calculated above. Closed areas can be valuable in regulating F, especially in reef fisheries.

Table 1. Catch quotas as a function of stock size in the Californian fishery for Pacific mackerel *Scomber japonicus* (from Parrish and MacCall 1978).

| Spawning stock biomass | Catch quota |
|---|---|
| < 20 million lb | Total ban |
| 20-40 million lb | 20% of the excess over 20 million lb |
| > 40 million lb | 20 % of the amount between 20 and 40 million lb<br>+ 30 % of the excess over 40 million lb |

### D. To Maintain Present Conditions

In many cases, there may be insufficiently good biological data to allow a precise assessment of the fishery or to make accurate forecast, or there may be insufficient clarity of vision on the part of the fishery managers as to the desired objectives of management. A possible strategy in such cases is the so-called *"status quo"* in which management decisions are made to keep conditions in the fishery at the same level as in the last year for which there are data. If there are no good reasons to choose any particular management target, then a *"status quo"* is a reasonable management strategy (Shepherd 1984).

*D.1.* Status quo *F*. In such cases, regulating the fishery for constant F is the preferred option. This calculation can be made with relatively little data and yet with reasonable reliability. There are many advantages to choosing this as a working management target and fishery managers would be well-advised to consider this option first, rather than a doubtful MSY.

### E. To Optimize Likely Yield

A possible approach is a stepwise decisionmaking process which optimizes probable yield in the light of available information. This could be useful in developing and expanding new fisheries (Clark et al. 1985).

### F. Financial and Social Objectives

The above objectives are purely biological goals derived to protect the resources and no explicit account is taken of economic factors. However, using stock projection models, it is possible to construct virtually any number of 'what if?' scenarios, and to produce response surfaces that would allow maximization of, for example, employment, catch, C/f, etc. Detailed investigation of the effects of changes in gear or in effort limitation can also be considered.

Multispecies models that predict yield of an entire fishery must be used with predefined goal functions, which can be expressed in terms of, for example, catch value. A variety of such models exist, which allow multispecies VPA and multispecies catch projections. The latter can be used to generate response surfaces in terms of total catch, or in terms of net catch value (assuming a constant price for each species in the catch). The models are very demanding of data.

A number of workers have provided financially based fisheries management models (review by Hannesson 1987), and it is possible to generate management regimes designed to optimize labor, financial yield per vessel or other parameters, but in practice, management recommendations have almost invariably been issued purely on the basis of biological targets. The reason appears to be that whilst a fishery is profitable there is political pressure for new entrants to gain access. In effect, the real management goal in most fisheries is a complex minimization: the point of least political pressure on the fisheries manager. In most situations, this is achieved by maximizing access at the expense of profitability for the participants. Conversely, maximizing profitability at the expense of access is likely to generate increased political unease, generated by the potential fishermen who see a profitable fishery from which they are excluded. This seems to be why fisheries management objectives are determined principally by biological limitations of the resource and by political pressures, although the mathematical basis for applying economic objectives to fisheries management is well established.

### Which Target to Use?

Each will have his or her own preferences or prejudices, according to the stocks being managed. Here is a personal view:

1. In species that die after spawning, manage to a constant-escapement target (C.3);
2. If a management policy must be produced in the short term with insufficient data and uncertainty about sustainability of the fishery, use a *status quo* F (D.1);
3. If a medium-term management policy must be produced before a reasonable time-series of data is available, use $F_{0.1}$. (A.4). Do not try to reach MSY via TAC;
4. If there is little evidence of a stock-recruitment relationship, and the stock is not badly depleted, consider continuing to use $F_{0.1}$ in the long term. This is probably safe for many species of demersal fish, which are unlikely to undergo a rapid collapse in population size and may provide improved economic yields;
5. In fish which tend to have marked stock-recruitment relationships and a short lifespan, it is essential to maintain spawning-stock size. This can be done directly by managing the stock to a given size, or indirectly by using the $F_{med}$ or $F_{low}$ targets. The choice of the size of spawning stock biomass should be based on the lowest historical stock size at which recruitment appeared to be unaffected, or to about 30% of the unexploited spawning stock biomass;
6. If there is good evidence that stock-recruitment relationships are not a problem, and there is no worry about falling economic yields, consider using $F_{max}$ (A.3) if this can be calculated;
7. Where there is no worry about falling economic yields, consider using $F_{msy}$ as a target, but do not try to reach MSY via TAC;

Table 2. Some examples of targets suggested, or used in managing various fish stocks in recent years.

