6.3.1 Advice June 2013

ECOREGION North Sea
STOCK Multispecies considerations for the North Sea stocks

ICES intends to gradually start providing multispecies advice on fisheries for some ecosystems (see Section 1.2) and encourages managers to get familiar with multispecies considerations in the North Sea. The present section may serve as a starting point for a dialogue between ICES and managers, to foster the development of a multispecies management system for the North Sea. Implicit management objectives and risk tolerance that are presented will need to be validated by managers. The selection of preferred options for these parameters would be best made through discussions within an inclusive governance process.

The North Sea has a complex foodweb which leads to more trade-offs in yield between species compared to simpler foodwebs (e.g., Baltic foodweb). If managers decide to adopt a multispecies management approach, a transition period from the present management will be required. This work is meant to be only illustrative, to highlight the most important trade-offs between species and to give a first indication how multispecies MSY reference points might compare to single-species ones. In this work, ICES focuses on the most obvious interactions between most commercially exploited fish stocks in the area and does not attempt to provide a full foodweb model.

ICES used one model to perform a multispecies assessment (SMS). Results are interpreted by ICES qualitatively, to highlight important features of multispecies considerations instead of focusing on absolute values. It should be noted that no value of multispecies F_MSY can be considered precautionary until a formal evaluation has been done.

The main results of the present multispecies analysis for the North Sea are that:

- Potential target multispecies F_MSY depends on the management objectives and SSB constraints used. There is no single maximum sustainable yield solution in a multispecies context, and policy choices will have to be made. ICES multispecies simulations provide the trade-offs of identified scenarios that can be used to inform on the possible consequences of various policy decisions.

- Yield of virtually all species is strongly affected by the abundance of cod and saithe, which are the main predator fish species. Changing management target fishing mortality (target F) for cod and saithe therefore influences the yield of other stocks more than the management targets for these other stocks. Indirect predation effects are also important. For example, a lower F on cod increases cod biomass, which leads to a decrease in SSB and yield for whiting and haddock (direct predation effect) but also to an increase in SSB and yield for herring, sandeel, Norway pout, and sprat. The increase in SSB for these prey species is due to the reduction in predation pressure from whiting and haddock, which more than compensates the increase in direct predation from a larger cod stock (indirect effect).

- Due to predation, it is unlikely that all stocks can be maintained above precautionary single-species biomass reference points simultaneously. Whiting is the most extreme example of this. Small whiting suffers from high predation pressure by grey gurnard and additionally a recovery of the cod stock deteriorates the situation for whiting in the model. A new approach is needed to define what precautionary means in a multispecies context.

- Target fishing mortalities leading to close-to-maximum average yield (F_MSY) in a multispecies context are in general higher than the agreed single-species F_MSY values. The model simulations show that the predators cod and saithe should be fished at higher F to lower the predation pressure on their prey, and in case of cod also to avoid too much loss in yield due to cannibalism. This highlights the previous point that the target F_MSY depends on defining agreed constraints and acceptable risk levels by managers.

- Due to a successful reduction in fishing mortality for many stocks, natural mortality is becoming the dominant source of mortality in the North Sea. This means that the stock dynamics are increasingly more influenced by natural processes than by fisheries. At the same time, improving estimates of consumption of fish by top predators, such as seals and cetaceans, is very important, particularly when these predator populations are expected to increase further.

Results should be interpreted qualitatively. The applied simulation model (SMS) focuses on the effect of species interaction (mortality due to predation) and fish catches without considering other factors that can change future stock sizes and yield. Even with such a simplification, a number of assumptions are made to model the complex foodweb. In addition, the conclusions are based on long-term changes due to changes in fishing mortality, while other factors such as effects driven by environmental conditions are assumed constant for a long period. Therefore, the model output
should not be used as a quantitative prediction of future yield, but may provide guidance on possible future trade-offs and constraints.

