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6–10 October 2008

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Executive Summary

This is the second report of the pan-regional Working Group on Multispecies Assessment Methods (WGSAM). The group met at ICES Headquarters, Copenhagen and reviewed ongoing multispecies and ecosystem modelling activities in each ICES ecoregion (including the North Sea, Baltic Sea, Bay of Biscay, Iceland, Barents/Norwegian Seas, eastern Canada and USA). The participants provided an updated inventory, to supplement the information collated in 2007 (ToR 'e'). The group then provided an exploration of the likely implications and consequences of trying to achieve 'maximum sustainable yield' (MSY) for all fish stocks simultaneously within a multispecies context (ToR 'a'), as mandated by the World Summit on Sustainable Development (WSSD). Several existing studies using MSVPA/SMS and Ecopath with Ecosim (EwE) were reviewed as well as outputs from a series of bespoke foodweb models that were constructed specifically for the 2008 working group. One of the main conclusions was that the high yields predicted at low F by single-species models are almost certainly unrealistic, as biomass cohorts will be 'eroded' by predation pressure and density-dependent reductions in growth. Furthermore, system-wide analyses tended to suggest that the optimum strategy to maximize yield overall (harvested biomass) usually involves the depletion of top predators, although this may be politically unacceptable. Management objectives need to be very clear – to maximize overall yield (protein production), to maximize economic returns or to prevent the loss of any species (biodiversity objectives). These objectives are almost certainly mutually incompatible.

Multispecies models have often been used to provide updates of natural mortality *M* for inclusion in conventional single-species stock assessments. Consequently it is considered useful to have occasional 'key-runs' of multispecies models for each region, whereby time-series are updated and model configurations are agreed by a number of regional experts. Within the 2008 working group, participants presented 'key-runs' for the North Sea and Baltic (ToR 'b') and made significant progress towards a GADGET key-run for hake and anchovy in the Bay of Biscay.

The group compared the outputs of different multispecies and ecosystem model types, including those comparison exercises conducted under the auspices of the EU UNCOVER project (ToR 'c'). When EwE and SMS models were 'tuned' to the same historical data and were then projected into the future (from 2006 to 2030), they tended to provide markedly different conclusions especially with regard to short and medium-term yields. However, the long-term equilibria estimated for most stocks were broadly similar irrespective of the model type used.

WGSAM considered the available evidence of interannual variability in feeding patterns of fish throughout the ICES region (ToR 'd'). Time-series of stomach contents data were available for several subregions (notably the Celtic Sea, North Sea, Barents Sea and Newfoundland Shelf), and examination of these data suggested major shifts in feeding preferences, often reflecting changes in the availability of particular prey resources. For example, short-term variability in the abundance of capelin and blue whiting were reflected in the diet of cod in the Barents Sea, as were longer term (50–100 year) changes in the availability of sandeels and certain slow-growing bivalve molluscs within the stomach contents of fish predators in the North Sea. The predictability of changes in feeding preference was examined in the North Sea and Baltic, where the importance of understanding predator-prey spatial overlap and environmental variability were highlighted.

WGSAM issued a request to the Working Group on Data and Information Management (WGDIM), suggesting that they should work towards making the 'Year of the Stomach' datasets for North Sea and Baltic more readily available to the ICES community.

1 Opening of the meeting

The **Working Group on Multispecies Assessment Methods** [WGSAM] met at ICES Headquarters, Copenhagen, Denmark from 6–10 October 2008. The list of participants and contact details are given in Annex 1. The two Co-Chairs, John Pinnegar (CEFAS, UK) and Bjarte Bogstad (IMR, Norway) welcomed the participants and highlighted that like last year, the Working Group had a broad geographic scope, this year encompassing research in the Bay of Biscay, Barents Sea, Norwegian Sea, North Sea, Icelandic waters as well as the east coast of North America. The Terms of Reference for the meeting (see Section 2) were discussed, and a plan of action was adopted with individuals providing presentations on particular issues and allocated separate tasks to begin work on all ToRs.

1.1 Acknowledgements

WGSAM would like to thank Claire Welling of the ICES Secretariat for her support with the WGSAM SharePoint site and logistics during the meeting in Copenhagen.

2 Adoption of the agenda

2.1 Terms of reference (ToRs)

2007/2/RMC06 The **Working Group on Multispecies Assessment** Methods [WGSAM] (Co-Chairs: John Pinnegar, UK and Bjarte Bogstad, Norway) will meet at ICES Headquarters, Copenhagen, Denmark from 6–10 October 2008 to:

a) Explore the concept of Maximum Sustainable Yield (MSY) within a multispecies context;

b) Report on ‘key-runs’ (standardized model runs updated with more recent data, and agreed upon by WGSAM participants) of multispecies fisheries models for the North Sea and Barents Sea, and work towards similar standardized outputs and reporting protocols for the Bay of Biscay and Iberian Peninsula;

c) Report back on model comparison exercises, carried out under the auspices of the EU FP6 UNCOVER project;

d) Evaluate interannual variability in feeding patterns. Explore the implications for multispecies models;

e) Review further progress in multispecies and ecosystem modelling throughout the ICES region.

WGSAM will report by 16 November 2008 for the attention of the Resource Management Committee, and ACOM.

3 ToR a) – Explore the concept of Maximum Sustainable Yield (MSY) within a multispecies context.

3.1 Some lessons learned about MSY within a multispecies context

a) The high yields predicted at low F by single-species models are almost certainly unrealistic, as these will be 'eroded' by predation pressure and density-dependent growth reductions.

b) Multi-species models indicate that the MSY is achieved at different fishing mortalities compared with single-species approaches.

c) It is impossible to attain the high yields predicted by single-species models for all stocks simultaneously, because achieving B_{MSY} for one species may result in stock declines for other species that are prey and/or competitors.

d) System-wide analyses suggest that the optimum strategy to maximize yield (harvested biomass) usually involves the depletion of top predators.

e) Management objectives need to be very clear – to maximize overall yield (protein production), to maximize economic returns or to prevent the loss of any species (biodiversity objectives). These objectives are almost certainly mutually incompatible.

f) Predators might provide other 'services' in ecosystems which could be impacted if system-wide strategies are pursued to maximize yield.

3.2 Why should we care about MSY?

The development of an ecosystem based approach to fisheries management (EAFM) has been a long time in the making; driven by numerous international initiatives starting in 1982 with the UN Convention on the Law of the Sea (1982) and reinforced most recently by the 2002 Johannesburg World Summit declaration on Sustainable Development (WSSD). In Europe, political and legislative support for EAFM comes from the European Union Action Plan for Biodiversity in Fisheries, the Bergen Declaration, the Oslo and Paris (OSPAR) Biodiversity Strategy, the EU Common Fisheries Policy and the Reykjavik Declaration on Responsible Fisheries in the Marine Ecosystem.

Signatories of the WSSD declaration subscribed to an international political commitment to maintain or restore stocks to levels that can produce the maximum sustainable yield (MSY), with the aim of achieving these goals for depleted stocks on an urgent basis, and where possible not later than 2015. The US Magnuson-Stevens Fishery Conservation and Management Act also mandate 'precautionary management to attain optimum yield', and the technical guidelines refer specifically to MSY. In addition some international management bodies, e.g. the International Commission for the Conservation of Atlantic Tunas (ICCAT), have MSY as a management objective. However, there are well-documented problems with the definition and performance of MSY targets in fisheries; especially where there are natural fluctuations in the resource (see Mace 2001, Powers 2005).

The principle and likelihood of achieving MSY simultaneously for multiple stocks has been challenged on the basis that the concept of MSY is intertwined with the dynamics of biological, ecological, economic and social processes, and as such is unlikely to be an objective that is robust (Larkin 1977, Punt and Smith 2001, Mace 2001). What B_{MSY} implies within a multispecies context has yet to be established, because achieving B_{MSY} for one species may result in stock declines for other species that are prey and/or competitors.

Fishing multiple species within an ecosystem requires a trade-off among the species being harvested. *MSY* and related reference points for a given species are dependent of the exploitation levels of all other species in the system (Gislason 1999). In addition, the maximum biological yield potentially extracted from an ecosystem does not necessarily correspond to the optimum economical solution, and neither of these two necessarily ensures that the best social/employment situation will be attained (Larkin 1977, Gislason 1999, Punt and Smith 2001, Mace 2001, Walters *et al.*, 2005, Matsuda and Abrams 2006).

3.3 The problem of high yields at low F in single-species models

The standardized ICES single-species advice on long-term F could be problematic, because if followed, low F values might be expected to result in very large stock sizes if species are treated in isolation, but in a multispecies context these high yields are never attained as a result of increased predation pressure and density-dependent growth reduction.

For example the ICES 2007 advice for Irish Sea cod was:

> "Fishing mortalities between $F_{0.1}$ and F_{max} can be considered as candidate target reference points, which are consistent with taking high long-term yields and achieving a low risk of depleting the productive potential. The present fishing mortality is uncertain; however, it is estimated to be well above any candidate reference points."

If the SSB/R value given in the single-species advice is multiplied by the mean R at SSB, it will give 4.5 times the largest SSB ever observed for this stock. Similar simple calculations have been made for 6 other cod stocks and the results are given in Table 3.1.

Table 3.1. SSB levels at $F_{0.1}$, calculated based on data contained in the ICES Advisory Report 2007. The R values used are the mean for SSB above B_{lim} as R should not be impaired at these SSB sizes.

Data from ACFM 2007						
Cod stock	SSB 2007 in '000t	Max historic SSB '000t	Year of max historic SSB	SSB/R at F0.1, in kg	R at SSB above Blim in millions	SSB at F0.1 in '000t
North Sea	37	253	1971	2.767	764	2114
Baltic 22–24	22	56	1980	5.19	94	488
Baltic 25–32	101	697	1980	4.006	338	1354
Barents Sea	590	1165	1947	7.54	646	4871
Iceland	241	1137	1955	7.84	188	1474
Faroe	13	123	1976	9.52	15.9	151
Irish Sea	3	20	1973 1982	12.746	7	89

From Table 3.1 one can see that for North Sea cod, SSB would be anticipated to reach 2.1 million t! This is more than 8 times higher than ever observed (even during the widely reported 'gadoid outburst' of the 1970s). For Barents Sea cod it is 4.9 million t, more than 4 times the historical record.

This is extrapolating far outside our range of experience. At such high biomass levels multispecies and density-dependent mechanisms are almost certainly very strong –

multispecies models and reports of reduced growth at high stock sizes show this. The Y/R values in the ICES Advice report also shows that reducing F to $F_{0.1}$ will give only small improvements in Y/R. These calculations ignore multispecies and density-dependent mechanisms. It is therefore very likely that the standard statement in the Advisory report: " …$F_{0.1}$ …are consistent with taking high long-term yields…", are not necessarily correct.

It is suggested that ACOM reconsider this paragraph in the standard 'Single Stock Summary template'.

3.4 Previous work by ICES multispecies groups on MSY

Gislason (1999) used single and multispecies models (VPA, MSVPA, and an extended MSVPA (MSGVPA) in which cod growth and maturity were modelled as a function of available food), to estimate and compare a few of the commonly used reference points (including MSY) for cod, herring, and sprat in the central Baltic. The results of this analysis clearly demonstrated how single-species reference points are affected by biological interactions. Instead of being point estimates, they are turned into reference curves or surfaces when two or more fisheries (pelagic and demersal) and species are considered. Furthermore, the single-species estimates do not always fall on the curves generated by the multispecies models.

Reference limits for forage fish cannot be defined without considering changes in the biomass of their natural predators. Likewise, reference limits for predators cannot be defined without considering changes in the biomass of their prey. The author concluded that F_{MSY} could be a dangerous reference point to use in a multispecies context. For all three species it lies beyond the range of historical observations where uncertainty about the stock dynamics may lead to an unacceptable high risk of stock collapses.

Figure 3.1 shows how F_{MSY} for cod depends on the relative fishing effort in the pelagic fishery. In the single-species model, where natural mortality and growth are constant, F_{MSY} is constant. In the two multispecies models, F_{MSY} depends on the amount of pelagic fishing effort, because cod cannibalism increases as the pelagic fishery reduces the biomass of herring and sprat. An increase in the fishing mortality of cod will counteract the increase in cannibalism by reducing the biomass of older cod.

F_{MSY} is higher in MSGVPA than in MSVPA. In MSGVPA, a higher fishing mortality and lower stock size will be counteracted by increases in cod growth. The effort in the pelagic fishery that will generate the maximum catch of herring and sprat combined is likewise a function of cod effort (Figure 3.1b). If the biomass of cod is high (low cod fishing mortality), predation mortality is high. With high predation mortality, fishing mortality has to be reduced in order to avoid recruitment overfishing. Except for herring and sprat at low cod fishing mortality, the single-species model produces lower F_{MSY} values than the two multispecies models.

An alternative would be to define F_{MSY} as the effort combination that generates the maximum total yield from the system. In the single-species situation the result is trivial: the maximum yield is generated by keeping fishing mortality at F_{MSY} in each of the fisheries, i.e. by decreasing cod effort by 30% and increasing pelagic effort by 26%. In the multispecies situation, both models show that cod should be fished down to the lowest biomass possible in order to benefit from the higher productivity of its prey. Because cod is more valuable than herring and sprat these results make little sense in a management/economic context.

When the total monetary value of the catch was considered, the single-species model suggested that cod effort should be reduced by 30% and that pelagic effort should be increased by 26% to achieve 'Maximum Economic Yield'.

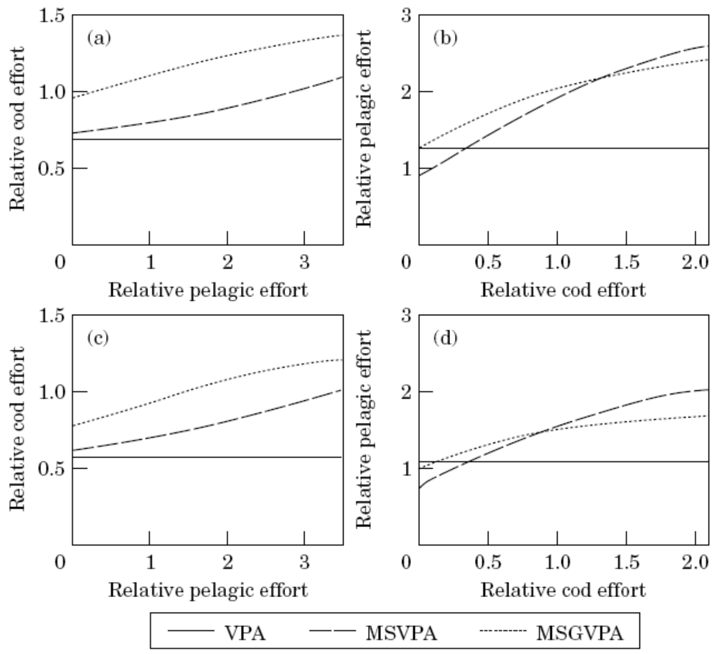


Figure 3.1. Relative effort corresponding to FMSY (a) or F0.1 (c) in the cod fishery vs. relative effort in the fishery for pelagic species, and relative effort corresponding to FMSY (b) or F0.1 (d) in the pelagic fishery vs. relative effort in the cod fishery.

In 1997, the ICES Multispecies Working Group (MAWG) carried out an analysis of the predicted yield following a reduction in F by 10% (from the 1990–1994 mean) for all stocks in the North Sea, using the MSVPA model. Recruitment was assumed constant (by contrast, a Ricker stock-recruit relationship was assumed by Gislason 1999), and the simulation was carried out using different combinations of stomach-content datasets; all stomach records (key-run), and incorporating the 1981 or 1991 datasets separately (Figure 3.2).

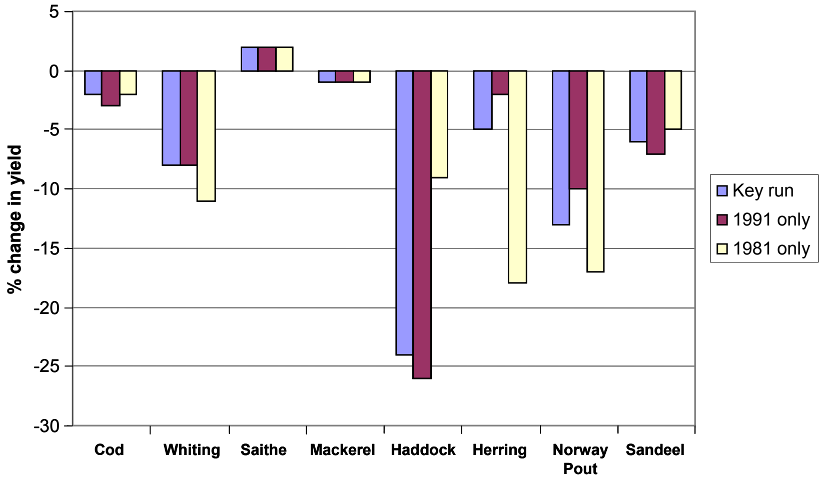


Figure 3.2. Changes in predicted yield following a reduction in F by 10% (from the 1990–1994 mean) for all stocks in the North Sea.

The results of this analysis (reported in ICES CM 1997/Assess:16) suggested that predicted yields would decrease for most species compared with those predicted from single-species models, with the exception of saithe which would be expected to experience a slight increase in yield. The impact of predation (including cannibalism) by predators such as cod and saithe were predicted to be particularly important for prey species such as whiting, Norway pout and sandeels (as well as haddock).

A similar analysis was performed at the Multispecies Working Group (MAWG) in 1989 (ICES 1989), using a simple multispecies Schaeffer model. In a working document (Pope, 1989), it was demonstrated that quadratic approximations to the yield and value surfaces with respect to the six standard fleets could be fitted using estimates of the partial derivatives of yield and value of each fleet with respect to changes in fishing effort in each other fleet. Such partial derivatives can be calculated from the output of MSFOR when runs are made for the status quo situation and with each fleet effort increased by 10% in turn.

The analyses indicated that both the MSY and the overall $F_{0.1}$ were apparently at higher levels than the status quo (1989 situation) for all fleets except for the industrial pelagic fleet. Reference points with respect to multispecies value (Maximum Economic Yield) occurred at lower values of effort than the yield results. The MSY result was, however, rather unsatisfactory in that the effort of 4 fleets had to be arbitrarily constrained in order to allow a model solution to be found.

In 2003, the ICES Study Group on Multispecies Assessment in the North Sea (SGMSNS) attempted to evaluate the newly conceived 'harvest-control-rules' proposed as part of the North Sea cod recovery programme. When the proposed harvest control rules were applied, both single and multispecies models predicted cod recovery. However, the predicted recovery of cod SSB was much slower when taking multispecies interactions into account compared to single-species simulations, and the precautionary biomass reference point (B_{pa}) was reached approximately one year later, (in 2008 instead of 2006 / 2007). In terms of the impact of a cod recovery on other species in the North Sea, multispecies simulations predicted that Norway pout SSB would fall below B_{pa} after approximately 5 years of the application of the harvest-control-rules for cod, whereas single-species simulations predicted that SSB would remain stable above B_{pa}. Similarly, sandeel (a major prey for cod) was predicted to stay above the precautionary reference limit when using single-species models, but to fall below the precautionary reference limit and continue to decline in the long-term under multispecies considerations (ICES 2003). Thus it would seem that it may be impossible to 'recover' all species in the North Sea simultaneously, and therefore by implication, it may be impossible to meet commitments under the World Summit on Sustainable Development (WSSD).

3.5 MSY in North Sea Demersal Stocks

The European Commissions' objectives on MSY have fuelled debate and helped catalyze the Regional Advisory Councils' (RACs) thinking on the development of Long-term Management Plans. The North Sea RAC (NSRAC) has focused its attention on the challenge of developing long-term management plans for the 'mixed demersal fishery' that targets cod, haddock and whiting. Discussion between the NSRAC and fisheries scientists has led to a series of logical questions:

1) What level of fishing mortality (F) is likely to result in MSY for mixed demersal species and how does this equate to fishing effort?

2) Can MSY targets for individual species be achieved simultaneously for North Sea demersal stocks?

3) What is likely to happen to yield and revenue in each of the main fisheries in attempting to reach candidate management targets.

4) How might the North Sea stocks and the fisheries exploiting them be affected when environmental effects are included as a driver of the stock dynamics?

Mackinson *et al*., in a paper submitted to the Canadian Journal of Fisheries & Aquatic Science, has worked with members of the NSRAC to explore some of these questions using a complex ecosystem model (EwE), which incorporates 68 functional groups and 12 fleet categories defined by the EU Data Collection Regulations. Commercially important fish species are divided into juvenile and adult groups (e.g. cod, whiting, haddock, saithe, herring). Of particular importance to this study is the specification of parameters that determine the relative differences in average recruits-per-spawner, because this determines the relative productivity of each group. The methodologies used by Mackinson *et al*. are based on those developed by Walters *et al*. (2005), who applied such techniques across a range of Ecopath with Ecosim (EwE) models.

For each of the target species, Mackinson *et al*. ran a long-term simulation (1000 years), where fishing mortality rate (F) of that species was incremented or decremented slowly, while holding all other F values constant at Ecopath base levels. F_{MSY} for the species was taken to be the F that resulted in maximum catch for the particular species. Comparison was made of the ecosystem model's equilibrium predictions of F_{MSY} and B_{MSY} for cod, haddock and whiting separately when species interactions were turned off and when turned on. When species interactions are turned off, the biomass of other groups is held constant and thus food availability and predation impacts are constant; in effect the ecosystem model mimics a single species stationary assessment with the biomass of the harvested group responding to changes in F.

When species interactions were taken into consideration, predictions of F_{MSY} for cod, haddock and whiting were slightly higher than when species interactions were not included, but predicted overall yields remained relatively similar (Figure 3.3).

