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Guide to Fishing at Maximum Sustainable Yield (MSY)

This Guide provides a detailed description of how MSY reference points are derived and discusses some of the uncertainties and implications of managing fish stocks at MSY.

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SR743 Version 2 February 2022

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. To achieve this, the requirement is to optimise growth of the fished population and ensure that there is adequate reproduction to ensure recruitment of young fish into the stock.

Optimising growth requires that the population consists of young relatively fast growing fish. However, a sufficient biomass of spawning fish is necessary to provide adequate reproduction and hence recruitment of young fish. Ideally a stock should consist of young, fast growing fish, of which, a sufficient number are mature enough to reproduce, satisfactorily providing a sustainable catch at the highest practicable level. This is the condition which enables the stock to produce the maximum sustainable yield.

The International Council for Exploration of the Seas' (ICES, the scientific body responsible for carrying out stock assessments in the Northeast Atlantic and Baltic Seas), Maximum Sustainable Yield approach (ICES MSY approach) is based on a long-term strategy whereby exploitation rates (fishing mortality or F) are at levels consistent with maximum sustainable yield (F_{MSY}). Management action is taken if the spawning stock biomass falls below a pre-determined trigger level, MSY $B_{trigger}$, when there is an increased risk of recruitment failure, that is there are insufficient young fish (recruits) to support a fishery. Scientists use information on the age and size structure and death rates of fish in the stock to explore its population dynamics, and records of spawning stock biomass and recruitment of young fish are used to estimate the level of spawning stock biomass consistent with sustainable reproduction.

Simulations of the stock dynamics are modelled in order to estimate F_{MSY} and MSY $B_{trigger}$. An element of randomness or stochasticity is built into the model, in which the component variables are set slightly different each time in a large number of runs of the model. This simulates real world uncertainty and gives an indication of the possible variations in the outcome.

These maximum sustainable yield reference points (F_{MSY} and MSY $B_{trigger}$) are supported by reference points relating to maintaining adequate levels of spawning stock biomass for reproduction, the precautionary approach (PA) approach reference points termed Safe Biological Limits (SBL).

This Guide summarises the methods used by ICES scientists to derive these reference points for long-lived stocks (e.g cod, haddock, mackerel), short-lived stocks (e.g; sand eels, sprats) and *Nephrops* stocks and compares the ICES methods briefly with those used in other parts of the world. It also discusses the implications of fishing at maximum sustainable yield in relation to sustainable ecological, economic and social conditions.

ISBN 978-1-911073-49-9

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Glossary of terms

Term	Definition
Biomass at MSY: B_{MSY}	This is defined as the estimated level of biomass of a stock which produces MSY at long term equilibrium. In production models it corresponds to the level of biomass at which the surplus production of the stock is maximised
½ Biomass at MSY: ½ B_{MSY}	Level of Biomass corresponding to half of B_{MSY}. ICES uses this as proxy for MSY $B_{trigger}$ (see below) when stocks are assessed using a production model.
Biomass limit: B_{lim}	Biomass limit reference point; stocks with spawning stock biomass below this level are considered to suffer from impaired recruitment (recruit overfished) and hence may not be able to sustain a fishery.
Precautionary Biomass level: B_{pa}	Precautionary biomass level; stocks with spawning stock biomass below this level are at risk (around 5-10%) of being below the Biomass limit reference point (B_{lim}).
Fishing Mortality: F	The rate of mortality due to fishing expressed as an instantaneous rate; see Appendix
Fishing mortality at MSY: F_{MSY}	Rate of Fishing mortality consistent with achieving Maximum Sustainable Yield (MSY).
Fish Stock	"A relatively homogeneous and self-contained sub population of a species, whose loses by emigration and accession by immigration are, if any, minimal in relation to the rates of growth and mortality." See Guide to Fish Stock assessment and ICES reference points (Seafish, 2022b) page 6 for further information.
International Council for Exploration of the Sea: ICES	International scientific body responsible for carrying out fish stock assessments in the ICES Area: the Northeast Atlantic and Baltic Seas. Also advises governments on other scientific issues concerning the marine environment www.ices.dk
Maximum Sustainable Yield: MSY	Catching the maximum quantity that can safely be removed from the stock while maintaining its capacity to produce sustainable yields in the long term.
MSY Biomass trigger level: MSY $B_{trigger}$	When the stock is above this level the stock it is considered capable of being sustainably harvested at F_{MSY}. When the stock is below this trigger level ICES Advice is given for management action to bring the stock back above this level.
Natural Mortality: M	The rate of mortality due to natural causes expressed as an instantaneous rate; see Appendix
Nephrops	*Nephrops norvegicus;* Dublin Bay Prawn, Norway lobster, langoustine used for making scampi
Safe Biological Limits: SBL	When a stock is inside safe biological limits there is sufficient reproductive capacity to support a fishery.
Target reference point	Target reference points are levels of fishing mortality and/or Biomass of a stock which managers aim for in the long term

Term	Definition
Total Allowable Catch: TAC	The Total Allowable Catch (TAC) is a catch limit (expressed in tonnes or numbers) set for a fishery generally for a year or a fishing season.
Trigger reference levels	Trigger reference levels are levels of fishing mortality and/or Biomass of a stock which should trigger management action to bring the stock back towards the target
Yield per Recruit	The total yield (catch) in weight to the fishery for each juvenile fish recruited into the stock

1 Introduction

There is consensus that stocks should be managed so that they produce 'Maximum Sustainable Yield' (MSY); this means catching the maximum quantity that can safely be removed from the stock while maintaining its capacity to produce sustainable yields (catches) in the long term. The concept of MSY dates back to the 1950s and it has been adopted as reference point in many fisheries since that time. It is in more widespread use follows commitments made at the World Summit on Sustainable Development (WSSD), in Johannesburg in 2002, to aim towards MSY in world fisheries.

The process of assessing fisheries and giving advice to managers, as practised in the Northeast Atlantic by the International Council for Exploration of the Sea[1] (ICES; the scientific body responsible for carrying out fish stock assessments in the ICES Area; the Northeast Atlantic and Baltic Seas) is described in Guide to Fish Stock assessment and ICES reference points (Seafish, 2022b), which should be read in conjunction with this guide.

