Biodiversity Series

North Sea Pilot Project on Ecological Quality Objectives

Background Document on the Ecological Quality Objective for Spawning Stock Biomass of Commercial Species in the North Sea

OSPAR Commission

2005

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

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contents

1. Background

This Background document aims to explain the thinking behind the ecological quality objective (EcoQO) on commercial fish species.

The Bergen Declaration of the 5th North Sea Conference identified ten issues relating to the ecological quality of the North Sea for the development of ecological quality objectives (EcoQOs). "Commercial fish species" is one of these ten issues. One Ecological Quality (EcoQ) element has been developed for this issue: *(a) Spawning stock biomass of commercial fish species in the North Sea.*

This is among the ten elements included in the North Sea Pilot Project. An EcoQO was adopted for this element in the Bergen Declaration: "*Above precautionary reference points*[1] *for commercial fish species where these have been agreed by the competent authority for fisheries management*".

This Background Document was prepared by Norway (lead country for this EcoQO in OSPAR) as input to the review of the advanced EcoQOs under the North Sea Pilot Project.

2. Importance of the EcoQO element

Commercial fish species are important components in marine ecosystems. Several species have large populations in the North Sea (e.g. herring and mackerel), and they have major roles in the structuring and functioning of the North Sea ecosystem. North Sea fisheries have a major impact on the North Sea ecosystem, directly on the targeted fish stocks, and indirectly through trophic (e.g. predator-prey) interactions. Inclusion of commercial fish species in the set of EcoQOs for the North Sea is therefore highly relevant if the EcoQO system is to reflect the major features of the marine ecosystem.

3. Role of OSPAR

OSPAR has no competence to adopt programmes and measures on questions related to the management of fisheries. Application of the proposed EcoQO for commercial fish species must therefore be regarded as the responsibility of the competent fisheries management authorities. This is significant as it contributes to the further integration of fisheries and environmental protection, conservation and management measures, as called for in the Statement of Conclusions from the Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues in Bergen in March 1997.

4. Technical basis for the EcoQO

The status of fish stocks are evaluated based on two parameters:

- Spawning Stock Biomass (SSB or B)
- Fishing mortality (F)

Spawning stock biomass (SSB) is the mass (usually expressed as wet weight) of the individuals in the population that are mature and take part in the (usually) annual spawning event. The SSB may be composed of several age groups, comprising fish that spawn for the first time and fish that spawn for a second time or even more times.

The fishing mortality (F) is an expression of the fraction of the population that is removed by fishing in each unit of time. The reduction in number of individuals of a year-class follows an exponential decay function, and F is the exponential coefficient (with a negative sign in the equation). The unit of time is usually one year, so F relates to the fraction of the population removed by fishing from one year to the next. For low values, F is roughly equivalent to percentage of the population removed by fishing; i.e. $F = 0.2$ corresponds to removal of 18 % of the initial population. With increasing values of F, the difference from percentage values increases. Thus $F = 0.5$ corresponds to removal of 39 % of the initial population, $F = 1.0$ to 63 % and $F = 1.5$ to 78 % of the population.

SSB and F are related. With high F, few fish live to become mature and join the spawning stock, and few individuals of the first-time spawners survive to spawn a second time. Therefore the SSB tends to be reduced for high values of F. *Vice versa*, at low F values, more fish survive and accumulate in the population to form a larger SSB.

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[1] The Bergen Declaration adds that, in this context, precautionary reference points are those for spawning stock biomass, also taking into account fishing mortality, used in advice given by ICES in relation to fisheries management.

The management of the fish populations is guided by reference points set both for SSB and F for each population. The key element here is a limit reference-point set for SSB, denoted as $\mathbf{B_{lim}}$. B_{lim} is defined in relation to the reproductive potential of the stock in terms of producing offspring as new recruits to the population. B_{lim} is identified as a value of SSB, below which recruitment is impaired and there may be a danger of stock collapse, or of getting into a zone of low population-size with unknown dynamic properties. Above B_{lim}, the size of the spawning stock is assumed to have a minor role in effecting recruitment (Fig. 1).

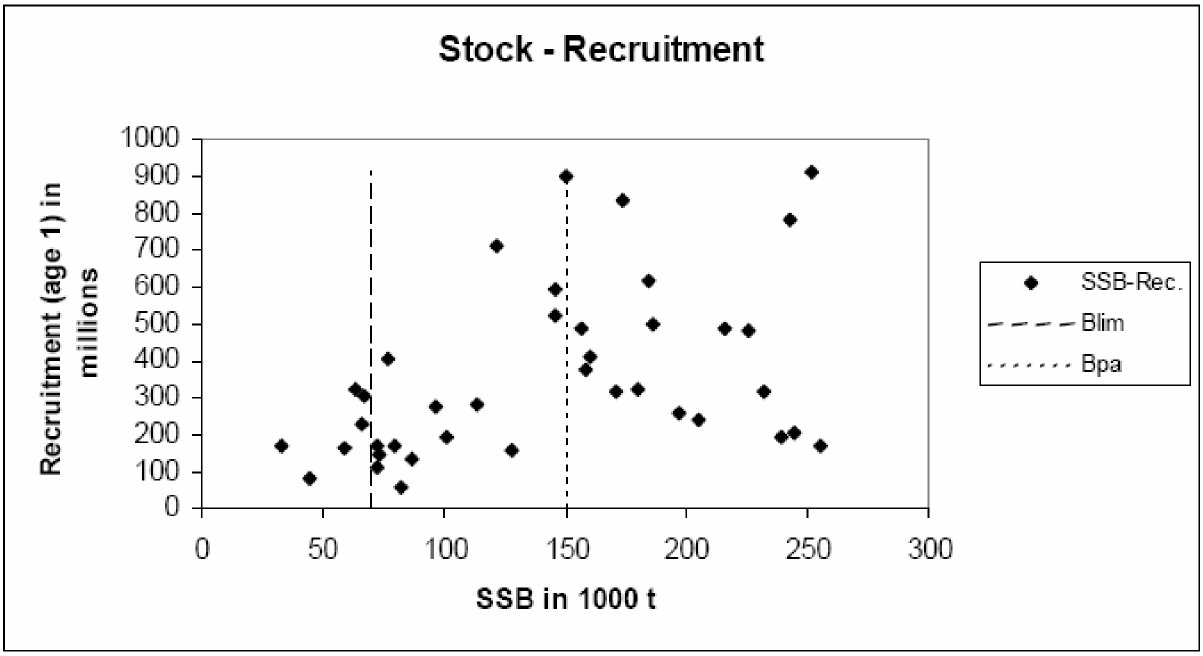


Fig. 1. Plot of recruitment vs. spawning stock biomass (SSB) for North Sea cod. Each point is the year-class strength as numbers of recruits (one-year old fish) in a given year plotted against the SSB that produced that year-class. Based on data for the period 1963-2003. The positions of B_{lim} and B_{pa} are shown by the vertical broken lines. From ICES ACFM http://www.ices.dk/committe/acfm/comwork/report/2003/oct/cod-347d.pdf.