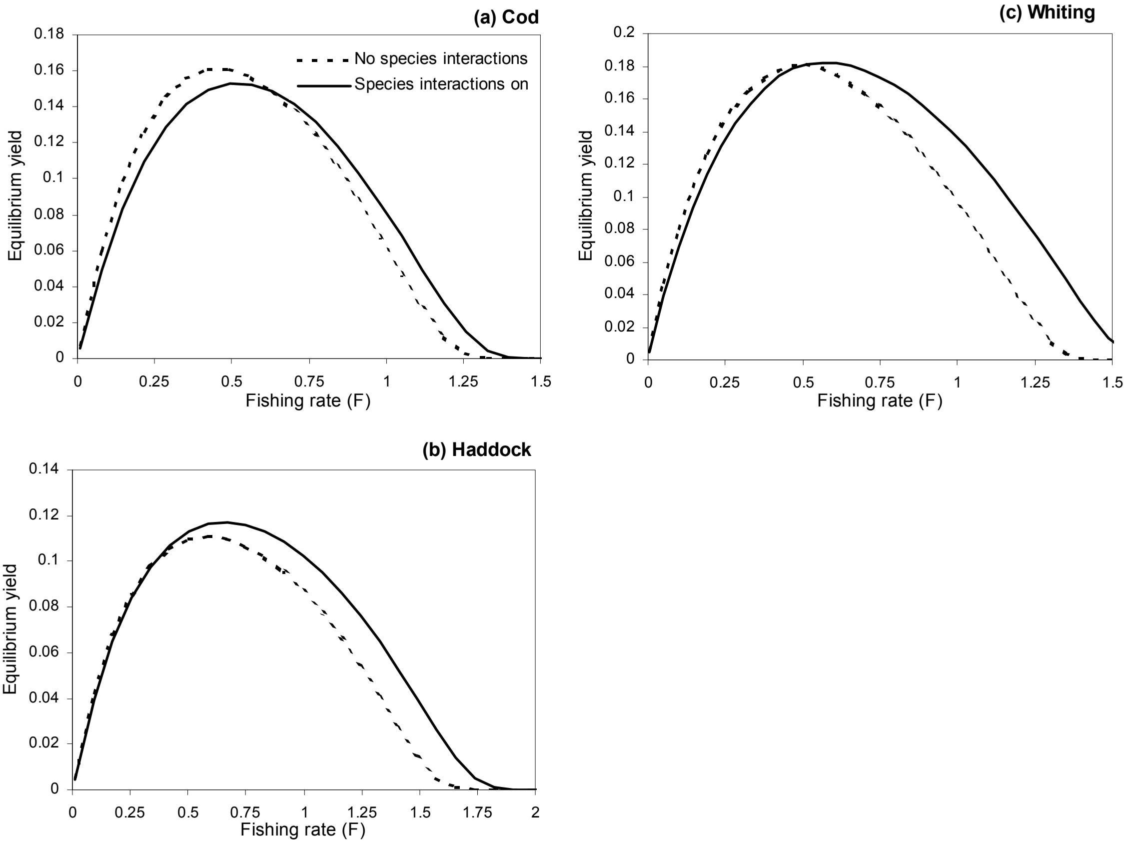


Figure 3.3. Ecosystem model predictions of the equilibrium relationship between fishing mortality rate and yield when the biomass of three species in the North Sea is held constant (no species interactions, i.e. stationary assessment) and when species interactions are allowed to vary in response to changes caused by fishing on the target species (full compensation assessment).

The net effect of including species interactions (allowing for compensatory responses) is that the rate of change in biomass for each species is slower, biomass is depleted more slowly at higher fishing and thus slightly higher levels are fishing can be sustained.

So that results from the ecosystem model could be considered within a broader contextual background, comparisons were made with the European Commission’s (EC 2006), single species model and MSVPA estimations of F in the model baseline year (1991) and with predictions of FMSY (or other comparable reference values). Estimates of FMSY from MSVPA were derived from data in Collie *et al.* (2003) by multiplying estimates of relative effort at maximum sustainable yield with partial fishing mortalities, then summing to obtain total F.

The European Commission’s proposed proxies for FMSY, are around half that predicted by the EwE model. In contrast, estimates of FMSY from MSVPA are about double those predicted by the ecosystem model for cod and haddock, but broadly similar for whiting.

Furthermore, results indicate that it is not possible to achieve yields equivalent to the ‘single species’ MSYs when individual species target FMSY’s are applied simultaneously. When FMSY targets for cod, haddock and whiting are implemented together (a mixed-fishery approach), predicted yield of cod is higher than its corresponding individual species MSY, but that of whiting and haddock are lower. When FMSY targets are implemented simultaneously for all harvested species (ecosystem scale target), the predicted MSYs are different again; this time being much lower for cod, haddock and whiting. These results indicate that the responses of cod, haddock and whiting are influenced more broadly through their interactions with other species in the ecosystem and by the management actions for other fisheries. They bring in to question the notion that the mixed fisheries for cod, haddock and whiting can somehow be divorced from the dynamics of other system components.

In response to sustained fishing at EC defined F_{msy} proxies, applied simultaneously for cod, haddock and whiting, equilibrium biomass of cod and haddock are 3.5 and 2 times higher than in the base year, 1991 (Figure 3.4) and, give rise to higher catches. Whiting biomass declines as a consequence of increased predation by cod.

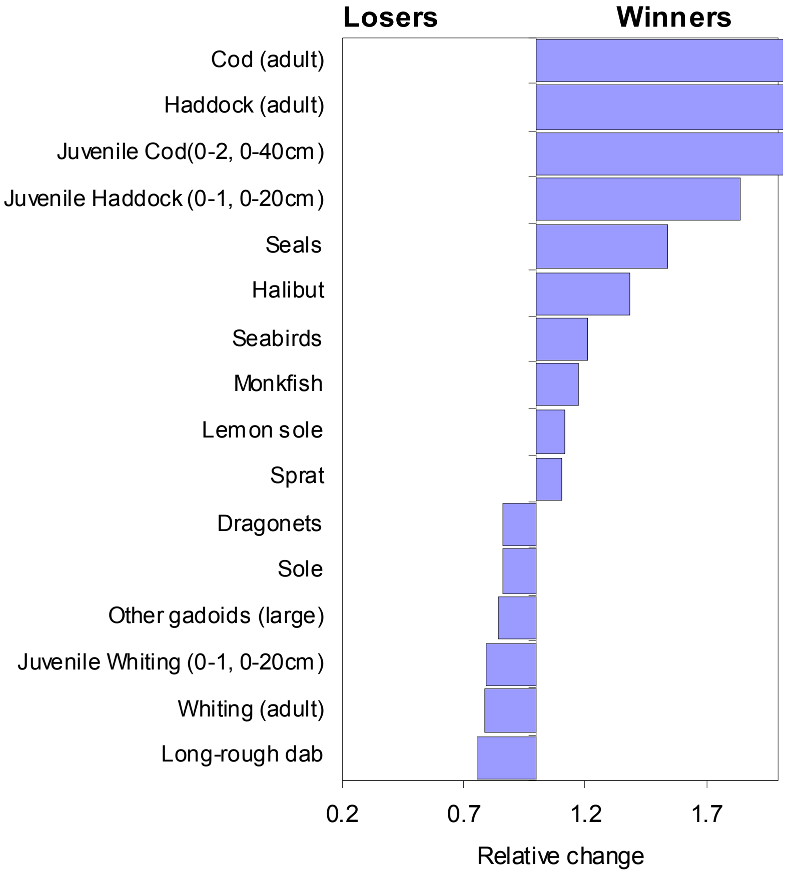


Figure 3.4. Relative change in biomass (End/Start) of selected (change >+-10%) groups in the ecosystem when EC F_{msy} proxy rates are applied to cod, haddock and whiting.

The effort required in achieving maximum long-term combined yield of cod, haddock and whiting is different from the effort to achieve maximum yield of each species alone. For example, when the relative effort of pelagic trawlers is maintained at baseline, the maximum yield of cod by demersal trawlers is achieved at half the effort. However, maximum mixed demersal yield is achieved with a doubling of effort.

Cod and haddock are compatible in their responses to changes in effort, the similarity in the overall pattern of long-term yield and value for these species suggesting that a reasonable balance between effort levels can more easily be obtained. It is the contradictory response of whiting that is central to the trade-off of the mixed demersal fishery. With increased effort, whiting biomass increases in response to fishery-induced reductions in cod, its main predator.

The principal fisheries appear to be at odds with each other, as evidenced by the asymmetric payoffs that result from the changes in species biomasses at alternative effort levels. Pelagic trawl fisheries benefit from higher levels of demersal trawl effort because of the positive impacts that culling of predators (demersal species) has on their prey (pelagic species).

3.6 MSY of Baltic Sea cod in a multispecies context

In a paper with the title "Eastern Baltic cod recruitment depends on environment: Implications for biological reference points", Köster *et al*. (submitted) investigated the consequence of environmental changes for fisheries management and suggested a revision of biomass reference points.

Scenarios were made with varying F and a number of different stock- recruitment relationships derived from the full time-series (1974–2005) and the period 1987–2005 with 'bad' environmental conditions for cod recruitment. Geometric mean recruitment and "Hockey stick" stock-recruitment relationships were fitted for the two periods and used in projections. For the most recent period, two inflexion points (160 000t and 92 000t B_{lim}) were used in the hockey stick model.

Figure 3.5 shows that for all investigated scenarios an F below F=0.5 gave a very low probability of stock size being below B_{lim}. The risk to B_{lim} was mainly dependent on the period used to derive the stock recruitment relationship and to a lesser extent on the actual shape of the relationship. The effect of introducing multispecies interactions, and in particular cod cannibalism, was not pronounced. The scenarios fitted to the full recruitment time-series and an assumed inflection point at 160 000 t (and hence a higher productivity), exhibited much higher values of F, which ranged between 0.6-0.8.

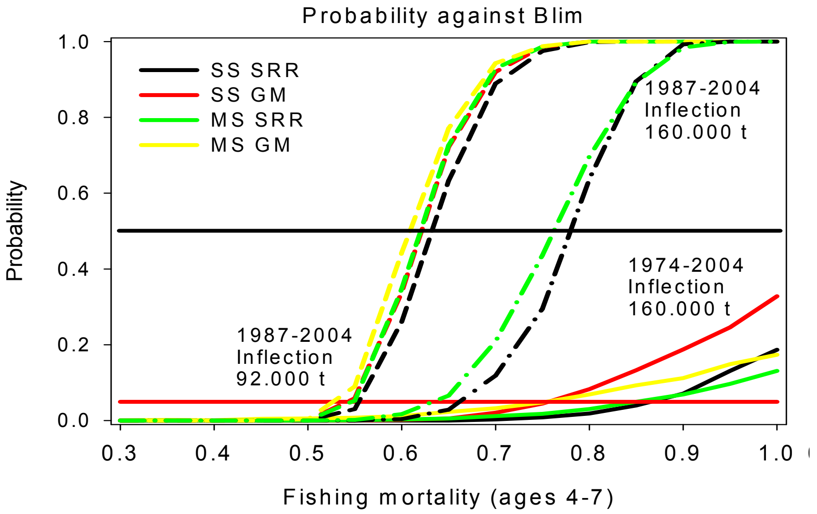


Figure 3.5. Probability of SSB being at or below B_{lim} at different fishing mortalities, assuming single- (SS) or multispecies (MS) interactions and different recruitment models (SSR: stock recruitment relationships with different inflection points and GM: geometric mean) fitted to different time periods with low recruitment (1987–2005) and the entire time-series (1974–2005); horizontal lines represent the 5% (red) and 50% (black) percentile, respectively.

The equilibrium SSB (Figure 3.7) was, in general, higher for simulations without species interactions included, for F up to and around 0.5–0.6. For higher values of F, projections including species interactions suggested higher SSB. When multispecies effects are assumed a high F will reduce the SSB and thereby the number of predators on juvenile cod leading to a higher survival rate of juvenile cod. In a system without cannibalism a decrease in SSB will have no effect on recruitment, as long as SSB is above the inflection point used for the Hockey stick model.

In single species mode, the general advice with respect to maximum yield, would be to decrease F to obtain the highest yield (Figure 3.6). However, in multispecies mode the general advice is the opposite – increase F to obtain the highest yield.

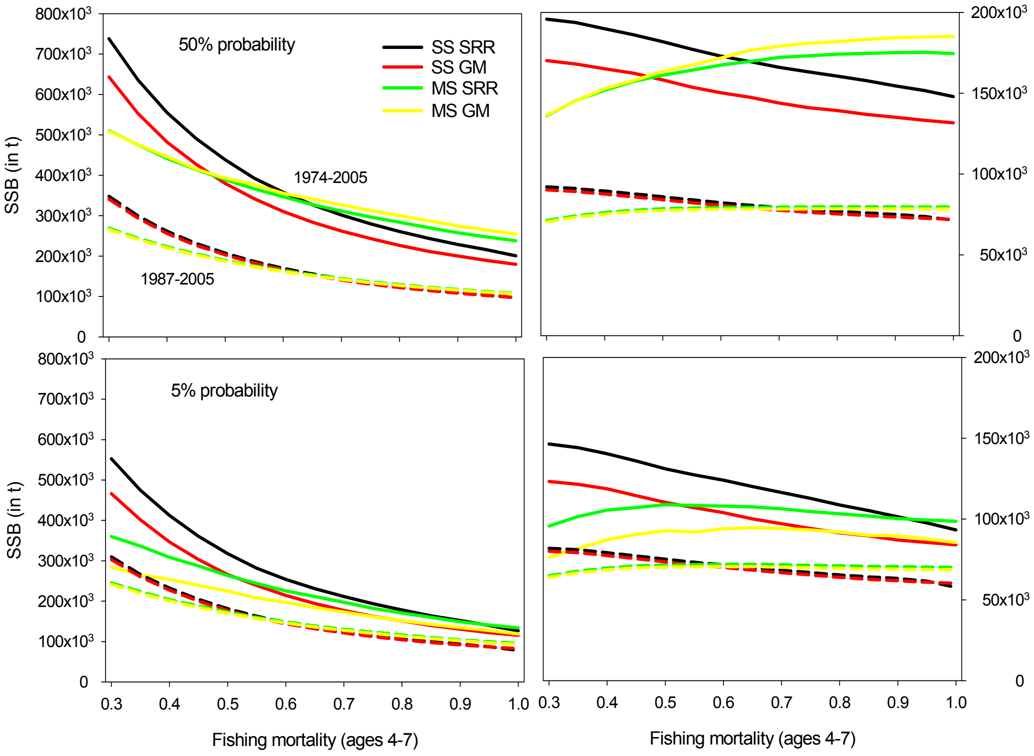


Figure 3.6. Equilibrium SSB (50% and 5% percentile) and corresponding yield at different fishing mortalities in single- (SS) and multispecies (MS) simulations with stock recruitment relationships fitted to different time periods with low recruitment (1987–2005, inflection points 92 000 t) and the entire time-series (1974–2005, inflection point 160 000 t) as well as geometric mean recruitment for both periods respectively.

For multispecies scenarios two possible levels of cod cannibalism ("observed" from available stomach data) were taken into account. The effect of the level of cannibalism is visible for SSB and yield in Figure 3.7, but not as pronounced as the effect of environmental conditions or system productivity. In general, a higher cannibalism leads to a higher F_{max}.

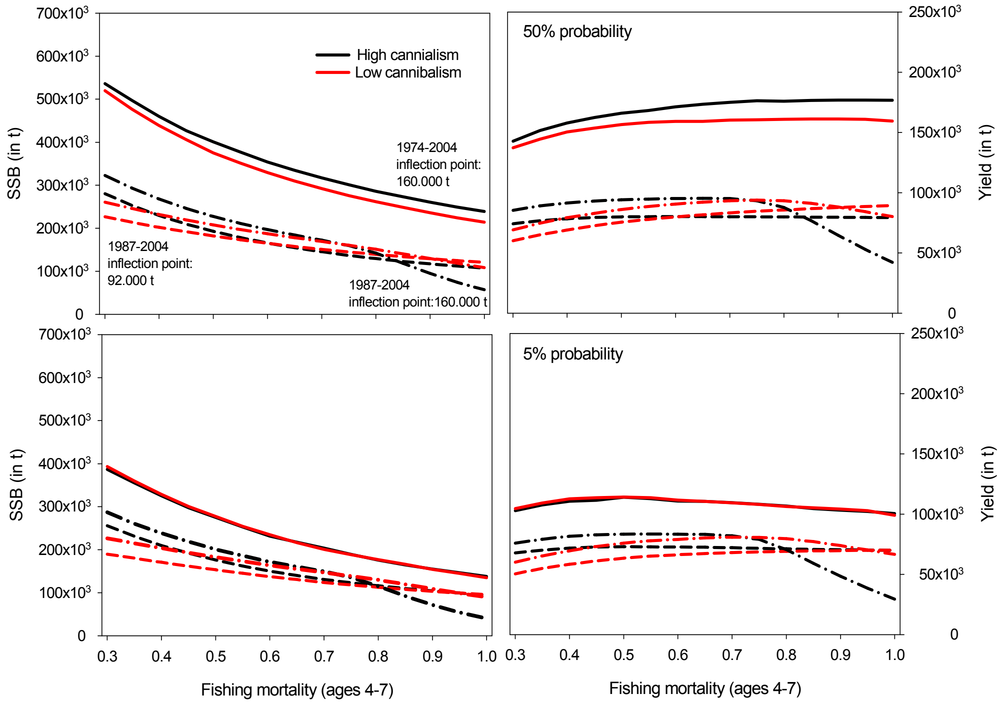


Figure 3.7. Equilibrium spawning stock size (50% and 5% percentile) and corresponding yield at different fishing mortalities, assuming high- (stomach content 1977–1986) or low cannibalism (stomach content: 1987–1994) and stock recruitment relationships fitted to different time periods with low recruitment (1987–2005, inflection points 92 000 t as dashed line and 160 000 t as dashed line with points) and the entire time-series (1974–2005, inflection point 160 000 t as solid line).

The scenarios show that management targets like F_{MSY} or F_{max} clearly depend on the prevailing environmental conditions and on whether biological interactions are taken into account. When multispecies effects are included the observed increase in both SSB and yield resulting from a decrease in F becomes significantly smaller compared to the gain obtained in a single species system. This suggests that single species reference points are misleading for management of stocks with a distinct element of cannibalism.

3.7 MSY for stocks in the Barents Sea

Barents Sea capelin is managed taking predation by northeast Arctic cod into account (Gjøsæter *et al.*, 2002). Thus, single-species MSY for Barents Sea capelin is not a meaningful concept; it should be calculated for different stock levels/management strategies for cod. Because the effect of young herring abundance on capelin recruitment is strong, MSY of capelin should also be calculated for different stock levels/management strategies for herring.

Tjelmeland (2005) explored the long-term yield for capelin, cod and herring for a wide range of harvest control rules using the Bifrost model. Cod cannibalism and effects of capelin abundance on cod population dynamics (growth, maturation) were included in those simulations. The results are considered preliminary and are thus not reported here. Other multispecies models for the Barents Sea have also explored the consequences of various management strategies for the species included, but this was done in a less comprehensive way. Models used for such purposes include MULTSPEC (Bogstad *et al.*, 1997); Scenario Barents Sea (Schweder *et al.*, 1998, 2000), Systmod (Hamre, 2003), Stocobar (Filin, 2005, 2007) and Gadget (Lindstrøm *et al.*, 2008).

A comparison of the models Bifrost, Gadget and Stocobar is proposed for the 2009 WGSAM meeting, and should give more insight in how the various multispecies model structures and assumptions affect MSY for the main Barents Sea fish stocks.

3.8 MSY of Icelandic deepwater shrimp, taking account of cod predation

Models can be used to calculate yield as a function of fishing on multiple species simultaneously. These models can then be compared to results for single species models to evaluate the consequences of management actions (see above). Where significant differences exist, the links causing these should be identified and the quality of the supporting data evaluated in detail. It is important to note that technical interactions also have to be quantified as reducing effort towards one species might be impossible without reducing effort on other species. Similarly, discarding and other unreported (mesh penetration) mortality caused by the fisheries need to be taken into account.

An example of a simple multispecies model is that used for assessment of deep-water shrimp north of Iceland. Here abundance of cod in the shrimp survey is used as a proxy for cod preying on shrimp. To get a good predictor of shrimp predation in a multispecies model would need suitability (or migration) of cod to be estimated every year. However the model explains the shrimp data reasonably well but is not good for prediction, as the survey index next year has to be predicted in advance, most likely by using a first order auto-regressive model or simply assuming last years value.

Figure 3.8 shows shrimp yield-per-recruit as a function of shrimp fishing mortality for various relative levels of the cod stock. 'Survey-index 0' indicates the level of yield that might be expected in the complete absence of cod (effectively a single-species model); 'survey-index 20' is a simulation including a low level of cod predation pressure etc.

This analysis suggests that the anticipated yield of shrimp will be significantly higher under single-species conditions ('Surveyindex 0') compared with simulations where cod are present in the area. Also, that the maximum yield of the shrimp fishery (light grey in Figure 3.8) will be attained at a higher value of F when predation by cod is taken into account.

When looking at the picture it should be born in mind that shrimp smaller than 13mm are hardly seen in the fisheries and little is known about their abundance except in relative terms.

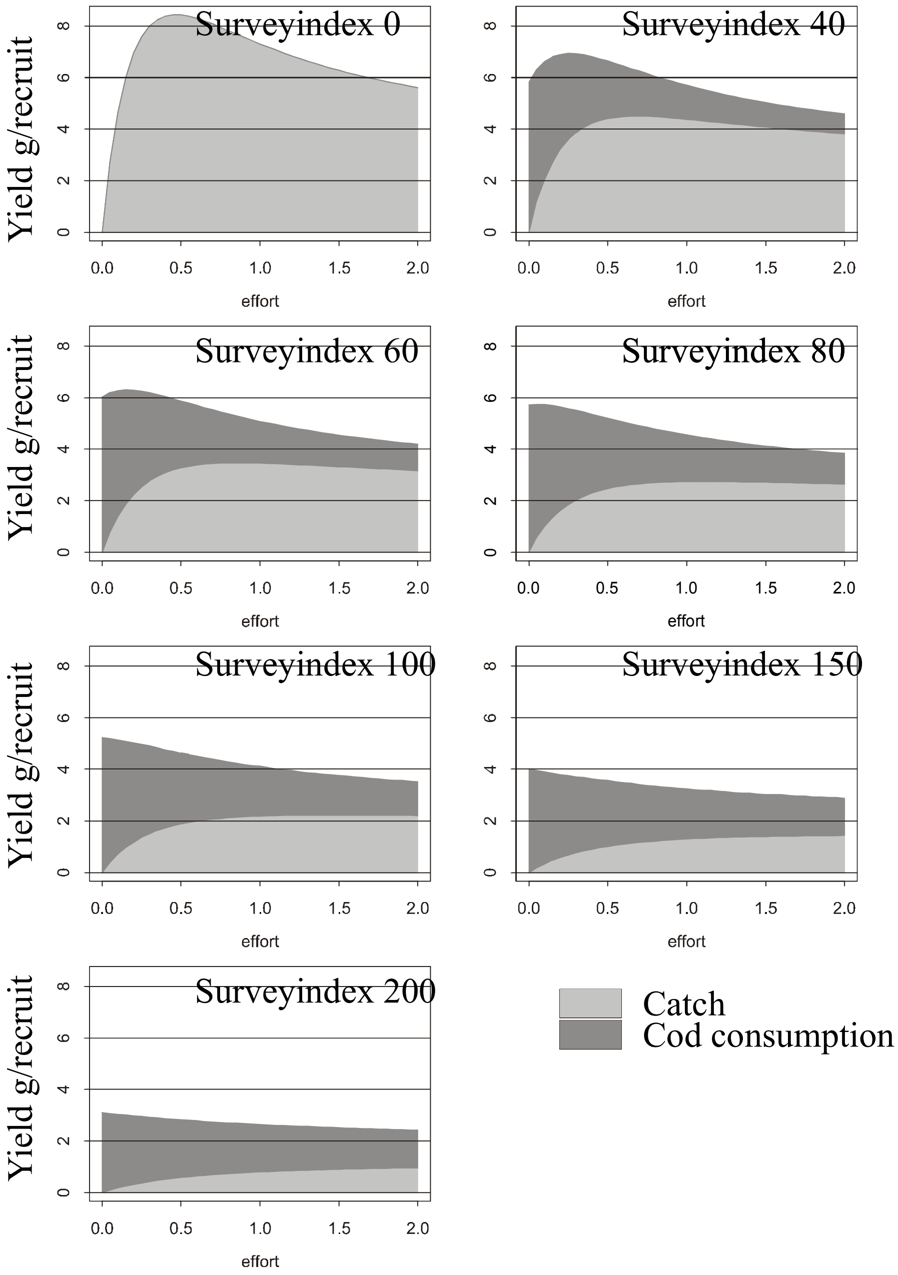


Figure 3.8. Anticipated yield-per-recruit of deep-water shrimp as function of fishing effort and relative cod abundance in the shrimp survey.