**Background**

*Information on the modelling approach*

Extensive multispecies and ecosystem research has been performed in the North Sea in the past 30 years. ICES, together with several institutes around the North Sea, has invested substantially in the research on multispecies interactions, ecosystem functioning, and integrated assessment. Currently, several multispecies and ecosystem models exist for the North Sea (for an overview cf. ICES, 2012a). One of them, the stochastic multispecies model (SMS), was chosen for a more detailed scrutiny in 2012 by ICES in cooperation with the EU STECF (2012) for the Baltic. The North Sea SMS model was updated and reviewed at WGSAM in 2011. Results of simulations presented here have been carried out as part of the EU project MYFISH and were discussed and adopted during WGSAM in 2012. Specific details on model settings are available in ICES WGSAM 2011 and 2012 reports (ICES, 2011, 2012a).

Stomach data are of vital importance for predator-prey multispecies analyses. Stomach data available to parameterize the North Sea SMS model are mainly from the “years of the stomach” in 1981 and 1991. In the last 20 years no internationally coordinated stomach sampling programme has been carried out. This lack of data represents a main difficulty for this work, as conclusions are sensitive to the diet data used. In 2012 a “Study on stomach content of fish to support the assessment of good environmental status of marine foodwebs and the prediction of MSY after stock restoration” was funded to run until November 2014. Sampling has started on IBTS surveys, with the main aim of getting up-to-date information on the importance of grey gurnard, mackerel, and hake in the North Sea foodweb.

The present analysis covers the eight main commercial roundfish stocks in the North Sea:

- Cod in Subarea IV (North Sea) and Divisions VIIId (Eastern Channel) and IIIa West (Skagerrak)
- Haddock in Subarea IV (North Sea) and Division IIIa West (Skagerrak)
- Herring in Subarea IV and Divisions IIIa and VIIId (North Sea autumn spawners)
- Norway pout in Subarea IV (North Sea) and Division IIIa (Skagerrak–Kattegat)
- Sandeel in Division IIIa and Subarea IV
- Saithe in Subarea IV (North Sea), Division IIIa (Skagerrak), and Subarea VI (West of Scotland and Rockall)
- Sprat in Subarea IV (North Sea)
- Whiting in Subarea IV (North Sea) and Division VIIId (Eastern Channel)

Flatfish stocks are not included, as they do not enter in major direct predation relationships with other fish stocks.

Some other aspects of interactions related to these stocks are presently not included in the SMS model, the most important being: (1) the variation in spatial overlap between stocks, and (2) correlation in recruitment between stocks.

The simulations exploring multispecies reference points applied a sliding harvest control rule, where target F_{MSY} is used for SSB above B_{pa} and with a linear decrease to zero fishing mortality below B_{lim}. Therefore, the so-called multispecies “target F_{MSY}” refers only to the value of F used when SSB is above B_{pa}.

ICES can delimit the space for sustainable exploitation within acceptable good environmental status as proposed by participants of the Stakeholder Workshop on North Sea and Baltic Sea Multispecies Trade-offs (WKM-Trade; ICES, 2012b). However, further input from stakeholders on management objectives, constraints, and risk tolerance is needed to reduce the number of possible options to the most relevant ones.

*Overview on the modelled North Sea foodweb (with focus on commercially important fish species)*

The North Sea model includes the main species interacting with fish stocks through predation (Figure 6.3.1.1). Top predators form an important part of the foodweb, including numerous charismatic species such as seabirds and marine mammals that eat fish. Within the fish community a number of fish eat other fish, and some of those spend only part of their time in the North Sea. The fish species can be divided into four categories: forage fish, fish that eat small fish, benthic-feeding fish, and fish that eat large fish (top predators). Forage fish feed on plankton in the water column. The majority of forage fish are also targeted directly by the fishery (herring, sandeel, sprat, Norway pout). Together with typical forage fish, juvenile gadoids are also an important food source in the North Sea foodweb. Fish that eat small fish belong to a wide range of species, including some that are targeted by fisheries (e.g. whiting, haddock), some that are only occasionally landed (e.g. grey gurnard, starry ray), and some that enter the North Sea only in specific seasons (e.g. western horse mackerel and mackerel). Benthic-feeding fish include all kinds of flatfish that feed on prey in or near the bottom. The majority of flatfish species only eat a small amount of commercially important fish species and have not
been included as a fish predator. Fish that eat large fish are mainly large cod and saithe, which also have almost all other fish in their diet. Elasmobranchs (e.g. spurdog) are also important top predators in the North Sea foodweb, but the abundance of most species is currently at a low level and data on their diet is scarce, so they have not been included in the model.