A limit reference-point for SSB marks a level which fisheries management should aim to keep the SSB comfortably above. The precautionary reference-point for SSB, $\mathbf{B_{pa}}$, is designed with the aim of ensuring a high probability of staying above B_{lim}. The stock fluctuates through natural variability as well as from the influence of varying fishing pressures. The stock size is in most cases estimated annually, and the estimates are associated with a degree of uncertainty. The distance by which B_{pa} is higher than B_{lim} is intended to cover this estimation uncertainty. Thus, when the stock is estimated to be at the level of B_{pa}, there should be a low probability of the true value of the SSB being lower than B_{lim}. B_{pa} can therefore be characterised as a limit-based reference-point. Its purpose is to give a high probability of staying above the limit reference-point. It is not a target in any sense other than that of ensuring that the limit is avoided.

Similarly, reference points are set for the fishing mortality F. The limit reference-point, $\mathbf{F_{lim}}$, is identified as a value of fishing mortality above which there is high probability that fishing will cause the stock to decline. This may bring the stock down below B_{lim}, causing impaired recruitment. F_{lim} should therefore be avoided and F_{pa} is designed to ensure a high probability of achieving this. F_{pa} is a fishing mortality value lower than F_{lim}, where the distance by which F_{pa} is lower than F_{lim} reflects the estimation uncertainty. If F is estimated to be at or below F_{pa}, there should be a low probability that the true value of F is higher than F_{lim}. Again, as with B_{pa}, F_{pa} can be characterised as a limit-based reference-point.

The system of limit reference-points and limit-based precautionary reference-points is simple in principle, but there are several conceptual and practical limitations. On the conceptual level, the soundness of the approach hinges on the degree to which B_{lim} is a break-point or discontinuity in the relationship of new recruitment as compared with the SSB. If there is a sharp break-point separating an initial slope from a plateau, as is often assumed, it would be a good concept, as a value separating a zone below B_{lim} where recruitment is influenced by SSB from a zone above B_{lim} where it is not (Fig. 2). On the other hand, if there is a gradual and slight levelling off in the recruitment function, B_{lim} would be more an arbitrary value, above which recruitment may be somewhat less influenced by SSB than below. There is limited evidence for the existence of a sharp break-point and it appears more to be a gradual and less pronounced change, as can be seen from the large number of plots contained in the annual reports of the ICES Advisory Committee on Fisheries Management showing recruitment as compared with SSB.

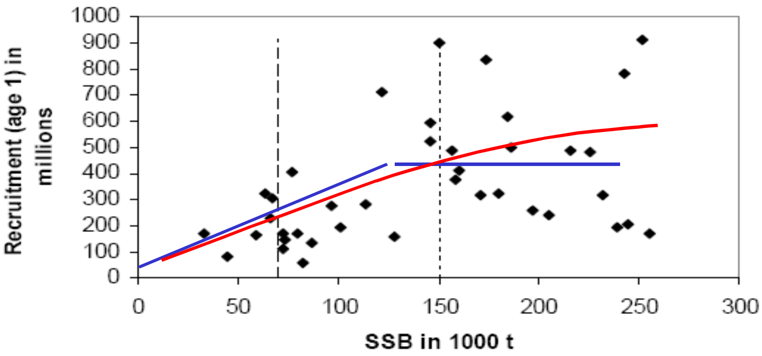


Fig. 2. Recruitment versus SSB plot for North Sea cod (see Fig. 1), with two possible relations indicated.(1) Initial slope and a plateau (blue line). 2) Gradually curving relationship (red line). The curves are drawn by hand.

On the practical level, large estimation uncertainty poses a challenge in the application of the reference points. In principle, the estimation uncertainty is taken into account in determining the distance between B_{lim} and B_{pa}. If fisheries management succeeds in keeping the stock (SSB) at or above B_{pa}, than the median estimate will be at or above B_{pa} (assuming no bias in the estimate), with a probability function corresponding to the variance in the estimate on both sides of the median estimate. If the distance between B_{lim} and B_{pa} is properly scaled, than the lower tail of the probability function should have a low probability of extending below B_{lim}, and the extent to which it does will depend on the level of probability that is chosen. As shown in Fig. 3, the annual point estimates of SSB will vary around the median, with a 50 % probability of being below and a 50 % probability of being above. If the median is at B_{pa}, there will be a 50 % probability that point estimates will fall below B_{pa}.

Only if the true stock size is kept well above B_{pa} (again assuming unbiased estimates) could there be a high probability that the point estimates would fall above B_{pa}. The distance that the median estimate of the stock size needs to be above B_{pa} in order to achieve a low probability that point estimates would fall below B_{pa}, would correspond to (but would not necessarily be the same as) the distance between B_{pa} and B_{lim}. Therefore a requirement that point estimates should have high probability of falling above B_{pa} would be the equivalent of applying precaution twice.

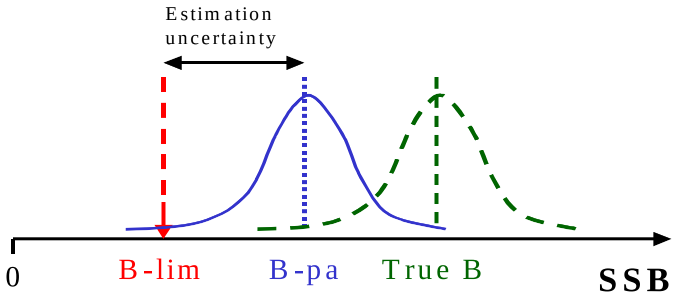


Fig. 3. Schematic illustration of the positions of B_{lim} and B_{pa} on the SSB (spawning stock biomass)s axis. B_{pa} is positioned higher than B_{lim} with a distance related to the estimation uncertainty. This is determined by the probability distribution around the median estimate and the level set to ensure a low probability of estimates falling below B_{lim}. If the point estimates of SSB are to have a high probability of falling above B_{pa}, then the true biomass value must be some distance above B_{pa}, corresponding to the estimation uncertainty.