3.9 System-wide MSY within a theoretical context

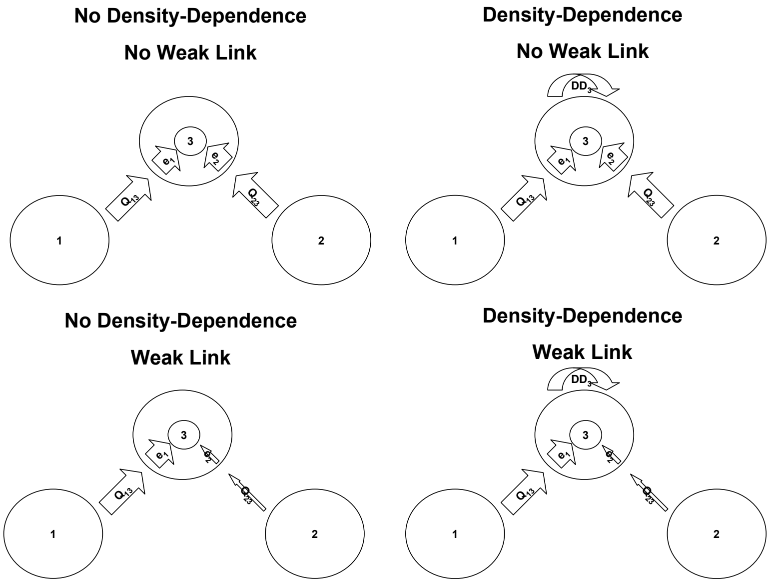
Typically the study of *MSY* in a multispecies context have been addressed by comparing the summation of individual single species *MSY* values with the yields obtained by applying these species-specific F_{MSY} simultaneously (e.g. Walters *et al.*, 2005, Mackinson *et al.*, MS). This type of comparison, although it does not actually optimize the multispecies yield, matches well the type of practical management procedures that are more likely to be explored towards achieving ecosystem-wide *MSY*s.

At the present time, only theoretical studies are available to explore how true system-wide maximum yield strategies may look like (Matsuda and Abrams 2006). By allowing all species in these foodweb models to be harvested in search for a system-wide *MSY*, these simulations deviate from the reality of exploited systems where only a subset of species are usually harvested. Furthermore, in real systems the selection of the species to be exploited is most certainly not a random process. Nonetheless, the results of the Matsuda and Abrams study are truly interesting. Among others, it suggests that unconstrained system-wide *MSY* strategies will tend to simplify the original foodwebs through both, intentional elimination of species from the ecosystem to favour others (ecosystem engineering), as well as extinctions triggered by indirect effects (ripple effects). It also indicates that top predators are always harvested in ecosystem-wide *MSY* strategies, and these strategies are often achieved by exploiting one or few trophic levels. This study explored how the application of biodiversity constraints (i.e. do not allow species to go extinct) affect these system-wide *MSY* strategies. In most cases this constraint did not reduce yields in any major way, but often caused an increase in both the number of species and the trophic levels being exploited to achieve the system-wide *MSY*. The structure of the foodweb models used for this exploration was a generalized logistic formulation including linear and unbounded functional responses. In terms of the impact of model structure on the results, the inclusion of density-dependent mortality in the consumers produced significant changes in the optimal system-wide harvesting strategies, often broadening the number of species harvested (Matsuda and Abrams 2006).

In order to contribute to the ongoing discussion, a series of simple foodweb models were developed within the working group. The goal of these preliminary analyses was to investigate how the strength of the link between predator and prey, in combination with the presence or absence of density-dependent predator mortality could impact some of these results.

3.9.1 Model structure

Given the preliminary nature of this study, a simple three species model composed of one predator and two prey species was considered. The model was used to explore four different structural scenarios. These scenarios corresponded to the combination of presence and absence of density-dependent mortality in the predator with the presence and absence of a weak link between the predator and one of its prey (Figure 3.9). Weak links are a common feature in natural communities (Paine 1992) and have been found to enhance the stability in multispecies foodweb models (McCann *et al.*, 1998).


No Density-Dependence
No Weak Link

Density-Dependence
No Weak Link

No Density-Dependence
Weak Link

Density-Dependence
Weak Link

Figure 3.9. Schematic representation of the three species foodweb model considered. The parameters indicated in this figure correspond to the main features that were varied to explore these four different scenarios (see text for details).

This simple foodweb was described using the following set of ordinary differential equations:

$$\frac{dB_1}{dt} = r_1 B_1 \left(1 - \frac{B_1}{K_1}\right) - Q_{13} B_3 - F_1 B_1$$

$$\frac{dB_2}{dt} = r_2 B_2 \left(1 - \frac{B_2}{K_2}\right) - Q_{23} B_3 - F_2 B_2$$

$$\frac{dB_3}{dt} = B_3 \left(-T_3 + e_{13} Q_{13} + e_{23} Q_{23}\right) - d_3 B_3^2 - F_3 B_3$$

where

$$Q_{i3} = \frac{a_{i3} B_i^{b_3}}{1 + h_3 a_{13} B_1^{b_3} + h_3 a_{23} B_2^{b_3}} \quad with \quad i = \{1,2\}$$

The model was developed using a bioenergetic-allometric approach (Yodzis and Innes 1992). Species 1 was parameterized to mimic a forage fish, species 2 to mimic a fast growing pelagic invertebrate (e.g. zooplankton species), while species 3 was intended to mimic a groundfish predator. For both prey, their intrinsic growth-rates were set as 0.1 of the physiological maximum derived from allometric reasoning (i.e. r_1=1.83 and r_2=9.2; Yodzis and Innes 1992). In an analogous manner, the maximum ingestion rate for the predator was set in such a way to produce a maximum growth-rate of 10% of the physiological maximum in conditions of feeding saturation. In this case, because respiration for the predator was set as T_3=2.74, setting this maximum growth-rate was accomplished by using a common handling time for both prey of h_3=0.28. The carrying capacities for the prey were arbitrarily set to K_1=1 and K_2=0.6 million tonnes for species 1 and 2 respectively. Density dependent mortality for the predator was assumed quadratic. Q_{13} and Q_{23} represent the consumption by the predator (species 3) of species 1 and 2 respectively. F_1, F_2, and F_3 are the corresponding fishing mortalities. The functional response was set as a type 3 functional response with $b_3=2$.

Attack rates, assimilation efficiencies and the predator's density-dependent mortality factor were chosen in each case to match the target scenarios while keeping the system in a region without oscillatory dynamics (Table 3.2). The avoidance of cyclic dynamics was chosen to simplify the analysis as well as to approximate a more realistic fishery system for which true oscillatory dynamics are not usually the norm.

Table 3.2. Parameters used to define the different scenarios considered. DD: density-dependent predator mortality. WL: weak link present.

		SCENARIO			
		# 1	# 2	# 3	# 4
Symbol	Parameter	No DD No WL	DD No WL	No DD WL	DD WL
e13	Assimilation efficiency of species 3 for prey 1	0.8	0.95	0.95	0.95
a13	Functional response coefficient of species 3 on species 1	2.5E-10	5.5E-10	5.5E-11	9.0E-09
e23	Assimilation efficiency of species 3 for prey 2	0.8	0.95	0.65	0.70
a23	Functional response coefficient of species 3 on species 1	2.5E-10	5.5E-10	9.5E-12	9.5E-10
d3	Density-dependent mortality factor for species 3 (predator)	0.0	4.0E-06	0.0	6.0E-06

Because no thorough exploration of parameter space was performed, the results obtained are only valid for the specific parameter values considered. Nonetheless, because these parameters were chosen to cover specific scenarios, it is reasonable to assume that these results can provide some indication of what could be expected.

3.9.2 Estimation of single species maximum sustainable yield

For each species in each scenario, the single species maximum sustainable yield was estimated by starting the system at equilibrium without catches and then gradually increasing fishing mortality and letting the system achieve a new equilibrium at each particular level of F_i. Once the system was at equilibrium the yield produced at that particular fishing mortality was calculated as $Y_{F_i} = F_i B_i^*$. Classical plots of yield as a function of fishing mortality were produced.

For Scenario 1 (no density-dependent mortality in predator, no weak link), the single species yield curves exhibited an asymmetrical dome shape, skewed slightly to the right for species 1 and species 3 (the predator), while the shape was much more symmetrical for species 2 (Figure 3.10). Equivalent yield curves obtained using Ecopath with Ecosim (EwE) also tend to show asymmetric domes, but in that case the skewness of the available examples consistently appears to the left (Walters *et al.*, 2005, Mackinson *et al.*, Figure 3.3).

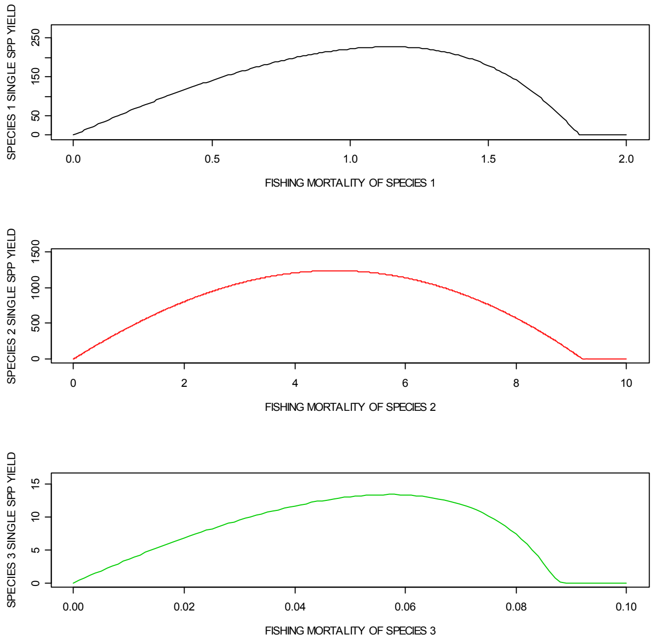


Figure 3.10. Single species yield curves for Scenario 1 (no density-dependent mortality in predator, no weak link). Note the skewness to the right in this yield curves.

For Scenario 2 (density-dependent predator mortality and no weak link), the yield curves where slightly skewed to the left, especially for species 1 (Figure 3.11). The predator (species 3) showed a more symmetrical yield curve.

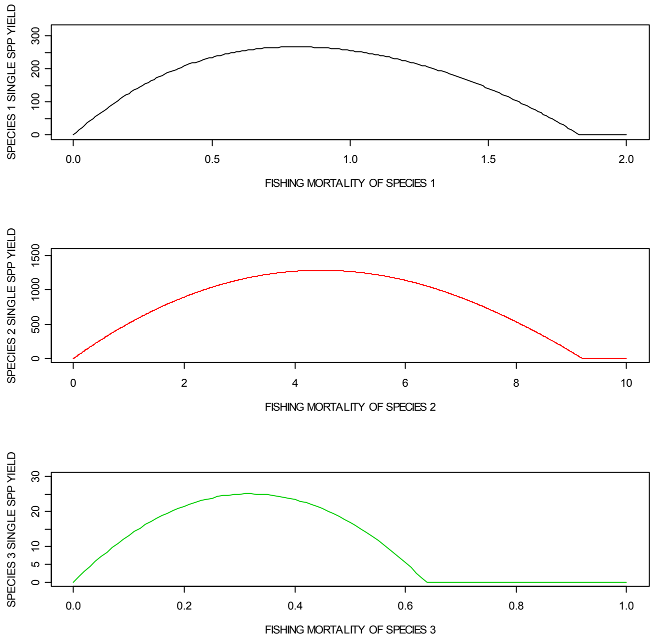


Figure 3.11. Single species yield curves for Scenario 2 (density-dependent predator mortality, no weak link). Note the light skewness to the left in the prey yield curves (species 1 and 2).

For Scenario 3 (no density-dependent predator mortality and weak link present), the yield curves where also asymmetrical, especially for species 1 and 3 (Figure 3.12). The predator (species 3) shows a yield curve skewed to the left, but the most interesting shape is the one obtained for species 1 (Figure 3.12). In this case, the yield curve was virtually linear until F_1=0.8. Above this threshold the curve takes a more traditional shape. This point is associated with the extinction of the predator in the system (Figure 3.13). One interesting observation is that species 1, even with increasing fishing mortality, remains at a relatively constant level (top panel in Figure 3.13). This is possible as a result of the decline in its predator (species 3, bottom panel in Figure 3.13). The almost constancy in species 1 equilibrium biomass and the linear increase in its yield during the period with predator present is due to compensation between fishing and predation mortality. This compensatory effect keeps total mortality for species 1 virtually constant until the disappearance of the predator. Once the predator is gone, there is no compensatory mechanism possible and the full effects of fishing are felt by the target species. In this particular scenario it is the predator that is the one paying the ecological price of fishing.

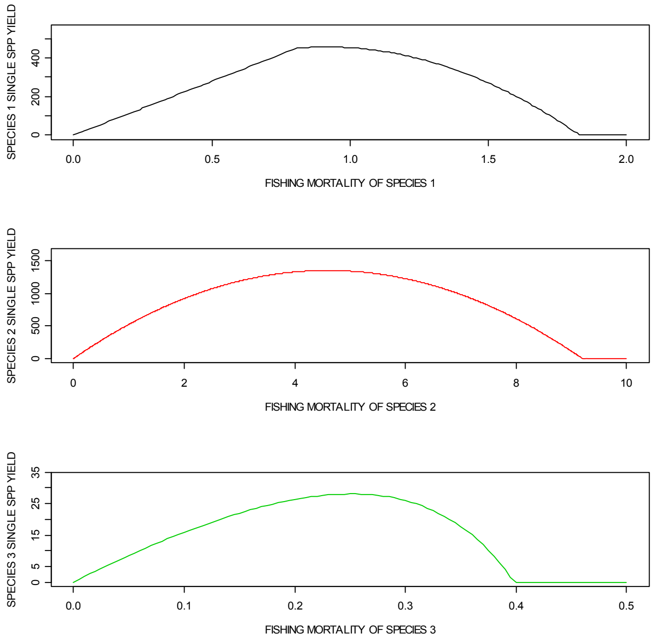


Figure 3.12. Single species yield curves for Scenario 3 (no density-dependent predator mortality, weak link present).

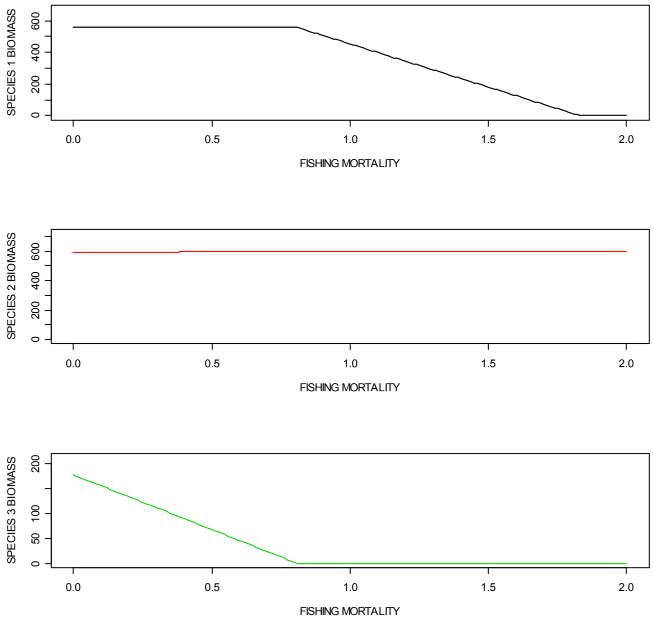


Figure 3.13. Scenario 3 equilibrium biomass for all species in the model as a function of fishing mortality of species 1 (top panel in Figure 3.12). The remaining two species are not harvested. Note that the predator goes extinct as a consequence of fishing its more profitable prey (species 1); while the predator was present the equilibrium biomass of the harvested prey remained virtually unchanged.

For Scenario 4 (density-dependent predator mortality and weak link present), the yield curves for species 2 and 3 were fairly symmetrical, but species 1 again exhibited an awkward shape (Figure 3.14). The sudden drop in yield above F_1=1.6 also coincides with the extinction of the predator in the system (Figure 3.15). In this case, the compensation between predation and fishing mortality is not enough to keep the exploited population constant, but the rate of decline of the equilibrium biomass of species 1 as a function of its fishing mortality certainly increases after the disappearance of the predator (Figure 3.15).

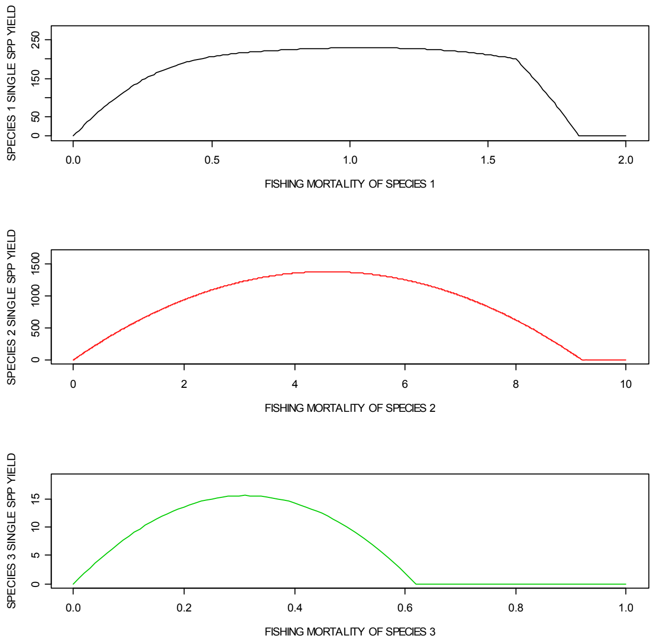


Figure 3.14. Single species yield curves for Scenario 4 (density-dependent predator mortality, weak link present).

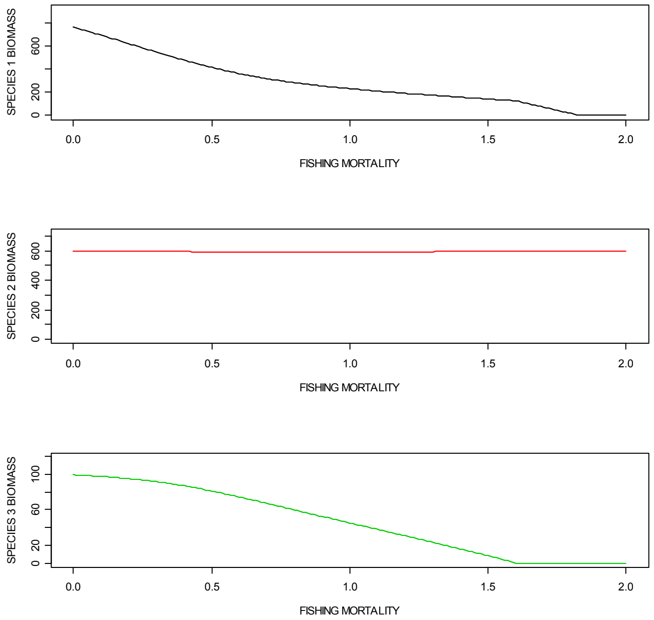


Figure 3.15. Scenario 4 equilibrium biomass for all species in the model as a function of fishing mortality of species 1 (top panel in Figure 3.14). The remaining two species are not harvested. Note the increased slope of the decline in species 1 after the extinction of the predator (species 3).

3.9.3 Single species and multispecies fisheries yields

The yields obtained from the simultaneous application of the estimated single species *FMSY* were compared with the summation of the yields obtained by applying these fishing mortalities one at a time to the virgin system. Because absolute values have no particular significance in this exercise, the yields obtained were compared by calculating ratios between them. In all cases these ratios were based on the equilibrium yields obtained by applying the specified set of F_{MSY} values.

Several combinations of F_{MSY} were applied to each one of the scenarios considered (Table 3.3). In some cases, the simultaneous application of all three F_{MSY} values drove the predator (species 3) to extinction. In these cases, F_{MSY} for all species were reduced by factors of 0.1 (i.e. starting at 0.9* F_{MSY}, then 0.8* F_{MSY} etc.) until the simultaneous application of these reduced F_{MSY} rendered an equilibrium system with all species present. In these cases, the yields obtained under these reduced fishing mortalities were used to define the denominator of the total and the species-specific ratios.

Table 3.3. Ratios calculated to compare the yields from single species MSY values (SSPP) with the yields obtained by applying these very same FMSY to mixed fisheries (MSPP). In all equations the species is indicated in parentheses while the applied FMSY to the system are indicated in the subscripts. In all ratios the single species case is used as numerator and the multispecies case is used as denominator (SSPP/MSPP).