![Figure 6.3.1.1](image)

Overview of the important predators and prey in the North Sea SMS model foodweb. Other fish include grey gurnard, North Sea and western horse mackerel, and starry ray. Seabirds include fulmar, gannet, great black-backed gull, guillemot, herring gull, puffin, and razorbill. Seals and porpoises include grey seal and harbour porpoise. An “Other food” pool with constant biomass is included in the model to represent all prey types that are found in the stomachs but that are not modeled explicitly (e.g., crustaceans, mollusks, other prey fish). The colour of the line indicates which predator the species is eaten by, the thickness of the line indicates the biomass removed in this interaction (average from 1963 to 2010).

**Results of the SMS model**

**Important interactions**

SMS simulations show that the stock size of the predators cod and saithe has a large influence on both biomass and yield of other species. Hence, the choice of target fishing mortality for cod and saithe affects the yield of all other species considerably (Table 6.3.1.1). Changes in F on haddock influence the yield of sandeel and Norway pout. Fishing for sandeel has relatively strong indirect effects on the three gadoids cod, whiting, and haddock (see Section 6.3.2 for a detailed description). Fishing for sprat and Norway pout has hardly any influence on the yield of other stocks.

**Table 6.3.1.1** Effect of changes in fishing mortality (rows) on yield (columns). Dark shading indicates a large impact, light indicates low impact. White diagonal line indicates effects of species F on species yield.

<table>
<thead>
<tr>
<th>F</th>
<th>YIELD</th>
<th>Saithe</th>
<th>Cod</th>
<th>Whiting</th>
<th>Haddock</th>
<th>Herring</th>
<th>Sandeel</th>
<th>Norway Pout</th>
<th>Sprat</th>
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<tr>
<td>F</td>
<td>Saithe</td>
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<td>F</td>
<td>Whiting</td>
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<td>F</td>
<td>Haddock</td>
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<td></td>
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<tr>
<td>F</td>
<td>Herring</td>
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<tr>
<td>F</td>
<td>Sandeel</td>
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<tr>
<td>F</td>
<td>Nor. Pout</td>
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<td>F</td>
<td>Sprat</td>
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</table>

In addition to the predators above, the so-called “other predators” play an important role. The stock dynamics of “other predators” are not modelled explicitly, but their stock sizes are instead given as input to the model. Seabirds, marine mammals, grey gurnard, starry ray, mackerel, and horse mackerel are treated as “other predators”. The importance of these “other predators” is clearly shown for cod as prey (Figure 6.3.1.2). Grey gurnard has become the most important predator on 0-group cod, due to a substantial increase in abundance over the 1990s. Similarly, harbour porpoise and seals have become more important predators on cod, due to both an increase in seal abundance and a decrease in the cod stock which has reduced cannibalism. It was assumed that “other predators” would remain at their current abundance levels as it was hard to predict how they would develop in the future (either because there is no assessment or because, in the case of western mackerel and horse mackerel, migration into and out of the North Sea is difficult to quantify and...
predict). The assumption of constant abundance of “other predators” has, of course, an impact on the results (e.g. it precludes changes in grey gurnard abundance as the cod stock increases).

![Figures showing predation mortality (M2) on cod age 0–2, inflicted by predator species over time.]

**Main trade-offs**

Figures 6.3.1.3 (average long-term yield) and 6.3.1.4 (average long-term SSB) present the main results of the SMS simulations. Each column of small graphs represents the effect of varying target fishing mortality on individual species in turn, on the yield (or SSB) of each species. Target fishing mortalities are on the horizontal axes and yield (or SSB) on the vertical axes.

In each graph, the solid horizontal lines represent the median yield or SSB at the given target fishing mortality, where the median is taken across all combinations of target F on other species. Boxes represent the range of yields and SSB derived when excluding the bottom 25% and the top 25% ranked yields (or SSB). Whiskers (vertical dashed lines) represent the range of yields which are less than 1.5 times the interquartile distance (height of the boxes) away from the upper or lower margin of the boxes. Dots represent observations outside that range. A long box and whiskers implies that the yield or SSB of that species is heavily influenced by fishing pressure on other species than the one depicted on the horizontal axis. In contrast a short range suggests that the yield or SSB is relatively insensitive to variations in fishing pressure on species other than the one on the horizontal axis.

The panels in the diagonal from the top left corner to the bottom right corner show the change in yield or SSB of the specific species that can be obtained by changing the target fishing mortality on that species (similar as represented in single-species advice). Off-diagonal elements represent the effects of species interaction. For example, the change in average SSB of whiting (top row, second plot, Figure 6.3.1.4) shows the effect of the resulting lower cod stock when cod target fishing mortality is increased. A lower cod stock eats less whiting, resulting in higher average SSB of whiting.

The main trade-offs can be found between top predator performance of cod and saithe and their prey species (Figure 6.3.1.3 and 6.3.1.4). The effect of changes in predation on prey SSB is as large as, or larger than the effect of changing target F for these species. The effects of a decrease in target F are similar for cod and saithe. Indirect predation effects seem to be important, which leads to counter-intuitive outcomes. For instance, a decrease in F on cod will give a larger
cod stock (top left corner of Figure 6.3.1.4) and more predation on its prey species. For whiting and haddock lower cod F leads to a decrease in SSB (increase in direct predation effect), while SSB of herring, sandeel, Norway pout, and sprat will increase (top row of Figure 6.3.1.4). This increase in SSB for forage fish is due to the loss in whiting and haddock SSB, which induces less predation on the forage fish prey species than the predation from a larger cod stock (indirect predation effect). This contrasts with results from less complex foodwebs (e.g. Baltic), where lower trophic level predators such as whiting and haddock are hardly present and a higher cod SSB has a direct negative effect on forage fish.

Fishing on sandeel leads to direct and indirect effects on predator stocks in the North Sea simulations. An increase in target F on sandeel leads to a smaller sandeel biomass (Figure 6.3.1.4), which induces a higher cannibalism for cod and whiting, leading in turn to a decrease in SSB and yield for those predator species. Due to cascading effects haddock is positively impacted. The fishing on sprat, Norway pout, and herring has less influence on other species.

Figure 6.3.1.3  Average yield of cod, whiting, haddock, saithe, herring, sandeel, Norway pout, and sprat (columns from left to right), as a function of target F on the same species (rows from top to bottom). Note that a HCR was used with F = 0 if the stock falls below B_{lim} and a linear increase in F between B_{lim} and a higher MSY B_{trigger} biomass (usually B_{pa}). The F-value on the horizontal axis is the target F for SSB above the specified MSY B_{trigger} biomass. For SSB below the trigger value, the F realized might be considerably lower. The graph by species shows the distribution of yields for any given F shown on the horizontal axis, taking into account the range of Fs for the other species.
### Figure 6.3.1.4

Average SSB of cod, whiting, haddock, saithe, herring, sandeel, Norway pout, and sprat (columns from left to right) as a function of target F on the same species (rows from top to bottom). Note that a HCR was used with $F = 0$ if the stock falls below $B_{\text{lim}}$ and a linear increase in $F$ between $B_{\text{lim}}$ and a higher MSY $B_{\text{trigger}}$ biomass (usually $B_{\text{pa}}$). The $F$-value on the horizontal axis is the target $F$ for SSB above the specified MSY $B_{\text{trigger}}$ biomass. For SSB below the trigger value, the $F$ realized might be considerably lower. The graph by species shows the distribution of SSB for any given $F$ shown on the horizontal axis, taking into account the range of $F$s for the other species.

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**Single-species $F_{\text{MSY}}$ in a multispecies context**

Single-species $F_{\text{MSY}}$ is currently 0.19 for cod and 0.3 for saithe, but the lowest value presented here is 0.4 for both stocks as this represents the bulk of the dynamics observed. Also, lower values resulted in collapse of several stocks in the simulations. Model results for values of fishing and natural mortality outside the observed historical values are considered less reliable. With $F$ fixed at 0.4 for both cod and saithe (Figure 6.3.1.5), a low $F$-value ($F \leq 0.25$) for haddock maintains median haddock SSB above $B_{\text{pa}}$ (140 000 tonnes), but median whiting SSB is below 80 000 tonnes, and thereby considerably below the 250 000 tonnes used as proxy for $B_{\text{pa}}$ here (no official value defined) for combinations of target $F$ for whiting in the range 0.3–0.6. Lower target $F$ values have so far not been evaluated; however, it seems unlikely that such values will provide a SSB three times higher than for whiting $F = 0.3$.

In conclusion, fishing cod and saithe at target $F = 0.4$ (when SSB is above $B_{\text{pa}}$) and, therefore, at higher $F$ than the single-species $F_{\text{MSY}}$, resulted in scenario SSB above $B_{\text{pa}}$ for all species, except for whiting where SSB is considerably...
below a possible $B_{pa}$ proxy. However, historically whiting had a rather large stock size concurrently with high stock sizes of cod and saithe during the gadoid outburst in the 1970s. The main difference between the scenario situation and the state of the stocks in the 1970s is the assumption that the present high stock size of grey gurnard is maintained in the scenarios. Grey gurnard was responsible for more than half of the high predation on 0-group whiting in the most recent years, whereas the predation mortality in the period before 1985 was quite low. A higher biomass of larger cod in the future may reduce the biomass of grey gurnard, although few stomach observations exist to quantify this predation. This possible effect has not been included in the simulation scenarios.

Figure 6.3.1.5

Average SSB of cod, whiting, haddock, saithe, herring, sandeel, Norway pout, and sprat (columns from left to right) as a function of target $F$ on the same species (rows from top to bottom). Note that target $F$ for cod and saithe was fixed at 0.4. A HCR was used with $F = 0$ if the stock falls below $B_{lim}$ and a linear increase in $F$ between $B_{lim}$ and a higher MSY $B_{trigger}$ biomass (usually $B_{pa}$). The $F$-value on the horizontal axis is the target $F$ for SSB above the specified MSY $B_{trigger}$ biomass. For SSB below the trigger value, the $F$ realized might be considerably lower. The graph by species shows the distribution of SSB for any given $F$ shown on the horizontal axis, taking into account the range of $F$s for the other species.

Close-to-maximum sustainable yield

The results from the previous section suggest that fishing mortality on the predators cod and saithe must be higher than the single-species $F_{MSY}$ to maintain all stocks within precautionary limits as far as possible. Given a fixed target $F$ at 0.5 for cod and 0.45 for saithe, a sequential approach was tried to identify fishing mortalities close-to-maximum sustainable yield for all species. In addition, target $F$ for whiting was fixed at 0.3 (lowest value tested in the simulations) to ensure
that the whiting stock as a minimum reaches a biomass close to a potential Blim proxy. The approach is a stepwise exclusion of the scenario F combination that provides the lowest yield relative to the estimated maximum sustainable yield for each particular species. The procedure is applied repeatedly until only one F combination (F value) is left.

As already noted, target FMSY values in the simulations were used for SSB above Bpa. For SSB lower than Blim fishing mortality was set to zero, with a linear reduction of F for SSB between Blim and Bpa. This ensures that stocks can recover during the long-term simulations. It is also consistent with many management plans currently implemented, where F must be reduced if the stock falls below certain biomass trigger points. The rule presented here does not fully match both the ICES method for estimating FMSY and the harvest control rule used in the MSY approach for single species. This does not affect the qualitative conclusions of the multispecies model.