This Guide is intended to provide a more detailed description of how MSY reference points are derived and discusses some of the uncertainties and implications of managing stocks at MSY. This Guide refers in detail to the ICES MSY approach, but also refers to approaches elsewhere.

A 'fish stock' is a population of fish which has sufficient integrity to be used as assessment and/or management unit. That is, it has identifiable biological characteristics; occupies a limited area; and mixing with adjacent stocks of the same species is minimal compared to production within the population unit. 'Stock assessment' is the process by which scientists bring together data and construct a mathematical model of the population's dynamics to enable advice to be given to fisheries' managers.

2 Stock assessment for MSY

'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.

The concept of MSY originates from the 1950s (Finley and Oreskes, 2013). The main conceptual approaches are based on either 'Production models', where there is a lack of data on the population age structure, or 'Analytical models', where there is good information on age and size structure in the population.

[1] ICES www.ices.dk

3 Production models

The assumption behind production models is that if an unfished population is reduced by fishing there will be compensatory growth and/or reproduction. That is, the fish will grow and/or breed faster, creating ‘surplus production’. By modelling the surplus production response at different levels of biomass, the biomass which produces MSY (B_{MSY}) is estimated.

The surplus production is modelled as a characteristic dome-shaped curve as shown in Figure 1. When there is no fishing, the stock biomass is assumed to be at full carrying capacity of the population’s environment, which limits surplus growth or reproduction. As fishing increases, biomass levels reduce and there is compensatory surplus production as more resources are available for the fish to grow and reproduce. The maximum catch or yield at around half of the estimated unfished biomass in Figure 1 implies that growth and/or reproduction is maximised at this point and corresponds to B_{MSY}.

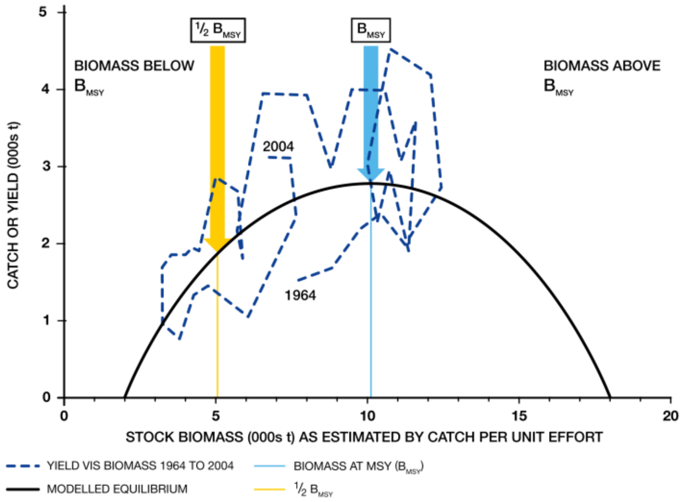

Figure 1 Illustrates a simple surplus production model. The stock yield (catch in 1000s of metric tonnes per annum) is plotted against the corresponding estimates of stock biomass over the period 1964 until 2004 in blue. The curved line shows the model at equilibrium, fitted by an iterative method. When the stock biomass is at 10,000 metric tonnes this corresponds to Biomass at maximum sustainable yield (B_{MSY}) with a maximum sustainable yield (MSY) of 2,900 tonnes per annum. The reference point ½B_{MSY} can be used as a trigger level; that is, when the stock falls below this level management action should be taken to reduce fishing and boost the stock.

Fitting a production model is simplistic, because the modelled yields (catches) are assumed to be at equilibrium, whereas fish stocks are rarely at equilibrium either with the exploiting fisheries or the environment. The approach is to plot catch per unit effort, preferably from a standardised research vessel surveys that is independent of the fishery, as an index of stock biomass, against catch as an index of surplus production as in Figure 1.

As can be seen in this example, there can be considerable uncertainty in the fit to the model. For each level of stock biomass (B) there is a corresponding level of equilibrium fishing mortality (F). At B_{MSY} the corresponding level of fishing mortality is F_{MSY}. In ICES advice based on production, as distinct from analytical, models (see Section 4) the ½B_{MSY} level is considered a proxy for the MSY $B_{trigger}$ level, below which fishing mortality is reduced in order to bring stocks back towards B_{MSY} (see also Guide to Fish Stock assessment and ICES reference points (Seafish, 2022b) for details of how ICES’ Advice is formulated).

Through time, methods for fitting production models have improved and ICES uses these models as a part of their data limited assessment methods; see Guide to Data-limited stock assessment (Seafish, 2022d).

4 Analytical models

Analytical stock assessments models are used to estimate the population structure and reproductive success of fish stocks, and fishing and natural mortality levels affecting them. This type of model is used for most of the major pelagic and demersal stocks. A full description of how the ICES uses these models to give advice on stock status and predict medium term catches is given in Guide to Fish Stock assessment and ICES reference points (Seafish, 2022b). In this guide, we discuss how the ICES reference points for MSY are derived where analytical models are available.

4.1 Types of overfishing

Conventionally, there are two types of overfishing relating to population growth and recruitment. 'Growth overfishing' is a situation where the fish are being caught at too high a rate to allow optimum growth, hence depressing the potential yield. 'Recruit overfishing' occurs where the spawning stock biomass has been reduced to a level where insufficient recruits are produced to support a fishery.

4.1.1 Growth overfishing

The yield per recruit is the total yield (catch) in weight to the fishery for each juvenile fish recruited into the stock. When a stock is subject to growth overfishing, the 'yield per recruit' of young fish entering into the stock is reduced. Yield per recruit assessments are made by modelling the fate of a year class (or cohort) of recruits as it passes through the stock.

Consider a single year class or cohort of 1000 recruits passing through the stock. The individual young fish grow in weight as they get older and they are subject to mortality from natural causes (M) and fishing (F)[2]. Multiplying the numbers of fish at each age by the mean weight of individual fish at that age gives biomass at age profiles as shown in Figures 2 and 3. Figure 2 shows that for the unfished stock, the age at maximum biomass, indicating optimum growth, is 3 years, and for the stock fished at F=0.3 it is around 2.25 years. So the biomass at age profile and hence the available yield varies with the level of fishing mortality.