The current system of reference points is therefore based on ensuring a high probability of staying away from the limit B_{lim}, based on decisions triggered by the position of point estimates relative to B_{pa}. The decisions may be taken on wrong basis in up to half of the cases. That is, the true SSB may be above B_{pa} while the point estimate is below and, *vice versa*, the true SSB may be below B_{pa} while the point estimate is above. This may result in wrong decisions in a given year – that is, fishing may be maintained or increased when it should have been decreased, or fishing may be decreased when it could have been maintained or increased. Repeated over several decision cycles, however the system should correct itself. Too-high fishing in one year may reduce the SSB. This reduction will make it less likely that the point estimate in the second year will erroneously fall above B_{pa}, and thus continue wrongly to signal that fishing may be maintained or increased. An analogy to this system is a thermostat with low precision in registering the temperature. Averaged over time, the thermostat will maintain the chosen temperature, but there will be large fluctuations around the mean.

In the fisheries management system, there should be fewer errors in the positions of point estimates in comparison to B_{pa} the further the true SSB values are away from B_{pa}. The system may also be less prone to error when the precision in point estimates is low. However, in principle, the estimation uncertainty should be reflected in the distance between B_{lim} and B_{pa}. High estimation precision may therefore be reflected in a small distance between them.

5. The objective of the EcoQO

There remains some lack of clarity on the objective is that is currently embodied in this EcoQO. The formulation in the Bergen Declaration from the 5th North Sea Conference is, in effect:

> *To keep spawning stock biomass of commercial fish species above precautionary reference points where these have been agreed by the competent authority for fisheries management, also taking into account fishing mortality, used in advice given by ICES in relation to fisheries management.*

While this refers to the system as used in fisheries management, and therefore implicitly "takes into account" the precautionary reference point for F, ICES (2003) suggested that this should be stated more explicitly. ICES (2003) also advised that the wording of the EcoQO should make it clear that it is the annual estimates of SSB and F that should comply with their respective reference points, and not the true SSB and F, which cannot be known when the management decisions must be made.

Somewhat surprisingly, the objective in current fisheries management of using the system of precautionary reference points appears not to be clearly formulated by the managers. This poses a difficulty when we try to evaluate, according to the Bergen Declaration, whether the objectives are met. ICES (2004) has assumed that the objective of management is to maintain or move spawning stock biomass (SSB) above the biomass conservation limit (B_{lim}) with high probability and to keep fishing mortality sustainable (F being below F_{lim} with high probability). Since this is consistent with the design and logic of the system of limit and precautionary reference points, this should also be the objective used in the evaluation of whether the objectives are met in the EcoQO context.

We need here to distinguish between an underlying objective and an operational objective. The underlying objective for each stock is:

> *To maintain or move spawning stock biomass (SSB) above the biomass conservation limit B_{lim} with high probability, and to maintain or move fishing mortality (F) below its conservation limit F_{lim} with high probability.*

The associated operational objective is then:

> *To maintain or move the(annual) point estimate of SSB above B_{pa} and to maintain or move the point estimate of F below F_{pa}.*

The underlying objective relates to the true spawning stock biomass, while the operational objective relates to the annual point estimates that trigger management actions that help to achieve the underlying objective. The operational objective needs only to be met on average to achieve the underlying objective, given that the distances between the precautionary and limit reference points are properly scaled to take into account stock variability and estimation uncertainty (including any bias resulting form the estimation method).

ICES (2004) advised that this EcoQO should be applied at the aggregate level for all commercial fish stocks and not for each single stock that is managed according to limit and precautionary reference points. ICES suggested that a revised EcoQO should be:

> *For 100% of North Sea commercial fish stocks, the estimates of spawning stock biomass (SSB) and fishing mortality(F) should be above the precautionary spawning-biomass reference-point and below the precautionary fishing-mortality reference-point, respectively.*

This could be taken to be a stricter requirement than the one implied in the description of the underlying and operational objectives set out above. This would happen if the formulation were to be taken to mean that the aim is to ensure a high probability that the true value of the SSB and F for all North Sea stocks will fall above B_{pa} and below F_{pa}, respectively. To deliver this, there would need to be a requirement that there should be a low probability that the point estimates for each single stock would fall on the wrong side of their respective precautionary reference points. As explained above, this would mean that “buffer zones” would have to be in place above B_{pa} and below F_{pa}, similar to those separating B_{pa} from B_{lim} and F_{pa} from F_{lim}. As said above, this would in practice mean that precaution would be applied twice over, given that the distances between the precautionary and limit reference points were realistic for the desired level of low probability.

ICES (2002, ACFM) has stressed in its previous advice that the precautionary reference points should be treated as boundary-limits on SSB and F rather than as targets. The intent has been that the SSB should be maintained somewhat above B_{pa} and F somewhat below F_{pa}. There is no clear indication, however, of how much “somewhat above” and “somewhat below” would represent. Without any clear advice on targets, and with the logic implied in the design of the system of limit-based precautionary reference-points, it should be no surprise that the precautionary reference points become *de facto* targets. When the underlying objective is to have a high probability of staying on the respective right sides of the limit reference points (B_{lim} and F_{lim}), then this objective is met when the median of point estimates is at or above B_{pa} or at or below F_{pa}. (This again assumes that the distances between the precautionary and limit reference points are correctly scaled.) If these distances and the associated uncertainties are underestimated (and there are indications that they are; see Sparholt 2002), then the median estimates must be above the precautionary reference points for the underlying objective to be achieved. Alternatively, it would mean that we were in practice accepting of a lower value for the “high probability” of staying on the respective right sides of the limit reference-points.

However, if the ICES advice is interpreted to mean that there should be a high probability that the annual estimates, rather than the true values, for all North Sea stocks will fall above B_{pa} and below F_{pa}, respectively, then it is consistent with the descriptions of the underlying and operational objectives above.

6. Monitoring, data and time-series

Many commercial fish populations in the North Sea are regularly monitored and assessed annually by ICES as a basis for advice to fisheries managers. The data sources used in the assessments are information from scientific surveys and data collected on catch statistics. Agencies and scientific institutes in the various North Sea countries carry out the data collection and scientists from these countries contribute data and expertise into stock-assessment working groups (WGs) in ICES. The assessments done by the ICES WGs form the basis for the advice from the ICES Advisory Committee on Fisheries Management (ACFM) to fisheries managers on quotas and other aspects of fisheries.