| Species | Area | Target and management tool[a] | Ref.[b] |
|---|---|---|---|
| Sardine | Biscay | $F_{med}$ by TAC | (1) |
| Horse mackerel | NE Atlantic | SSM by TAC | (1) |
| Anchovy | Biscay | Environmental factors thought to dominate recruitment variability; SSM not recommended. | (1) |
| Herring | Norway | SSM by TAC | (2) |
| Capelin | Barents | SSM by TAC | (2) |
| Capelin | Iceland | SSM by TAC | (2) |
| Herring | North Sea | SSM by TAC | (3) |
| Herring | Clyde | SSM by TAC | (3) |
| Herring | Celtic Sea | SSM by closed area | (3) |
| Herring | Irish Sea | SSM by TAC and closed area | (3) |
| Redfish | Iceland | $F_{0.1}$ and $F_{max}$ given | (4) |
| Cod | Irish Sea | Uncertain due to multispecies effects (pred. on Nephops) | (5) |
| Plaice | Irish Sea | Status quo TAC | (5) |
| Sole | Irish Sea | $F_{max}$ by TAC | (5) |
| Cod | Celtic Sea | SSM by TAC | (5) |
| Sole | Celtic Sea | $F_{max}$, $F_{med}$, Status quo options discussed | (5) |
| Mackerel | North Sea | SSM by TAC and closed area | (6) |
| Pacific mackerel | California | SSM by TAC | (7) |
| Shortfin squid | Falkland Islands | 40 % escapement | (8) |
| Hake | South Africa | $F_{0.1}$ by TAC | (9) |
| Bombay duck | India | Max YPR discussed | (10)[c] |
| Kiddi shrimp | India | Max YPR discussed | (10)[c] |
| Threadfin bream | India | Max YPR discussed | (10)[c] |
| Shad | India | Max YPR discussed | (10)[c] |
| Various stocks | Southeast Asia | MSY | (11)[c] |
| Various stocks | Canada | 1973-76, $F_{max}$, $F_{msy}$ by TAC after 1976, $F_{0.1}$ and SSM by TAC | (12) |
| Shortfin squid | Canada | 60 % escapement | (13) |
| Pacific sardine | California | MSY by TAC (caused collapse) | (14) |
| Shortfin squid | Mexico | 40 % escapement recommended | (15) |
| Various fish | Amazon | MSY discussed | (16) |
| Sparids | West Africa | Max YPR discussed | (17) |
| Shad | Mozambique | Max YPR by mesh size reg. | (18) |
| Shrimp | Mozambique | Status quo F recommended | (18) |
| Catfish | Malawi | Max YPR by mesh size recc. | (19) |
| Small pelagics | Philippines | MSY and MEY discussed | (20) |
| Mixed demersal | Tonga | MSY | (21) |
| Mixed demersal | Cyprus | SSM by closed season | (22) |
| Cod | North Sea | SSM by TAC | (23) |
| Haddock | North Sea | SSM by TAC | (23) |
| Whiting | North Sea | SSM by TAC | (23) |

[a] Abbreviations: MSY, Maximum sustainable yield. Max YPR, Maximum yield per recruit. TAC, Total allowable catch. SSM, spawning stock maintenance. $F_{msy}$, fishing mortality at which it is estimated that the maximum sustainable yield will be caught. $f_{msy}$, fishing effort at which it is estimated that maximum sustainable yield will be caught. MEY, Maximum economic yield.

[b] Sources: (1) to (6): Anon. (1989a-f) respectively; (7): Parrish and MacCall (1978); (8): Rosenberg et al. (1990); (9): Andrew and Butterworth (1987); (10): Venema and van Zalinge (1987); (11): Pauly (1979); (12): May et al. (1980); (13): Caddy (1983); (14) MacCall (1979); (15): Ehrhardt et al. (1983); (16): Montreuil et al. (1990); (17): Mennes (1985); (18): Sousa (1988); (19): Alimoso (1989); (20): Dalzell (1988); (21): Langi and Langi (1987); (22): Garcia (1986); (23): Anon. (1987).

[c] Several authors in (10) have confused $F_{max}$, YPR and $F_{msy}$.

8. If there is a clear need to maximize another factor, other objectives (e.g., to maximize economic yields) can be used. Models that allow target for such objectives to be calculated will usually be highly demanding of data.

Some examples of managed stocks, together with the management targets used and the management tools used to manage the stock, are given as Table 2. Unfortunately many of these are examples from temperate and subtropical areas, so some stock assessments from tropical waters have been included even though these results may not have been translated into management action.

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