[2] Fishing and natural mortality are expressed as rates; see Appendix for further explanation

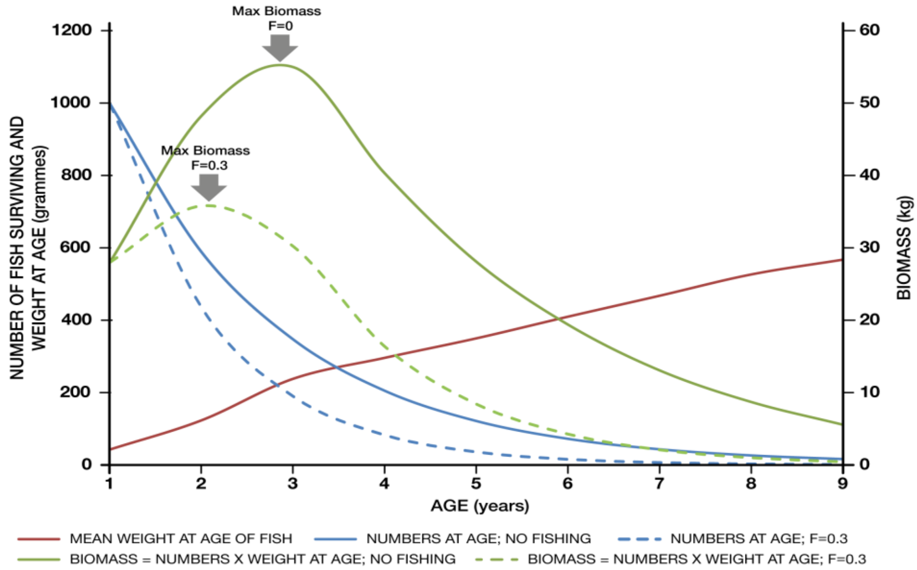

Figure 2; The calculation of the biomass of a cohort of 1000 fish with an age of first capture of age 1 over the time it passes through the stock. The red line is the growth in weight with age of individual fish in grams, the blue lines are the number of fish surviving with age and the green lines are the number of fish surviving multiplied by the weight at age showing how the biomass of the cohort varies with age (the dashed lines represent a fishing mortality of F=0.3).

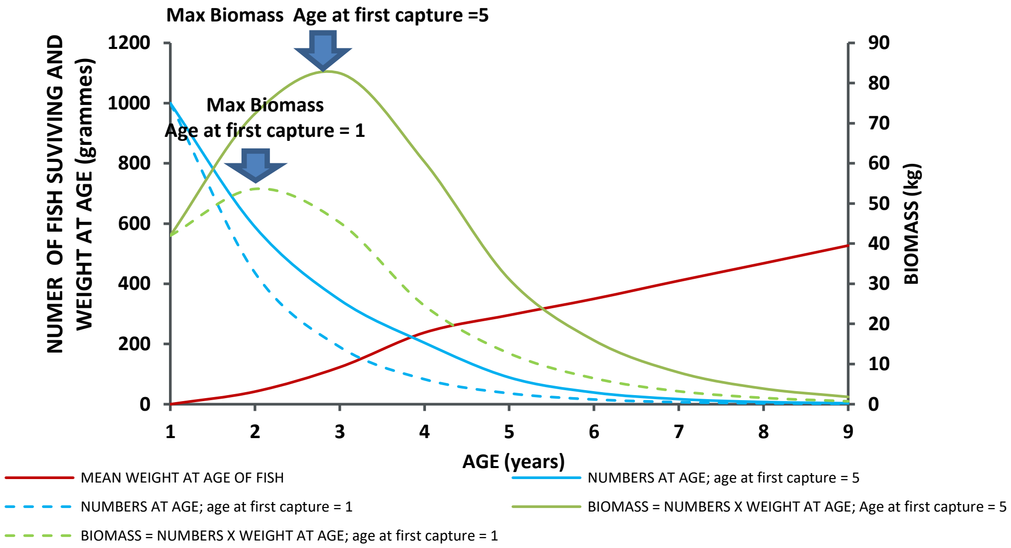

Figure 3 The calculation of the biomass of a cohort of 1000 fish subject to a rate of fishing mortality of 0.3 and with two different ages at first capture; age 5 (solid lines) and age 1 (dashed lines). The red line is the growth in weight with age of individual fish in grams, the blue lines are the number of fish surviving with age and the green lines are the number of fish surviving multiplied by the weight at age showing how the biomass of the cohort varies with age.

The growth of a cohort for a given fishing mortality also varies with the age at first capture. By delaying age at first capture, more fish are able to grow for longer, being subject only to natural mortality before fishing mortality commences. This is illustrated in Figure 3, where fishing mortality is F= 0.3 and age at first capture is varied. For an age at first capture of 5 years the age at maximum biomass is 3 years compared to 2.25 years where age at first capture is 1 year.

This yield per recruit model shows that the growth of the recruits into the stock varies with the way in which it is exploited. Changes in the fishing mortality and/or age at first capture have an effect on the growth of the recruits.

Therefore, the two main measures available to fisheries' managers to reduce growth overfishing are; control of fishing mortality, through effort and catch controls, and control of age at first capture through altering gear selectivity and/or spatial management measures designed to protect young fish. To analyse the effects of these two factors, estimates of the biomass and yields (catches) per recruit for different combinations of fishing mortality and age at first capture are made.

These calculations are presented as an isopleth or contour plot in Figure 4, which shows how the yield (total catch) per 1000 recruits varies with different levels of fishing mortality and age at first capture. Similar plots could be made for total biomass and spawning stock biomass.

Cross-sections through this yield isopleth plot can be made to examine optimum age at first capture for a given level of fishing mortality (line A____A in Figure 4), and optimum fishing mortality for a given age at first capture (line B_ _ _ B).