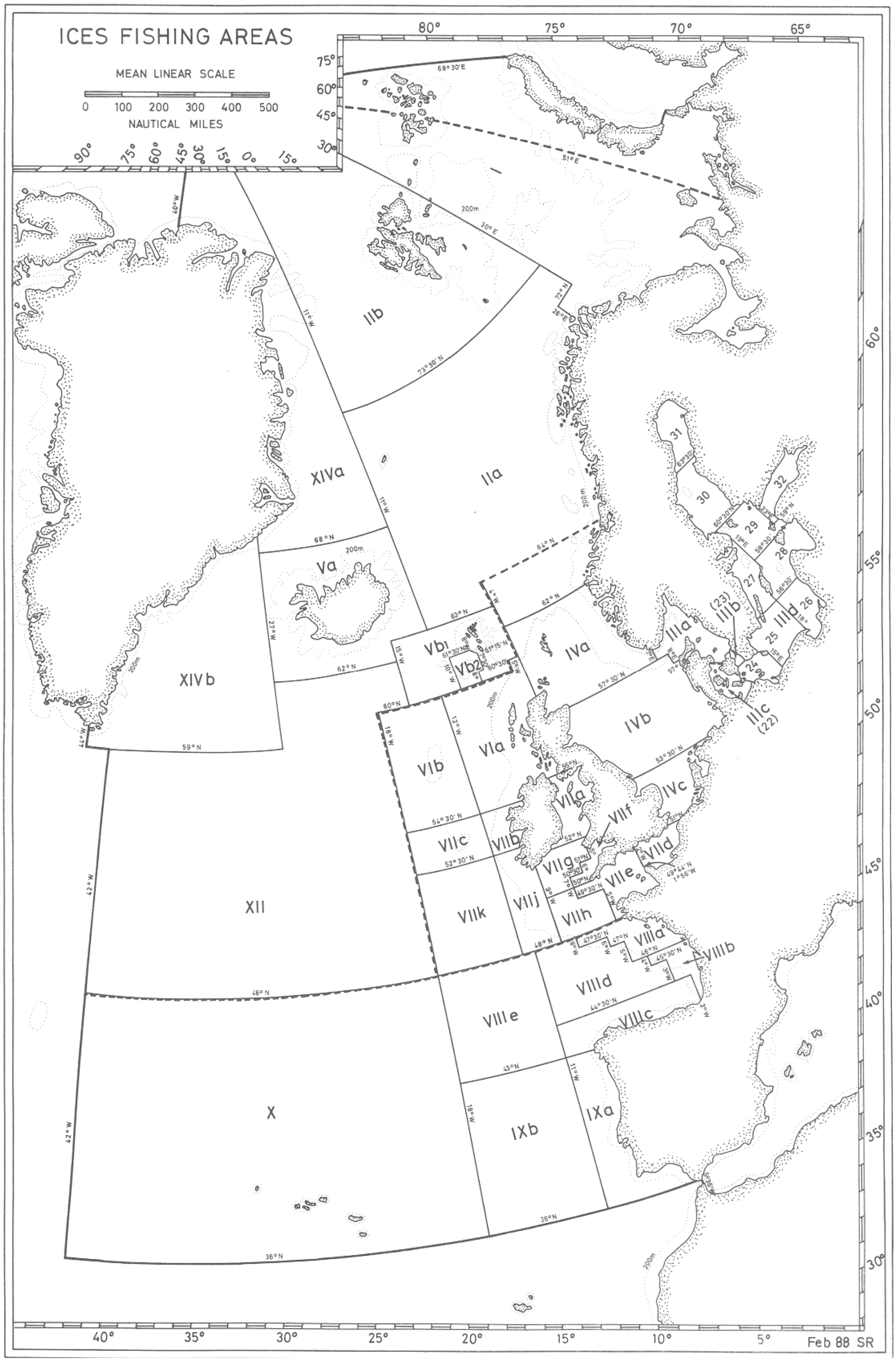


Fig. 4. Map of ICES Fishing Areas. The North Sea is Sub-area IV, Skagerrak and Kattegat comprise division IIIa, while the Eastern Channel is division VIId. Stocks from these areas are summarised in Table 1.

ICES has divided the ICES area into Sub-areas and Divisions within sub-areas (Fig. 4) which form the basis for catch statistics and separation of population units. Table 1 lists the fish species and stocks in the North Sea for which ICES provides assessment and scientific advice on their management. The table also shows whether precautionary reference points are established and used as the basis for advice.

The stocks listed in Table 1 can be grouped into two main categories. The first contains the main North Sea fish stocks that have wide distribution in the North Sea and fairly large population sizes (of the order 100 000 to 1 000 000 tonnes). To this group belong the North Sea stocks of cod, haddock, saithe, whiting, plaice, sole, herring, sprat, mackerel, horse mackerel, and sandeel. The distribution of some of these stocks extend into Skagerrak and/or the Eastern Channel and/or the waters west of Scotland. The other group of stocks are more locally distributed in the Skagerrak, the Kattegat or the Channel, and have much smaller population sizes (of the order 10 000 tonnes). The scientific basis for treating locally-occurring fish as part of local populations or as part of the wider North Sea stocks is not always that clear and is often done on a pragmatic and practical basis.

The time series of data and assessments of the major North Sea stocks extend back over the last four or five decades. The empirical data for recruitment, SSB and F form the basis for establishment of the limit and precautionary reference-points for the stocks. Reference points have been determined for most of the major North Sea stocks (cod, haddock, saithe, whiting, plaice, sole, and herring) and for some of the local stocks (Table 1). Reference points have also been established for the widely distributed stocks of blue whiting and mackerel (combined spawning components). For sandeel and Norway pout (which are fished for industrial purposes), precautionary reference-points are set for biomass (B_{pa}) but not for fishing mortality. For North Sea sprat, there are no reference points.

In the Statement of Conclusions from the Intermediate Ministerial Meeting on the Integration of Fisheries and Environmental Issues in Bergen in March 1997, the Ministers invited the competent authorities (without delay) to establish target reference-points for all major North Sea fish stocks listed in a Table in an Annex. ICES indicated that this could be possible within a time frame of two years from the start of the process for the major North Sea stocks (cod, plaice, herring, mackerel, haddock, whiting, saithe, sole, Norway pout, sandeel, and northern prawn). This work has now been started. The aim is to have established target reference-points for many of the stocks by 2005.

7. Status of North Sea fish stocks

Table 1 provides a summary of the most recent assessments and advice provided by ICES on the stock status relative to limit and limit-based precautionary reference points. ICES provides advice through ACFM twice a year[2].

The current status of stocks presents a mixed picture (Table 1). Of the major North Sea stocks, cod, plaice, and sole are outside safe biological limits and their populations are at historically low levels (below B_{lim} for cod and plaice and close to B_{lim} for sole). Also the northern hake stock is outside safe biological limits. The North Sea stocks of haddock, saithe, herring, and Norway pout, in contrast, are now inside safe biological limits. The stocks of mackerel (combined) and blue whiting have biomasses above B_{pa} but are being harvested at rates above F_{pa}.

Table 1 – Commercial fish stocks and their status

Species	Area	B_{lim}	B_{pa}	F_{pa}	SSB 2003	Stock status
Cod	North Sea, Eastern Channel, Skagerrak	70 000	150 000	0.65	53 000	Outside safe biological limits
	Kattegat	6 400	10 500	0.60	3 000	
Haddock	North Sea. Eastern Channel, Skagerrak	100 000	140 000	0.70	457 000	Within safe biological limits
Saithe	North Sea, Skagerrak, West of Scotland	106 000	200 000	0.40	364 000	Within safe biological limits
Whiting	North Sea and Eastern Channel	225 000	315 000	0.65		Uncertain
	Skagerrak, Kattegat	NA	NA	NA	NA	
Hake	Northern stock (Biscaya/Celtic Sea/North Sea)	100 000	140 000	0.25	114 000	Outside safe biological limits
Plaice	North Sea	210 000	200 000	0.30	152 000	Outside safe biological limits
	Skagerrak, Kattegat	NA	24 000	0.73	55 000	Harvested outside safe

2 *The information on stock status used in Table 1 has been downloaded from the ICES website (www.ices.dk) at the middle of September 2004. The most recent advice then was from October 2003 for some stocks and from May 2004 for others.*

Species	**Area**	**B_{lim}**	**B_{pa}**	**F_{pa}**	**SSB 2003**	**Stock status**
						biological limits
	Eastern Channel	5 600	8 0000	0.45	7 900	Outside safe biological limits
Sole	North Sea	25 000	35 000	0.40	29 000	Outside safe biological limits
	Skagerrak, Kattegat	770	1 060	0.30	1 300	Within safe biological limits
	Eastern Channel	NA	8 000	0.40	13 300	Within safe biological limits
Herring	North Sea, Eastern Channel, Skagerrak	800 000	1 300 000	0.25	1 740 000	Within safe biological limits
	Kattegat, Western Baltic	NA	NA	NA	160 000	
Sprat	North Sea	NA	NA	NA	NA	Unknown
	Skagerrak, Kattegat	NA	NA	NA	NA	Unknown
Mackerel	North Sea stock component					Believed to be severely depleted since 1970s
	Combined (Western, Southern, North Sea)	NA	2 300 000	0.17	3 100 000	Harvested outside safe biological limits
Horse mackerel	North Sea, Eastern Channel, Skagerrak	NA	NA	NA	NA	Uncertain
	Western stock component	NA	NA	NA	NA	Uncertain
Norway pout	North Sea, Skagerrak	90 000	150 000	NA	170 000	Within safe biological limits
Sandeel	North Sea	430 000	600 000	NA	1 370 000	Uncertain
	Skagerrak, Kattegat	NA	NA	NA	NA	Uncertain
Blue whiting	Portugal - Norway	1 500 000	2 250 000	0.32	4 300 000	Harvested outside safe biological limits
Anglerfish	North Sea, Skagerrak, Kattegat, West of Scotland	NA	NA	0.30	6 600	Harvested outside safe biological limits

For North Sea whiting, the status is uncertain, because ICES considered the most recent assessment not to be reliable. While some surveys indicate that the stock has increased in recent years, ICES considers that the stock is likely to be still outside safe biological limits. For sandeel, the status is also uncertain. The 2002 year-class was estimated to be extremely weak. ICES believed (in its October 2003 advice) that the stock should have increased from below B_{lim} in 2002 to above B_{pa} in 2003. Recent information indicates, however, that the situation for sandeel in the North Sea is poorer than expected in 2003. The status of the North Sea sprat stock is unknown.

The ICES advice contains time series of the historical developments of SSB and F for the stocks over recent decades, going back to the 1950s for some stocks. The historical development since the 1960s of six of the major North Sea fish stocks is shown in Fig. 5.

North Sea cod increased during the 1960s to a maximum SSB of about 250 000 tonnes around 1970. This increase was part of what has been called “the gadoid outburst”, which was a period with marked increases in the stocks of several gadoid roundfish species (cod, haddock, saithe, whiting). The gadoid outburst has been related to the climatic conditions and occurred during a cooling period with predominantly northerly winds during spring (Cushing 1984). From this maximum, the North Sea cod has steadily declined to a current stock level well below B_{lim} (Fig. 5A). The fishing mortality F has shown an inverse pattern to that of SSB, increasing steadily from a value of about 0.6 around 1970 to more than 1.0 around 2000 (Fig. 5B).

The high fishing pressure has no doubt contributed much to the current situation with a very low stock size of cod. Cook et al. (1997) showed, from equilibrium considerations, that recruitment could not balance such high exploitation rates and that a stock collapse was to be expected. In addition to the high exploitation rate, the generally warm climate in the recent years has been unfavourable for cod recruitment (Planque and Frédou 1999). There have also been changes in the plankton in the North Sea that may have contributed to the poor recruitment of cod (Beaugrand et al. 2003). Unfavourable natural conditions may thus have made the cod stock more susceptible to over-fishing and augmented the effect of the high exploitation rates.

North Sea haddock has shown greater variability in stock size than has cod. From a maximum level of SSB of about 900 000 tonnes in 1970, the haddock stock decreased to levels below B_{lim} in 1990-91 and 2000 (Fig. 5C). In the most recent years the stock has increased and is now well above B_{pa} and within safe biological limits. This increase is due to a very strong year-class formed in 1999. The fishing mortality increased in the late 1960s, and has since remained very high, fluctuating around 1.0 (Fig. 5D). The assessment indicates that F may have been reduced during the last two years.

North Sea saithe is another species that now is considered to be within safe biological limits. From a maximum of about 500 000 tonnes in the mid 1970s, the SSB decreased to a minimum below B_{lim} in the early 1990s (Fig. 5E). There has subsequently been an increase to a recent stock level well above B_{pa}. Changes in fishing mortality reflect the changes in SSB. F increased during the 1970s and high F values coincided with the marked decrease in the stock in the mid 1970s (Fig. 5F). Following a period of some years with lower F, F again increased during the 1980s to high values that preceded the very low stock level in the early 1990s. Since then, F has steadily reduced, allowing the recent increase in SSB.

North Sea plaice has had a SSB fluctuating between about 300 000 and 400 000 up to about 1990. During the 1990s, the stock decreased markedly, and has since remained well below B_{lim} (Fig. 5G). The fishing mortality has increased steadily from about 0.3 in 1970 to a maximum of 0.65 in 1997 (Fig. 5H). The increase in the plaice stock during the 1980s, despite high F, was due to good recruitment during this period.

The North Sea sole has a smaller population than plaice, and has shown considerably more variability in its SSB. From a maximum stock level of more than 100 000 tonnes in the early 1960s, there was a decrease to a level of about 40 000 tonnes during the 1970s and 80s (Fig. 5I). The stock increased to about 90 000 tonnes in 1990 due to the recruitment of the strong 1988 year-class. The stock has subsequently declined to a current level below B_{pa}. The fishing mortality increased markedly in the 1960s and has since shown a fluctuating upwards trend from around 0.5 in 1970 to a maximum of 0.7 in 1996 (Fig. 5J).

The North Sea herring has shown very large changes in SSB, from a maximum of about 2 000 000 tonnes in 1965, through a minimum of about 50 000 tonnes in 1977, and back to the current high level of about 2 000 000 tonnes (Fig. 5K). The fishing mortality increased markedly during the 1960s to very high levels in the range 1.0-1.5 during the late 1960s and early 1970s (Fig. 5L). This very high exploitation rate caused the stock to collapse to its very low level in the late 1970s. The herring fishery was closed in 1978 and the fishing mortality fell to close to zero. The herring stock then recovered and the fishing mortality increased to levels between 0.45 and 0.75 between 1985 and 1995. At these fairly high exploitation rates, the stock again declined. After 1995 the fishing mortality was substantially reduced and the stock has since been increasing.

The time series of the six major North Sea fish stocks shown in Fig. 5 all demonstrate a close connection between stock level and fishing mortality. There is a clear inverse relationship where SSB tends to decrease when F is increasing or remains at a high level. Conversely, SSB tends to increase when F is decreasing to A feature worth noting is that, for all the stocks in Fig. 5 except herring, the B_{lim} values have been set very low in the dynamic range of SSB, either at or close to the minimum observed in the time series. For the stocks with large dynamic ranges, notably haddock and sole (Fig. 5 C, I), the B_{pa} values are also set low in the range of SSB values. The biological justification for setting the B_{lim} values so low is not particularly clear, and it can be questioned whether recruitment would not be impaired as a result of a low SSB, even though that SSB was well above these B_{lim} values. The choice of the low B_{lim} values has two consequences when examining the historical developments of the stocks. The first is that the stocks rarely will have been below B_{lim}. The second is that the seriousness of being below B_{lim}, or even below B_{pa}, is greater if we may have underestimated the importance of SSB for sustained reproduction over time, particularly in periods with poor environmental conditions for recruitment.

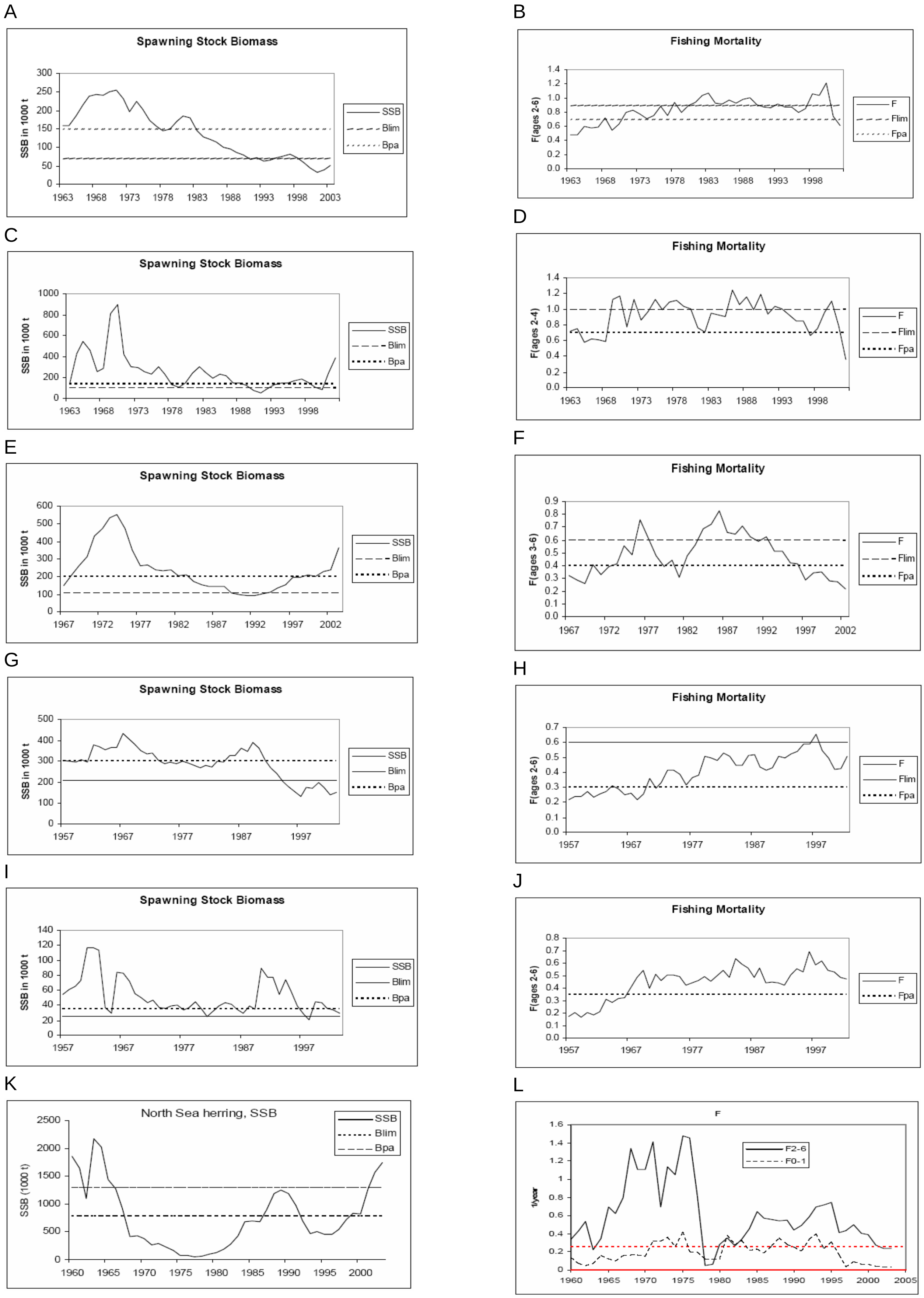


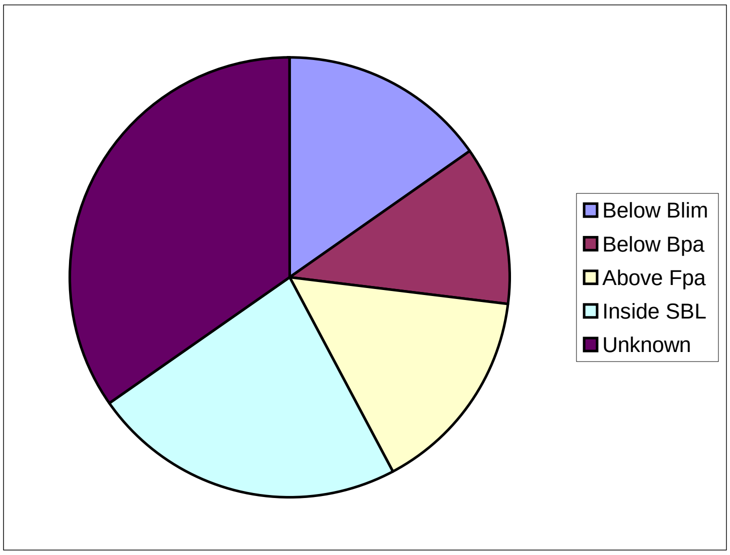
Fig. 5. Time series of spawning stock biomass (SSB) and fishing mortality (F) for North Sea stocks of cod (A, B), haddock (C, D), saithe (E, F), plaice (G, H), sole (I, J), and herring (K, L). The levels of limit and precautionary reference points are shown as horizontal lines.

8. Are the EcoQOs met?

Whether the EcoQO for commercial fish species is met depends on the interpretation of what is the objective, as described above. Assuming that it is to keep the stocks above B_{lim} with high probability, we can use the information summarised in Table 1 to address the question. The ICES advice on status is based on the last annual estimates of SSB and F, which are not the same as the true stock status which cannot be known accurately in the assessment year.

Of the 26 stocks listed in Table 1, 11 are assessed to be outside safe biological limits, 6 to be inside, while for 9 of the stocks the situation is unknown or uncertain (Fig. 6). Of the 11 stocks that are assessed to be outside safe biological limits, 4 are below B_{lim}, 3 are below B_{pa} (but not below B_{lim}), while 4 are harvested outside safe biological limits (F above F_{pa}, but SSB above B_{pa}).

Figure 6. Proportions of North Sea fish stocks outside and inside safe biological limits. Three categories are used for stocks outside safe biological limits: stocks below Blim, stocks below Bpa but above Blim, and stocks harvested above Fpa but with SSB above Bpa. Based on the information on 26 stocks in Table 1.



The four stocks estimated to be below B_{lim} are the North Sea cod, cod in the Kattegat, North Sea plaice, and North Sea mackerel. We have included North Sea mackerel here even if it is not assessed separately and B_{lim} is therefore not defined, because it is considered by ICES to be severely depleted. Four out of 26 stocks constitutes about 16 % and is more than one out of 20, corresponding to a 5 % probability of being lower than B_{lim}. The percentage of stocks below B_{lim} increases to 24 % if the 9 stocks of unknown or uncertain status are not included in the total.

The number of stocks outside the precautionary reference points (below B_{pa} and above F_{pa}) is 11 (including the four which are also below B_{lim}), compared to 6 stocks which are inside safe biological limits. Again, this comparison shows that too many stocks are outside the precautionary reference points, allowing for the possibility that the median expected value could be up to 50 %.

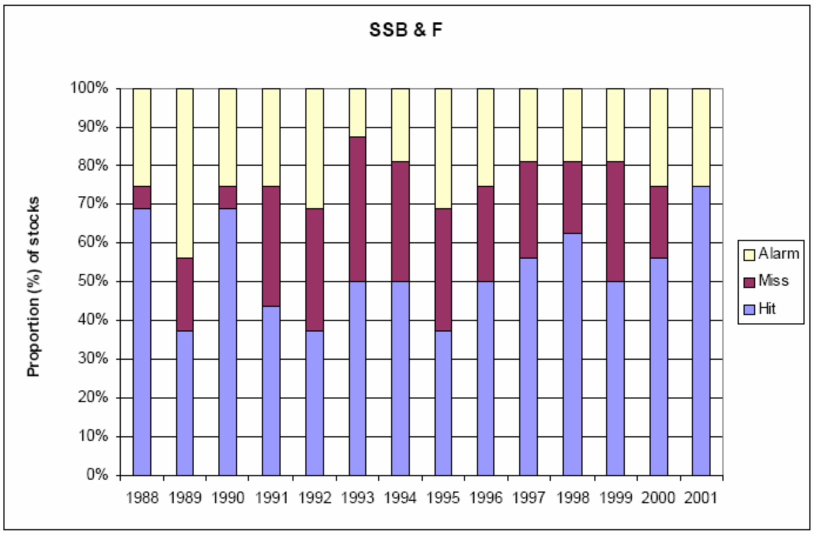
These comparisons of number of stocks below B_{lim} and below the precautionary reference points, respectively, indicate that the objectives are not met. This is not surprising news: it is something that is very well known among fisheries managers and their scientific fisheries advisors. The situation particularly reflects the high exploitation rates of demersal roundfish and flatfish and the difficulties caused by them being caught in complex mixed fisheries. This situation is currently being addressed by the fisheries managers.

In terms of achieving the objectives in the EcoQO related to SSB and exploitation of commercial fish populations, we may not be so far from the goals as may have appeared previously. If the recovery plans which are implemented (or planned) for the depleted stocks are effective, a change in status of a relatively small number of stocks will markedly improve the overall situation. In particular, this is the case for the stocks that are now below B_{lim}, such as North Sea cod and plaice.

ICES (2003) carried out a retrospective analysis of the performance of the assessments relative to the precautionary reference points. The “true” stock situation was taken as the converged assessment results after some years when the year-classes had been in the fisheries for most or all of their life span and a maximum amount of information could be extracted from catch statistics and survey data. The analysis then compared the annual estimates of status with the “true” status known in retrospect. If the stock status did not change, the annual assessment was considered to be correct – to be a “hit” in signal-detection terminology.

If the stock status changed in retrospect, the annual assessment was considered not to be correct. This could be in two ways. If the assessment indicated that the stock was inside safe biological limits, while it in retrospect in fact was outside, this was considered a “miss” in signal-detection terminology. If the error went the other way, that is the assessment indicated that the stock was outside safe biological limits, while it in fact in retrospect was inside, this was called “false alarm”.

Fig. 7 shows a time series of the performance of the assessments of North Sea fish stocks from 1988 to 2001. As an average over this period, the assessments were correct in just over half the cases (53 %), being wrong in the remainder cases (47 %). The wrong cases were distributed about equally between “misses” (stocks erroneously estimated to be inside safe limits) and “false alarms” (stocks erroneously estimated to be outside safe limits). The errors in these cases are not due to mistakes by the scientists, but reflect the inherently low precision in stock assessments. This is precisely the reason for the buffer zone between B_{lim} and B_{pa}. If the stocks in reality are kept at or close to B_{pa}, then the stock estimates should be expected to vary around the precautionary reference points.



There was a marked difference in the number of stocks that were assessed to be inside the biomass and fishing mortality precautionary reference points, respectively (Fig. 8). While the proportion of stocks that were inside the reference point for SSB (above B_{pa}) varied between 35 and 65 %, the proportion of stocks inside the reference point for F (below F_{pa}) varied from 0 to 25 %. These proportions of stocks showed opposite trends, decreasing over the time series for SSB and increasing for F.

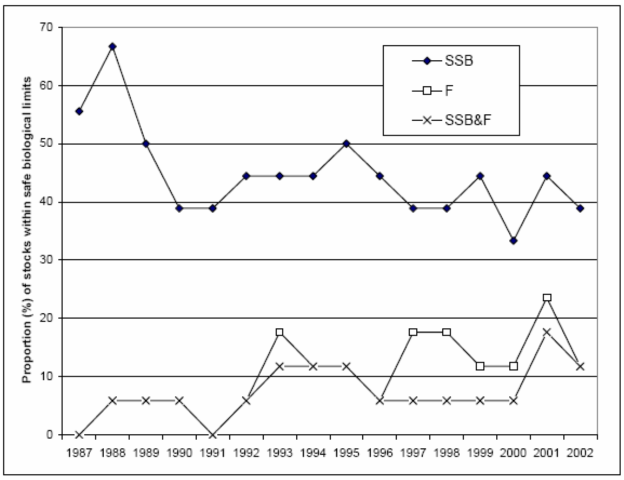


Figure 8. Proportions of North Sea fish stocks inside safe biological limits with respect to spawning stock biomass (SSB), fishing mortality (F), or both SSB and F, for the period 1987-2002. From ICES (2003).

Fig. 9 shows a time series of the stock status according to the most recent assessment by ICES. This illustrates clearly the same feature as shown in Fig. 8 – namely, that the stocks are more often outside the reference points for F than for SSB. The North Sea cod stock was fished outside the precautionary reference point (light blue) during the 1970s and outside the limit reference point (yellow) during the 1980s. This changed the stock status to below B_{pa} by the early 80s and to below B_{lim} (red) by the early 90s. The stock has since remained close to or below B_{lim}. For North Sea haddock and saithe, there were similar developments with fishing mortality above F_{pa} or F_{lim} (light blue and yellow) during the 1970s and 80s. This caused the stocks to fall below B_{lim} by around 1990. For these stocks, however, the fishing mortality has been reduced sufficiently to allow the stocks to recover to the present situation when they are within safe limits both for SSB and F (green in the figure).

For the stocks of plaice and sole, a similar situation has occurred with fishing mortality generally higher than F_{pa} and in periods also higher than F_{lim}. This has contributed to stocks falling below B_{pa} and, for North Sea plaice, below B_{lim} during the 1990s (Fig. 9).

North Sea herring has been outside safe limits for most of the time series. The exception is the current situation where the stock has recovered to high level and the fishing mortality is kept low (below F_{pa}) (Fig. 9). For the combined mackerel stock, the fishing mortality has with few exceptions been above $F_{pa,}$ and, for 3 years in the 1990s, also above F_{lim}. The stock has however not fallen below B_{pa}. For Norway pout, no reference points have been set for F. The stock fell below B_{pa} for some years during the late 1980s and early 1990s, but has since then been above B_{pa}. The northern hake stock has been fished outside safe limits (above F_{pa} or F_{lim}) for most years since the early 1980s. This caused the stock to fall below B_{pa} by 1990 where it has since remained. The stock of blue whiting has been harvested outside safe limits for most years since the early 1980s. The stock level has also been below B_{pa} for most of this time, and, for two years around 1990, it was also below B_{lim}. In the recent years there has been an increase in the stock to above B_{pa}, but there has also been an increase in fishing mortality to current levels above F_{lim}. The increase in stock level has been caused by unprecedentedly high recruitment since 1995. This has prevented a stock collapse that could otherwise have had serious ecological consequences in several ecosystems where blue whiting play key roles.

Figure 9. Time series of stock status for main North Sea fish stocks for the period from 1970 to recent. The stock status is shown by colour codes as identified in the key. <pa in yellow cells indicates SSB below Bpa. <pa in orange cells indicates F below Fpa.

Collectively, the time series in Fig. 9 convey a clear message. The fishing mortality is generally kept too high over long periods, causing declining trends in the stock, resulting in many cases to the stocks falling below B_{lim}. At such levels, recruitment is impaired. The time series also demonstrate that the system of dual reference points both on stock level (SSB) and fishing mortality is, in principle, working as intended. Fishing mortalities above F_{pa}, or even worse above F_{lim}, should be avoided as such levels of fishing mortality fairly consistently result in stock declines and impaired recruitment. The empirical evidence also suggests that there are time lags in the reaction, because there may be a period of several years (even more than a decade for some stocks) before the stock level drops below B_{lim}. As noted earlier, B_{lim} is set very low for the major North Sea stocks. It is therefore serious that the stocks can fall down to such low levels. Recruitment may be impaired even at values above B_{lim}. Managers should therefore pay close attention to rising or high levels of fishing mortality, and take every measure to reduce fishing mortality to below F_{pa} to avoid jeopardising the recruitment and production potential of the stocks.

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