Overview of Maximum Sustainable Yield

Summary

Fishing at maximum sustainable yield (MSY) levels aims to catch the maximum quantity of fish that can safely be removed from the stock while, maintaining its capacity to produce sustainable yields in the long term. This requires that, over the long term, biomass added through reproduction and growth of fish is balanced against the fish removed by fishing or predation. At MSY these processed are optimised so catches are maximised for long term sustainability.

The process of calculating MSY, and assessing where a stock is in relation to this target, requires that the growth and breeding capacity of the stock are maximised. Maximising growth is achieved by ensuring the growth of the fish entering into the stock as recruits is optimised. To maintain the breeding capacity of the stock, measured by the quantity of fish that are able to reproduce (the spawning stock biomass), management action is taken if the spawning stock biomass falls below a set threshold to try and restore the stock to levels that can sustain fishing at MSY.

Given the many unknowns of wild-caught fish stocks, the spawning stock biomass needed to sustain the stock can't be calculated exactly, but can be estimated using simulations. Real-world uncertainty is built into the models to make the advice precautionary and reduce the risk of accidentally over-exploiting a stock.

The principles behind assessing stocks against MSY are the same in all stock assessment regimes; that is to maximise growth and reproduction of the fish stocks. However, there are differences in approach between scientific bodies and variations in the way management regimes use these principles to guide the management of stocks towards MSY.

The [International Council for Exploration of the Seas (ICES)](#) is responsible for stock assessments in the Northeast Atlantic and Baltic Seas and uses it's 'ICES MSY approach' to inform management practices of the stocks in this area. For more on the ICES approach the Seafish Guides to Fish Stock assessment and ICES reference points and Fishing at Maximum Sustainable Yield. The latter contains comparisons between the ICES approach and elsewhere in the world.

Background

The concept of MSY dates back to the 1950s and it has been adopted as an approach in many fisheries since that time. It's more widespread use in the 21st century follows commitments at the World Summit on Sustainable Development in Johannesburg in 2002

Stock assessment

A 'fish stock' is a population of fish considered as a unit. That is, it has distinct biological characteristics, occupies a limited area, and has limited mixing with other

stocks of the same species. 'Stock assessment' uses real-world data to build a picture of a stock's population, in terms of the life-cycle, age structure, growth, mortality, and reproduction of the fish – the stock's population dynamics – in order to offer management advice.

More information is given in the Seafish Guides to Fish Stock assessment and ICES reference points and Fishing at Maximum Sustainable Yield. The Seafish Guide to Fisheries Management discusses the framework for implementation of this advice.

'Target', 'trigger' and 'limit' reference points indicate a stock's health and are used to assess its status:

- **Target reference points** – levels that managers are aiming for (e.g. MSY)
- **Trigger reference points** – levels at which action should be taken to bring the stock back towards the target, before stocks decline to the limit reference point.
- **Limit reference points** – the 'Safe Biological Limits' for the fishery.
  Under the precautionary approach, stocks that fall below these limits are considered to suffer from impaired reproduction and hence may be unable to support a fishery.

There are two main approaches for calculating MSY:

- **Production models** – used when there's a lack of data on the population age/size structure; and

- **Analytical models** – used when there's good information on population age/size structure.

Production models
Production models assume that a fish stock will compensate for being fished by growing and/or breeding faster, so-called **surplus production**. These models are used in assessments where the information on growth and age structures of the population is relatively poor. Many tuna stocks are assessed using these models.

The models assume that the surplus production is related to the biomass of the stock. Lightly exploited stocks close to the carrying capacity of the environment and heavily exploited stocks with a low biomass are situations where stocks are likely to be less productive. Therefore, surplus production corresponding to MSY is maximised at some point between these extremes, usually at around half the unfished biomass. Biomass cannot usually be measured directly, so catch rates (the fishing effort required to land a catch of a certain size, or catch per unit effort) is used to estimate biomass.

Production model reference points
The target reference points generally used for production models are the biomass that produces MSY (B_{MSY}) and the corresponding rate of fishing mortality (F_{MSY})

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which keeps the stock at this level of biomass. This can be estimated by modelling surplus production for stocks of differing biomass. Trigger levels are also used by managers, usually when biomass falls below a certain threshold; often half of the biomass that produces MSY; ½ B_{MSY}. When a stock falls below this level further action may be implemented by management to reduce fishing mortality to bring stocks back towards target levels.

If there are less data available on the stock, assessment scientists have developed methods which utilise such data as is are available within a precautionary framework. See Guide to Data-limited stock assessment.

Analytical models

Analytical models estimate the population structure, growth and reproductive success of fish stocks, and the effect of fishing and natural mortality on them. These models are used for many major stocks. However, use of these models is contingent on having good data on the dynamics of the stocks over substantial periods of time.

Analytical models enable enhanced information to be available to managers, including projections of the effects of different levels of catch on stock status. This approach allows the risks of different types of overfishing (growth and recruitment overfishing – defined below) to be assessed, enabling fishery managers to intervene appropriately.

Growth overfishing

Growth overfishing is when smaller/younger fish ('recruits') are being caught at too high a rate to allow optimum growth. Changes in the fishing mortality and/or age at first capture have an effect on the growth of the recruits. Assessment of growth overfishing is made by modelling the fate of an age group (or cohort) of recruits as it passes through the stock, estimating the yields available at different conditions of mortality and age at first capture.

To reduce growth overfishing, fisheries managers can:

- Reduce fishing mortality via effort and catch controls; and/or

- Increase age at first capture by altering gear selectivity or by avoiding capture of young fish, or through spatial management of fishing effort leading to reducing mortality of juvenile fish on the nursery grounds

Reference points: yield per recruit

The yield per recruit is the quantity of fish caught per recruit entering the stock as young fish, over the time which they are in the stock. Reference points can be calculated which maximise the yield per recruit for given conditions of exploitation; fishing mortality and age at first capture.

However, as well as maximising yield per recruit, enough fish need to survive (the spawning stock biomass) to reproduce in order to produce further young fish to recruit into the stock (see below), so for some stocks reduced yield per recruit is accepted to ensure there are sufficient fish surviving to spawn.

Recruit overfishing

As well as maximising yield per recruit, enough fish need to survive in order to contribute to the spawning stock biomass and hence reproduce in order to produce further young fish to recruit into the stock.

Recruit overfishing occurs when spawning stock biomass falls to a level where it cannot produce enough new recruits to sustain the stock. Many factors affect reproductive success and hence the number of recruits entering the stock, so the relationship between spawning stock biomass and recruitment is often unclear. Scientists use historical data on the relationship between the spawning stock biomass and recruitment to identify at what levels of biomass there is a risk of recruit overfishing.

Reference points: safe biological limits

Scientists assess stocks' status in relation to safe biological limits to warn managers with the aim to prevent recruit overfishing. If stocks fall below these reference points, they are considered to suffer from impaired recruitment and hence may not be able to support a fishery. This is potentially damaging to the stock and the fishery dependent on it. Therefore the scientists use "Precautionary" warning levels which are levels below which stocks are 'at risk' of being outside safe biological limits;

- **Biomass limit (B_{lim});** the level of spawning stock biomass below which recruitment is considered impaired, that is recruit overfishing

- **Precautionary biomass level (B_{pa});** the level at which there is a 5-10% risk that spawning stock biomass is below the biomass limit in any given year.

The Biomass limit (B_{lim}) is used as a 'limit' reference point beyond which stocks should not be allowed to drop. Scientific advice may be to 'stop fishing' that is a zero TAC when a stock reaches this level. The precautionary biomass level can be used as a trigger reference point. The advice would be to find measures, possibly through a management plan to recover the stock to above B_{pa}.

Reference points for MSY

In the ICES MSY approach the two reference points used are F_{MSY} and **MSY $B_{trigger}$.** F_{MSY} corresponds to the level of fishing mortality (F) associated with MSY and **MSY $B_{trigger}$** is the level of spawning stock biomass above which the stock is considered capable of being sustainably harvested at F_{MSY}.

The ICES advice rule requires that reference points (F_{MSY} and **MSY $B_{trigger}$**) should be set at a level where there's 95% probability that the spawning stock biomass will remain within safe biological limits (B_{lim}) in any given year. The reference points are set using simulations of stocks which test different levels of F_{MSY} and **MSY $B_{trigger}$.**

Assessment scientists use information on fishery selectivity and population parameters; growth, maturity, mortality and stock and recruitment relationships, together with a range of errors in the assessment. Therefore, both growth and

recruitment overfishing are taken into account. The models are run many times simulating a number of years, with different elements being changed randomly in each run to build randomness or 'stochasticity' into the modelling to simulate real world conditions. Levels of **F_{MSY}** and **MSY $B_{trigger}$** are selected which fulfil the advice rule set out above.

This generally results in levels that are similar to – or more precautionary than – those derived using the precautionary approach. If not, precautionary reference points are used instead.

In applying this advice rule the **F_{MSY}** is a target level for fishing mortality and **MSY $B_{trigger}$** is a trigger level. The ICES advice would be for a reduction in fishing mortality below **F_{MSY}** proportionate to the extent to which the stock is below **MSY $B_{trigger}$.**

The ICES approach for analytical assessments differs from those used elsewhere in that **B_{MSY}** is regarded as a consequence of fishing consistently at **F_{MSY}** rather than a target reference point.

There are variations on this approach for short lived species and for *Nephrops* (Dublin bay prawn, Norway lobster or langoustine) stocks where it may be difficult to obtain a full suite of reference points; see Guide to fishing at Maximum Sustainable Yield.

Scientific limitations
While models are vital tools, they also simplify factors affecting stock dynamics. It is therefore important to keep their limitations in mind when using them for management.

- **Estimating natural mortality** – all MSY reference points are affected by the estimated natural mortality, but estimating this is challenging, especially if the stock has historically been consistently fished so there is no record of the levels of natural mortality prior to fishing. A variety of ecosystem-based and 'trial-and-error' approaches to fishing can be used to calibrate a value.

- **Spawning stock composition** – models assume that breeding success is related to spawning stock biomass, but other factors are also likely to have an effect. For example the size and age composition the spawning stock may affect its ability to breed. Larger, older experienced fish may produce more viable eggs and larvae.

- **Environmental factors** – models simplify environmental effects. While random variation within the models used helps to simulate these effects into account, conditions can change directionally (e.g. oceans getting warmer due to Climate Change). Consequently, reference points need regular re-evaluation.

- **Ecological implications** – fishing affects stock biomass and abundance; his alters food web dynamics and impacts other species. These interactions are often very complex, although modelling is improving.

Fisheries Implications

Whilst MSY is important, it's not the only factor affecting fish stocks, and the effects of fishing at MSY can potentially be sub-optimal for other stocks, or for economic and social goals.

- **Variation in yield** – environmental factors can dramatically affect recruitment and fish stock biomass. Therefore catch levels associated with MSY may vary from year to year. This means that stocks are often fished under management plans where managers limit the change in catches (a 'change limit') to, for example $\pm$15%.

- **Stock recovery** – Fisheries on stocks which are experiencing a recovery from an overfished state must decrease their catches (and fishing mortality) in order to recover the stock to a state where MSY can be obtained. Where decreased fishing mortality is necessary and a gradual transition towards MSY needed, managers sometimes including a 'change limit' as above to avoid large changes in catch from year to year. This may slow recovery, but reduce undesirable economic effects.

- **Economic yields** – profitability of individual boats is more closely related to absolute stock biomass than to MSY. If there are more fish around, they are easier and cheaper to catch. This leads to the concept of Maximum Economic Yield (MEY), where fishing mortality and overall yield is lower than fishing at MSY, but has a greater overall profitability.

- **Mixed fisheries** – Demersal fisheries mostly catch a mixture of species, each of which is likely to have a different optimal management regime. All of these have to be taken into account to avoid long-term depletion. See Guides to Fish Stock assessment and ICES reference points and Fisheries management for further discussion of how ICES has introduced flexibility into the advice to allow for management of mixed fisheries

ICES advice

ICES publishes its advice online in a PDF document for every stock that it covers. The advice documents include historical information, current stock status, catch options and fishing opportunities as well as details relevant to management, including the quality of the stock assessment, the basis for the advice and relevant issues see Guide to fish stock assessment and ICES reference points and Guide to data-limited stock assessment methods for detailed interpretation of the advice.

Responsible fishing

The FAO 'Code of Conduct for Responsible Fishing' is a set of guidelines for responsible fishing at all levels, and, with other documents, forms the basis of seafood Certification for Eco-labels. See the Seafish Guide to Responsible and Sustainable Sourcing. The Responsible Fishing Vessel Standard (RFVS) is a voluntary vessel-based programme certifying high standards of crew welfare and responsible catching practices on board fishing vessels.

Further information

Seafish Guides;
Guide to Fisheries Management SR741 ISBN 978-1-911073-47-5

Guide to Fish Stock assessment and ICES reference points SR742 ISBN 978-1-911073-48-2

Guide to Fishing at Maximum Sustainable Yield SR743 ISBN 978-1-911073-49-9

Guide to Data-Limited Stock Assessment SR744 ISBN 978-1-911073-50-5

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