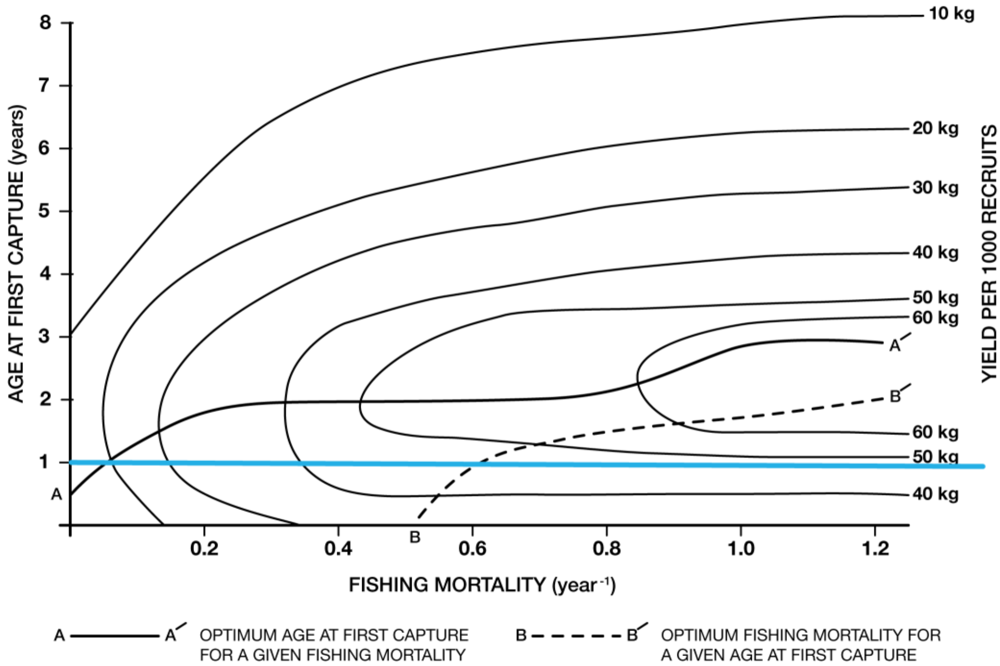

Figure 4; Yield isopleth (contour) plot, showing how the yield per 1000 recruits varies with fishing mortality and age at first capture.

Maximising Yield per Recruit

To demonstrate the effect of variations in fishing mortality on yield per recruit, Figure 5 shows a cross-section of the yield isopleth plot along the blue line in Figure 4. The age at first capture is constant at age 1. The fishing mortality for maximum yield per recruit (F_{MAX}) is the intersection of the line B_ _ _ B' and the blue line in Figure 4 and is estimated at F=0.6. This figure also shows the estimated weight of spawning stock biomass per 1000 recruits (Spawners per Recruit; SpR), illustrating the trade-off between yields and spawning stock biomass.

There are some circumstances when F_{MAX} may be considered too high a target; for example, as in this case, if it is likely to result in too low a spawning stock biomass. Other reference points can be used, such as the fishing mortality resulting in 35% of the unexploited spawning stock biomass per recruit ($F_{35\%SpR}$), which is considered to be biologically sustainable for many stocks.

Alternatively, the $F_{0.1}$ reference point is calculated by finding where the gradient of the yield curve is $1/10^{th}$ the gradient at the origin. It reflects a level of fishing mortality where the additional returns from fishing at F_{MAX} may be considered limited. However, this reference point is not based on biological considerations and is used only limited circumstances; *Nephrops* stocks for example

The choice of reference point for optimising yield per recruit depends on the circumstances of the individual stock. In the ICES Approach, options are identified through simulation at the ICES 'Benchmark working groups'; see Guide to Fish Stock assessment and ICES reference points (Seafish, 2022b).

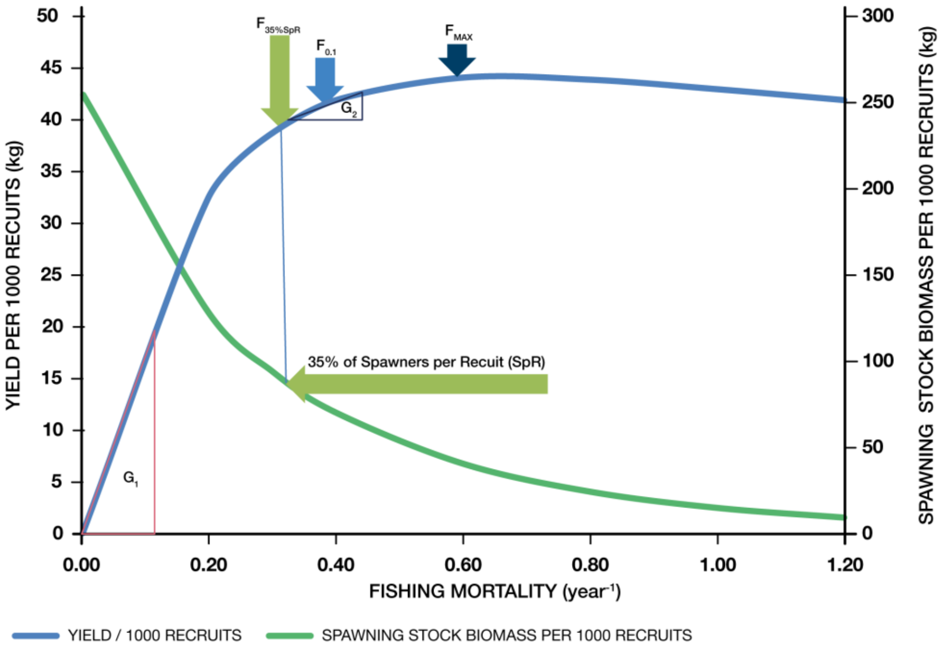

Figure 5; **Yield per recruit curve. This is a cross-section through the yield isopleth plot (blue line in Figure 4) at age at first capture =1 and estimated spawning stock biomass per 1000 recruits at age 1. Fishing Mortality reference points; $F_{35\%SPR}$ = Fishing mortality at 35% of the unexploited spawning stock biomass per recruit, $F_{0.1}$ fishing mortality where the gradient (G) of the Yield Curve is $1/10$ of the slope at the origin: comparing G_1 with G_2, F_{MAX} = fishing mortality at maximum yield per recruit.**

4.1.2 Recruit overfishing

'Recruit overfishing' is the condition where there is insufficient biomass of spawning stock to produce sufficient young fish to support the stock (and fishery). Most bony (teleost) fish such as cod, haddock, plaice and sole produce millions of eggs per female. Many factors affect the survival and growth of fish larvae and juveniles, so there is seldom a clear relationship between spawning stock biomass and subsequent recruitment. It is, however, clear that if the spawning stock is zero, there will be no spawning and therefore no recruitment of young fish. Some possible relationships are shown in Figure 6.