Label	Calculated ratio
SP 1	$\lfloor Yield(sp1)_{F(sp1)_{MSY}} \rfloor / \lfloor Yield(sp1)_{F(sp1)_{MSY}+F(sp2)_{MSY}+F(sp3)_{MSY}} \rfloor$
SP 2	$\lfloor Yield(sp2)_{F(sp2)_{MSY}} \rfloor / \lfloor Yield(sp2)_{F(sp1)_{MSY}+F(sp2)_{MSY}+F(sp3)_{MSY}} \rfloor$
SP 3	$\lfloor Yield(sp3)_{F(sp3)_{MSY}} \rfloor / \lfloor Yield(sp3)_{F(sp1)_{MSY}+F(sp2)_{MSY}+F(sp3)_{MSY}} \rfloor$
ALL SPP BUT SP 1	$\dfrac{\lfloor Yield(sp2)_{F(sp2)_{MSY}} + Yield(sp3)_{F(sp3)_{MSY}} \rfloor}{\lfloor Yield(sp2)_{F(sp2)_{MSY}+F(sp3)_{MSY}} + Yield(sp3)_{F(sp2)_{MSY}+F(sp3)_{MSY}} \rfloor}$
ALL SPP BUT SP 2	$\dfrac{\lfloor Yield(sp1)_{F(sp1)_{MSY}} + Yield(sp3)_{F(sp3)_{MSY}} \rfloor}{\lfloor Yield(sp1)_{F(sp1)_{MSY}+F(sp3)_{MSY}} + Yield(sp3)_{F(sp1)_{MSY}+F(sp3)_{MSY}} \rfloor}$
ALL SPP BUT SP 3	$\dfrac{\lfloor Yield(sp1)_{F(sp1)_{MSY}} + Yield(sp2)_{F(sp2)_{MSY}} \rfloor}{\lfloor Yield(sp1)_{F(sp1)_{MSY}+F(sp2)_{MSY}} + Yield(sp2)_{F(sp1)_{MSY}+F(sp2)_{MSY}} \rfloor}$
ALL SPP	$\dfrac{\begin{bmatrix} Yield(sp1)_{F(sp1)_{MSY}} + Yield(sp2)_{F(sp2)_{MSY}} \\ + Yield(sp3)_{F(sp3)_{MSY}} \end{bmatrix}}{\begin{bmatrix} Yield(sp1)_{F(sp1)_{MSY}+F(sp2)_{MSY}+F(sp3)_{MSY}} + Yield(sp2)_{F(sp1)_{MSY}+F(sp2)_{MSY}+F(sp3)_{MSY}} \\ + Yield(sp3)_{F(sp1)_{MSY}+F(sp2)_{MSY}+F(sp3)_{MSY}} \end{bmatrix}}$
ALL SPP REDUCED TO 60% MSY	$\dfrac{\begin{bmatrix} Yield(sp1)_{F(sp1)_{MSY}} + Yield(sp2)_{F(sp2)_{MSY}} \\ + Yield(sp3)_{F(sp3)_{MSY}} \end{bmatrix}}{\begin{bmatrix} Yield(sp1)_{0.6F(sp1)_{MSY}+0.6F(sp2)_{MSY}+0.6F(sp3)_{MSY}} + Yield(sp2)_{0.6F(sp1)_{MSY}+0.6F(sp2)_{MSY}+0.6F(sp3)_{MSY}} \\ + Yield(sp3)_{0.6F(sp1)_{MSY}+0.6F(sp2)_{MSY}+0.6F(sp3)_{MSY}} \end{bmatrix}}$

For scenario 1 (no density-dependent predator mortality, no weak link; Figure 3.16), the simultaneous exploitation of the two preys at their single species F_{MSY} produced a slightly higher yield than the expectation from single species analyses. However, this small increase in yield is a consequence of a heavily reduced predator population. This becomes evident when fishing on the predator is included. In all these cases, the predator is driven to extinction. It was necessary to reduce all F_{MSY} values to 60% of their single species levels to get a mixed fisheries system with all three species present. In this scenario, the overall yield was not much different from that expected from single species analyses, but the distribution of this yield among species differed dramatically. Species 1 showed a large increase in its yield in the mixed fisheries scenario (50% increase), species 2 showed a small reduction, and the predator showed a dramatic reduction in its yield (Figure 3.16).

In the case of Scenario 2, the full multispecies yield was virtually identical with the expectation from single species analyses (Figure 3.17). Here again the distribution of this yield among species showed clear differences. The simultaneous exploitation of the three species produced a decline in the yield for the predator but an increase in the yield of species 1. Another observation here is that the lack of predator exploitation produces a lower yield than expected from single species scenarios (Figure 3.17).

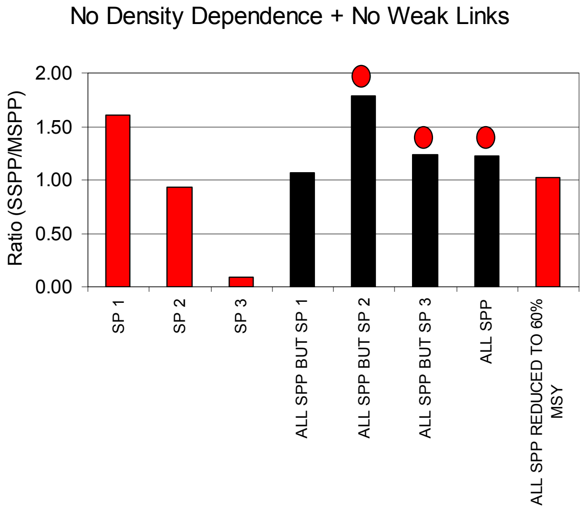


Figure 3.16. Ratios calculated for Scenario 1. The red dots indicate the cases where the simultaneous application of the fishing mortalities involved in the denominator (Table 3.3) rendered an equilibrium system where the predator was extinct. The red bars indicate the ratios calculated using as denominator the reduced *FMSY* instead of its full values (see text for details).

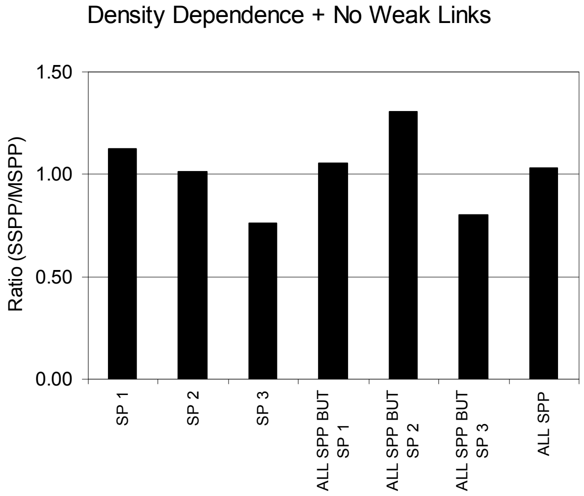


Figure 3.17. Ratios calculated for Scenario 2.

Scenario 3 showed a similar pattern to Scenario 1. The simultaneous exploitation at single species F_{MSY} drives the predator to extinction (Figure 3.18). Likewise, a reduction of 60% in F_{MSY} values was required to retain the predator under the three species mixed fisheries exploitation. However, in this case both the total and individual yields were smaller than expected from single species analyses, with the predator showing the most dramatic reduction in yield (Figure 3.18).

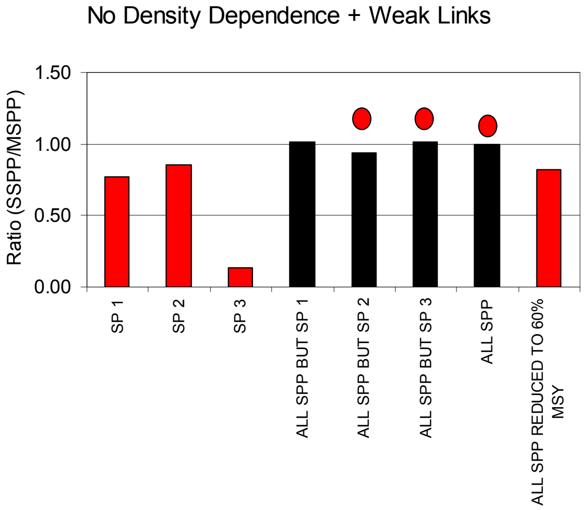


Figure 3.18. Ratios calculated for Scenario 3. The red dots indicate the cases where the simultaneous application of the fishing mortalities involved in the denominator (Table 3.3) rendered an equilibrium system where the predator was extinct. The red bars indicate the ratios calculated using as denominator the reduced F_{MSY} instead of its full values (see text for details).

Finally, Scenario 4 did not show a dramatic change in the total yield between single and multispecies conditions, but the yield for the predator was reduced by half in the multispecies case (Figure 3.19). This mismatch between an unchanged total yield and a significant reduction in predator yield is due to the magnitudes of the yields from the different species. Even with these differences, the lack of predator exploitation ("ALL BUT SP 3" case) still generated a reduction in prey species yield (Figure 3.19). Interestingly, the lack of exploitation of the least profitable prey (species 2) generates a 50% increase in yield compared with the expectation from single species analysis (Figure 3.19). This is due to the predator consuming more of species 2, the more abundant but least profitable prey (junk food effect on the predator).

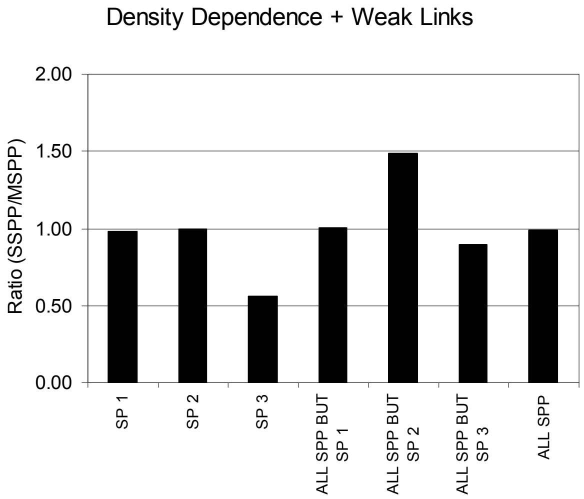


Figure 3.19. Ratios calculated for Scenario 4.

3.9.4 Concluding remarks

The results from these exercises support some of the observations made by previous work and highlight some potentially interesting mechanisms that could be at play and may affect our perceptions and expectations about what the yield at the ecosystem level should be.

First of all, and not surprisingly, the lack of exploitation of the top predator in the system tended to reduce the overall yield compared with expectations based on single species approaches. This observation matches the Matsuda and Abrams (2006) simulation results where all ecosystem-wide *MSY* strategies involved the harvesting of top predators. However, this study also highlights that in mixed fisheries scenarios the top predator was the species that suffered the highest reduction in yield, and even went extinct in several cases. This clearly shows that, if the results from this theoretical exercise have any resemblance with reality, top predators are potentially the most vulnerable component in the foodweb when mixed fisheries are at play. In agreement with many previous studies, keeping them in the system would often require that their prey is harvested at levels that could be well below the *MSY* level estimated from single species approaches.

Another more intriguing and potentially controversial result is the observation that the presence of top predators in the system, through compensatory mechanisms between fishing and predation mortality, could "buffer" the response of a prey stock to increments in its fishing mortality (e.g. Figure 3.13, top panel). This does not mean that fishing yields will be lower than in absence of the predator (on the contrary, for a given fishing mortality, the yield without predator will be higher), what it means is that the relative decrease in the equilibrium biomass of the prey for a given increase in fishing mortality will be much larger in the absence of the predator than would be the case with a predator present in the system. Furthermore, if mechanisms like this are actually at play, it would be expected that if the predator disappears (or effectively stops to play a regulatory role through predation), then the prey population being harvested could suddenly collapse for no apparent reason. In some ways, this result matches recent studies that suggest that top predators have a vital role at providing stability to foodwebs (McCann *et al.*, 1998, 2005a, 2005b, Rooney *et al.*, 2006).

In more structural terms, the predator went extinct in those cases without density-dependent mortality (scenarios 1 and 3), while the presence of weak links made the compensatory behaviour detailed above more evident due to the difference in relative preference for the two prey and the higher profitability of one prey over the other. This buffering effect only occurred when the more profitable prey was the one being harvested, making this "buffering" effect an asymmetric one.

Finally, and to come back to the original issue of *MSY* in a multispecies context, it is clear that although many policy documents and political agreements make reference in one way of another to *MSY*, this concept is often qualified to include ecosystem considerations, protection of biodiversity, social and economic issues, etc. With that perspective in mind, and the results from available studies like the ones discussed here, it is obvious that the definition of the objective function to be maximized by the exploitation of resources is truly a multidimensional entity. Even if we keep this discussion truthful to the initial intent of focusing only on the biological yield, still we need to revise the concept of biological yield as purely extraction of biomass. The simple exploration performed here clearly suggests that in biological terms the yield gathered from exploiting the system should obviously include the biomass extracted from it, but it may also need to include the ecological services, for example, the suggested "buffer" that top predators may provide in certain circumstances. Furthermore, even if this particular mechanism is simply a mathematical oddity from a very simple model, there will clearly be other, more realistic, ecological services that potential target species for fisheries are currently providing. These services, in addition to the actual biomass removed, must be considered as part of the biological yield that is extracted from the ecosystem. If this way of thinking about yield is explored further, some of the trade-offs that become apparent when simply biomass extraction is taken into account may vanish because not only getting biomass out of the system becomes biological yield, also leaving biomass there becomes biological yield measured in terms of ecological services provided.

4 ToR b) – Report on 'key-runs' of multispecies fisheries models for the North Sea and Barents Sea, and work towards similar standardized outputs and reporting protocols for the Bay of Biscay and Iberian Peninsula.

The working group agreed that 'key-runs' are an important output of the group and should ideally be produced for as many regions as possible. Input and output data from the key-runs should be made freely available online. This accessibility is important to ensure that estimates of natural mortality of fish stocks are readily available to assessment working groups and that information on the exchange of biomass between different compartments in the North Sea fish community can be obtained by the public. The working group further agreed that a key-run in a specific area should only be updated every three years or when significant changes were made in the models. To ensure that the individual key-run receives the necessary attention, the group agreed to review a selection of the regions every year. This year, the North Sea and Baltic Sea were chosen and it was decided to work towards a key-run in the Barents Sea and Icelandic waters in 2009. Work on producing key-runs for the Bay of Biscay and the Iberian Peninsula will continue at next year's meeting. The work on multispecies fisheries models not producing key-runs is reported on under ToR e).

4.1 North Sea (ICES area IV)

4.1.1 Overview

The key-run for the North Sea is produced with the SMS model. SMS (Lewy and Vinther, 2004) is a stock assessment model including biological interactions estimated from a parameterized size dependent food selection function. The model is formulated and fitted to observations of total catches, survey cpue and stomach contents for the North Sea. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.

In the present SMS analysis the following predator and prey stocks were available: predators and prey (cod, whiting, haddock), prey only (herring, sprat, sandeel, Norway pout), predator only (saithe), 'external predators' (8 seabird species, starry ray, grey gurnard, Western stock mackerel, North Sea mackerel, North Sea horse-mackerel, Western stock horse-mackerel (Figure 4.1). The population dynamics of all species except 'external predators' were estimated within the model. Residual natural mortality (natural mortality not caused by the included predators) was set to 0.2.

Due to problems in the assessment of North Sea sprat (ICES 2006, 2008) and fitting problems for this stock inside SMS, it was decided to leave this prey species out. Sprat was therefore treated as 'Other Food' and the sprat component of predateor stomach contents was added to the observed relative stomach contents for 'Other Food'. In this setting, sprat was still available as prey for the model predators in an indirect way. However, as the amount of other food is constant, the amount of sprat available does not vary between years. Plaice and Sole were included for single-species assessment. These species have no influence on model results of other species because they do not interact with them. They were included to ensure that the output datasets available online included population estimates of all assessed demersal species.

Grey seals were included in the last key-run using the 4M model (ICES SGMSNS 2005, ICES CM 2005/D:06). Because then, population numbers of seals have been updated as part of the BECAUSE project. However, seal diet data are only available as numbers eaten by age group of each species (recorded from scat otoliths) and as SMS models predation by length group, these data cannot be inserted directly in this model. To include seals as predators in SMS will require a length distribution of the prey eaten. Seeing as this was the basis of the original seal diet data, it should be relatively straightforward to reintroduce seals at a later date.

4.1.2 Data update

Data on catch at-age was derived from the assessment reports of WGNSSK, HAWG and WGWIDE.

4.1.2.1 Quarterly distribution of catches

WGNSSK unfortunately no longer provide information on the quarterly distribution of catches. To estimate these proportions, the average proportion of the catch taken in each quarter was calculated for the years 1972 to 2003 where quarterly catch data were available without discard and unallocated landings. The working groups who do provide information on quarterly catches have in many cases revised data to include discard and unallocated landings and these revisions have not been accompanied by revised estimates of the proportion of the catch taken in each quarter back in time. Using the average proportions from the years 1972–2003 corresponds to using the same discard percentage in all quarters. While this is probably not correct in the strictest sense, the working groups were unable to provide better estimates without new information on the quarterly distribution of catches, discards and unallocated landings being made available by national institutes.

4.1.2.2 Proportion of mackerel and horse mackerel stocks present in the North Sea

Historically, information on the proportion of the mackerel and horse mackerel stocks which were inside the North Sea has been provided by the relevant working groups. However, in later years updated information was not available, and in 2007 it was decided not to continue the acoustic survey of mackerel due to large variation in the measurements. The values from the most recent update were therefore used for all following years.

4.1.3 Seasonal vulnerability of sandeel and 'other food'

Examination of the residuals of the 'other food' component in stomach contents showed a seasonal cycle in most cases (Figure 4.2). During the second and third quarter the relative prey abundance in the stomach contents were often underestimated, while during the 1st and 4th quarter often an overestimation was observed. Similar patterns were found for sandeel prey. In addition, the relative stomach contents for 'other food' of larger predator size classes were systematically overestimated for the main predator species (Saithe, haddock, whiting, gurnard, western and North Sea mackerel (Figure 4.3). This reflected the ontogenetic diet shift of predators from 'other food' to fish prey as they grow larger.

To incorporate this information in the model, vulnerability of 'other food' and sandeel was allowed to vary between winter (quarter 4 and 1) and summer (quarter 2 and 3) for the predators cod, haddock, saithe and whiting (in all 8 additional parameters). The relationship between size and suitability of 'other food' was modelled by inserting a species-specific linear effect of length on suitability for the predators Saithe, haddock, whiting, gurnard, western and North Sea mackerel (in all 6 parameters).

The additional 14 parameters provided a highly significant improvement of the fit of the model (X^2_{14}=26.68). Visual inspection of the stomach data residuals showed that the systematic overestimation of 'other food' was to a large extent eliminated by extending the model.

The estimated slope of the relationship between predator length and suitability of other food was negative for all predator species (Table 4.1). Larger predators thus had a lower preference for 'other food' than smaller ones. The seasonal vulnerability parameters of both sandeel and 'other food' were larger in summer than in winter (winter values were fixed to equal 1) (Table 4.2). This presumably reflects a higher availability of these prey species during summer as there are seasonal production cycles contributing to 'other food' and sandeel is buried in the sediment during winter.

4.1.4 Results

The population dynamics of all species except 'external predators' were estimated within the model. Suitability of sandeel and 'other food' to the predators cod, haddock, saithe and whiting was estimated separately in summer and winter and suitability of 'other food' was modelled as a linear function of length for the predators saithe, haddock, whiting, gurnard, western and North Sea mackerel. The key-run converged and results are seen in Figure 4.4.

The input and output from the model is available online as ASCII file downloads http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=193

4.1.5 Comparison with single species assessments

Previous work of the multispecies working groups has demonstrated that SSB and estimated fishing mortality are to a large degree insensitive to the addition of species interactions. Hence, multispecies models do not tend to differ in their assessment of whether or not the stocks are inside safe biological limits relative to single species reference points. In contrast to this, the historical development in recruitment differs greatly between multispecies and single species assessments. This pattern is caused by the temporal variation in predation mortality which mainly affects young ages.

4.1.6 Predation mortality (M2)

Cod and whiting predation mortality has increased severely for 0-groups over the period, changing from around 1 before 1990 to around 1.5 in 2000 (Figure 4.4, Table 4.3.). This is caused in the model by grey gurnard predation (Figure 4.5). In contrast to this predation mortality of cod of ages 1 and 2, whiting ages 2+, haddock ages 2+ has decreased from before 1980 to about half that recorded for year 2000 as the biomass of large gadoids decreased following the end of the gadoid outburst. Predation mortality of whiting age 1, haddock age 0 and 1, herring age 1+ has remained virtually constant, albeit with yearly fluctuations. The predation mortality of 0-group herring has decreased in the 1980's and has because then been rather stable just below 1.0 with perhaps an increase in later years. This pattern is caused almost entirely of predation from mackerel (Figure 4.5).

Predation mortality of sandeel has decreased since the 1960s and 70s as gadoid and North Sea mackerel stocks have diminished and except for a large temporary increase in 0-group mortality caused by horse mackerel in the early 1990s M2 has remained at a low level. There is no indication of a substantial increase in later years which could otherwise have been a contributing factor to the current low sandeel stock. Norway pout predation mortality has increased since year 2000 and age 3 now has historically high mortality whereas 1 and 2-year olds are experiencing natural mortalities at least at the same level as during the gadoid outburst in the 1970s. This is primarily caused by the present large saithe stock.

4.1.7 Main consumers of each prey

Investigation of which predators are the most important consumers of a given prey provides important knowledge not only of the trophic interactions but also of places where limited knowledge of predator stock size and diet may have the most significant effects in the model. Historically, the assessed predator species have caused the majority of the modelled prey M2 (Figure 4.5). However, during the 1990s, a significant increase in the grey gurnard stock has changed the picture so grey gurnard is now the most important predator on 0-group cod and whiting and an important consumer of sandeel, Norway pout, 0-group haddock and 1-group whiting. The population numbers of grey gurnard are estimated from survey indices and an estimate of long-term average population size and hence may not be accurate. Furthermore, the diet of this predator is estimated from a single year of stomach sampling. The diet of other predators in this year were characterized by a higher consumption of fish than was seen in 1981, and is therefore possible that the high consumption of juvenile fish by grey gurnard in 1991 was an exceptional case rather than a general pattern. To determine whether this is the case, additional stomach sampling is required.

Mackerel and horse mackerel are responsible for virtually all of the predation on 0-group herring as well as a large part of the consumption of 0-group Norway pout and all ages of sandeel. The diet of horse mackerel is also based on a single year of ′stomach sampling and the total number of stomachs sampled was less than a third of those of grey gurnard (12800 stomachs). Similarly, though western mackerel was sampled in both 1981 and 1991, more than two thirds of the stomachs were sampled in 1991 and the total number sampled was less than half that of grey gurnards. In addition to this, the numbers of these three predators in the North Sea are likely to be poorly known at best. Firstly, there is the general uncertainty about the absolute stock abundance (ICES 2008b). Secondly, the knowledge of the proportion of the stock which enters the North Sea and the amount of time they spend in this area is extremely limited.

To improve estimates of natural mortality of both pelagic and demersal species in the North Sea it is crucial to obtain more detailed information on the quantity of grey gurnard, mackerel and horse mackerel in the North Sea as well as of the diet composition of these three species.

4.1.8 Conclusions

The reliability of the SMS hindcast suffers from poor data availability. There has been a shift of dominance between the assessed predators towards external predators, for which rather uncertain stock abundance estimates exist (Figure 4.6). Stomach sampling has historically been focused on the assessed predators and for most of the external predators the number of stomach samples is quite low. In addition, the estimation of predation mortalities for the whole assessment period 1963–2007 is based on stomachs sampled in the years 1981–1991. This dataset might not reflect the diet composition of predators in other time periods (1963–1980 and 1991–2007). This may bias the estimated predation mortalities substantially. Therefore, the historical stock trends must be interpreted with care especially for species and age groups exerted to high predation mortalities.