The target fishing mortalities leading to “close-to-maximum-sustainable-yield” for each species are presented in Table 6.3.1.2. MSY and equilibrium SSB values in the table represent the mean value for the time period 2016–2070. According to the simulations fishing at multispecies FMSY leads to average SSBs above Bpa for cod, saithe, herring, sandeel, and sprat. Average SSBs for haddock and Norway pout are between single-species Blim and Bpa values. Whiting SSB is below Blim (200 kt is chosen as proxy for Blim).

The mean realized F values are considerably lower than the target multispecies FMSY for whiting, haddock, and Norway pout (Table 6.3.1.2). The discrepancy between multispecies FMSY and realized F shows that SSB was considerably lower than Bpa in most of the forecast years and F had to be reduced according to the harvest control rule (HCR) used in the simulations. The discrepancy between target and realized F may also indicate that the currently used SSB trigger values, or the type of HCR, are not appropriate. Further work is needed to come up with precautionary reference points and HCRs in a multispecies framework.

The multispecies FMSY values that lead to a yield close-to-maximum sustainable yield for each species in a multispecies context are higher than the similar single-species (SS) ones (Table 6.3.1.2). The model simulations show that the predators cod (SS FMSY = 0.19) and saithe (SS FMSY = 0.3) could be fished at higher F in order to lower the predation pressure on their prey and, in the case of cod, also to avoid too much loss in yield due to cannibalism. According to the simulations herring, a typical prey species, could also be fished at considerably higher target F values than the agreed single-species one (0.55 multispecies versus 0.24–0.3 single species). However, the realized F is 0.4, showing that fishing mortality had to be reduced quite often during the forecast because the stock biomass fell below Bpa. This highlights that appropriate FMSY values depend on the constraints and risk levels considered acceptable.

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**Table 6.3.1.2**

<table>
<thead>
<tr>
<th></th>
<th>Single-species</th>
<th></th>
<th>Multispecies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FMSY (target F above Bpa)</td>
<td>Blim/Lower trigger biomass (thousand tonnes)</td>
<td>Bpa/Higher trigger biomass (thousand tonnes)</td>
</tr>
<tr>
<td>Cod</td>
<td>0.19</td>
<td>0.50</td>
<td>70</td>
</tr>
<tr>
<td>Whiting</td>
<td>0.30</td>
<td>0.35</td>
<td>10</td>
</tr>
<tr>
<td>Haddock</td>
<td>0.3</td>
<td>0.45</td>
<td>106</td>
</tr>
<tr>
<td>Saithe</td>
<td>0.24–0.3</td>
<td>0.55</td>
<td>800</td>
</tr>
<tr>
<td>Sandeel*</td>
<td>0.55</td>
<td>0.55</td>
<td>(787)</td>
</tr>
<tr>
<td>Norway pout*</td>
<td>0.60</td>
<td>0.55</td>
<td>(263)</td>
</tr>
<tr>
<td>Sprat*</td>
<td>0.55</td>
<td>0.55</td>
<td>(157)</td>
</tr>
</tbody>
</table>

* Trigger biomass refers to total stock biomass (TSB). Simulations indicate that an HCR based on TSB performs better than using SSB.

Values in brackets indicate that a single-species reference point does not exist or is not useful in multispecies context.
Additional information

Percentage of total mortality caused by natural sources

In the SMS model, the total mortality (Z) is the sum of fishing mortality (F), predation mortality estimated in the model (M2), and a residual natural mortality assumed known and constant (M1). With the exception of older cod and sprat, natural mortality (M1 + M2) has represented an increasing proportion of the total mortality (Z) in recent years (Figure 6.3.1.6). Due to a successful reduction in fishing mortality for many stocks, natural mortality is becoming the dominant source of mortality.

![Graphs showing percentage of total mortality due to natural causes for different species](image)

**Figure 6.3.1.6** Percentage of total mortality due to natural causes (M1+M2) by species, year, and age. Black line = age 0, red = age 1, green = age 2, and blue = age 3.

**Sources**