Figure 6A shows the relationship suggested by Beverton & Holt (1957) where, above a certain level of spawning stock biomass, recruitment and spawning stock are independent (the horizontal section of the line). The ‘Hockey Stick’ (Figure 6B) is a simplification of the Beverton & Holt curve and is used extensively by ICES.

The ‘Ricker curve’ (Ricker, 1954) (Figure 6C) shows an increase in recruitment as spawning stock decreases, reaching a peak which is followed by a decrease. Here, it is postulated that high densities of parent stock may affect survival of young fish through cannibalism, or the young fish compete with each other for food, so they suffer “density dependent” mortality. In theory, then, a reduced spawning stock may result in better recruitment, though this particular dynamic is difficult to demonstrate in marine fish stocks because of the natural high level of variability in recruitment.

The relationship proposed by Cushing (1971) may be particularly relevant to herring stocks, where recruitment increases close to proportionally with stock size (Figure 6D); that is larger stocks result in higher recruitment, with some reduction in the rate of increase at higher densities.

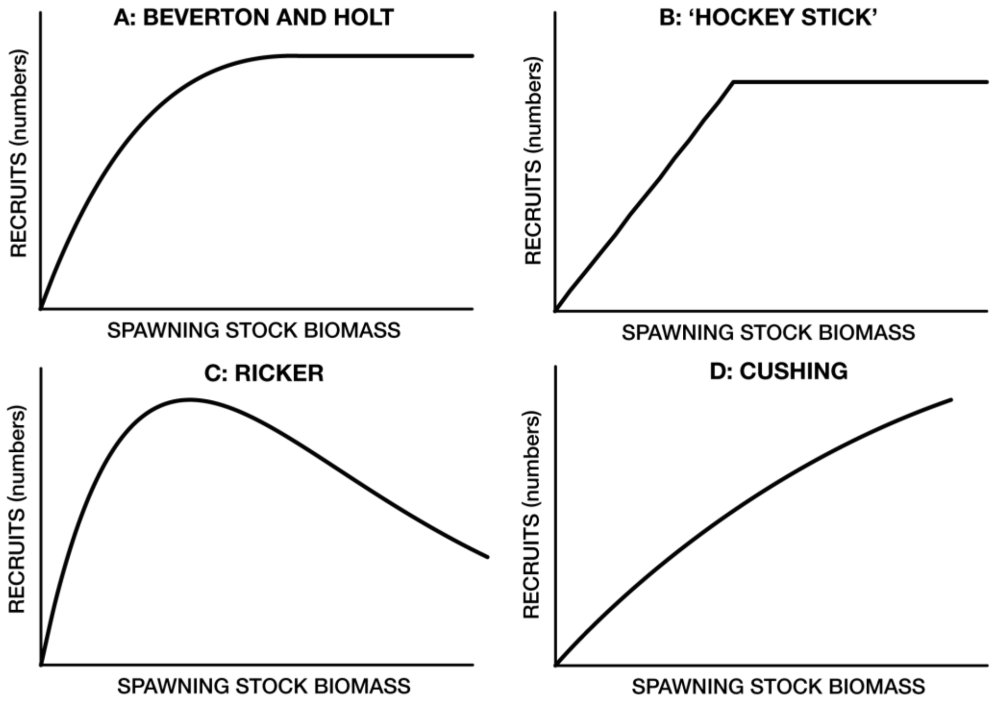

Figure 6 Possible relationships between spawning stock size and recruitment A Beverton and Holt flat topped curve; B ‘Hockey Stick’ or ‘segmented regression’, relationship C; Ricker curve, D; Cushing curve.

The Precautionary Approach defines safe biological limits designed to prevent recruit overfishing. Understanding the spawning stock-recruitment relationship for a stock is the key to preventing recruit overfishing. In ICES advice designed to prevent recruit overfishing, the key limit reference point is the Biomass limit or B_{lim}. This is the level of spawning stock biomass below which recruitment is considered to be impaired and when ‘recruit overfishing’ occurs.

5 Defining Safe Biological Limits

The Biomass limit reference point (B_{lim}) is defined by reference to the stock-recruitment plot (Figure 7), which links the annual levels of young fish recruiting into the stock against the spawning stock biomass that produced that level of recruitment. Since not all stocks have been subject to a wide range of spawning stock sizes over their assessment period, it is not always possible to clearly identify the stock-recruitment relationship across the potential range of stock sizes. ICES, (2017) define six types of stock-recruitment plot and, using various criteria, define B_{lim}, taking into account the way in which the points are distributed on the plot.

In the example shown in Figure 7, B_{lim} is defined at a spawning stock biomass of 107,000 tonnes, which is the lowest spawning stock biomass (the 1996 year class) associated with above average recruitment. B_{pa} is the Precautionary Biomass level at 150,000 tonnes, the level at which there is a 5-10% risk that the spawning stock biomass is below B_{lim} in any one year, given the uncertainties in estimation.

MSY $B_{trigger}$ on this plot is coincident with B_{pa}, but this is not always the case. MSY $B_{trigger}$ is the level of spawning stock biomass which triggers a cautious approach in catch advice under the ICES advice rule for MSY, see Section 6.1.

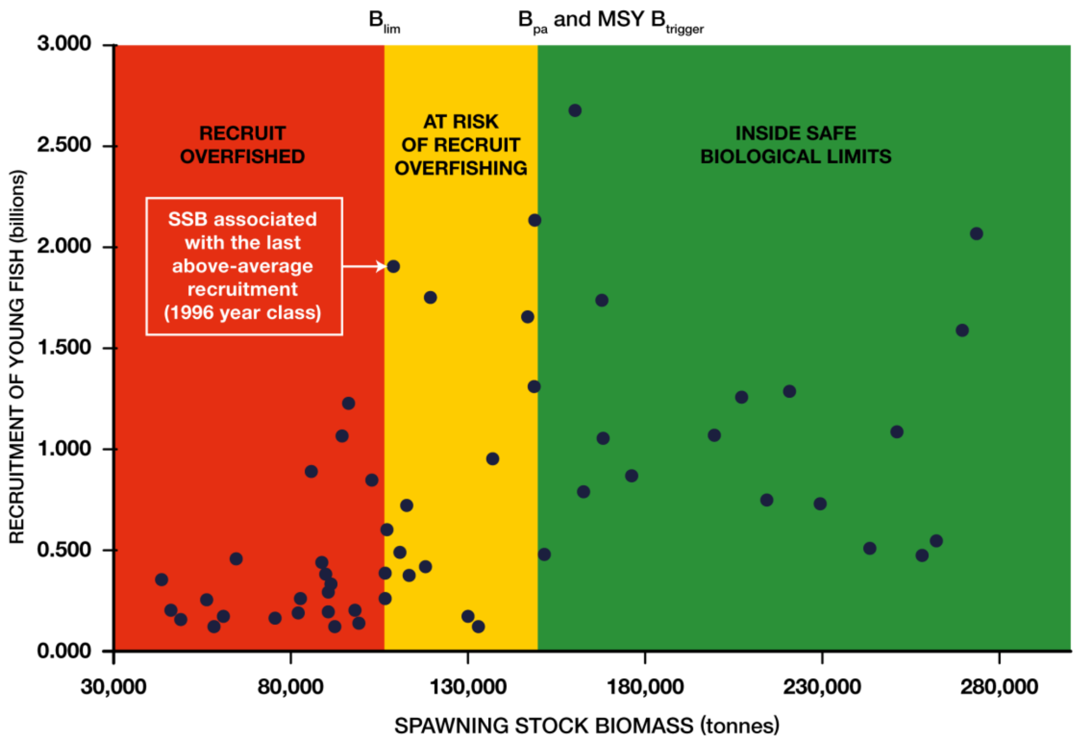

Figure 7 Stock-recruitment plot for North Sea cod 1963-2016. Each point represents one year's data.

6 Reference points for MSY

ICES, (2017) outlines the approach that their expert benchmarking working groups, which include scientists and stakeholders, should take to set MSY reference points. The methods used vary between long-lived stocks, where there are a larger number of year classes in the stock, and short-lived stocks which may only have a few (1-3) year classes.

6.1 Long lived species

The ICES advice rule for MSY (see Guide to Fish Stock assessment and ICES reference points (Seafish, 2022b), page 20) requires that the fishing mortality associated with MSY (F_{MSY}) and MSY $B_{trigger}$ reference points are set a level at which there is 95% probability that the stock will remain within safe biological limits (above B_{lim}) in any one 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.

Generally, this procedure has resulted in MSY reference points (F_{MSY} and MSY $B_{trigger}$) being more precautionary than those derived using precautionary approach. However, if the resulting reference points are not compatible with the precautionary approach; that is F_{MSY} is greater that F_{pa} or MSY $B_{trigger}$ being below B_{pa}, then precautionary approach reference points are used instead.

ICES defines the B_{MSY} level as the spawning stock biomass that results from fishing at F_{MSY} for a long time. This is not normally used as reference point for ICES stocks except when using a production model (Figure 1) when ½ B_{MSY} is used as a ‘proxy’ for MSY $B_{trigger}$, the biomass trigger level.

6.2 Short lived species

Stocks of these species are characterised by only one or two year classes in the fishery. They are therefore very dependent on recruitment of young fish into the population. For these species the ICES MSY approach aims at achieving a target escapement (survival rate) to ensure that there are adequate fish left to spawn and that there is a 95% probability of the stock being above B_{lim} the following year. For these ICES uses a biomass reference point, MSY $B_{escapement}$.

The ICES approach assesses stock size at the start of the year, and then estimates a harvest level such that the biomass of the stock should not decrease below MSY $B_{escapement}$. For some stocks there is also a reference point which caps fishing mortality (F_{cap}) when the stock size is above MSY $B_{escapment}$, thereby improving the precautionary level of the advice. As for the long lived stocks, an element of stochasticity is included in the models, enabling estimates to be made of the variations which could occur, and hence the degree of confidence which can be ascribed to the stock being above B_{lim} the following year.

6.3 *Nephrops* stocks

Nephrops norvegicus that is Dublin Bay prawn, Norway lobster or langoustine also used to make scampi are assessed in 'Functional Units', defined as *Nephrops* in a patch of suitable muddy habitat in which they construct burrows. This constitutes a *Nephrops* stock. *Nephrops* stocks are assessed using underwater television cameras mounted on sleds, which are towed in straight lines (line transects) across the seabed by research vessels on known *Nephrops* grounds. The abundance of *Nephrops* is estimated from the number of occupied burrows per unit area as counted in the resulting images raised up to the area of the habitat. This information is used with catch data (including discard data) to obtain a harvest rate or fishing mortality for the *Nephrops*.

The fishing mortality reference points used are derived from the yield per recruit reference points shown in Figure 5; F_{MAX}, $F_{0.1}$, $F_{\%SpR}$. The choice of which one to use is dependent on the circumstances of the stock, taking into account burrow density, variability in stock size, historical fishing levels and knowledge of the biological parameters of the stock.

It is difficult to obtain stock-recruitment relationships for *Nephrops*, so MSY $B_{trigger}$ is typically defined as the lowest historically observed stock level, although higher levels are set if the stock has shown signs of stress at this level of abundance. Because male *Nephrops* spend more time outside their burrows and suffer more fishing mortality, the sexes are assessed separately and then combined.

Precautionary advice is given if one sex is at levels below 20% of the estimated unfished (virgin) spawner per recruit level. The calculation of fishing mortality corresponding to 35% the spawner per recruit level ($F_{35\%SpR}$) is described earlier (page 11), and $F_{20\%SpR}$ is calculated in the same way. Since the males suffer higher levels of fishing mortality than the females there is a risk of a shortage of males available for mating.

7 MSY outside ICES

The principles of the F_{MSY} and B_{MSY} reference points are the same under stock assessment regimes other than ICES. However, management regimes may use the MSY and precautionary approach type reference points differently based on the design of their management system (Marchal et al, 2016). 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.

Also, the ICES approach does not in most cases attempt to quantify the biomass of the unexploited stock (B_o) in analytical assessments, which can be found, for example in the United States (National Oceanic and Atmospheric Administration; NOAA[3]) and New Zealand schemes (Ministry of Fisheries, 2008).

Where precautionary advice is given for recovery of 'at risk' or depleted stocks, it is generally in a similar manner to the use of action levels analogous to MSY $B_{trigger}$ and precautionary biomass levels and limits. For US groundfish stocks, the reference points used are based upon on the status and dynamics of the stock, the quality of available information, environmental conditions and other ecological factors, and prevailing technological characteristics of the fishery. Many of the assessments use stochastic simulation methods such as those discussed above (page 14) for defining ICES MSY Approach reference points.

[3] www.noaa.gov

8 Scientific limitations

The main scientific issues concerned with assessing stocks in relation to MSY are discussed below:

8.1 Estimating values for natural mortality (M)

The estimates of all the MSY reference points are dependent on the level of natural mortality. The relative magnitudes of fishing (F) and natural (M) mortality rates reflect the share of the stock being removed by the fishery and taken by predators and other causes. This is reflected in the shape of the yield and spawning stock biomass per recruit curves shown in Figure 5. Estimating natural mortality is an important aspect of stock assessments where F is at a similar level to or lower than M.

It is difficult to obtain information on natural mortality. Various approaches are used, ranging from estimating levels of mortality observed in stocks prior to exploitation, to studies of feeding relationships (food-webs) within ecosystems. Gislason et al, (2010) was able to relate growth rates to natural mortality of unexploited stocks, thereby providing a guide to natural mortality based on observed growth rates. ICES undertakes work on food web studies (ICES Working Group on Multispecies Assessment Methods; ICES, 2016), and in certain stock assessments (example Northeast Arctic cod) natural mortality is estimated by reference to stomach contents of predators.

A less direct approach is to examine the effects of variations in the estimates of natural mortality on the results of the assessments (conducting a sensitivity analysis). This allows a value to be chosen and used consistently from year to year (with reviews from time to time).

8.2 Composition of the spawning stock

The use of stock-recruitment relationships in current models assumes that the stock's reproductive capacity and hence recruitment is related to the biomass of the spawning stock.

However, other factors which could affect the stock-recruitment relationship include the size and age composition of the spawning stock. One effect of fisheries is that exploited stocks are composed of younger fish than unexploited stocks (see Section 4.1.1 Growth overfishing). Scientists have questioned whether young, inexperienced spawners have the same reproductive potential as the same biomass of older fish (Witthames & Marshall, 2008). This is of relevance to the recovery of North Sea cod, since the current spawning stock is composed of relatively young fish compared with the 1960s.

8.3 Environmental factors

The productivity of a stock can be affected by environmental conditions. The population models used to estimate production and yield per recruit reference points are usually run under the assumption of equilibrium conditions; that is, they provide a projection of the condition of the stock if it was fished in this way over long periods of time.

The simulation approach in the ICES (2017) guidelines helps to capture the uncertainty associated with variations in biological characteristics over time by using the time series available as inputs into the stochastic simulations used to define the reference points for F_{MSY} and MSY $B_{trigger}$. This way the uncertainties which affect the assessments can be estimated as probabilities of the stock being at a particular level; in this case inside safe biological limits in any one year with a probability of 95%.

When environmental conditions change, this may alter the biological characteristics of the stock. For example, it is believed that changes in the plankton community affecting the fish larvae in the North Sea may have contributed to good recruitment in the cod, haddock and whiting stocks there during the 'Gadoid outburst' of the 1960s, 1970s and early 1980s; see Why has the cod stock recovered in the North Sea? (Lart & Caveen, 2017).This means that there is a need to re-evaluate reference points from time-to-time, which is why ICES conducts regular (circa three to five yearly) benchmarking of the stocks.

8.4 Ecological implications

Maximum sustainable yield can be achieved at around a half or a third of the biomass that would be expected for an unfished stock. The reduced level of biomass which occurs may result in food web dynamics being altered. For example, fisheries for fish low in the food chain may remove fish which would have been available as food for predators. Fisheries on predatory fish would release predation pressure on species lower in the food chain. Progress in modelling such interactions has been made in some regions particularly the Baltic and the North Sea (ICES, 2016), but the complexity and uncertainty surrounding ecosystem processes mean that is it can be difficult to translate the results into advice at present.

9 Fisheries implications

Whilst fishing at MSY may be considered as desirable, there are implications for other aspects of fisheries management. The level of fishing that achieves MSY for one stock may not be optimal for other stocks or satisfy economic and social goals of fisheries management Issues include:

9.1 Variation in yield

Fish stock biomass can vary considerably from year to year depending on recruitment variability, and environmental factors, so catch levels corresponding to a fishing mortality of F_{MSY} are not constant. 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%. Under these circumstances stocks may never reach MSY, but fishers will experience lower variations in yield.

9.2 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. Hence, Fisheries' managers may elect to allow a smooth transition towards MSY under a management plan, constraining catches to a maximum change limit per year.

9.3 Economic Yields

Although fishing at MSY implies a maximum overall yield through time, the profitability of individual boats is likely to be related to the biomass of the stock. At high biomasses individual boats are likely to experience higher catch per unit effort and hence lower fuel costs per unit of catch, although the overall yield from the stock will be lower.

Vessels which have been in the fishery since the start of exploitation when the stock is at relatively high abundance are likely to experience a decreased catch per effort and become less profitable over time as the fishery develops.

The concept of Maximum Economic Yield (MEY), where the goal is to maximise the overall profit from the stock and is likely to occur at a higher biomass but a lower overall yield than MSY; see the Gordon-Schaefer model referred to in Seijo, et al., (1998) MEY has been used to set reference points in Australian fisheries (Marchal et al., 2016).

9.4 Mixed fisheries considerations

Since most European demersal fisheries catch a mixture of species' stocks, and each stock is likely to have a different optimal management regime, management decisions concerning the catch of one stock are likely to have an effect on the catches of other stocks. For example there may be more catch available of one stock in a mixed fishery even after the TACs of other stocks captured in the fishery have been used up.

Accordingly, ICES has developed advice based on mixed fishery considerations, where managers are presented with advice showing the impact of a range of fishing scenarios on the fishing mortalities, spawning stock biomasses and catches of all the relevant stocks; See Guide to Fish Stock assessment and ICES reference points, (Seafish, 2022b) page 21.

5 Other guides in this series

These Guides are designed to enable understanding without the need for previous training or expertise in fisheries science. Concepts are presented graphically and in words and the key elements are explained in the summaries.

The full list of Guides is given below, with the date and letter used for cross reference within this document

Seafish (2022a)
Guide to Fisheries Management
SR741 ISBN 978-1-911073-47-5

Seafish (2022b)
Guide to Fish Stock assessment and ICES reference points
SR742 ISBN 978-1-911073-48-2

Seafish (2022c)
Guide to Fishing at Maximum Sustainable Yield
SR743 ISBN 978-1-911073-49-9

Seafish (2022d)
Guide to Data-Limited Stock Assessment
SR744 ISBN 978-1-911073-50-5

Seafish (2022e)
Guide to Sustainable and Responsible Sourcing
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Guide to Illegal, Unreported or Unregulated (IUU) Fishing
SR753 ISBN 978-1-911073-59-8

Seafish (2022g)
Guide to Marine Protected Areas (MPAs)
SR754 ISBN 978-1-911073-60-4

Seafish (2022h)
Guide to Protected Species
SR755 ISBN 978-1-911073-61-1

These can be accessed through the search facility on https://www.seafish.org/

The content of these Guides can be used by Seafood business apprentices and others to study towards two occupational standards units:

- Principles of marine finfish product knowledge – Ref F-602-0617
http://seafoodacademy.org/pdfs/f-602-0617.pdf

- Principles of shellfish, non-marine finfish and marine food products, product knowledge – Ref A-602-0616
http://seafoodacademy.org/pdfs/a-602-0616.pdf

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Appendix: A note on mortality rates

Mortality rates in fisheries are conventionally expressed as rates per year. A constant mortality rate implies that a constant proportion of the population dies each year. Table 1 shows how the numbers of fish in a year class would change with time with a constant total mortality of 41.1% in each year. So a constant proportion of the year class is dying each year.

The numbers of fish surviving from year to year (or age) is smoothed and plotted in Figure 8. The percentage reduction is constant year on year resulting in a curved line, known as an exponential reduction, the slope of which is described mathematically by the instantaneous mortality rate for that year. In this case a percentage reduction of 41.1% per annum corresponds to an instantaneous mortality rate of 0.53 per year.

The use of instantaneous rates in calculating mortality in fisheries; Z for total mortality, F for fishing mortality and M for natural mortality, means that the probability of death due to each of these causes can be added together, thus increasing flexibility in the mathematical model. For full details see Gulland, (1969) Section 5.

Table 1 Numbers vis age of a cohort of fish entering the population at age 1

AGE	1	2	3	4	5	6	7	8	9
NUMBER OF FISH AT START OF YEAR	1000	589	346	204	120	71	42	24	14
% MORTALITY PER ANNUM	-41%	-41%	-41%	-41%	-41%	-41%	-41%	-41%	-41%

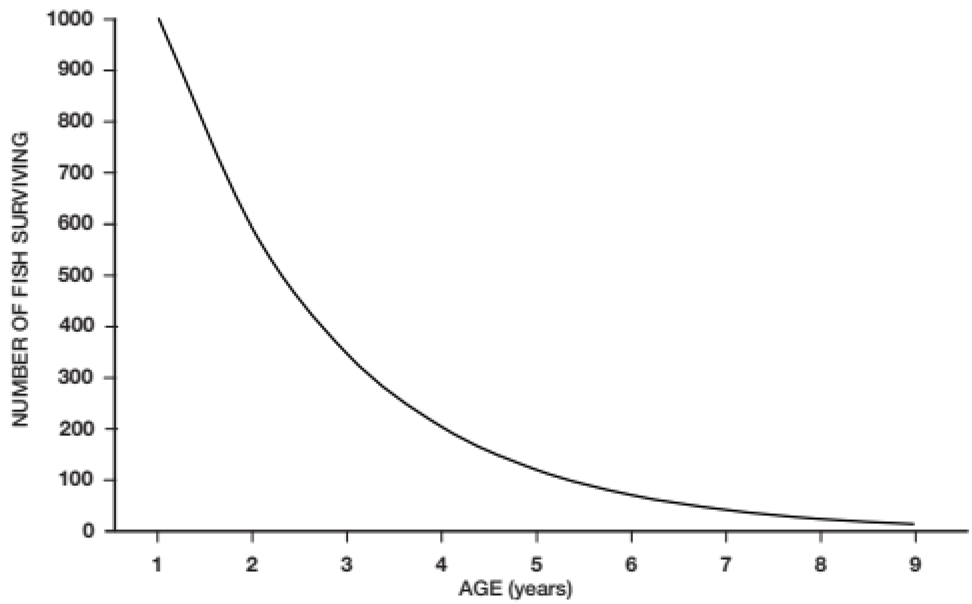

Figure 8 Numbers of fish vis time for a cohort of 1000 fish entering the stock at age 1

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