Table 4.1.Slope of the relationship between predator length and suitability.

PREDATOR SPECIES	'OTHER FOOD' SLOPE
Gurnard	-3.69
North Sea mackerel	-2.96
Western mackerel	-0.49
Whiting	-2.75
Haddock	-0.93
Saithe	-0.24

Table 4.2. Seasonal vulnerabilities of other food and sandeel. Summer vulnerabilities of both preys are relative to winter vulnerability.

PREDATOR SPECIES	SUMMER VULNERABILITY OF 'OTHER FOOD'	SUMMER VULNERABILITY OF SANDEEL
Cod	2.205	4.397
Whiting	2.606	2.789
Haddock	2.868	2.148
Saithe	4.164	6.327

Table 4.3. Predation mortalities estimated in the model (M2). Yearly average, the standard deviation between yearly values, the trend seen (correlation with year) and the significance of this trend. Total natural mortality is equal to M2 plus a residual natural mortality of M1=0.2.

SPECIES	AGE	QUARTER	MEAN	STD	CORRELATION WITH YEAR	P(CORRELATION=0)
Cod	0	all	1.281	0.266	**0.59**	<0.0001
	1	all	0.565	0.185	**-0.70**	<0.0001
	2	all	0.176	0.078	**-0.83**	<0.0001
	3	all	0.004	0.003	**-0.32**	0.0316
Whiting	0	all	1.339	0.383	**0.70**	<0.0001
	1	all	1.165	0.235	0.11	0.4728
	2	all	0.373	0.131	**-0.55**	<0.0001
	3	all	0.169	0.046	**-0.58**	<0.0001
Haddock	0	all	1.181	0.168	-0.13	0.3884
	1	all	1.252	0.297	-0.22	0.1553
	2	all	0.425	0.152	**-0.62**	<0.0001
	3	all	0.081	0.040	**-0.65**	<0.0001
Herring	0	all	1.118	0.242	**-0.35**	0.0178
	1	all	0.505	0.081	**-0.34**	0.0215
	2	all	0.238	0.059	0.12	0.4367
	3	all	0.171	0.049	0.11	0.4778
Sandeel	1	1+2	0.350	0.074	**-0.38**	0.0111
	2	1+2	0.336	0.076	**-0.41**	0.0054
	3	1+2	0.202	0.065	**-0.57**	<0.0001
	0	3+4	0.639	0.124	0.24	0.1089
	1	3+4	0.405	0.102	**0.37**	0.0112
	2	3+4	0.293	0.076	0.13	0.4101
	3	3+4	0.249	0.067	-0.07	0.6303
Norway pout	1	1+2	1.041	0.245	-0.08	0.6169
	2	1+2	0.844	0.232	0.19	0.2092
	3	1+2	0.750	0.230	0.20	0.1806
	0	3+4	1.101	0.185	0.14	0.3435
	1	3+4	0.674	0.170	**0.31**	0.0408
	2	3+4	0.524	0.152	**0.30**	0.0472
	3	3+4	0.436	0.157	**0.44**	0.0026

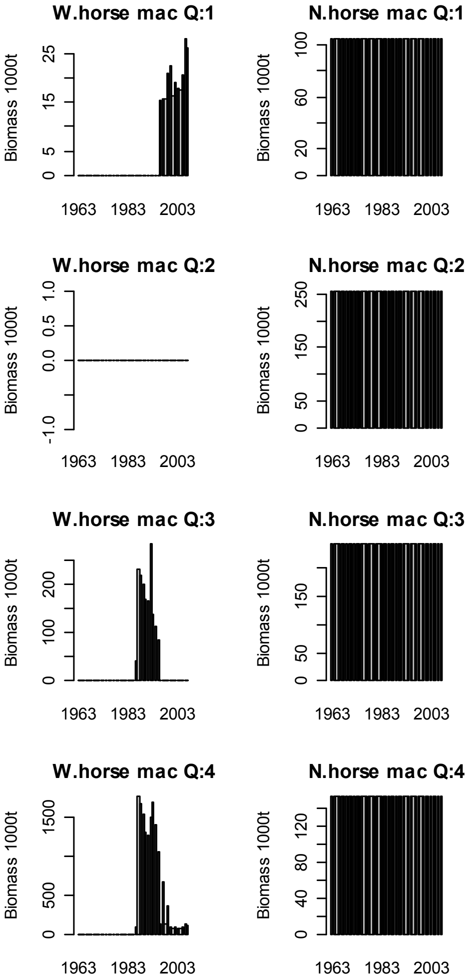


Figure 4.1. Estimates as used by SMS of the biomass of "other predators", Western horse mackerel and North Sea horse mackerel, present in the North Sea.

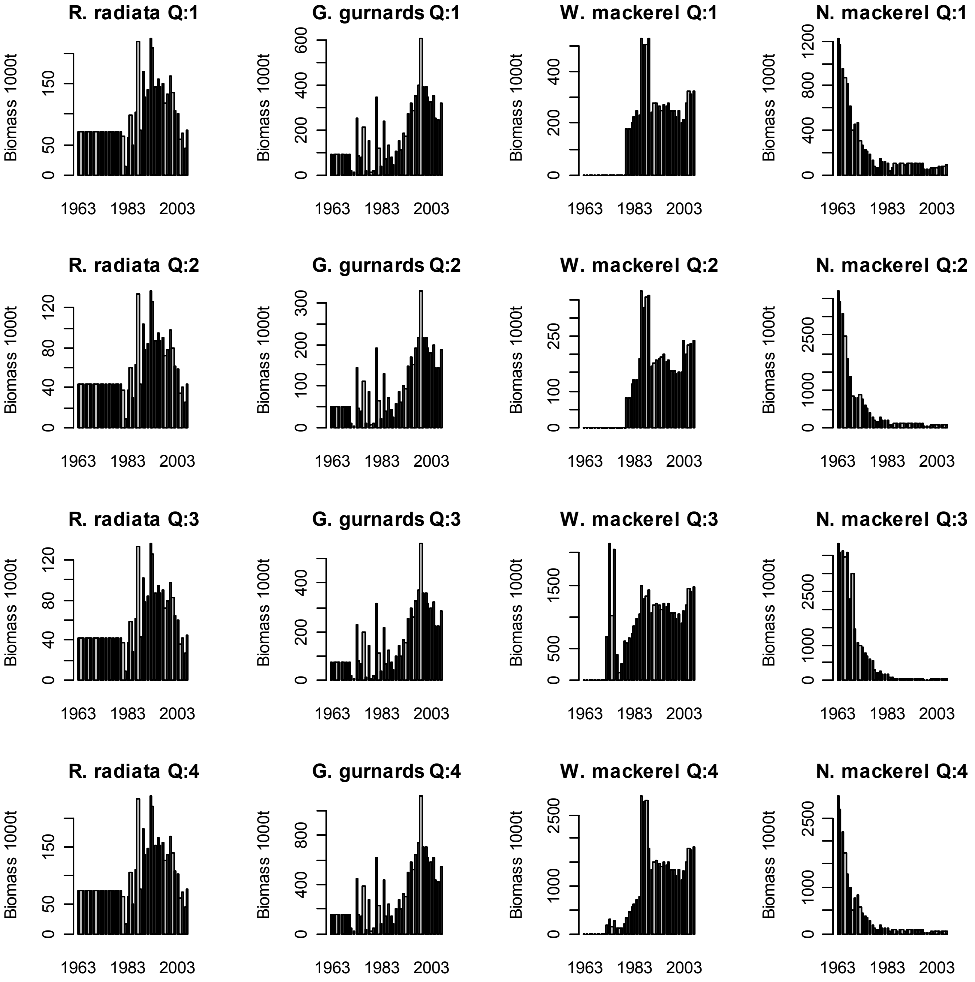


Figure 4.1 cont. Estimates as used by SMS of the biomass of "other predators": ***Raja radiata*****, grey gurnards, Western stock mackerel and North Sea mackerel, present in the North Sea.**

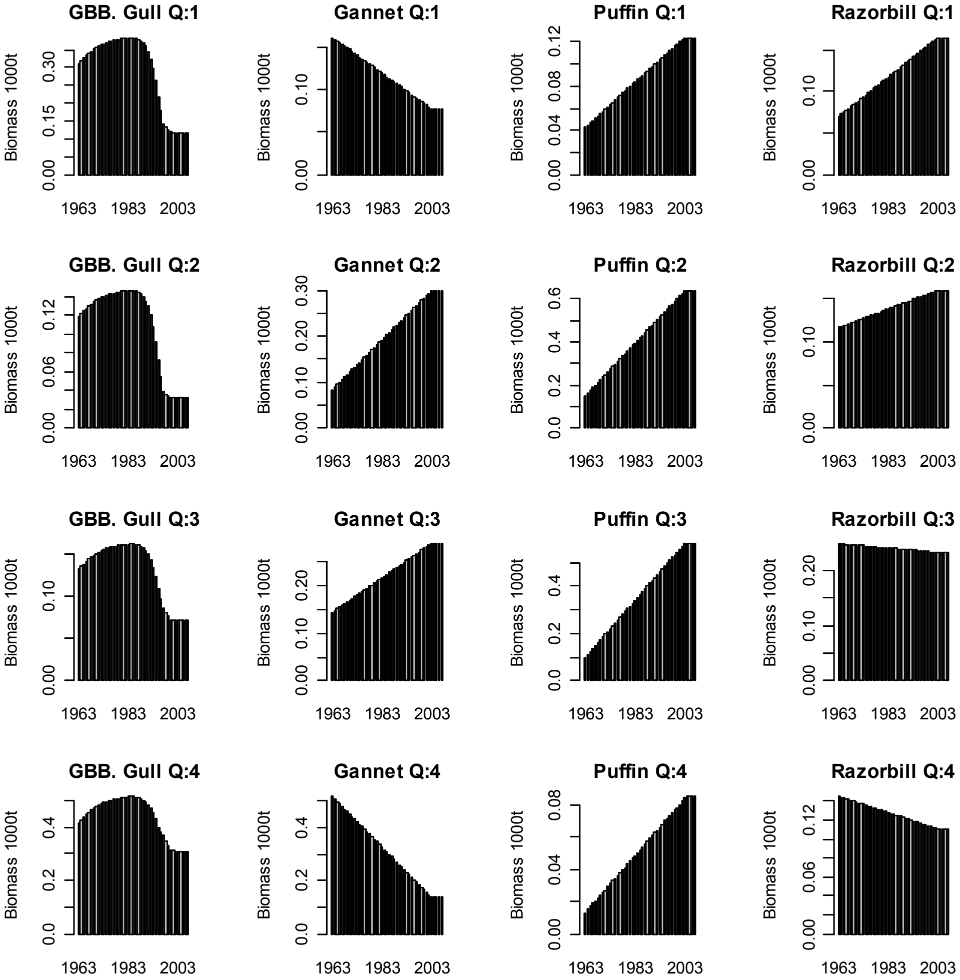


Figure 4.1 cont. Estimates as used by SMS of numbers (thousands) of "other predators": Great black-backed gull, Gannet, Puffin and Razorbill present in the North Sea.

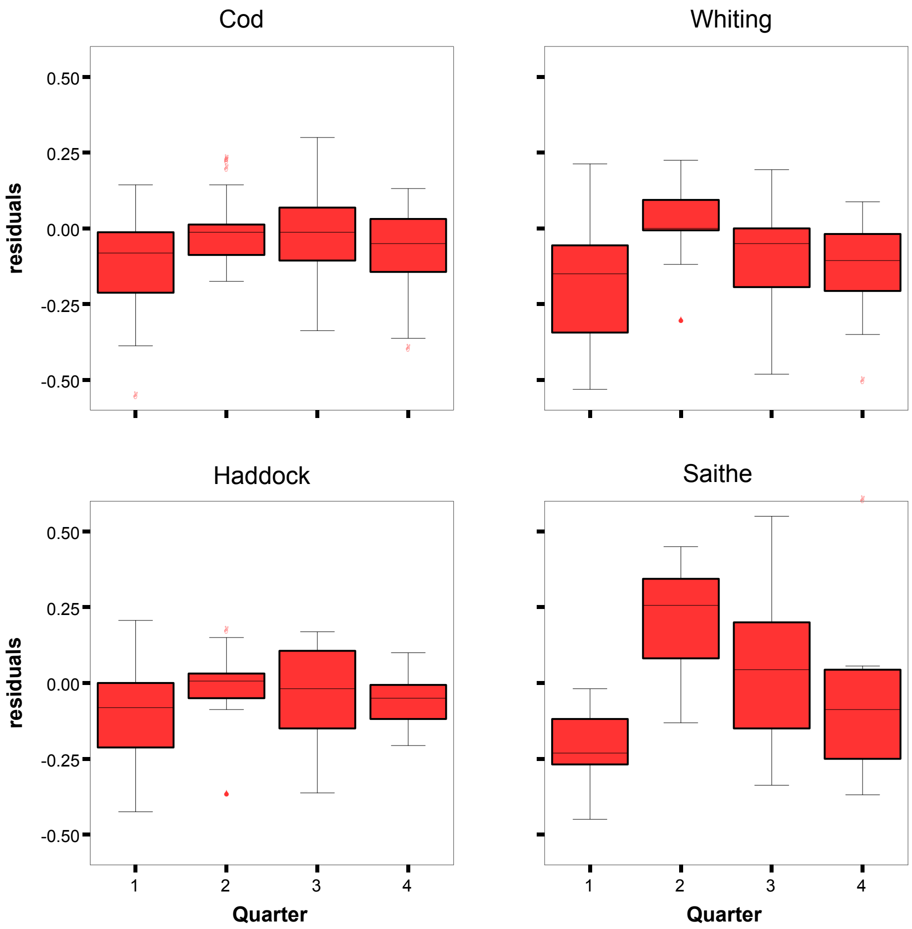


Figure 4.2. Seasonal pattern in the residuals of other food in the stomach contents of each of the four predators.

Figure 4.3. Examples of residuals of the stomach content of 'other food' as a function of the length of the predator species (in mm) gurnard, whiting and haddock in all four quarters (Q) before introducing a linear effect of length on suitability of 'other food'.

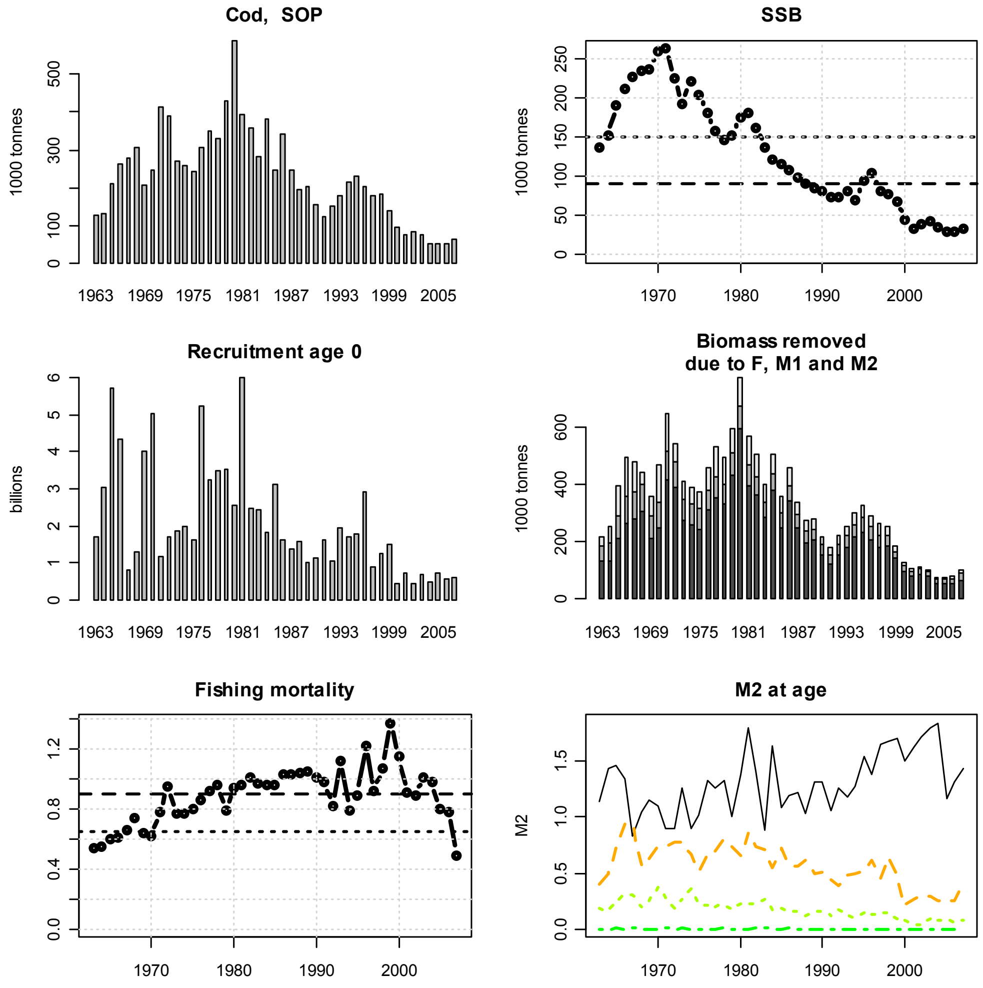


Figure 4.4. SMS output for cod. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black), predation by SMS species (M2, light grey) and residual natural mortality (M1, dark grey). The predation mortality (M2) on age 0 (solid black), age 1 (hatched orange), age 2 (dotted green) and older ages. Predation mortality (M2) on the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

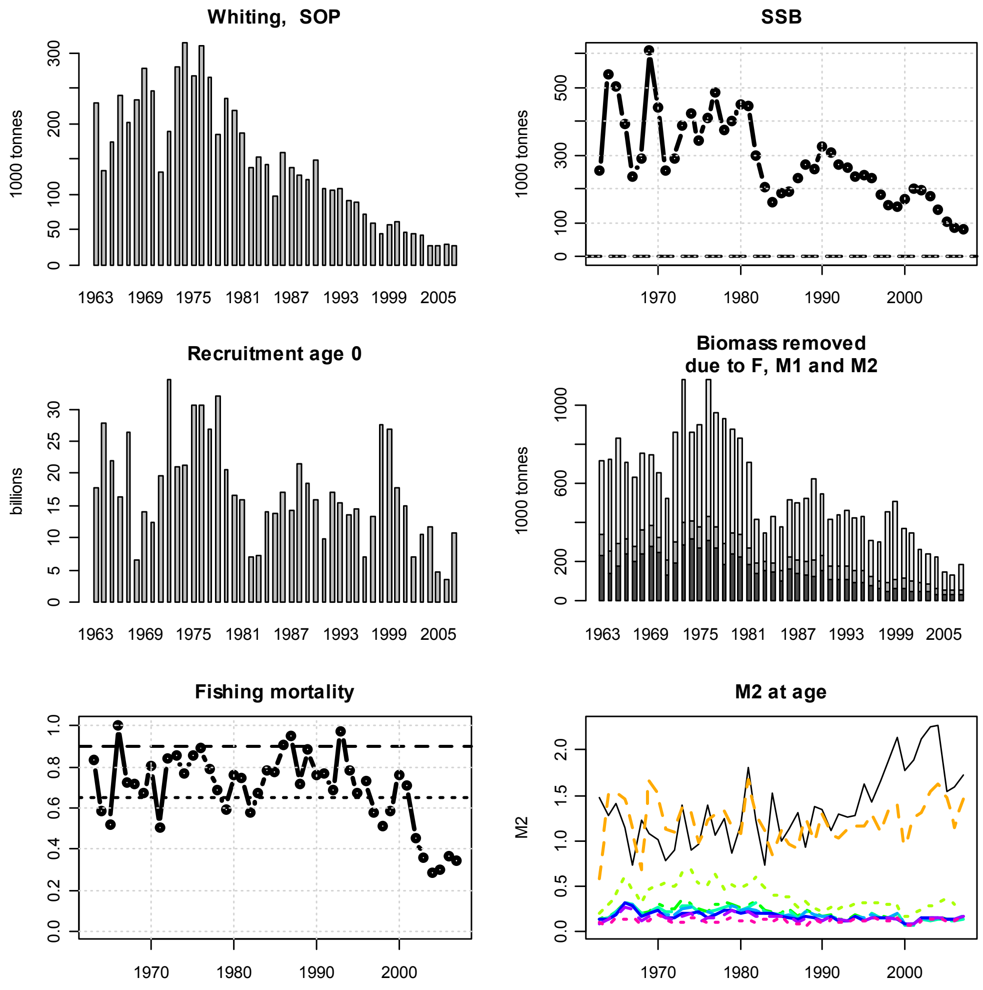


Figure 4.4 cont. SMS output for whiting. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black), predation by SMS species (M2, light grey) and residual natural mortality (M1, dark grey). The predation mortality (M2) on age 0 (solid black), age 1 (hatched orange), age 2 (dotted green) and older ages. Predation mortality (M2) on the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

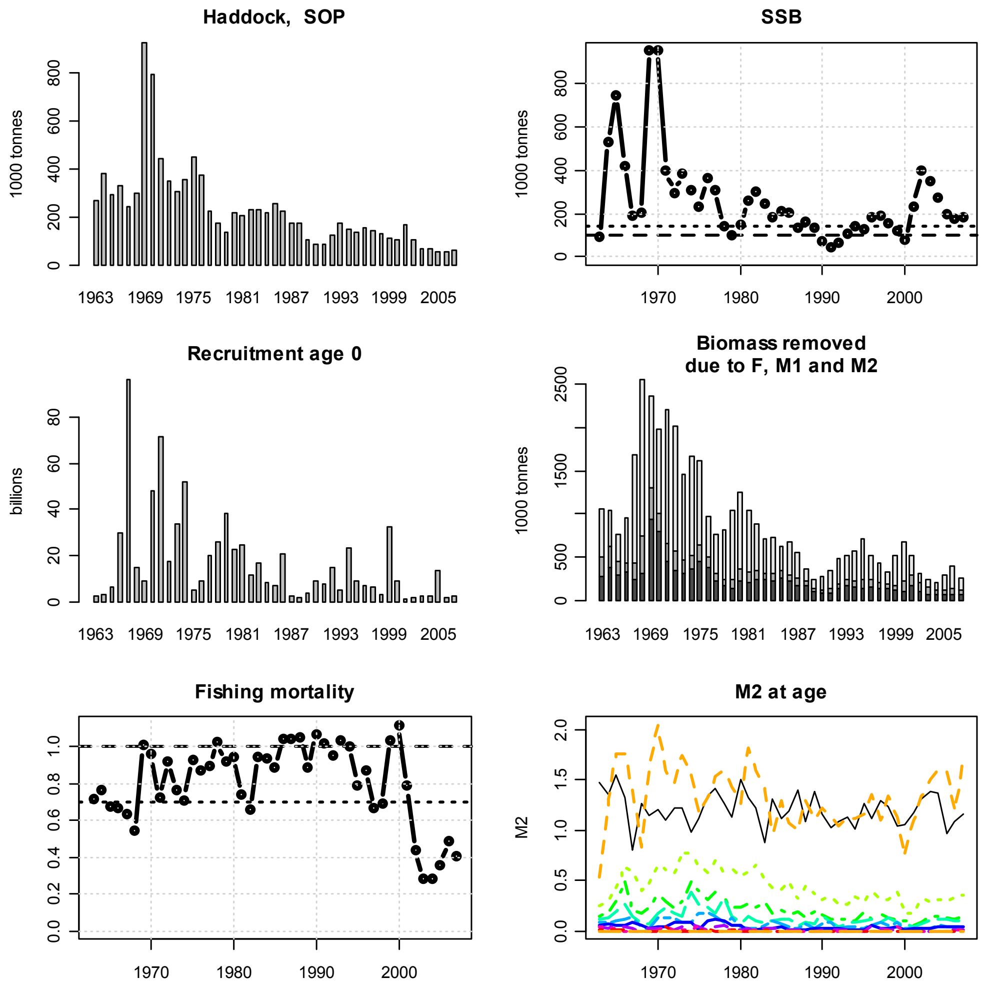


Figure 4.4 cont. SMS output for haddock. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black), predation by SMS species (M2, light grey) and residual natural mortality (M1, dark grey). The predation mortality (M2) on age 0 (solid black), age 1 (hatched orange), age 2 (dotted green) and older ages. Predation mortality (M2) on the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

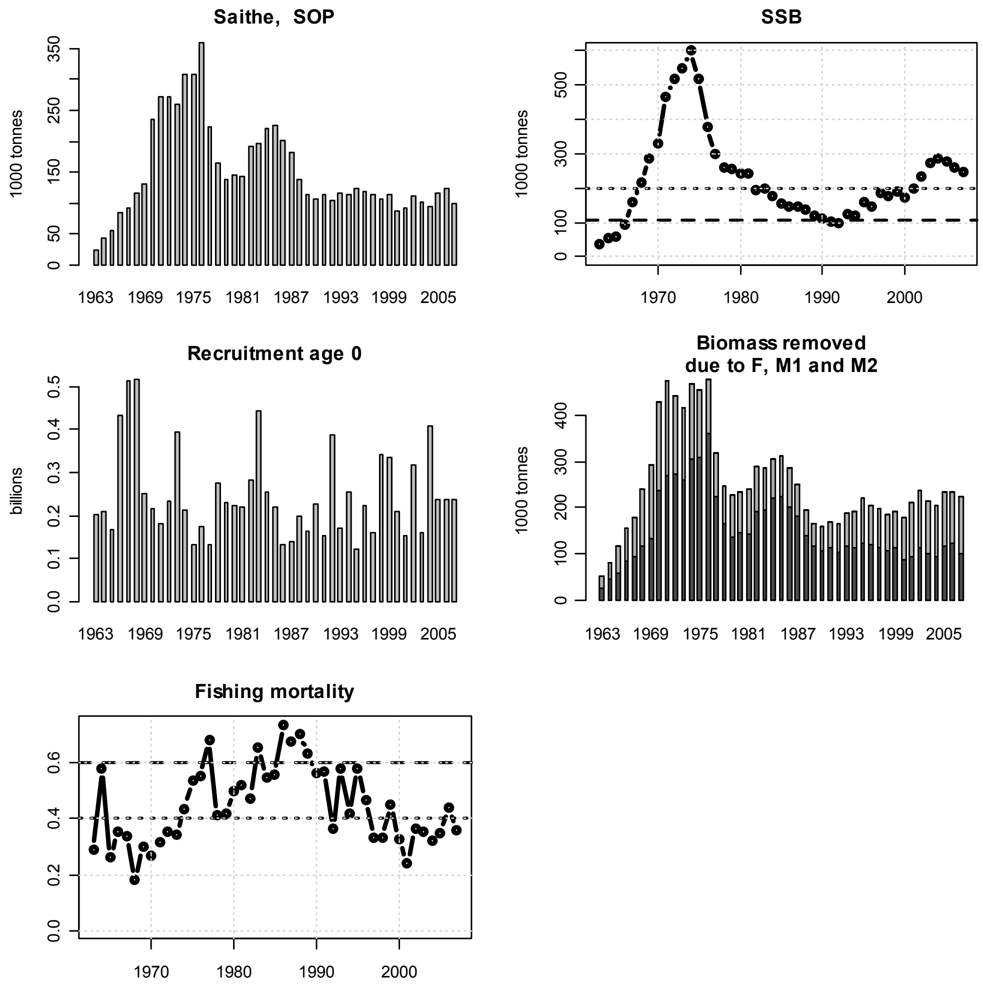


Figure 4.4 cont. SMS output for saithe. SMS output for cod. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black) and residual natural mortality (M1, dark grey).

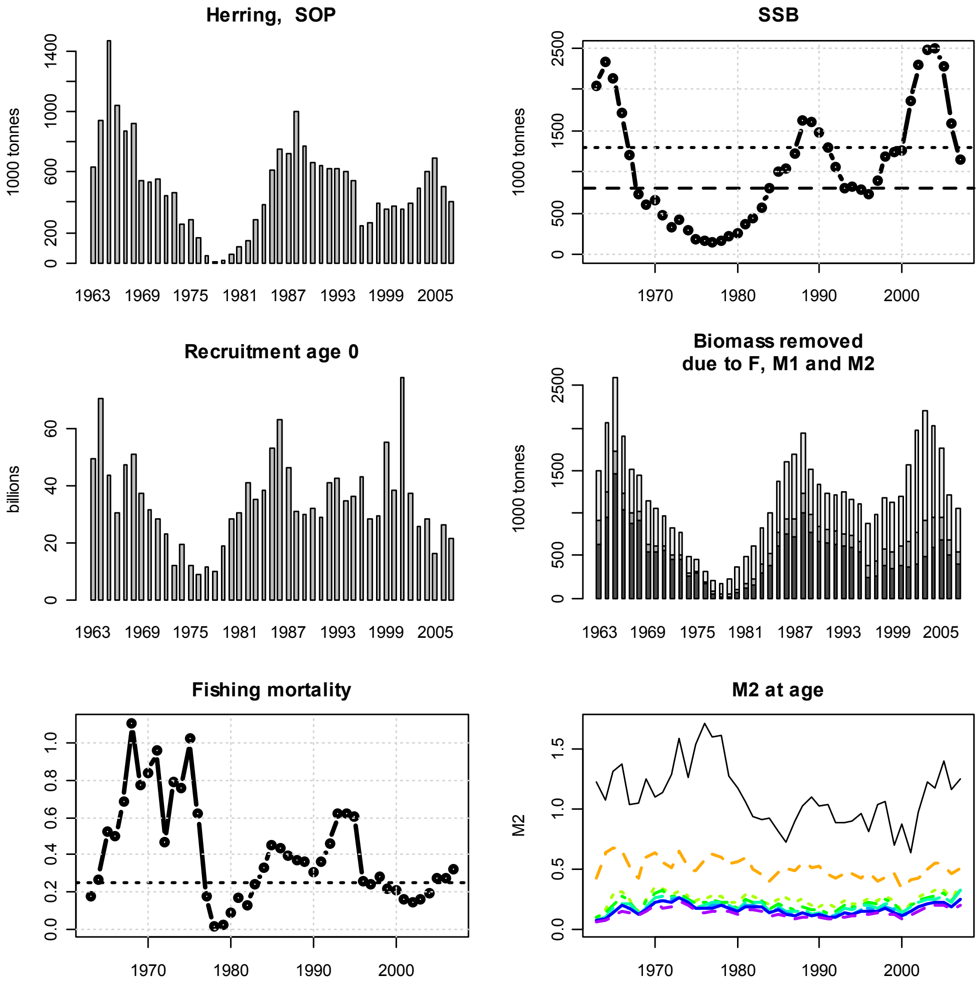


Figure 4.4 cont. SMS output for herring. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black), predation by SMS species (M2, light grey) and residual natural mortality (M1, dark grey). The predation mortality (M2) on age 0 (solid black), age 1 (hatched orange), age 2 (dotted green) and older ages. Predation mortality (M2) on the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

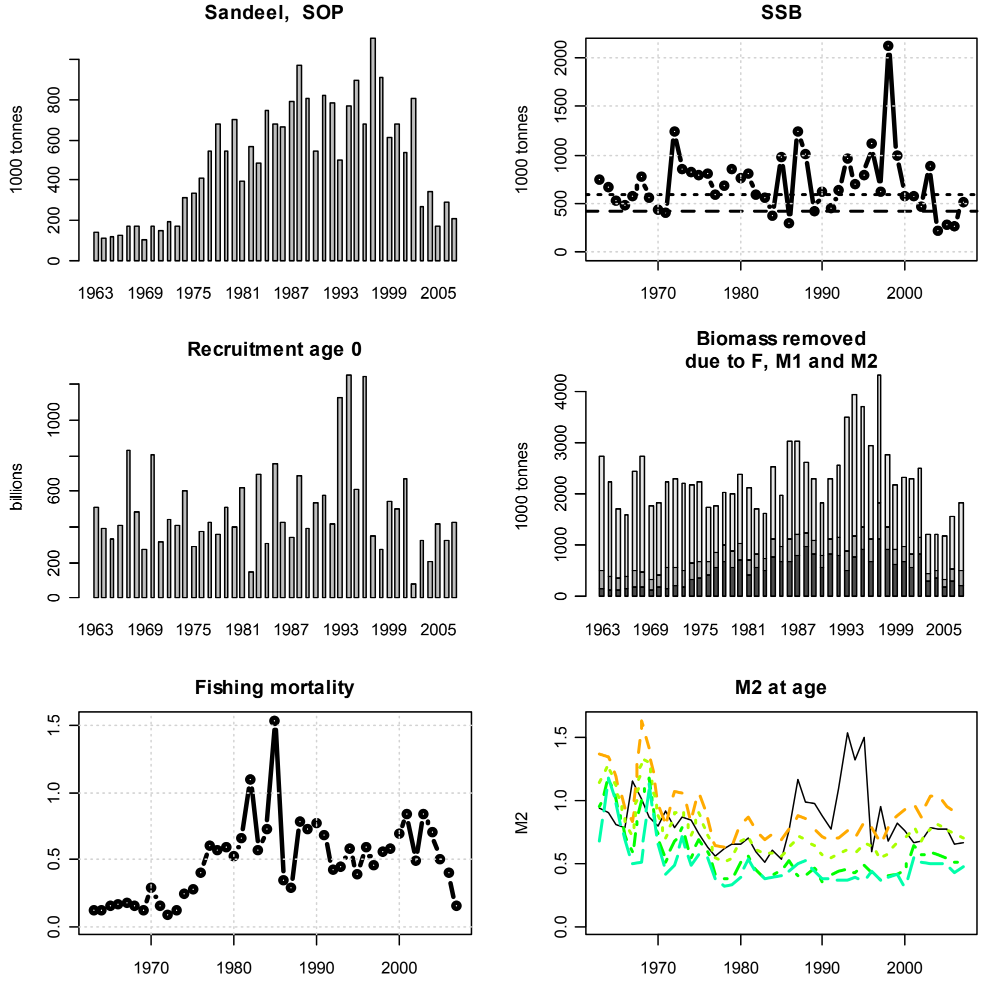


Figure 4.4 cont. SMS output for sandeel. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black), predation by SMS species (M2, light grey) and residual natural mortality (M1, dark grey). The predation mortality (M2) on age 0 (solid black), age 1 (hatched orange), age 2 (dotted green) and older ages. Predation mortality (M2) on the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

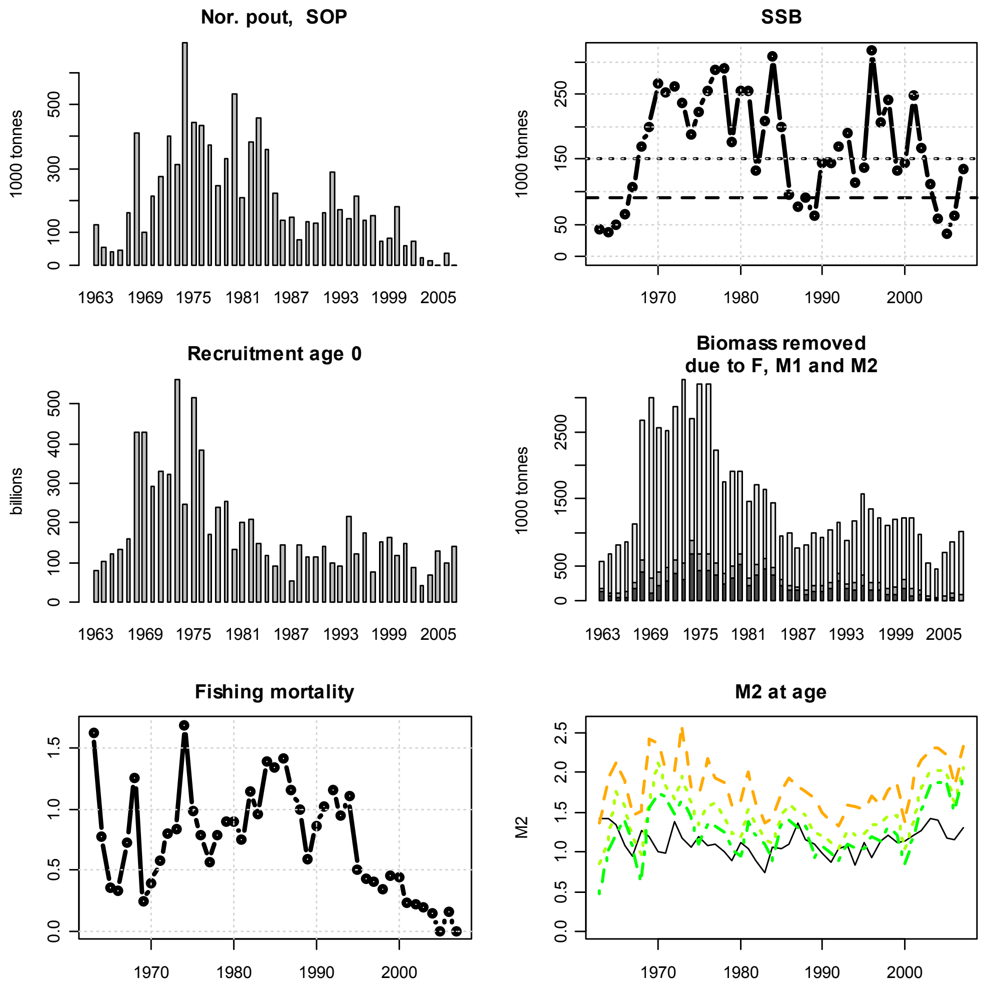


Figure 4.4 cont. SMS output for Norway pout. SOP (catch numbers * catch weight), Recruitment, F, SSB, Biomass removed due to fishery (F, black), predation by SMS species (M2, light grey) and residual natural mortality (M1, dark grey). The predation mortality (M2) on age 0 (solid black), age 1 (hatched orange), age 2 (dotted green) and older ages. Predation mortality (M2) on the 0-group (black solid line) is for the second half of the year. The M2 for the rest of the ages are annual values.

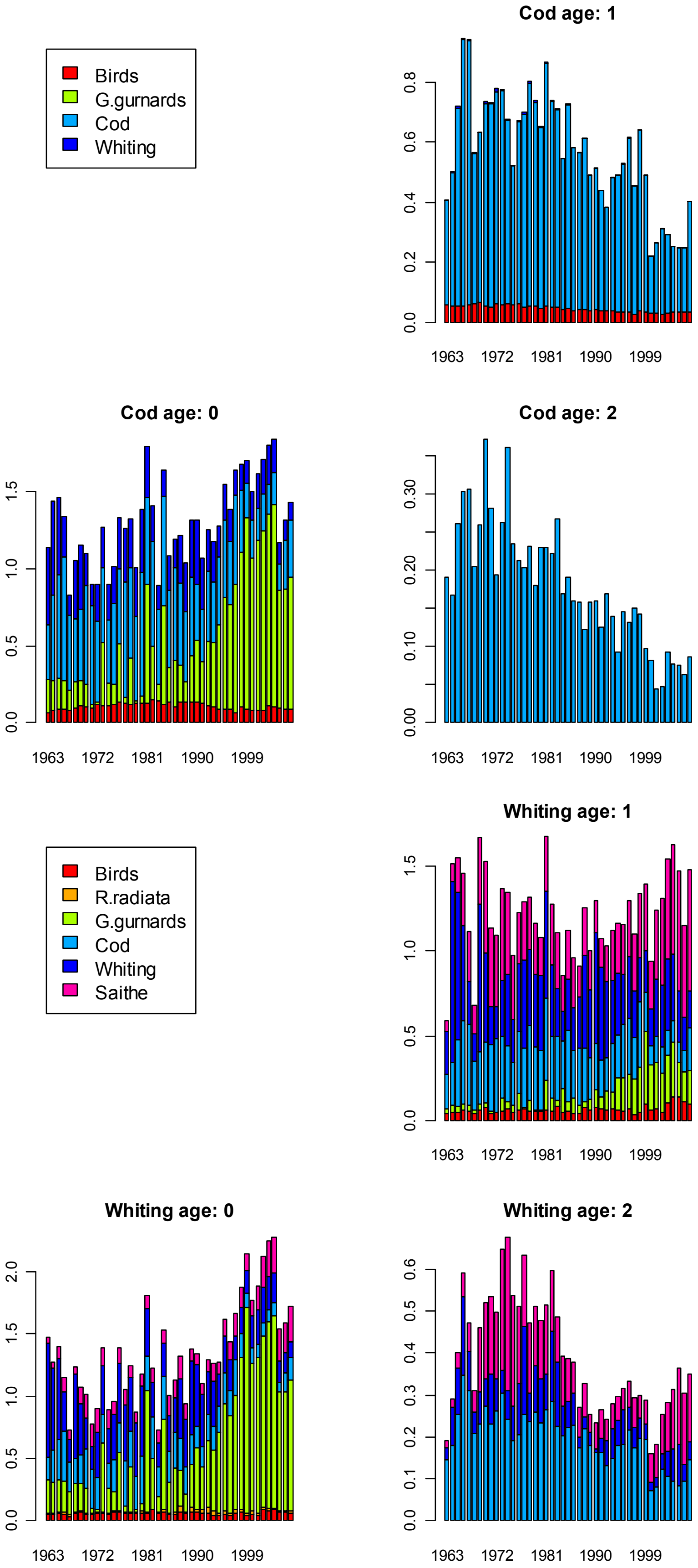


Figure 4.5. Distribution of predation mortality (M2) inflicted on each prey species and age.

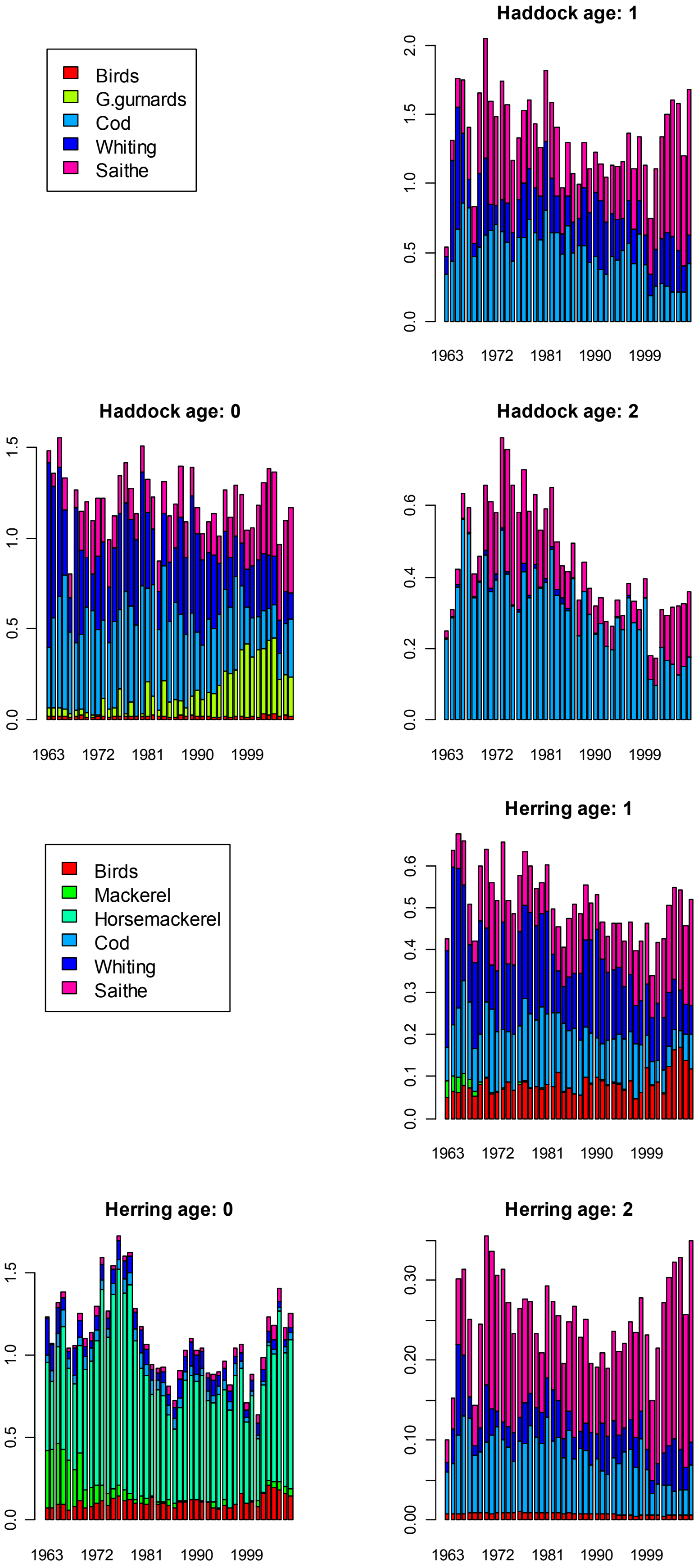


Figure 4.5 cont. Distribution of predation mortality (M2) inflicted on each prey species and age.

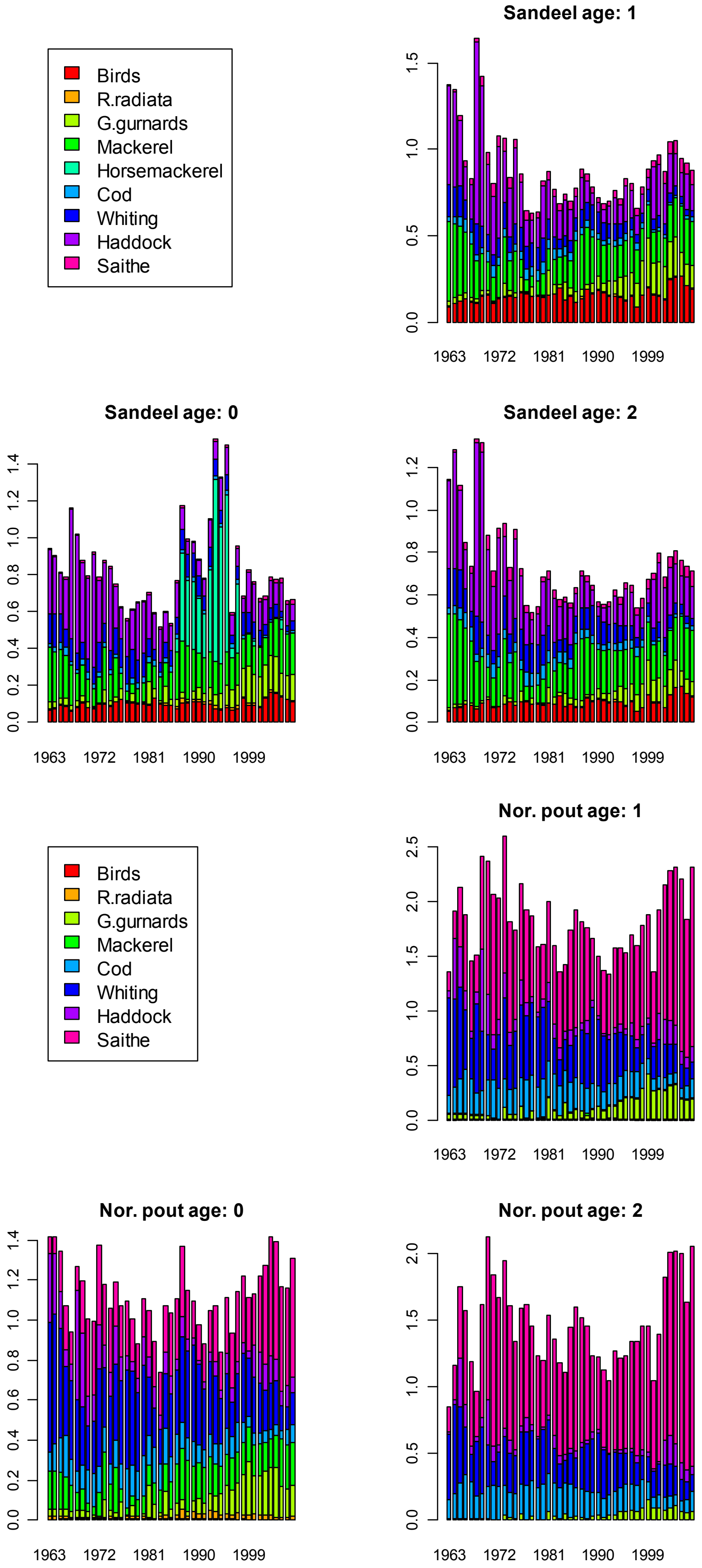


Figure 4.5 cont. Distribution of predation mortality (M2) inflicted on each prey species and age.

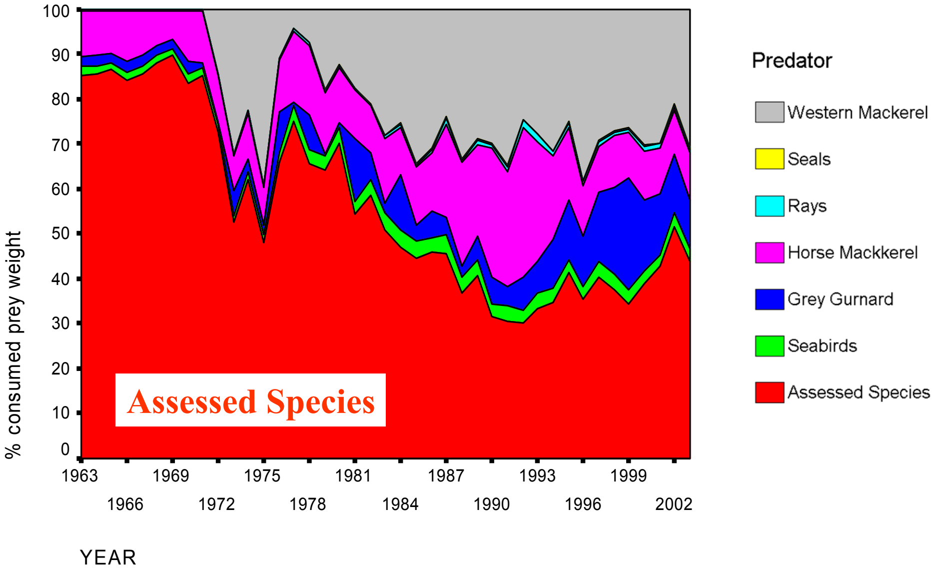


Figure 4.6 Comparison between assessed and non-assessed predator species according to the proportion of total prey biomass consumed (based on results of the 4M key-run from 2003).

4.2 Baltic Sea

4.2.1 Overview

The multispecies assessment for the Central Baltic Sea has been updated using SMS. SMS is a stochastic multispecies model describing stock dynamics of interacting stocks linked together by predation. It operates on annual or seasonal time-steps. SMS uses maximum likelihood to estimate parameters and the total likelihood function consists of four terms related to observations of international catch at-age, survey cpue, stomach contents observation, and a stock-recruitment (penalty) function.

The model developed is both age and size structured. The catch model is age-structured so that it can accommodate information prepared for conventional stock assessments, while the food preference model is size based because preference depends on size rather than age. This could also be said about fishery mortality as well, but catch data by size classes was not available for the Baltic Sea. The mixed age-size structure implies that data by age groups are transformed to sizes using age-length keys.

Uncertainties of parameters and output variables are estimated from the Hessian matrix, or alternatively using the Markov Chain Monte Carlo (MCMC) methodology. The model was run with cod as the only predator species and cod (cannibalism), herring and sprat as prey. 'Other food' was considered to be available at a constant biomass.

The major difference of this key-run to earlier key-runs for the Central Baltic is that Gulf of Riga herring was not included for 2005 to 2007, i.e. the last three years of the analysis. This is partly because cod is almost not occurring in the Gulf of Riga, and partly because quarterly catch at-age data could not be made available for the working group.

4.2.2 Input data

4.2.2.1 Stock and catch data

The stock units utilized in the present SMS analysis for the Central Baltic are: i) cod in Subdivisions 25–29 +32, ii) sprat in Subdivisions 25–32, and iii) herring in Subdivisions 25–29, 32 (Gulf of Riga included only in 1974 to 2004).

Cod and sprat

As the sprat population in Subdivisions 30 and 31 is rather low (landings are less than 5000 t in most recent years), the stock estimate is basically referring to Subdivision 25–29 +32.

To estimate the predation mortality on these stocks, the cod assessment unit was adjusted accordingly, thus not considering part of the stock in Subdivision 30 and 31. Landings reported in these Subdivisions are in general less than 1% of the total catch from the Central Baltic. Consequently the effect of ignoring the two Subdivisions should not hamper a direct comparison between single species and multispecies assessment output. For sprat, the multi- and single species assessment units are not directly comparable, as the sprat stock in the entire Baltic including subdivision 22–24, is treated as a single-stock unit in single species assessment.

Herring in Subdivisions 25–29 and 32

The ICES stock assessment of Central Baltic herring has been made on the basis of 3 different sub-units:

- • Herring in the SD 25–29 and 32 including Gulf of Riga;
- • Herring in the SD 25–29 and 32 excluding Gulf of Riga;
- • Herring in the Gulf of Riga.

This was done due to the complexity of stock structure and because the stock development trends in the Gulf of Riga and in SD 25–29 and 32 is opposite. ACFM advice is based on assessments of Herring in SD 25–29 and 32 excluding Gulf of Riga, and separately Herring in the Gulf of Riga.

The ICES Study Group on Multispecies Assessment in the Baltic Sea, SGMAB (ICES 2005) tended to use the main basin herring data, that is Herring in SD 25–29 and 32 including Gulf of Riga. Tests have been performed (ICES 2005) using data of the herring stock in SD 28 in– and excluding Gulf of Riga. However, it was not possible to compile the new set of quarterly dis-aggregated data for herring in the SD 25–29 and 32 excluding Gulf of Riga for the entire time-series. For the years before 2005 the total herring catches were reused, instead.

Input data to SMS

These are given by quarter of the year. This time-step was also used by ICES SGMAB (ICES 2005) and input to SMS was as far as possible copied from this SG. Such data by year, quarter and age include:

a) catch number
b) catch mean weight
c) proportion mature,
d) mean weight in the sea,
e) food consumption (ration)

f) M1 (residual natural mortality)

4.2.3 Survey cpue data

Survey indices at-age were copied from ICES single species assessment reports (ICES 2008, WGBFAS report). These time-series includes cpue indices from the commercial fishery, but as the commercial tuning data are also included in the catch data, the two sets are strongly correlated, which might bias the parameter estimate. The commercial cpue series were not used by SMS.

4.2.4 Stomach contents data

Stomach content data spanning 1977–1993 have previously been compiled for use in the age-based MSVPA and are used by SGMAB. The collation of a national stomach content dataset into one set for multispecies assessment has mainly been carried out by DIFRES and the result published in ICES papers (e.g. ICES 1991/J:30; ICES 1989/J:2; ICES 1990/Assess:25 and ICES 1993/J:11). Data and most of the software are still available at DIFRES. The existing software was initially applied in order to extract stomach data for SMS, which requires stomach content by predator and prey length group, and not by ages as used in MSVPA. This should theoretically be possible as prey data were originally collected by length group (1 cm groups) and thereafter transformed into ages (ICES 1993/J:11).

A closer inspection of this “intermediate” dataset by length groups showed however an odd length distribution of the preys. The original data from the period 1977–1980 were in most cases sampled by 5–10 cm classes for the preys. These size classes were transformed to one cm groups assuming a size distribution as in the sea and an estimated size selection function (ICES 1993/J:11). For later years, preys were measured to the nearest cm when possible. The combination of observed and estimated data resulted in many cases in a very odd length distribution, which could not be used by SMS to fit the prey size selection. Therefore a new data collation exercise was carried out using the “raw” stomach data.

4.2.4.1 Errors in “number of stomachs” previously used

A few errors in the previous version of stomach data were spotted in the re-compilation of data. When data were exchanged in “table format” for the initial sampling years, values in the table supposedly gave number of stomachs investigated and proportion empty, but in reality gave the number of ‘full’ stomachs, not the total number examined. This was only a problem where ‘pooled’ data were included in the database, as opposed to information from individual predator stomachs.

Example USSR, 1978, Q4, subdivision 26

a) length-group 21–25 cm, number stomach investigated: =5, proportion empty=0.29

5 full + 2 empty = 7; proportion empty 2/7=0.2857~0.29

b) length-group 26–31 cm, number stomach investigated=7, proportion empty=0.50

7 full + 7 empty = 14; proportion empty 7/14=0.5

In the previous compilation of data (ICES 1993/J:11) and that later used in MSVPA, it had been assumed that the “number of stomach investigated” included empty stomachs. However only half of all available stomachs (Poland, USSR, Latvia and GDR) were reported on the “table format” and bias in population mean stomach content might be heavily impacted.

When stomach data were given by individual stomachs (Denmark, Sweden and Germany) the previous compilation software correctly counted the number of empty and stomachs with food.

4.2.4.2 Re-compilation of stomach content data

Due to the mix of observed and estimated, and the wrong number of stomachs assigned to each sample, it was decided to abandon most of the original software for data compilation and repeat the task in a more suitable way for SMS.

Data compilation was done in two major steps:

1) Transform observations into a new exchange format similar to the one used in the North Sea (ICES Cop. Res. Rep. No. 219, 1997);

2) Aggregation of national data (at the common exchange format) into a dataset usable by SMS.

4.2.4.3 Standardisation of cod size classes

In the stomach database the length classes of cod have not been standardized between countries and hence for 1977, quarter 1 for example, the following disparate classes have been used:

26–31 cm,

26–35 cm,

31–35 cm,

36–40 cm,

36–45 cm

41–50 cm,

46–55 cm

Input to SMS is stomach content by distinct size class common for all observations within a given year and quarter. Therefore, the nationally defined size classes had to be standardized before they could be aggregated. Where one size class was as true subset of another, they were combined into one. (e.g. 26–31 + 26–35 + 31–35 = 26–35) "Odd" size classes were renamed to the nearest size class (e.g. 36–40 + 36–45 + 41–50 = 36–45). The standardization was carried out for each year individually such that the number of size classes remained high with as small amount of renaming as possible.

4.2.4.4 Weighting of stomach data by subarea

SMS uses stomach contents data by size classes for the whole Baltic Sea area. However, stomachs have been sampled and compiled for each subarea individually. To calculate a mean stomach contents by size class it is necessary to weight the mean stomach content data by subarea by the proportion of the stock thought to exist within the particular subarea.

Previous work by Sparholt *et al.* (ICES CM 1993/J:11) includes proportion (PRPOP) in the various subareas of the total cod stock in the Eastern-Baltic by age and quarter (these data are from research vessel data 1982–1989 and GLM analysis). Sparholt *et al.* (ICES 1993/J:11) also included cod mean length and standard deviation by age and quarter for the cod stock (derived from RV DANA surveys 1981–1988). These data were used to produce an age to length conversion key (ALK). Output from the 4M model produced by SGMAB (ICES 2005) give total stock numbers by age and quarter (N), such that the weighting factors (W) could be calculated.

$$W_{l,q,s} = \sum_{a} N_{a,q}\ PROP_{a,q,s}\ ALK_{a,l,s}$$

4.2.4.5 Treatment of "unidentified clupeids"

'Unidentified clupeids' in the stomach data were redistributed among sprat and herring according to their presence in the basic stratum (cod length, subdivision, year, quarter).

Alternatively by allocation keys based on the stratifications:

1) cod length, ICES SD, year
2) cod length, ICES SD,
3) cod length
4) all data

When allocation keys included more than one subdivision, the keys were based on a weighted average of the content within the basic strata using the proportion of the stock within the area as weighting factor. Length information of 'unidentified clupeids' were available in a very few cases, and so ignored in the data compilation.

4.2.4.6 Definition of prey size classes for herring and sprat

Prey sizes were mainly recorded by 5 cm groups for the period 1977–1981. In cases where data were given by smaller length classes they are allocated to the relevant 5 cm group.

Data for the period after 1981 were given by 1 cm class, which were maintained for sprat in the compilation. Herring preys were compiled by 2-cm groups.

4.2.4.7 Estimation of missing prey size for herring and sprat

Preys without size information were thereafter allocated to size classes according to their observed distribution in the stratum (cod length, prey, subdivision, year and quarter) or if data were unavailable according to the observed data in more widely defined strata:

1) cod length, prey, ICES SD and quarter
2) cod length, prey and ICES SD,
3) cod length and prey

When allocation keys included more the one subdivision, the keys were based on a weighted average of the content within the basic strata using the proportion of the stock within the area as weighting factor. The prey size classes were different for the two periods 1977–1981 and 1982–1995 and data were compiled separately.

4.2.4.8 Estimation of size distribution of cod as prey

Cod as a prey were originally not considered important in the initial period of the stomach samples and not reported routinely, thus they were not subject to the same data aggregation and 'pooling' problems as herring and sprat.

4.2.4.9 Prey mean size in the stomach

The size classes used for preys were first transformed into a mean-length for the size class. For one cm-groups the mean of the range was used as mean length. It was assumed that the prey mean length of five cm-groups followed the size distribution in the sea, which were estimated from 4M stock numbers and mean length and StD by age (see later section on prey ALK).

Mean weight per prey mean size was calculated from a length weight relation: $W=a*L^b$ (W in kg; L in cm)

Species	a	b
Cod	8.7E-9	3
Herring	4.9E9	3.089
Sprat	6.4E9	3.0

4.2.5 Age to Length Keys (ALK) and mean length at-age in the sea

ALKs were required for years with stomach content observations, and were calculated based on mean length at-age (ml) and the standard deviation (StD) of the length distribution at-age. Cod mean length at-age were copied from Table 5 in ICES 1993/J:11 (Based on RV DANA surveys in subdivision 25, 2 and 28 in 1981–1988). Sprat data were copied from Table 9 in ICES 1993/J:11 (based on Polish data on commercial catches in subdivision 25 and 26 in 1977–1989). Herring mean length at-age data were available from the same source, and were presented in 3 tables:

1) Table 6: Mean length at-age and quarter in subdivision 26 in 1985–1989 from Swedish hydroacoustic surveys and Polish commercial data)
2) Table 7: Conversion factors to get length at-age for 1977–1980 and 1981–1984 from length at-age 1985–1989, based on Polish commercial catches.
3) Table 8: Difference in mean length at-age of herring between subdivisions.

Stock numbers from an area disaggregated 4M run (ICES 2005) were used to weight the area specific length data calculated from table 6–8 input. Mean length estimated for herring in 1989 were copied to the period up to 1994. To avoid insignificant and unrealistic length observations, only data from a truncated normal distribution (ml ± 3*StD) were used.

4.2.6 Results

The summary output is presented in Figures 4.7–4.9.

Herring predation mortalities appeared to increase slightly in 2005 to 2007 (Figure 4.8). This was probably an effect of excluding the Gulf of Riga in this period. This is, however, not an artefact in the sense that predation is over-estimated in the last 3 years of the assessment, but that predation is probably under-estimated in the years before. Excluding the Gulf of Riga herring also for previous years would probably increase predation mortality estimates for herring for the earlier period.

On the other hand, the cod stock actually has increased slightly since 2004 (Figure 4.7), which resulted in an increased predation on sprat (Figure 4.9). Again, this effect is probably amplified by the exclusion of Gulf of Riga herring, which decrease the biomass of total available food, increasing the suitability for sprat as prey.

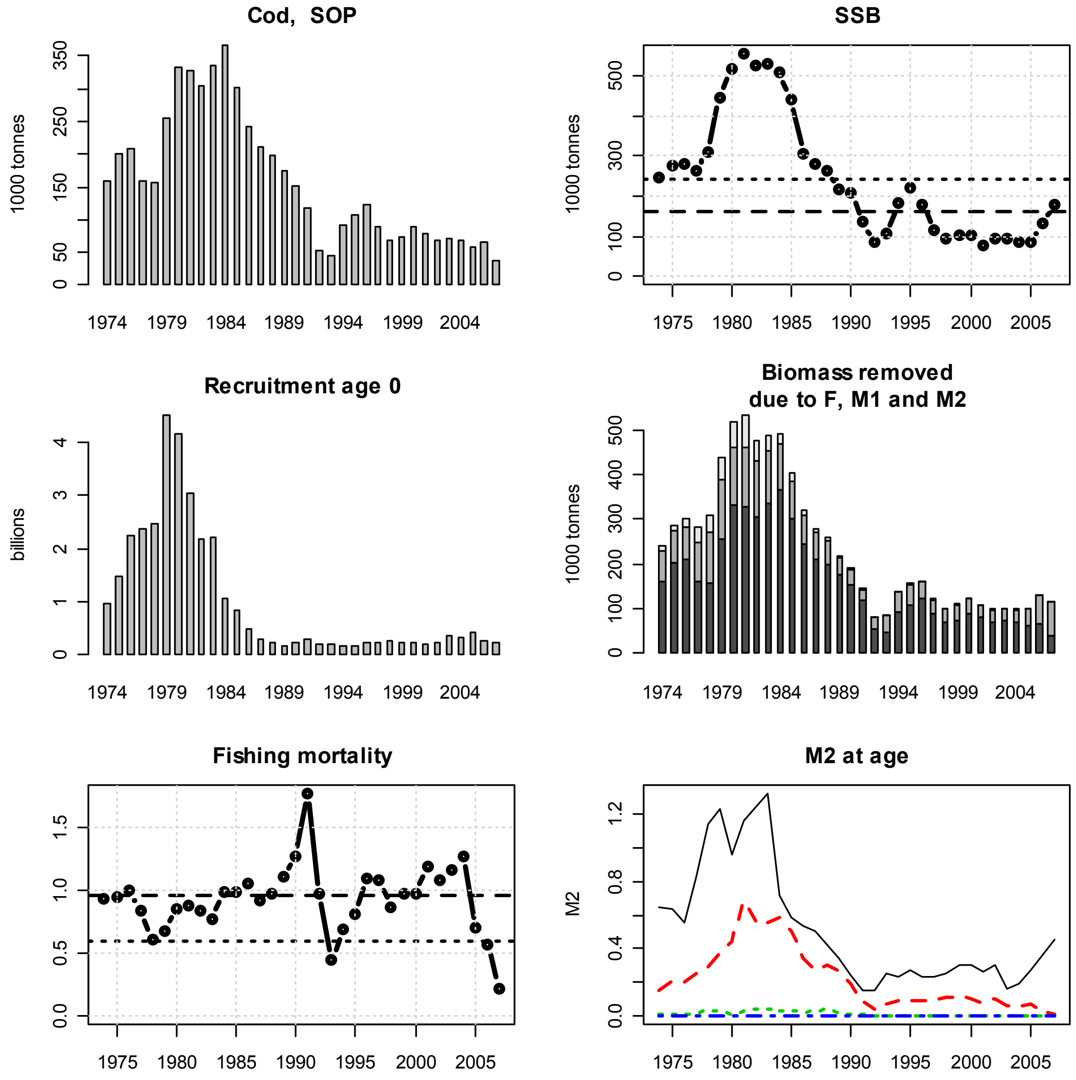


Figure 4.7. Summary output Central Baltic SMS: cod.

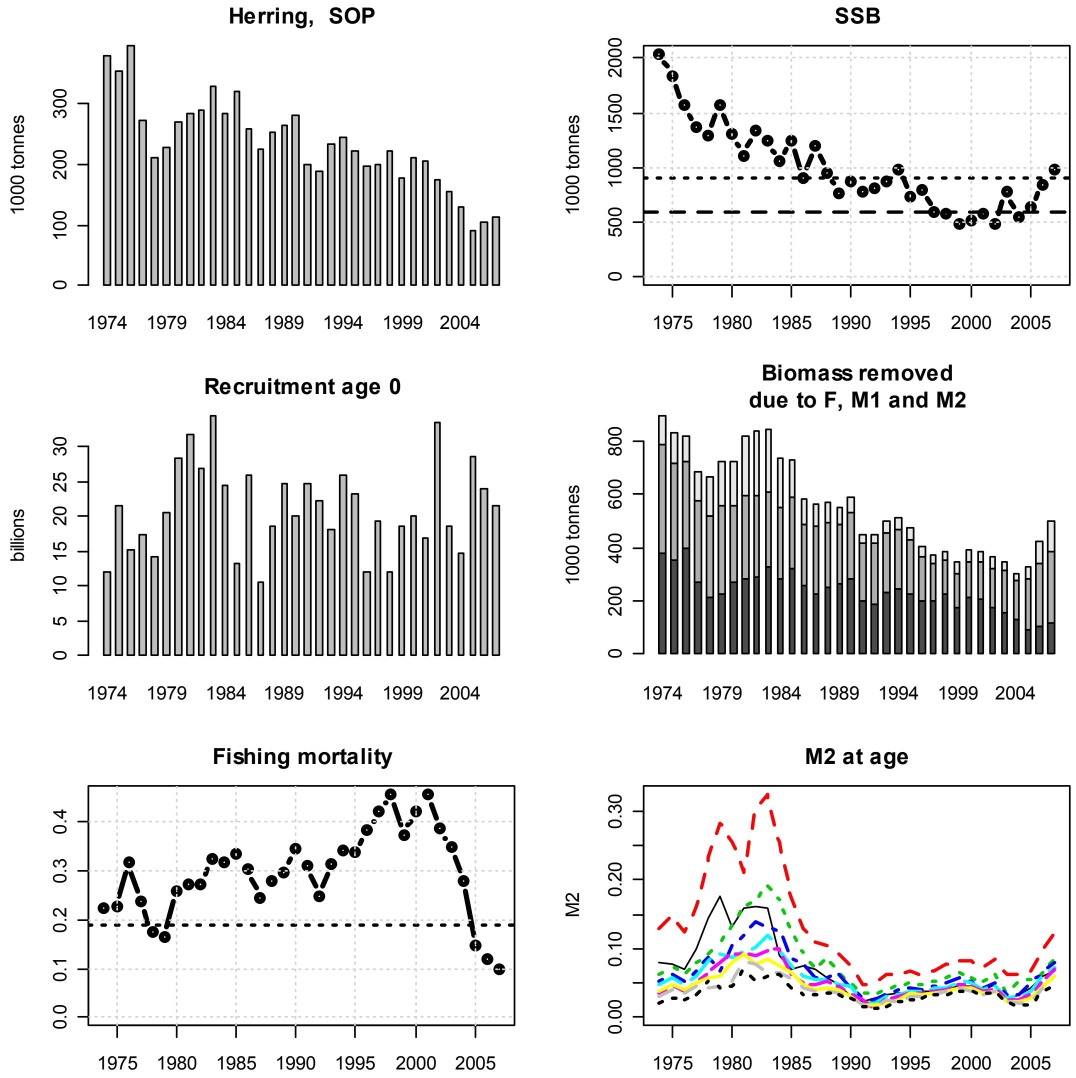


Figure 4.8. Summary output Central Baltic SMS: herring.

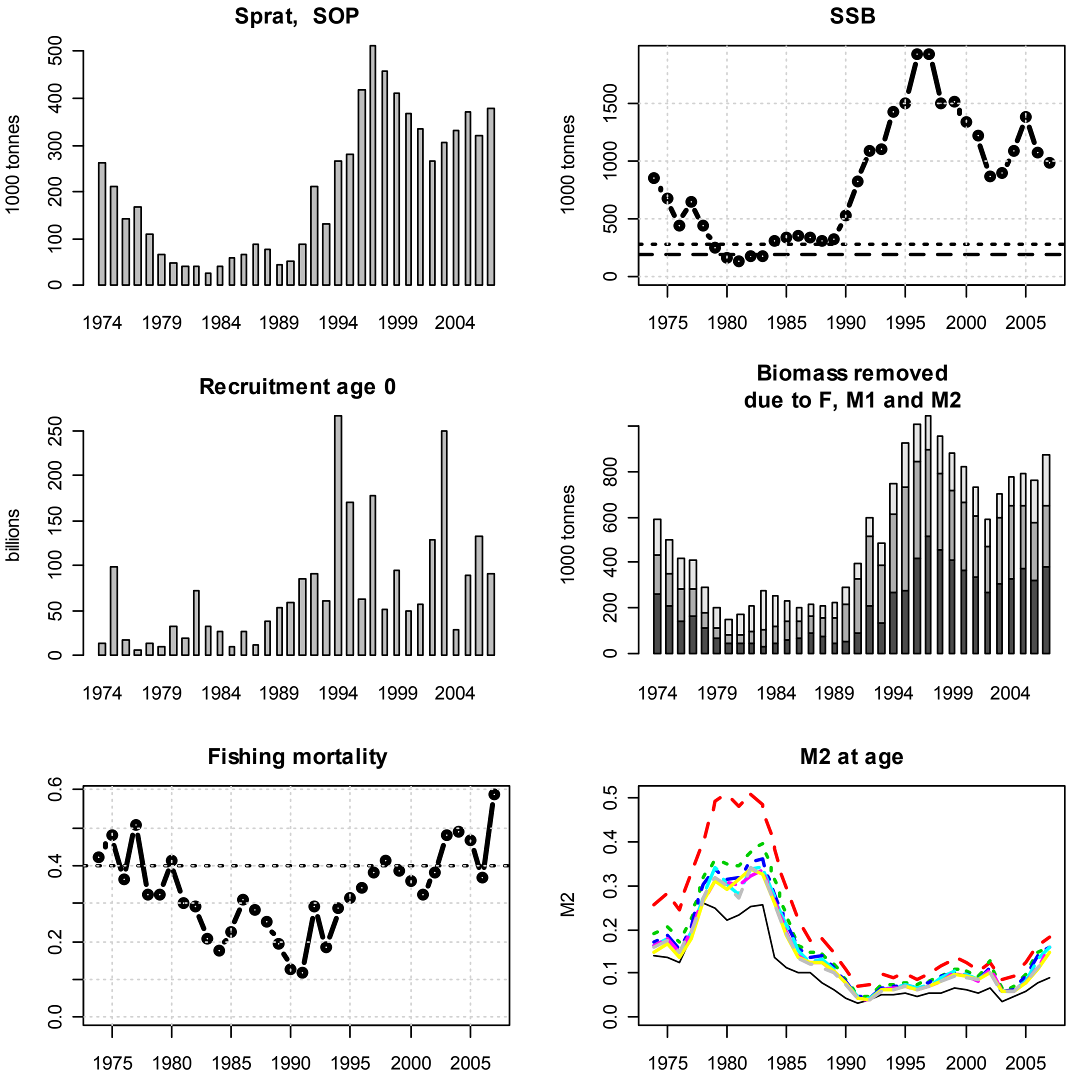


Figure 4.9. Summary output Central Baltic SMS: sprat.

4.3 Iceland

Most ``multispecies models'' constructed for Icelandic waters (using the BORMICON and GADGET approaches) have included 3 species; cod, capelin and shrimp. The reason for this relatively narrow scope is that the species have tended to be the most important ones in terms of commercial value. At the same time capelin has been by far the most important prey of cod and mean weight at-age of cod reduced by 20–30% in the period of low capelin biomass. The importance of capelin for cod has also been demonstrated by analyses of stomach content data and capelin is 45% of the content of all sampled cod stomachs since 1993 (160 thousand stomachs). The effect of cod predation on the capelin stock has not been included in capelin assessment although the amount consumed by cod is probably of the same order as the fisheries. In the cod assessment however, the amount of capelin has been used to predict mean weight at-age of cod. In the shrimp assessment the effect of predation by cod has also been included. The predation pressure exerted by cod on shrimp has turned out to vary significantly from year to year, and in the model the 'cod' term has been incorporated by including an index of cod abundance in the survey for deep-water shrimp. The spatial overlap between cod and capelin is also highly variable but less is known. Capelin is thought to migrate widely and is often distributed far from the Icelandic continental shelf.

The most recent version of the cod-capelin shrimp model is described in Taylor and Stefánsson (2004). This model was further developed during the BECAUSE project, and different levels of complexity in the spatial and stock structure were compared (BECAUSE final report 2007). The diet of cod is variable in space and time, including a large number of fish and invertebrate prey species. Little is known about the abundance of most invertebrates but more data tends to be available for other the fish preys (e.g. herring and blue whiting).

In recent years there have been short-term (1–2 year) increases in several important fish stocks in Icelandic waters. Among these stocks are haddock, herring, saithe and blue whiting. Of those fish blue whiting has been an important prey for cod according to stomach samples. The part of the blue whiting stock that migrates into Icelandic waters is variable from year to year and modelling it properly can be difficult. Blue whiting is not only an important prey for cod and saithe, but could also represent an important a predator on fish larvae and 0 group fish. The stocks of haddock, saithe and herring in Icelandic waters have all been relatively large recently and the effect of those stocks as predator and preys are probably large. Some information exists on the diet of haddock and saithe but little on the diet of herring, although herring are known to be an important predator on eggs and larvae elsewhere (e.g. Segers *et al.*, 2007).

Minke whales are also an important predator in Icelandic waters and stomachs sampled have demonstrated considerable prey switching with sandeel being the most important prey when they are abundant, but the low level of the sandeel stock in recent years may have lead to substantial change in spatial distribution and diet of minke whales. Sandeel is an important prey resource for saithe, haddock, cod, minke whales and many other species. In recent years increased effort has been put into research on sandeel. The reason for this increased research was that the recruitment failure of sandeel may be linked to nesting failure of birds such as puffin, that are of interest in Iceland both for commercial and for conservation purposes.

In the last two years, widely migrating stocks including mackerel and atlanto-scandian herring have been reported widely in Icelandic waters but how much there is of those stocks is not known. Blue whiting migrate to Icelandic waters for feeding and so they generally export energy from Icelandic waters, whereas capelin feed outside Icelandic waters and import the energy.

A future key-run using the GADGET framework should attempt to include the following species:

- Cod
- Capelin
- Shrimp
- Sandeel
- Haddock
- Saithe
- Herring
- Minke whale

- Blue whiting
- Puffin??? (as an indicator of sandeel).

Relevant data for most of the species is stored in relational databases at the MRI but also in the data warehouse developed for the DST2 project (dst2 Development of Structurally Detailed Statistically Testable Models of Marine Populations. QLK5-CT1999-01609. Final Report). Variability in spatial overlap of predator and prey species can either be accommodated by constructing multiple-area models which include interannual variability in migration or by making 'suitability' year-dependent.

The most detailed model configuration for a future 'key-run' will probably involve 6 areas within the Icelandic continental shelf and 1–2 outside to accommodate seasonal migration. The most common configuration however, will probably be 1 or 3 areas, 2 within the Icelandic continental shelf (north and south) and one outside it (shelter for capelin). Changes in spatial overlap between cod and shrimp could be included by linking the suitability of shrimp as prey for cod to an overlap index.

Ecological links between many of the listed species are not considered to be very strong and different submodels including 1–3 species will probably be the best option for testing management scenarios and for annual assessment. In some cases technical interactions might be crucial to the combination of species to include.

4.4 Bay of Biscay/Iberian Peninsula

4.4.1 Southern hake cannibal model

At the beginning of WGSAM 2008, progress with regard to the Southern hake GADGET model was presented and some critical problems were identified. Significant progress was made to resolve some of these issues during the meeting, and especially with regard to updating datasets from 2005 to 2007, the inclusion of stomach content data proportions for hake as a prey and 'other food', and the development of a new likelihood function to estimate consumption from these data. The main problem was the model's inability to satisfy the hake food requirements and fleet catches at the same time, driving the simulated population to an unrealistic collapse. A subgroup was commissioned to deal with this problem during the WGSAM meeting.

The work started with a full review of the model including data inputs and model structure. The model definition files were examined and a number of simulations were performed with the aim of identifying the source of the problem. During this review some underlying issues with regard to the basic model formulation were identified and solved. A more consistent trophic relationship was developed, and the model is now able to satisfy the hake food requirements without collapsing but the estimated amounts of cannibalism remain lower than that suggested by stomach data. The model is able to estimate about 1% of the diet to be due to cannibalism while the observed levels are about 5–10%.

Following the model review it became apparent that the problem may not be in the input data or model structure, but rather in some basic assumptions regarding hake population dynamics (e.g. the assumed natural mortality, growth or recruitment) that may not be compatible with hake predation derived from the stomach data. In particular the assumed natural mortality of 0.2 has never been confirmed, and there is evidence that hake growth-rate may actually be much higher than currently assumed. This evidence includes tag-recapture experiments (Bertignac and de Puntual, 2007; Piñeiro *et al.*, 2007) and recent work on food assimilation, considering consumption estimates based on stomach contents and metabolic rates (Velasco, 2007). Both lines of evidence suggest that hake growth-rate should be about twice that currently assumed.

Future modelling work using GADGET will be based on examining the hypothesis that the hake food requirements necessitate changes in other basic assumptions regarding hake population dynamics. A number of simulation experiments will be performed with the Gadget model in order to examine if realistic changes in natural mortality and/or growth-rates can produce a model delivering realistic hake consumption.

4.4.2 Bay of Biscay anchovy model progress

A Gadget model for Bay of Biscay anchovy (*Engraulis encrasicolus*) is under development. This model is intended to form a part of a hake-anchovy multi species model, with the hake eating both small hake and anchovy. The anchovy model was reviewed during the WGSAM 2008 meeting. The model is capable of producing trends in biomass and fishing mortality which are similar to those presented in the assessment working group (WGHMSA). However the absolute levels of modelled biomass (and hence fishing mortality) do not appear to coincide. A number of questions concerning the structure of the model (relating to anchovy biology, and the commercial fleet and survey data) have been identified from the analysis performed during the WGSAM meeting which cannot be answered from reading the WGANSA working group report. Further progress on the model is therefore dependant on discussions with anchovy experts in Spain on these issues. In addition a number of tests were performed on the model, and there may be some technical changes required (e.g. in the size of the time-step) that might improve model performance. Further development work on the model will continue during 2008 and 2009.

4.5 Barents Sea

No 'key-runs' for multispecies models from the Barents Sea were available to this year's meeting. WGSAM suggests that key-runs for the models Bifrost, Gadget and Stocobar should be established well before next year's meeting, in order to carry out model comparisons (*see Model comparisons Section 5.2):*

5 ToR c) – Report back on model comparison exercises, carried out under the auspices of the EU FP6 UNCOVER project.

5.1 Comparisons between SMS and EWE for the North Sea

For the first time a comparison between the stochastic multi species assessment model SMS and the ecosystem model EwE was carried out during the UNCOVER workshop in Tenerife. Estimated SSB trajectories from the currently available North Sea SMS version parameterized by the University of Hamburg were compared to SSB trajectories estimated by the EwE model for the North Sea, parameterized by CEFAS (Steve Mackinson). The EwE model was tuned to results of 4M, the deterministic version of SMS. Therefore, the historical SSB trajectories (1990 to 2005) showed large similarities in the general abundance trends between both models (Figure 5.1). The absolute estimates of the SSB values, however, were sometimes quite distinct. E.g. for cod SMS estimated a SSB of around 90 thousand tonnes in 1995, while EwE estimated a SSB of around 230 thousand tonnes. For haddock, the discrepancies were largest. For this species single recruitment events drive population dynamics which make the estimated trajectories sensitive to the very uncertain recruitment estimates.

The predictive capabilities of both models were compared. Predictions from 2006 to 2030 were carried out with both models assuming a constant fishing mortality at precautionary level (Fpa) for all stocks (Table 5.1). SMS and EwE came to different conclusions especially in short to mid-term SSB forecasts (Figure 5.1). In contrast, the long-term equilibria estimated for the different stocks were quite similar. However, both models came to substantially different results for herring stock development.

In conclusion, it is encouraging that both model approaches reached similar equilibria in the long run, although the differences between both models in short to mid-term predictions were often substantial. In general, EwE dynamics tended to be more dampened and tended to reach equilibria faster. This may be caused by the larger number of trophic links in the EwE model.

Table 5.1. Fpa values used in the predictions.

SPECIES	FPA
Cod	0.65
Haddock	0.7
Herring	0.25
Norway pout	0.35
Sandeel	0.4
Whiting	0.65
Saithe	0.4

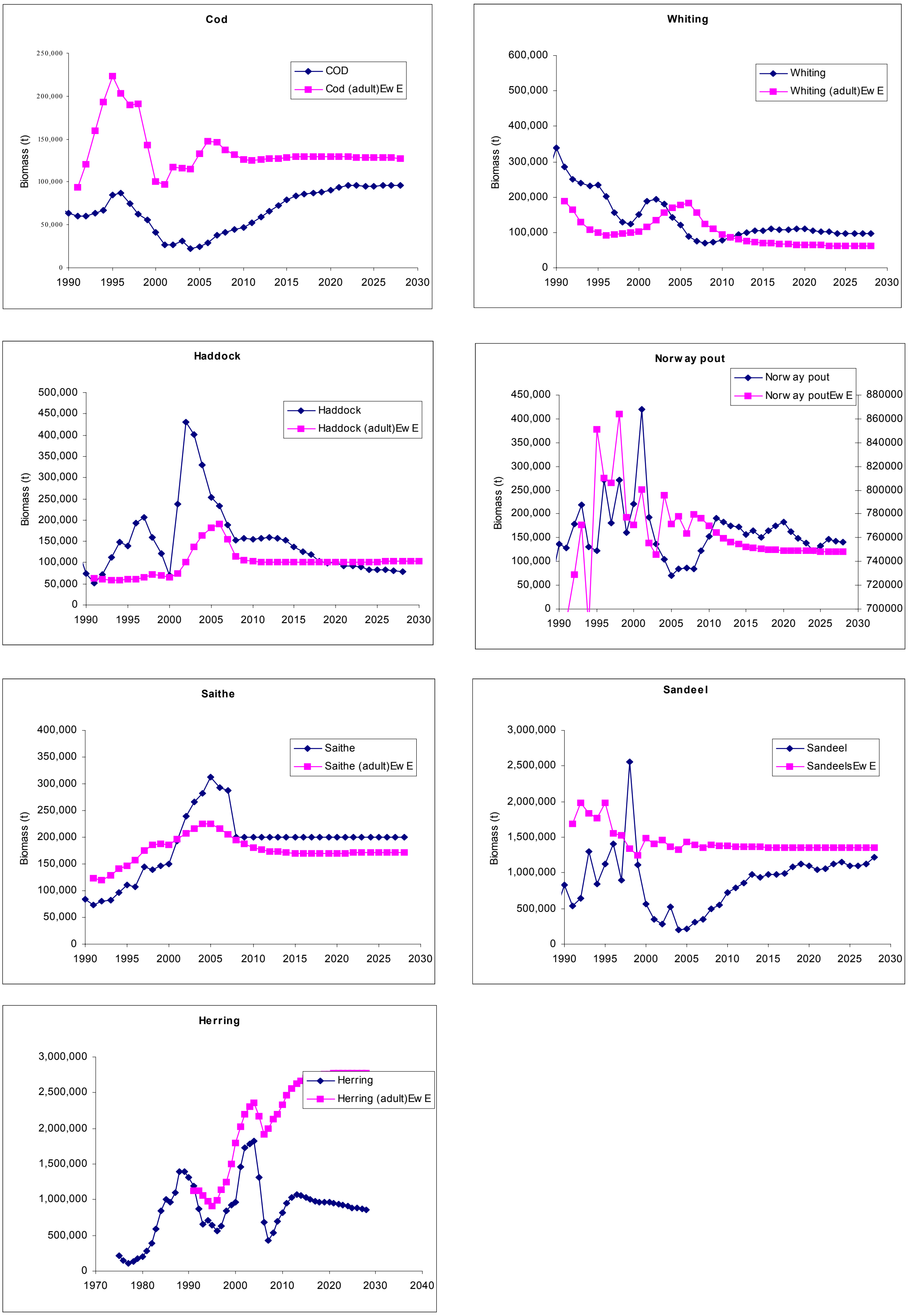


Figure 5.1. Comparison of estimated SSB trajectories between SMS and EwE

5.2 Model comparisons – Barents Sea

It is planned to provide key-runs for three models (Bifrost, Gadget, Stocobar) for the Barents Sea region before next year's meeting. Then the behaviour of these models can be compared. The models should be set up with the same species and links as far as possible. A cod-capelin-herring model would seem to be the most appropriate choice.

The comparison study should consider how the various models fit to historical data, as well as results (yield, biomass etc.) of runs into the future using a range of harvesting strategies for all the species involved.

6 ToR d) – Evaluate interannual variability in feeding patterns. Explore the implications for multispecies models.

Multispecies models are a complex; involving dynamics of the predator and preys as well as interaction between them. With respect to ToR 'd', this question can be considered to comprise two distinct components:

1) Changes in feeding patterns caused by changes in prey abundance.

2) Changes in feeding patterns caused by prey switching (including changes in spatial overlap.

Multispecies models are able to account for the first component if sufficient information about the relevant prey exists. Indeed, this is what multispecies models were originally designed to do. However, the latter is much more problematic and data-demanding, and makes the use of models for prediction difficult, particularly if unforeseen prey resources (including those not normally present in the area) suddenly become important to predators for inexplicable reasons, or similarly if new predators that are not included in the model, suddenly begin to assert significant predation pressure.

Many of the links in the system between predator and preys are poorly understood and highly variable from year to year due to changes in spatial overlap, size and age, and the amount and distribution of 'other prey'. We will never be able to include everything in a multispecies model. The results should therefore not be considered as the 'truth', but rather to indicate possible deficiencies of single-species models when exploring, for example, the possible implications of a reduction in fishing mortality to values not seen for a very long time. Such changes can lead to a shift in the size distribution of the affected species, i.e. larger (older) fish surviving, changing the diet and predation pressure exerted by the species compared to earlier periods, although the diet of a given size group does not change.

Abundance of many species in the ecosystem is also poorly known and this is especially true for those species that are referred to as 'other food' in multispecies models. Generally knowledge of non-commercial species is scarce, and seasonal migration of a large stock inexplicably into an area can be problematic for other species that are prey and/or competitors. In many cases the diet and abundance of important predators are also poorly known and there may well be substantial un-accounted for mortality.

Stomach content data and information on abundance of important predators and preys is the key to successful multispecies assessment. Knowing everything will never be possible and important "predation events" can take place in a relatively short period of time. For example Temming *et al.* (2007) demonstrated that 50 million juvenile cod were consumed in only 5 days by predatory whiting in the North Sea, and that only 32 'hot spots' of similar magnitude would be required to eliminate an entire year class of North Sea cod.

How stomach content data are prepared for the model can also be of critical importance. Direct use of stomach content data can lead to overestimation of the share of large preys in the diet. A number of evacuation rate models exist, e.g. the surface area model, volumetric model etc., some of which include different digestion rates for different preys (see Jobling 1981). The same applies when accounting for the size distribution of prey in a stomach since larger prey might well take longer to digest and therefore be identifiable by scientists for a longer period of time after ingestion. Unidentified prey in stomachs is also a problem that needs to be addressed, and is often reflective of the skill of the individual researcher/taxonomist doing the analysis.

Most multispecies models calculate annual consumption, but the observations reflect stomach content at a particular point in time. In order to make a comparison, it is necessary to convert between these two entities. Converting from stomach content to consumption requires an evacuation rate model (e.g. