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Guide to Fish Stock assessment and ICES reference points

This document outlines the stock assessment methods and advice as given by ICES for the Northeast Atlantic stocks

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Summary

This Guide outlines the process by which the International Council for Exploration of the Sea's (ICES)[1], carries out analytical fish stock assessments and gives scientific advice on fish stock management.

The main body of this document outlines the process of data collection, the basis of the models and reference points used by ICES and how the results are used to predict the consequences of a range of catch options. It provides a generic guide to the ICES advice as published for each stock annually.

Fish stock assessment is the scientific approach used to advise fisheries' managers on the sustainability of fished stocks so that catches ('yields') from the fishery can be optimised and measures taken to avoid stocks falling to dangerously low levels and avoid stock depletion, if necessary. Assessments are carried out at various levels of sophistication, dependent on the data that are available.

A biological stock of fish is a self-contained population with a low-level of immigration and emigration. This is the ideal unit for assessment and management. However, for a variety of reasons management stocks are defined by both species and sea area, and do not always correspond to biological stocks. The implications of these anomalies are discussed in the ICES advice.

Full analytical fish stock assessments evaluate the status of a stock relative to reference points that are designed to ensure sustainability and are used to predict the size of the stock and yields to the fishery under various exploitation scenarios in following years. There are many other stocks for which insufficient data are available for a full analytical assessment. These are described as 'data-limited stocks' and methods used to assess these stocks are outlined in the Guide to Data-limited assessments (Seafish, 2022d).

The basis for assessments are derived by sampling catches from the commercial fishery and using research vessel surveys to provide fisheries-independent catch and other information on the stock. Methods of age determination are used to describe the age structure of the stock and estimate growth. Scientists then use a mathematical (analytical) model of the stock to assess the reproductive performance and potential yields from the stock. These results are then evaluated in relation to reference points for long-term stock sustainability.

Two types of reference points are used:

- **Precautionary Approach (PA):** relates to limits above which a stock is considered to be at a safe level, as quantified by the weight of adult breeding fish, described as 'spawning stock biomass ('SSB')', for successful reproduction to support a fishery. They are termed 'safe biological limits'. Stocks within these limits can be harvested safely, but harvesting is not always optimal. To optimise harvesting, maximum sustainable yield (MSY) reference points are required.

[1] The scientific body responsible for carrying out analytical fish stock assessments in the Northeast Atlantic and Baltic Seas

- **Maximum Sustainable Yield ('MSY')**: refers to harvesting a stock at levels that maximise growth in the population and yields to the fishery in the long-term, whilst keeping the stock within safe biological limits.

These reference points are expressed in terms of weight of spawning stock biomass as a measure of reproductive potential, and the rate of fishing mortality as a measure of the fraction of the stock removed annually by fishing. More information on these reference points is given in Guide to fishing at Maximum Sustainable Yield (MSY) (Seafish, 2022c)

The information derived from routine ICES stock assessments is made available to managers in the form of advice on catch levels (Total Allowable Catch or 'TAC') that can be safely harvested from the stock in the next year, and the implications for future stock biomass. The headline advice normally relates to MSY, but advice may be given in relation to a 'management plan' if one is agreed for the stock.

If the stock is outside safe biological limits, the advice would be to aim for its recovery within safe biological limits. In extreme cases of stock depletion, the advice is to minimise catches (or a zero TAC).

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Glossary of terms

Term	Definition
Fishing Mortality: F	The rate of mortality due to fishing which is often expressed as an instantaneous rate; see Appendix. In some texts it is referred to as "Fishing pressure"
Harvest Control Rule: HCR	A Harvest Control Rule is a set of well-defined management actions that are taken in response to changes in stock status.
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.
Natural Mortality: M	The rate mortality due to natural causes expressed as an instantaneous rate; see Appendix
Plankton	Plankton is the diverse collection of organisms that live in large bodies of water and are unable to swim against a current.
Safe Biological Limits: SBL	When a stock is inside safe biological limits there is considered to be 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
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
See also Table 1 page 19 for Reference point definitions	

1 Introduction

Stock assessment is the process by which scientists investigate the population dynamics of fish stock. This enables advice on fisheries management measures to be given to Government officials charged with regulating fisheries (fisheries' managers). Assessments can be classified as:

- Analytical or data rich assessments, where a mathematical model of the stock is used.
- Data-limited assessments, where only limited data are available. The type of assessment is determined by the data available within a pre-agreed framework – see: Guide to Data-limited assessments (Seafish, 2022d).

This Guide explains the basis of the analytical stock assessment methods used by the International Council for Exploration of the Sea (ICES), the scientific body responsible for carrying out fish stock assessments in the ICES Area: the Northeast Atlantic and Baltic Seas. It describes and discusses the information contained in the ICES advice for single stocks.

The stock assessment process starts with collection of data on catches and fishing activities from commercial fishing operations and from research vessel surveys. These data are brought together in scientific working groups which construct mathematical models of the relevant fish populations.

The outcome is then used to evaluate the stocks' status in relation to pre-agreed reference points. The Precautionary Approach (**PA**) reference points define the acceptable boundaries for sustainable exploitation of the stock and the Maximum Sustainable Yield (**MSY**) reference points relate to optimum exploitation.

The scientific advice is used to inform the fisheries' managers on future management options, such as Total Allowable Catches (TACs) and their consequences for the stock. Usually headline advice is given based on a pre-agreed approach or management plan, but the implications of other options are also explored.

2 Definition of a fish stock

Fish populations are divided into 'stocks' for assessment and management purposes. A biological unit stock is defined by Harden Jones (1968) as:

> *"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*."

Various methods are used to establish the identity of biological stocks. These include tagging studies - where fish are tagged and released and the recapture locations plotted to understand migrations; genetic studies used to understand levels of interbreeding and isolation of the stocks; and the use of characteristics such as growth rates, vertebrae and fin ray counts to distinguish between stocks.

2.1 Biological and management stocks

Ideally, the assessment and management unit for a fish stock would be the biological stock, implying that a particular population is more or less isolated from other stocks of the same species, and hence self-sustaining. However, the units used in management – 'management stocks' do not always coincide with biological stocks. The reasons for this are various and related to the practicalities of fisheries management and historical rights as well as the characteristics of the stocks.

An example is the North Sea cod stock, as assessed by ICES, where the cod population is treated as a single biological stock for assessment purposes (Figure 1). However, there is genetic evidence for different sub-populations within this area, and the "stock" has shown different rates of recovery in different parts of the North Sea (ICES, 2017a). Currently, these sub-populations are not taken into account in management.

ICES' North Sea cod stock assessment provides an advised TAC for the whole area, which is divided for management, not biological reasons, into three separate TACs Sub-area 4 North Sea; Division 7d Eastern Channel; and Skagerrak Division 3.a.20. This allows the shares ('quotas') of the various nations exploiting the cod to be allocated appropriate quotas from these three TACs to be differentiated.

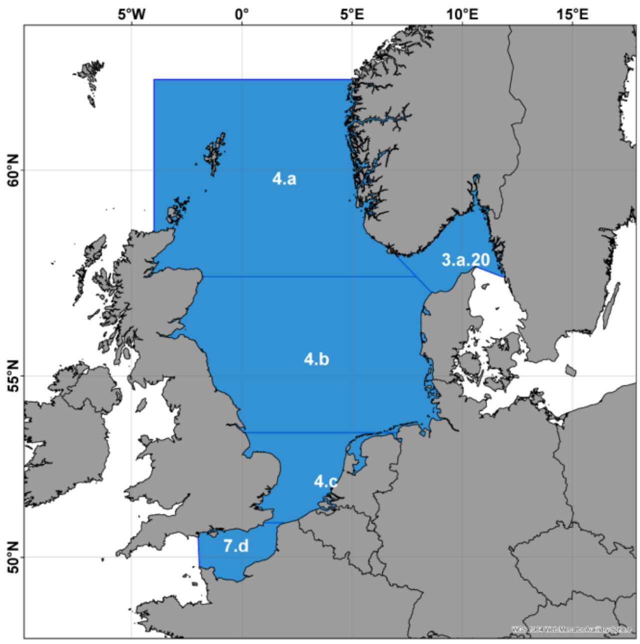

Figure 1 Stock area designation North Sea; Cod (*Gadus morhua*) in Subarea 4 (Divisions 4a,4b,4c), Division 7.d, and Subdivision 3.a.20 (North Sea, eastern English Channel, and Skagerrak) shaded blue.

There are other anomalies; for example, the catches from several independently assessed biological stocks may be managed by a single TAC. Separate stocks of *Nephrops* exist in a number of Functional Units (FUs) which inhabit well defined areas of muddy seabed. However, groups of these FUs are managed under a single TAC covering, for example, the whole of ICES Subarea 7 which includes a total of seven FUs in the Irish Sea, Celtic Sea and west of Ireland. Other examples are management stocks consisting of several species, such as anglerfish, or skates and rays, which can be difficult to distinguish and are managed by combined TAC for a given sea area.

In some cases, the migrations of stocks leads to them being caught together within the same management areas. An example is the western and eastern stocks of Baltic cod which mix,

seasonally, in the central Baltic. This is overcome by finding ways to distinguish the stocks biologically. Here the relative proportions of the two stocks in the catches are estimated using characteristic differences between the structures of the two stocks' otoliths (ear bones, used to determine age). See
Figure 6 for more information on otoliths.

These anomalies have implications for fisheries management because there is likely to be variation in the relative status of different stocks managed together. The effects of these anomalies are discussed in the ICES advice.

2.2 Fish life cycles

To build an analytical model of the population, scientists use their knowledge of the stock's age structure derived using data collected from the commercial and research vessel catches. Stock assessment models simplify the life-cycle of the fish and the rate at which the fishery harvests fish from the stock (Figure 2).

In bony or teleost species (such as cod, haddock, plaice and sole) the adult fish congregate on the spawning grounds where each female may release millions of eggs which are externally fertilised in the water column. The fertilised eggs hatch into larvae, which drift together with plankton for a period of weeks or months, before developing into juvenile fish in nursery areas away from the main adult population.

A key parameter in stock assessment is the relationship between the quantity of adult fish able to spawn and the subsequent abundance of juvenile fish entering stock and the fishery; the stock-recruitment relationship. Many factors such as the size and condition of the spawning stock and environmental conditions may influence breeding success. Conditions in the plankton, such as the availability of food, are considered important in influencing the survival of fish larvae, potentially affecting the level of recruitment of young fish into the stock (Cushing, 1976) and hence catches (yields) available to the fishery in future years. See Guide to fishing at MSY (Seafish, 2022c) for further discussion.

The process of recruitment consists of growth and migration of the young fish from the nursery areas into the area occupied by the adult fish, where most of the commercial fishery activity takes place. The fish are subject to natural mortality due to predation, disease, and other causes throughout their lives, but only vulnerable to fishing mortality when they have recruited into the area of the main fishery and are large enough to be retained by the gear.

The recruited fish grow and mature until they are able to spawn and so complete their life cycle. Most of the major stocks follow well described migratory patterns, with spawning taking place annually at a time and location when there is likely to be good availability of food for the young larvae, and they are able to drift into areas of suitable habitat for the juvenile fish.

There are variations on this cycle, for example, with stocks of herring laying their eggs on the seabed of specific gravel banks, larval herring being subsequently released to drift in the plankton. Cartilaginous fish such as skates, rays and sharks produce fewer eggs, perhaps 10-100 per female per year which are internally fertilised and are either laid on the seabed as so called "mermaid's purses", or in some species retained within the body of the females, which subsequently give birth to live young.

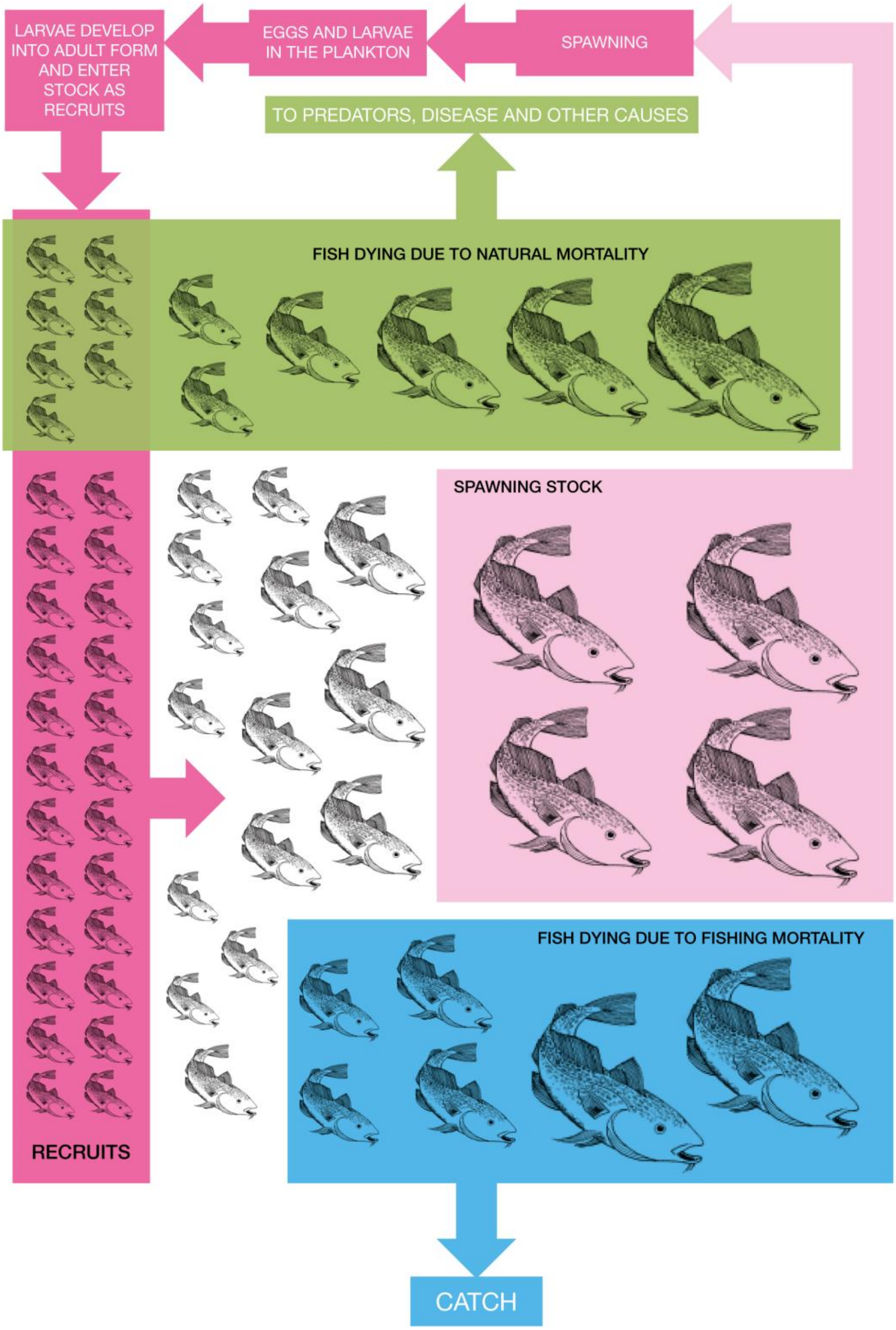

Figure 2 Illustration of a fish stock model; Spawning takes place on the spawning ground, with eggs and sperm being released into the water, where the eggs are fertilised and hatch into larvae which develop into young fish that subsequently recruit into the stock. Young fish grow in size, suffer fishing and natural mortality and some mature into adult spawning stock, contributing to spawning stock biomass. See also Figure 9

3 Stock Assessment

The data required for fish stock assessments are obtained by sampling commercial catches on board fishing vessels and at markets, to obtain information on age and size structure within the fished population. Similar, “fishery-independent” data are collected on research vessel surveys, dedicated to surveying fish populations. In order to sample the catches adequately, ICES (2013a) aims to measure and age a minimum of 200 fish per 1,000 tonnes landed from each stock, which equates to around 1.6 million fish from the 8 million tonnes of fish landed each year in the ICES Area.

Research vessel surveys are carried out regularly at the same time of year (annually or biannually), usually on a pre-arranged grid pattern (
Figure 3). They use the same gear, usually trawls, with small-meshed nets so that fish of all sizes are captured. Other research vessel surveys of planktonic eggs or fish larvae are used to estimate the number of eggs or larvae produced by the stock and, knowing the number of eggs produced per female (fecundity), the scientists can calculate the spawning stock biomass of the female fish (example in Figure 4). Acoustic surveys, using sonar are also carried out to estimate the biomass of pelagic fish, where the acoustic observations can be allocated by species at the same time by using trawl catch data.

Data on other aspects of the fishery are also available, such as the number and types of vessels engaged in the fishery, the amount of time the vessels spend at sea, and their ‘fishing effort’ in terms of vessel power and gear used.

The research vessel surveys give fishery-independent data which is consistent from year to year; whereas the data derived from commercial catches reflect the activities of the fleet which is likely to vary from year-to-year, depending on such factors as variation in fish behaviour and management measures. Data from both these sources are used in stock assessment where they are available.

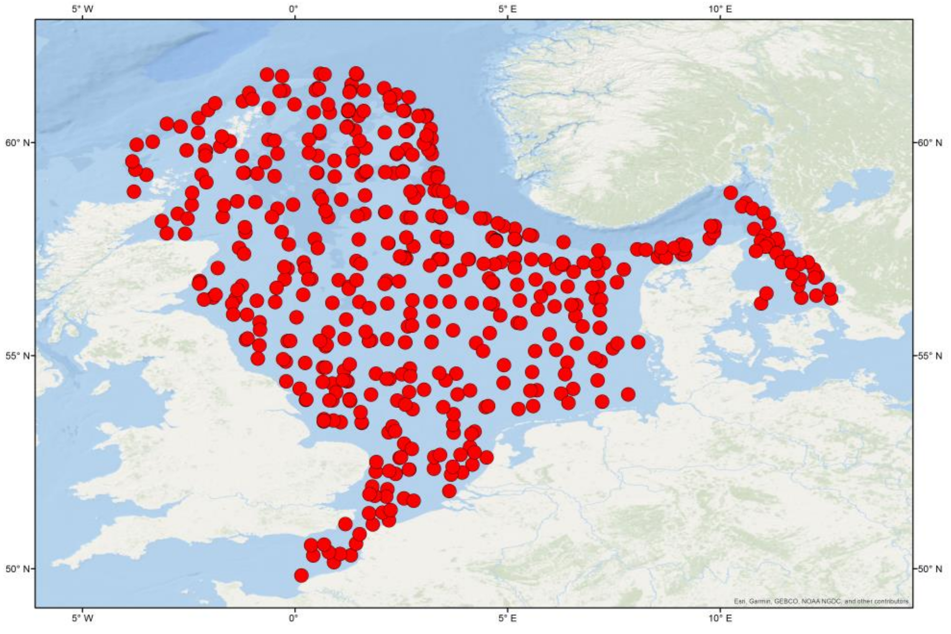

Figure 3 Fishery independent data; the North Sea International Bottom Trawl Surveys (IBTS) are carried out by in spring and autumn each year in the North Sea. Each point represents a survey station where standardised trawl gear was deployed during these surveys in 2018

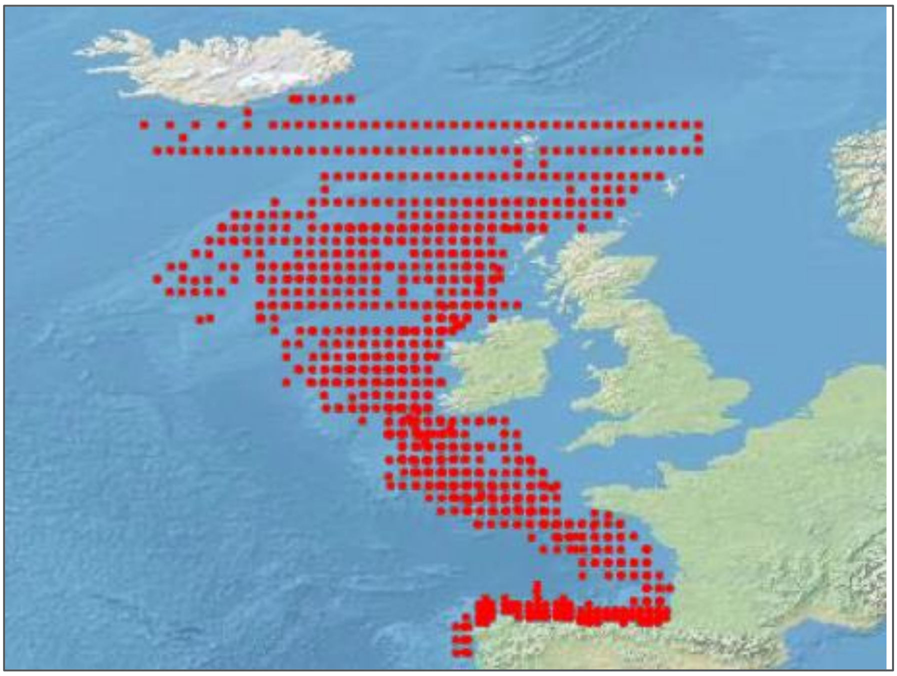

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Figure 4 Fishery independent data; the mackerel egg survey off Western European waters has been carried out every three years since 1977. Each of these points represents a survey station at which a calibrated plankton net capable of estimating the density of mackerel eggs in the surface 200 m of water was deployed during the spawning season. The eggs are counted in the samples as the survey is undertaken and, to ensure that the full extent of the spawning ground is mapped, the east-west transects are continued until no eggs are present in the samples (ICES, 2013b).

3.1 Ageing fish

Samples of fish are measured, and their otoliths or ear bones removed (
Figure 5). Annual growth rings are laid down on the otoliths (ear bones) and scales of teleost fish, and trained technicians can use them to determine a fish's age (
Figure 6). For flatfish, for example, the otolith is cut across the middle (black line) and the end is burnt in a small flame to blacken the organic matter in the annual rings. A thin coating of vegetable oil is applied to the cut end and examined under the microscope. For some species other structures within which growth rings form, for example scales or bones are used. Samples of fish across the population's size range are taken and aged.

The age readings are then used, together with length distributions measured from commercial catches and research vessel surveys, to describe the age structure (Figure 7) of the fish population and the catches. Data from research vessel surveys (where small-meshed gear is fished in a standardised way) are used to mitigate any bias in the commercial data so that the model informs on trends in the fish stock under assessment.

Figure 5 Above; measurement of fish on a measuring board and below; removal of otoliths

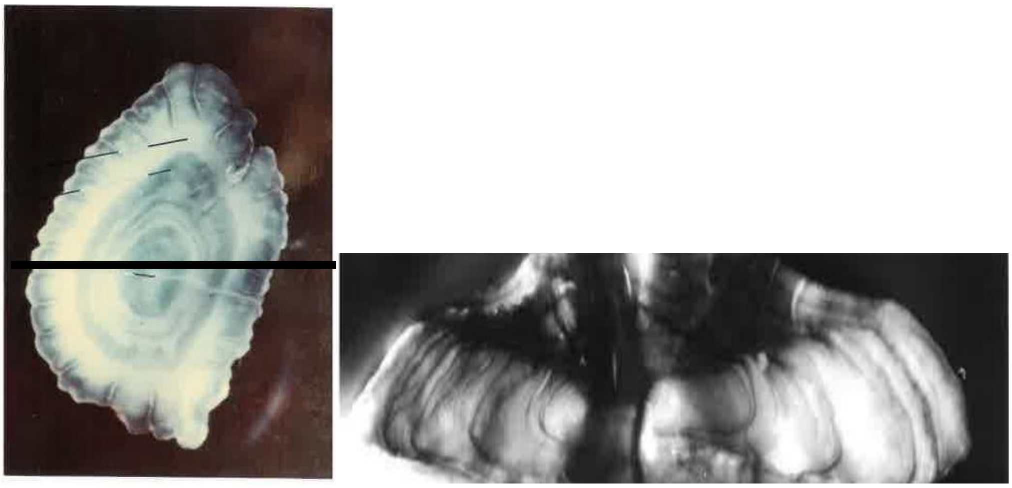

Figure 6 Otoliths from a flatfish, above shows a whole otolith (left; around 7 mm long and 5 mm wide), with annual rings visible, and on the right shows a section through the otolith, broken and burnt as discussed above. These otoliths are taken from a 5 year old fish; the dark line indicating the fish’s 5th winter can be seen on the outer edge of the otolith

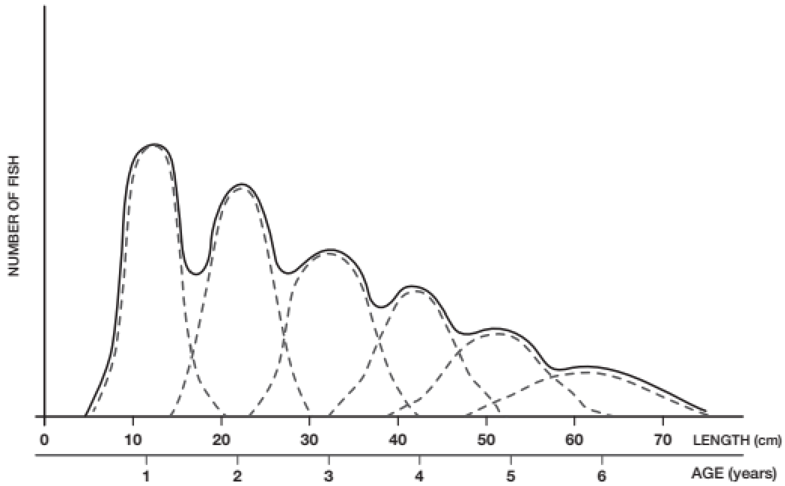

Figure 7 The length and age structure of a typical fish stock. This age structure is derived from information from age readings and the length distributions obtained from sampling the commercial and research vessel catches

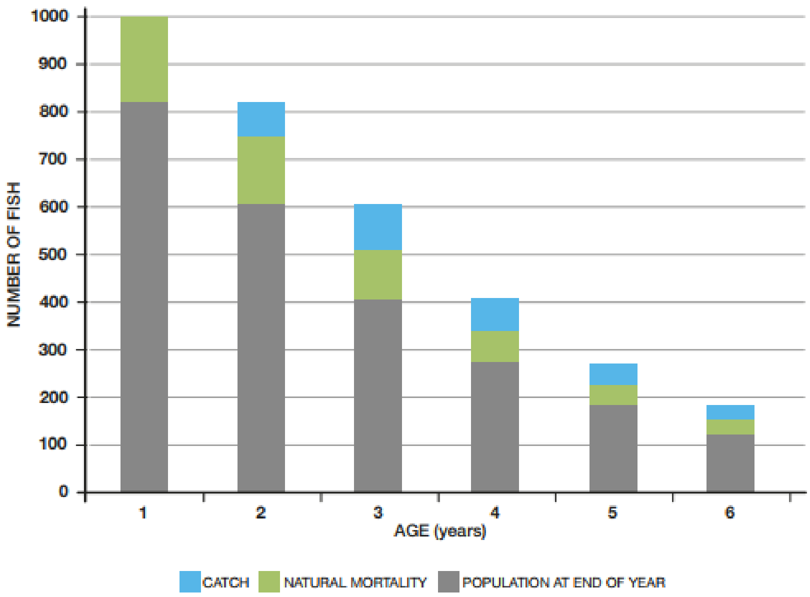

Figure 8 Fate of a year class of fish or 'cohort' passing through a fish stock. In this case 1,000 fish enter the stock at aged one-year. Due to 'natural mortality' around 800 are left at the end of the first year. During year two, the fish grow large enough to become liable to capture by the gear, so the fish are then subject to both fishing and natural mortality

3.2 Assessment models

The data on length and age distributions from market sampling and research vessel surveys are used to describe the age structure of the stock, as is illustrated in Figure 7. By combining several years' data, it is possible to track the progress of year classes (or 'cohorts') through the population as they enter the stock as recruits, until the whole of the year class is dead. Figure 8 illustrates this concept for a single year class.

By tracking the fate of each year class as it passes through the stock, scientists can assess the rates of death due to natural and fishing mortality over the years that successive year classes are present in the stock. By taking into account recruitment, growth and mortality of all the year classes in the stock, an appropriate model can be used to estimate the spawning stock biomass, which is related to reproductive potential via the stock-recruitment relationship (see page 16). These mathematical models perform progressively better as more and more years' data become available.

The inputs of recruitment and subsequent growth of young fish entering into the spawning stock and outputs in terms of fishing and natural mortality are illustrated in Figure 2 and shown diagrammatically in Figure 9.

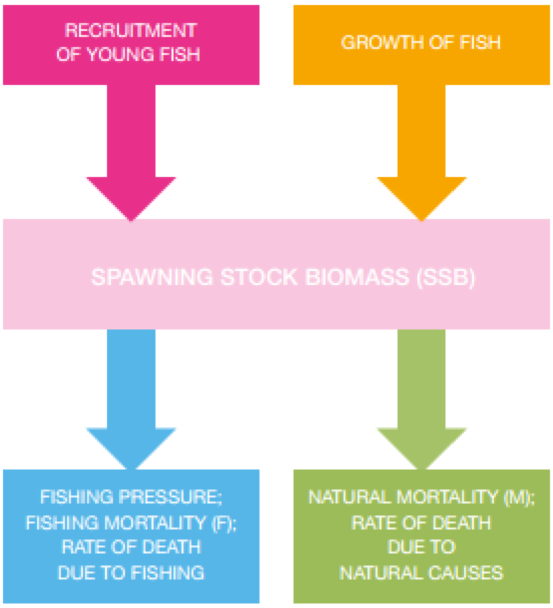

Figure 9 Elements of a fish stock model; the size of the spawning stock biomass (that is fish able to breed) is estimated from the number of adult fish at each age, derived from estimates of recruitment and the rates of death due to fishing and natural mortality. Where there is an independent estimate of spawning stock biomass from an egg survey (see Figure 4), this can be used to estimate the spawning stock biomass.

To keep the spawning stock biomass at equilibrium, the recruitment of young fish and their growth must balance the outputs due to death from fishing and natural mortality. Estimates of recruitment are made annually in numbers and the spawning stock biomass is calculated from knowledge of the age at maturity in the stock (which might span two or three ages) and numbers of fish at age and their average size. The fishing and natural mortality are expressed as rates (per year) at which the stock dies, due to fishing and natural causes respectively (see Appendix for a brief description of how mortality rates are expressed).

The level of spawning stock biomass is a key measure in fisheries management. It is affected chiefly by natural factors such as egg and larval survival, growth and mortality due to predation, and also by the pattern (that is the profile of catch-at-age) and level of fishing mortality. Estimation of predation ("natural") mortality can be difficult. In many cases it has been based on historical observations, when exploitation was low. Another approach is to assess the level of predation on a stock, based on models of food webs. However, this approach introduces a high-level of complexity into the model. See Guide to fishing at MSY (Seafish, 2022c) for further discussion of the implications of uncertainty relating to estimation of natural mortality.

Levels and patterns of fishing mortality are a function of fishing effort (number and size of vessels and their activity), which is controlled by management measures. The main purpose of the annual ICES assessments is to advise on the effect of future catch levels on the stock. Using the model, the scientists can make projections (see page 23) of what the likely effects of different levels of fishing mortality would be on catches and the size of the spawning stock biomass.

Other management measures, such as for example, changes in gear selectivity and spatial management designed to alter the age at first capture of the stock, can be modelled but this is not done routinely for ICES stocks.

4 Reference points

Stocks are assessed in relation to target, trigger and limit references. Target reference points are levels that managers are aiming for, and trigger reference levels relate to levels when action should be taken to enable the stock to be brought back on track towards the target. Limit reference points relate to the stock's ability to reproduce sufficiently to support a viable fishery.

Current ICES advice on stocks is given on the basis of two approaches. The **precautionary approach (PA)** relates to maintaining sufficient spawning stock biomass to enable the stock to breed successfully and support a fishery. 'Safe biological limits' under the precautionary approach relate to limit reference points, below which stocks are considered to suffer from impaired reproduction and may be unable to support a fishery. Precautionary reference levels relate to levels where stocks are considered 'at risk' of being outside safe biological limits, and where action should be taken by management to conserve stocks.

The ICES **maximum sustainable yield (ICES MSY)** approach refers to harvesting at safe and optimal levels to maximise yields from the stock in the long-term. This is achieved by exploiting the stock in a way which optimises its growth and reproduction.

The two variables which these reference points are defined by are;

- **Spawning stock biomass ('SSB');** which is an estimation of the quantity of breeding adults and hence the reproductive capacity of the stock, measured in tonnes.

- **Fishing mortality (F);** the rate per year at which fish are removed from the stock by fishing; described as 'Fishing Pressure' in some of the ICES' assessments (see Appendix for a brief description of how mortality rates are expressed).

In order to provide advice that can be used to determine appropriate management measures for the stock, scientists need to be able to define safe and optimum levels of spawning stock biomass and fishing mortality. If the spawning stock biomass is too low then there is a risk of the stock not being able to provide sufficient recruits to support a fishery. Stocks in this condition are termed 'depleted' or 'outside safe biological limits'. If the fishing mortality is too high the stock may not be harvested at its optimum rate and may risk depletion.

4.1 Process of deriving reference points

In the ICES area (Northeast Atlantic and Baltic) scientists and stakeholders meet in 'Benchmarking Workshops' where all information on the stock; ecosystem and fisheries data, stock distribution, candidate assessment models, forecast method and reference points is reviewed.

The process results in each stock having an agreed set of reference points and an analytical model that is used in assessments conducted annually (usually) by regional 'ICES Working Groups' of scientists. The reference points are reviewed at benchmarking workshop every three to five years for each stock. In some cases, this is done more frequently where there is evidence that this is required; these are termed 'inter-benchmark' workshops.

4.2 Spawning stock biomass reference points

Spawning stock biomass is defined as the quantity of fish in the stock capable of breeding. If the spawning stock biomass is of insufficient size, the reproductive capacity of the population may be impaired and therefore there is a risk of insufficient recruitment of young fish into the stock to replace those harvested by fishing and sustain the spawning stock. A stock in this condition is described as 'recruit overfished' and may not be able to sustain a fishery.

Since many environmental factors affect the survival of fish larvae in the plankton and young fish in the nursery areas, there is often no clear relationship between the spawning stock biomass and the recruitment of young fish into the stock. To investigate this aspect, scientists use stock-recruitment plots, where the number of recruits for each year is plotted against the spawning stock biomass which produced it.

Figure 10 shows a plot of spawning stock biomass against recruitment of young fish for the North Sea cod stock for the period 1963 to 2016; each year is one point. The precautionary approach reference points are derived by examination of the distribution of the spawning stock biomass and recruitment points (see Guide to fishing at MSY, Seafish (2022c) for details).

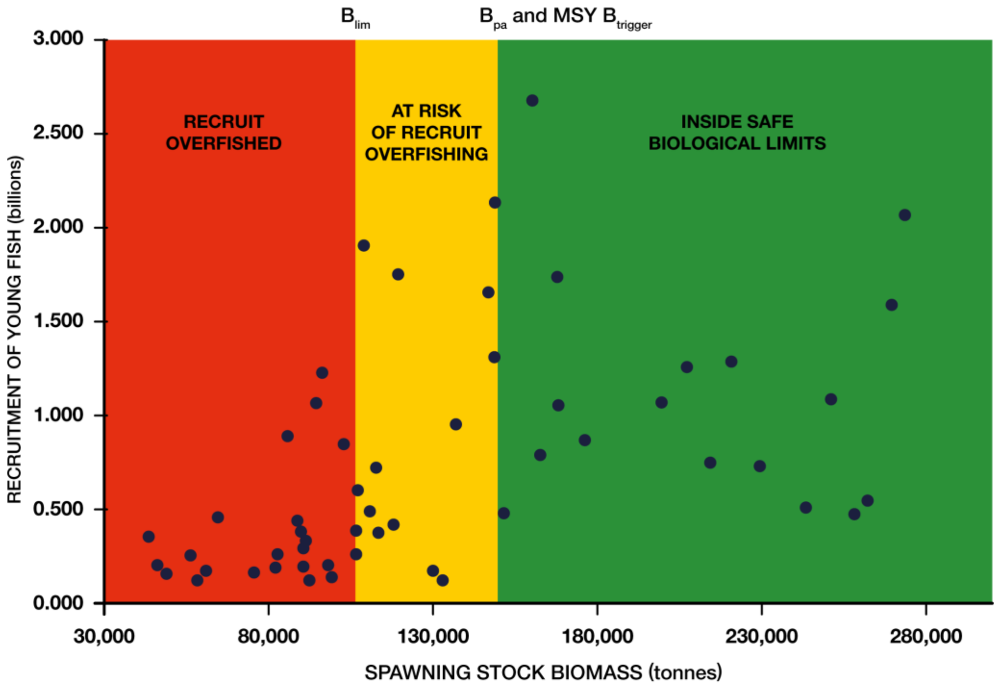

Figure 10 Spawning stock biomass vis Recruitment plot for North Sea cod 1963-2017. Each point represents one year's data. B_{lim} = Biomass limit reference point, B_{pa} = precautionary biomass level (see below). MSY $B_{trigger}$ = MSY Biomass trigger level; see Section 4.4

In general terms, recruitment is lower when spawning stock biomass is low. In the red section, the spawning stock biomass would be assessed to be below 107,000 tonnes, defined as B_{lim} (the Biomass limit reference point), and therefore outside safe biological limits and probably recruit overfished. That is there is considered to be insufficient reproductive capacity to produce enough recruits to sustain a fishery, and the stock is described as being outside safe biological limits.

Because there is uncertainty in the estimate of spawning stock biomass, the stock is considered *at risk* of being outside safe biological limits when it is below the precautionary Biomass reference level B_{pa}; the yellow section of the graph. When the spawning stock biomass is below this level, there is between a 5 and 10% risk of the stock being outside safe biological limits below B_{lim}.

See Section 5.1 on page 20 for information on how management advice is delivered in relation to these reference points.

4.3 Fishing mortality reference points

The relationships between the fishing mortality reference points are illustrated in Figure 11 which shows how long-term equilibrium catches would increase in line with increasing fishing mortality up to the peak of the curve, which represents optimal fishing mortality (F_{MSY}) at maximum sustainable yield (MSY); to successfully manage a stock at MSY harvesting should be at a level that maximises growth and reproduction of the stock in the long-term. Note: Figure 11 is a generalised diagram and is not intended to represent a particular stock.

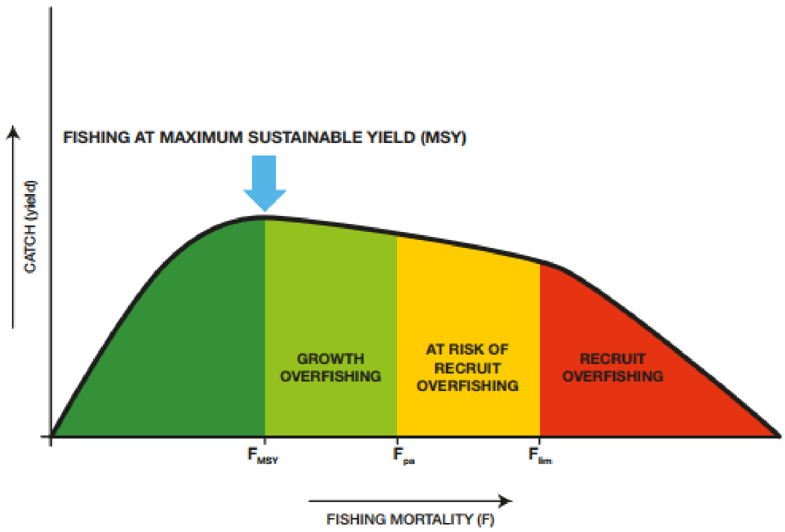

Figure 11 Schematic for Fishing Mortality reference points in relation to the Maximum Sustainable Yield (MSY) and Precautionary Approaches (PA)

Where the level of fishing mortality on the stock causes too many fish to be caught at a relatively small size, or the exploitation pattern (size distribution of the catch) is skewed towards young fish, the potential production of the stock due to growth of individual fish is not realised. This is described as ‘growth overfishing’ and is indicated by the light green area on Figure 11. However, even if a stock is growth overfished, providing sufficient fish survive to become adults and spawn, they should still have the reproductive capacity to replace themselves and the stock is described as being within safe biological limits under the precautionary approach.

Since management acts on fishing mortality rather than directly on spawning stock biomass, the precautionary spawning stock biomass reference points B_{lim} and B_{pa} (see Section 4.2 page 16) have corresponding fishing mortality reference points F_{lim} and F_{pa}. This means that, if the stock is fished for long enough at F_{pa} or F_{lim} then the spawning stock biomass will reach B_{pa} or B_{lim} respectively. Hence fishing at levels of mortality above F_{pa} places the stock at risk of depletion in the long term.

Managers use F_{MSY} as a target reference point. In Europe the Common Fisheries Policy (CFP)[2] aims to exploit stocks at maximum sustainable yield (MSY) by 2015 where possible and by 2020 at the latest. See also Section 5.3 on mixed fisheries assessments.

4.4 ICES Maximum Sustainable Yield (ICES MSY) reference points

The ICES MSY reference points relate to exploiting the stock at F_{MSY} as illustrated in Figure 11. MSY $B_{trigger}$ (See Figure 10) is the spawning stock biomass reference point used to assess whether the stock is capable of withstanding fishing mortality at F_{MSY}. When the stock is above the MSY $B_{trigger}$ level it is considered to be able to withstand exploitation at F_{MSY} with a 95% probability that the stock will be within safe biological limits (above B_{lim}) in any one year. When it is below this trigger level, the advice given to managers is to reduce fishing mortality under the ICES advice rule aiming to restore the stock to above MSY $B_{trigger}$. This is described in Section 5.2 page 20.

[2] https://ec.europa.eu/fisheries/cfp/fishing_rules_en

In the stock illustrated in Figure 10 , B_{pa} and MSY $B_{trigger}$ are at the same level. However, ICES is in the process of revising MSY $B_{trigger}$ levels using simulation studies (see Guide to fishing at MSY (Seafish, 2022c)) in order to better define MSY $B_{trigger}$ as the biomass action point under the ICES maximum sustainable yield (ICES MSY) approach. This process results in MSY $B_{trigger}$ being set at or above B_{pa}.

4.5 Summary of reference points

The main reference points used by ICES are summarised in Table 1. Note B_{MSY}, relates to the spawning stock biomass resulting from fishing at F_{MSY} for long periods of time, although it is not normally defined for ICES analytical assessments (chiefly because stock productivity is likely to change through time). It is used in certain types of models ‘production models see Guide to fishing at MSY (Seafish, 2022c).

Table 1 ICES Reference points (see Guide to fishing at MSY (Seafish, 2022c) for full details)

Approach	Reference points	Definition
Precautionary Approach; relates to safe biological limits	**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}).
	F_{lim}	Fishing mortality limit reference point; stocks fishing stocks at above this rate in the long-term will result in the spawning stock biomass being below the Biomass limit reference point (B_{lim}).
	F_{pa}	Precautionary fishing mortality level; stocks fished at this rate have a risk (around 5-10%) of being exploited at above the Fishing mortality limit reference level (F_{lim}) and hence a long-term risk of being below the Biomass limit reference point (B_{lim})
ICES Maximum Sustainable Yield Approach	**Maximum Sustainable Yield (MSY)**	Catching the maximum quantity that can safely be removed from the stock while, at the same time, maintaining its capacity to produce sustainable yields in the long-term.
	F_{MSY}	Rate of Fishing mortality consistent with achieving Maximum Sustainable Yield (MSY).
	MSY $B_{trigger}$	MSY Biomass trigger level; When the stock is above this level the stock it is considered capable of being sustainably harvested at F_{MSY} with a 95% probability that the stock will be within safe biological limits (above Blim) in any one year. It is used as a trigger reference level, when the stock is below this level the ICES approach is to reduce fishing mortality under the ICES MSY Advice rule (Section 5.2 p20)
	B_{MSY}	This is defined as the estimated level of biomass of a stock which produces MSY at long term equilibrium. B_{MSY} can also be defined as the level of biomass that results from fishing at F_{MSY} for a long time. B_{MSY} is not normally used as a reference point for ICES stocks that are assessed using analytical models.

5 ICES advice

To provide advice to managers, scientists calculate the status of the stock in relation to the biological reference points. As discussed above ICES refers to two sets of reference points - ICES MSY and Precautionary Approach. Where there is a management plan agreed on the stock, which has been assessed by ICES to be consistent with the Precautionary Approach, advice is given under this plan. Management plans may also have their own reference points.

The headline advice is given under the management plan or it defaults to the ICES MSY approach where there is no management plan, and further options are given in the 'Catch options' table in the ICES advice (see Section 8 page 25).

5.1 Precautionary Approach advice

The role of reference levels, B_{pa} and F_{pa} is to provide warning of the stock being at risk of being outside safe biological limits. B_{pa} is an action point and managers would be expected to take measures to reduce fishing mortality, aiming to restore the stock to being above B_{pa}, that is, within safe biological limits.

Where stocks are at spawning stock biomass levels outside safe biological limits (below B_{lim}; See section 4.2), the headline advised catches (that is the advised catch given in the first paragraph of the advice, see Section 8 page 25) would be given for recovery of stocks to inside safe biological limits within the next year. If there is no level of catch that would achieve this, ICES advice would be to stop fishing, or minimise unavoidable catches. However, when there is a management plan aimed at recovering the stock over an extended period of time, that has been assessed to be precautionary by ICES, then ICES will advise according to this plan.

5.2 ICES MSY Advice rule

Under the ICES MSY approach, provided that the spawning stock biomass is above the MSY $B_{trigger}$ level, ICES advises catches consistent with fishing mortality at F_{MSY}. However, if the biomass drops below the MSY $B_{trigger}$, a more cautious response is taken and ICES advises a decrease in fishing mortality proportionate to the extent to which the spawning stock biomass is below MSY $B_{trigger}$.

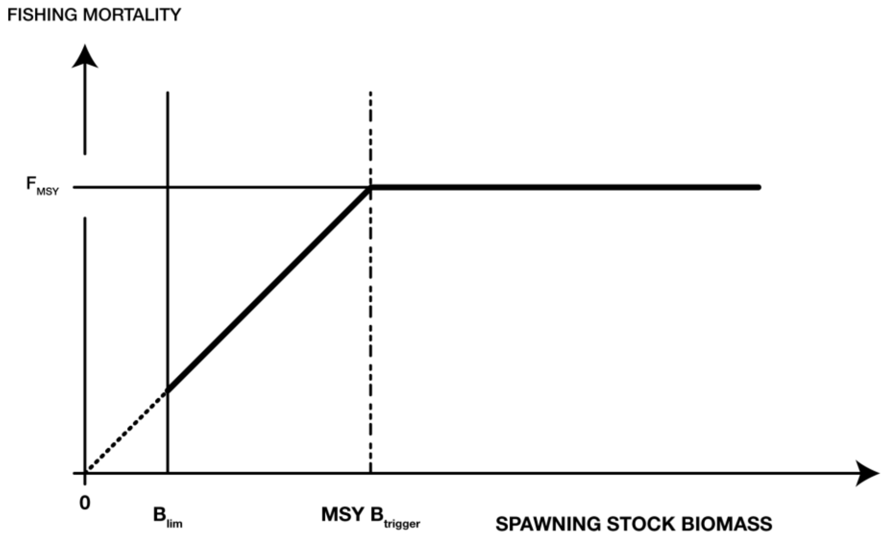

Figure 12 Harvest Control Rule (HCR) for the ICES MSY approach. Advised fishing mortality is reduced below F_{MSY} in proportion to the extent which the Spawning Stock Biomass is below the Biomass trigger level MSY $B_{trigger}$

This approach is described in Figure 12 as a Harvest Control Rule or HCR; so called because it defines the rate of harvest advised, that is fishing mortality under different conditions. At low levels of spawning stock biomass, below B_{lim} as represented by the dotted line on this plot, advice is given to recover the stock to within safe biological limits within the next year (see Section 5.1).

5.3 Mixed fisheries advice

It can be difficult to maintain fishing on all stocks at F_{MSY}, particularly in mixed fisheries, where different stocks caught in the same fishery have different optimum levels of exploitation. Therefore, the concept of F_{MSY} ranges (ICES, 2015) has been formulated to enable managers to resolve conflicts between stocks by exploiting some at rates slightly above F_{MSY} and some below F_{MSY}.

The ranges of fishing mortality that have been estimated to be within a chosen boundary of within 5% of maximum sustainable yield are illustrated in Figure 13. If this results in a value of F_{upper} being higher than the precautionary level F_{pa}, then the advice is to use F_{pa} as F_{upper}. This means that if the stock is exploited within this range of fishing mortality (between F_{lower} and F_{upper}) it will yield 95% of maximum sustainable yield in the long term.

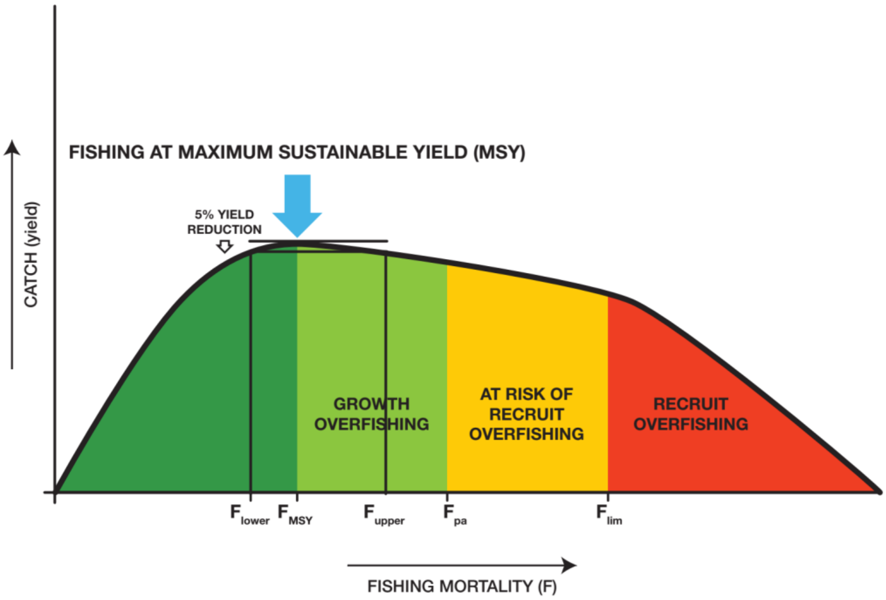

Figure 13 Schematic illustrating how the F_{MSY} ranges are formulated in the ICES advice. Maximum long-term yields are obtained at F_{MSY}, and F_{lower} and F_{upper} are calculated to result in no more than a 5% reduction in long term yield (see ICES, 2015).

This approach is being implemented in the EU Multi Annual Plans for the Baltic and North Seas. The advice is given using a multi-species assessment method (ICES, 2017b), which enables the scientists to advise on TACs for individual stocks which would keep all stocks exploited at within 95% of maximum sustainable yield. The objective is to provide balanced exploitation close to $F_{MSY,}$ not to exploit all stocks at F_{upper}.

6 Stock trajectories

Figure 14 shows graphical outputs from the ICES North Sea cod stock assessment in 2017 (ICES, 2017a). These graphs are a summary of the results of the assessment process and show a time series of catches, recruitment, fishing mortality and spawning stock biomass as presented in the ICES advice for this stock. The colour coding added to the graph on fishing mortality and spawning biomass correspond to the location of the stock in relation to the reference points described in Figure 10 and Figure 11. The reference points are shown as horizontal lines. As discussed above, when the spawning stock biomass is in the red zone of the graph, the stock is considered outside safe biological limits (depleted) and if the fishing mortality is in the red zone then the stock is likely to become outside safe biological limits in the future, if it is not already in this state.

The yellow area between the green and red zones represents levels of fishing mortality or spawning stock biomass within which the stock is considered to be ‘at risk of being outside safe biological limits’. Management should take measures to recover stocks if they are at risk of being (yellow) or outside safe biological limits (red). The blue line on the fishing mortality graph represents the condition of optimal harvesting at maximum sustainable yield F_{MSY}. The trajectories of fishing mortality and spawning stock biomass are shown in black with the thin black lines indicating the 95% confidence interval.

The assessment for North Sea cod shows very high catches and correspondingly increases in fishing mortality during the period up to 1983, associated with above-average recruitment, followed by a declining trend in catches associated with high fishing mortality that only fell after 1998. Spawning stock biomass suffered a long-term decline from around 1970 until the mid-2000s, after which it increased as management measures designed for stock recovery began to take effect.

It is likely that the decline in recruitment of young fish in the early 1980s was as a result of low spawning stock biomass, which in turn reduced the breeding capacity of the stock, although changes in the plankton may also have affected larval survival.

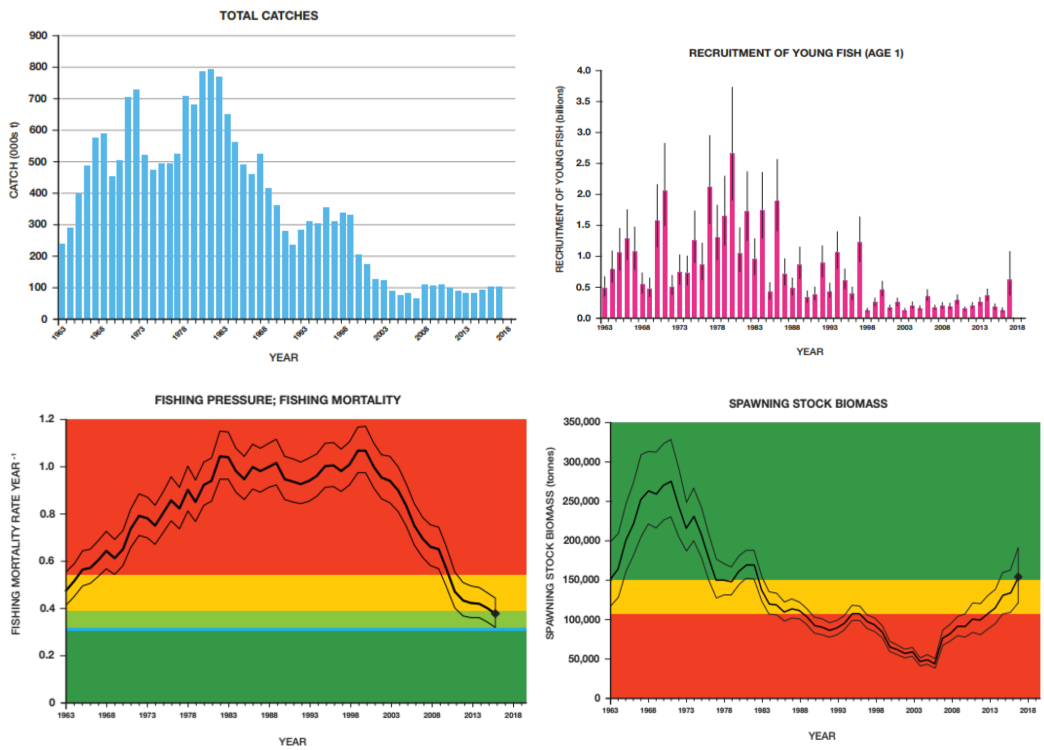

Figure 14 Summary of ICES assessment in 2017 for North Sea cod; time series 1963-2017. Top left; total catches including estimated discards. Top right; estimated levels of recruitment of young fish age 1 into the stock (with the 95% confidence intervals in grey). Bottom left: estimated fishing mortality, bottom right estimated spawning stock biomass with the 95% confidence levels shown by the thin black lines. The diamonds are estimated the locations of the stock at the assessment in 2017.

6.1 Quality and consistency of the assessment

In its working groups and workshops, ICES uses various statistical methods to assess the reliability of assessment models. In the North Sea cod assessment, this type of uncertainty is reflected in the widths of the 95% confidence intervals shown in Figure 14. Note how the width of the confidence interval for spawning stock biomass increases in more recent years, which indicate increasing uncertainty in these estimates due to the diminishing number of annual data sets incorporated in the model. This is particularly important in short lived and heavily exploited stocks that are highly dependent on recruiting year classes because there is less information on this component of the stock.

Each year's assessment is run with additional data for the extra year, plus any corrections to previous year's data together with changes to the assessment agreed at the benchmark workshops. Therefore, each year's assessment is independent of the previous years' and may produce a different result, though with each new assessment, the precision of estimates for previous years should be higher.

To understand the consistency of the assessments from year to year, comparisons are made retrospectively with previous assessments using current reference points. An example (North Sea cod for 2017) is shown in Figure 15

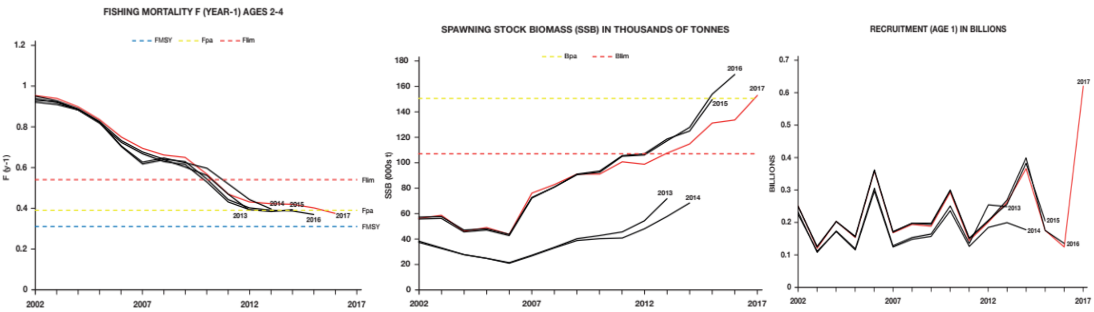

Figure 15 North Sea cod historical assessments. Each line relates to the results of the assessments in previous years with the red line is the result for the assessment in 2017

In these graphs, the output from the current assessment is shown as a red line whilst the outputs from the previous four years' assessments are shown in black. In this case the estimated values of spawning stock biomass vary considerably, due to recalibrations over the years, but the trends are similar across all three graphs, suggesting consistency in the estimates of fishing mortality from year to year. Not all assessments are as consistent, and ICES discuss inconsistencies and their implications in the advice.

6.2 Projections for future management options

In order to set management measures for future years, projections of the consequences of possible measures, usually in terms of an advised TAC for the next year, are required. ICES assessments model projections of fishing mortality and spawning stock biomass under different levels of catch for the following year. These are reliant on estimates of the most recent and recruiting year classes, and of recent stock biomass, the period where there is least certainty. The ICES advice presents these projections in the form of a 'catch scenarios' table, which enables managers to understand the implications of the choice of measures adopted.

The projections are made for the year following the assessment year, so the assessment carried out in 2017 is used in predictions for 2018. However, since the information for the 2017 assessment mostly relates to the years up to and including 2016, some parameters have to be estimated for 2017, described as the 'intermediate' year. Figure 16 and Figure 17 show projections (dotted lines) of fishing mortality and spawning stock biomass respectively from the 2017 ICES catch scenarios table for North Sea cod.

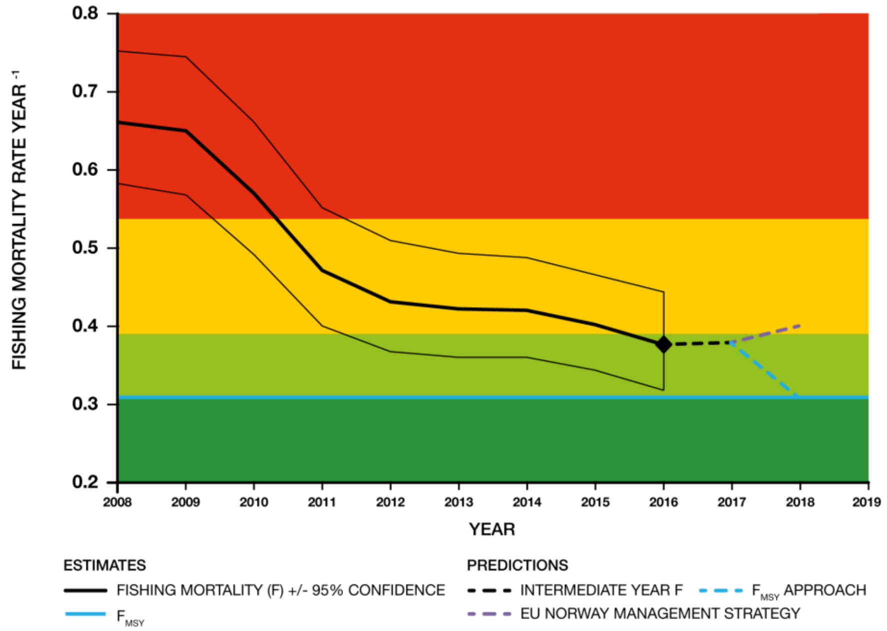

Figure 16 Fishing mortality estimates for the North Sea cod stock 2008-2016 and predictions for fishing mortality in 2018 two different catch scenarios for 2018; ICES F_{MSY} approach, and the EU Norway management strategy. Colour key as on Figure 10

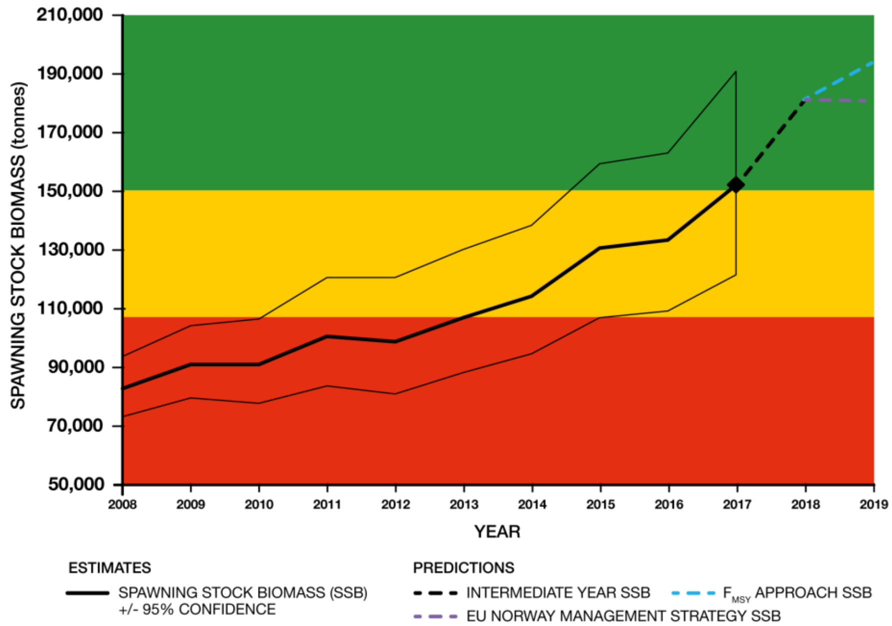

Figure 17 Spawning Stock Biomass (SSB) estimates for North Sea cod stock 2008-2018 and predictions for SSB in 2019 for two different catch scenarios for 2018; F_{MSY} approach and the EU Norway management plan. Colour key as on Figure 10

Two different catch scenarios are shown; catches of 53,058 tonnes in line with the ICES MSY approach (F_{MSY}), or 66,224 tonnes in line with the long-term management strategy originally agreed by the EU and Norway in 2008.

These projections show that the ICES MSY approach would result in fishing mortality coinciding with the reference point F_{MSY} in 2018, as would be expected, and the EU-Norway strategy resulting in a slight increase in fishing mortality to just above F_{pa}. Spawning stock biomass is projected to be stable if the management strategy was followed and show a slight increase if the stock were fished at F_{MSY}. The TAC agreed for 2018 was 52,884 t, closely aligned to the level consistent with F_{MSY}. However, since this assessment, there has been a decrease in the spawning stock biomass of North Sea cod, see ICES (2021).

7 Other assessment methods

The above description relates to assessments made using age-structured analytical models, where fish can be aged using annual growth rings on otoliths or scales, and there is good information on the age and length distributions of the catches. However, this information is not always available, and in these circumstances, scientists use other methods.

There is a range of assessment methods that can be used for these stocks dependent on how much information there is available. The last few years have seen considerable development in ICES' methods for the assessment of these 'data-limited' stocks, for which there are no analytical population assessments. These are outlined in Guide to data-limited assessments (Seafish, 2022c).

8 Understanding the ICES advice

ICES provides scientific advice to fisheries' and environmental managers for the northeast Atlantic. This includes national governments and international organisations such as the European Union and the North East Atlantic Fisheries Commission - the Regional Fisheries Management Organisation for these waters.

The link to the ICES advice can be found at https://www.ices.dk/advice/Pages/Latest-Advice.aspx which shows the latest advice by year and stock. Opening the species links show further links to the various stocks of this species, as defined by location. For example Figure 18 shows how to find the advice for the stock of cod in the North Sea, Eastern English Channel and Skagerrak for 2019.

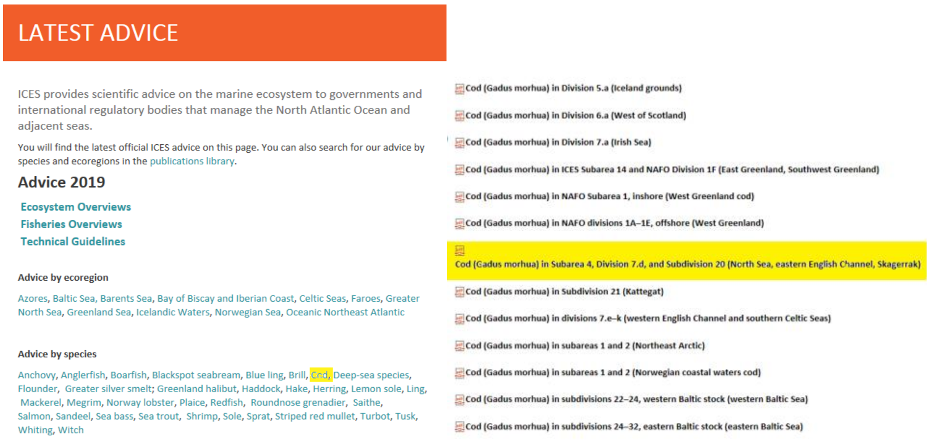

Figure 18 Screen shots of the page on the ICES website relating to the latest stock advice. Left; latest advice by species: click on the species required, in this case cod in 2019, and links to all the advice relevant to that species is selected (right). To open advice relevant to the stock, open the appropriate link- the link for the stock of cod in the North Sea and Skagerrak is highlighted.

Once the appropriate stock advice has been located, the advice can be downloaded as a pdf document. These documents have a number of standardised headings. The information given under these headings **in bold** is discussed below referring to the concepts described in this Guide. 'ICES Advice Table' numbers refer to the Tables in the ICES Advice.

Under the heading **ICES advice on fishing opportunities** the headline advised catch in tonnes is given for the next period under the current management plan, provided it is considered precautionary by ICES, or under the ICES MSY approach, if there is no management plan. If the management plan uses the F_{MSY} range as described in Figure 13 (page 21), the upper and lower ranges of advised catch is given.

The next heading is **Stock development over time**, which has a few sentences describing recent trends and then a set of four graphs showing annual catch and the most recent estimates of recruitment, fishing mortality and spawning stock biomass in the same format as shown in this document's Figure 14 (page 22), but without the red, yellow and green colour infill; the reference points for fishing mortality and spawning stock biomass are marked as horizontal lines.

The next section is headed **Catch scenarios** where the basis for predictions for the next year's catch options, including the intermediate year (see page 23 this document), are laid out in ICES Advice Table 1. The projections for spawning stock biomass and fishing mortality for various levels of catch corresponding primarily to the management plan, if it is in place and considered precautionary by ICES, but also to the ICES MSY and Precautionary Approaches and other possible levels of catch, are shown in ICES Advice Table 2. The projections are also made for mixed fisheries advice scenarios are shown in a separate table if these are available.

In some cases, for EU fisheries the terms 'Wanted catch' and 'Unwanted catch' are used as well as Total catch. The Unwanted catch relates to expected discard levels if discarding practices continue as they were in years prior to the Landing Obligation[3] and the Wanted catch relates to landings under these circumstances. However, as the Landing Obligation,

[3] EU Landing Obligation https://ec.europa.eu/fisheries/cfp/fishing_rules/landing-obligation-in-practice_en

which seeks to phase out discarding in European waters, becomes implemented, advice for Total catch will become the relevant quantity.

Under the next heading **Basis for the advice,** the ICES MSY approach and any agreed management plan for the stock is described briefly and referenced. The **Quality of the assessment** heading is important for information on uncertainties and recent developments in the assessment and how consistent the current assessment is with previous years; see Section 6.1 page 23 of this document for further information.

In the **Issues relevant for the advice** section the assessment scientists may add further text, graphics and tabulations to explain other issues relevant to the assessment. These can include uncertainties over catch data, further biological information and discussion about the mixed fisheries assessment where relevant

The next section **Reference points** tabulates (ICES Advice Table 4) the relevant reference points and briefly describes how they were derived, including a reference to the appropriate workshop or working group. **Basis of the assessment** details technical details of the assessment, date of the most recent benchmarking (see page 16 this Guide) and which ICES Working Group carried out the assessment (ICES Advice Table 5). If there is any **Information from the stakeholders** (such as information on recruiting year cases) it is included in the next section.

Under the heading **History of the advice, catch and management** in ICES Advice, Table 6 gives a time series of previous advised and agreed TACs, along with Official landings and estimates of catches carried out by ICES either from discard surveys or other sources. Under **History of the catch and landings** ICES Advice Table 7 breaks down the most recent catch information by gear type for this stock, and ICES Advice Table 8 provides a time series of landed catches by nation.

The next heading contains a **Summary of the assessment** which tabulates (ICES Advice Table 9) the assessment in the form of a time series of estimates of recruitment, spawning stock biomass, fishing mortality and catch. This is a tabulation of the information shown in graphical form under the heading **Stock development over time** (see above). Finally, the documents referred to in the text are listed under the heading **Sources and references**.

9 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 Assessments
SR744 ISBN 978-1-911073-50-5

Seafish (2022e)
Guide to Sustainable and Responsible Sourcing
SR752 ISBN 978-1-911073-58-1

Seafish (2022f)
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

10 References

Links checked at Feb 2022

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Gulland, J. A. (1969). Manual of Methods for Fish Stock Assessment - Part 1. Fish Population Analysis. Rome: FAO.

Harden Jones, F. R (1968). Fish Migration Published by Edward Arnold

ICES, (2013a). Fish Stocks; counting the uncountable? ICES, Copenhagen, Denmark

ICES, (2013b) Manual for the mackerel and horse mackerel egg surveys (MEGS): sampling at sea Version 1.3 The Working Group on Mackerel and Horse Mackerel Egg Surveys

ICES, (2015) ICES Special Request Advice Greater North Sea and Baltic Sea Ecoregions; EU request to ICES to provide FMSY ranges for selected North Sea and Baltic Sea stocks Book 6 Section 2.3.1 http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2015/Special_Requests/EU_FMSY_ranges_for_selected_NS_and_BS_stocks.pdf

ICES, (2017a) Cod (Gadus morhua) in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, eastern English Channel, Skagerrak) ICES Advice on fishing opportunities, catch, and effort Greater North Sea Ecoregion cod.27.47d20 published 14th November 2017 http://ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/cod.27.47d20.pdf

ICES (2017b) Mixed-fisheries advice for Subarea 4, Division 7.d, and Subdivision 3.a.20 (North Sea, eastern English Channel, Skagerrak) http://www.ices.dk/sites/pub/Publication%20Reports/Advice/2017/2017/mix-ns.pdf

ICES, (2021) Cod (Gadus morhua) in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, eastern English Channel, Skagerrak) ICES Advice on fishing opportunities, catch, and effort Greater North Sea Ecoregion cod.27.47d20 published 30th June 2021 cod.27.47d20 (ices.dk)

11 Appendix - note on mortality rates

Mortality rates in fisheries are conventionally expressed as rates per year, where a constant mortality rate implies that a constant proportion of the population dies each year. As an example, Figure 19 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 i.e. a constant proportion of the year class is dying each year.

The numbers of fish surviving from year to year (or age) shown in Table 2 is smoothed and plotted in Figure 19 below. 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 2 Number of fish at the start of each year subject to a constant mortality of 41.1% per annum

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%

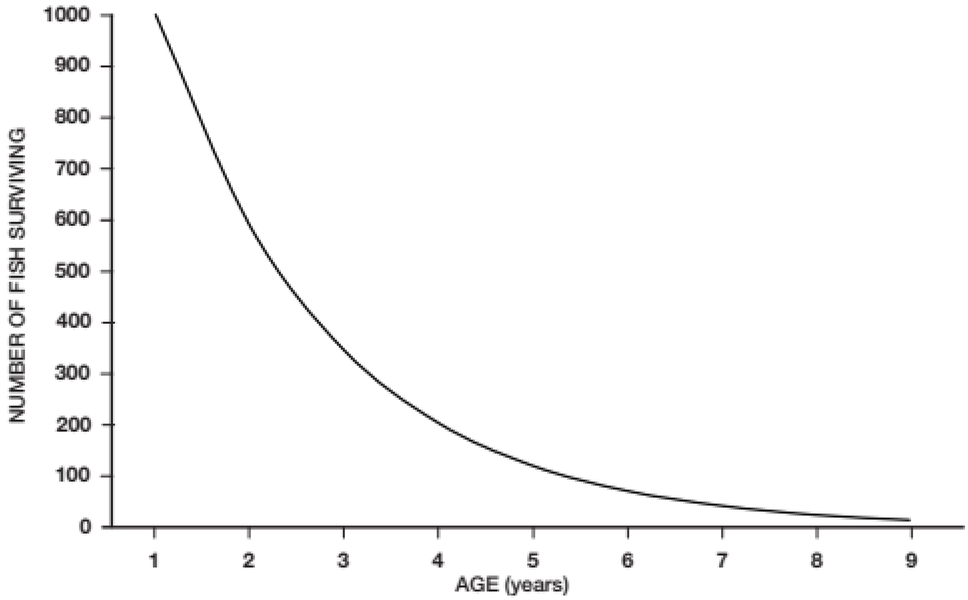

Figure 19 Numbers of fish vs time/age for a cohort of 1000 fish entering the stock at age 1

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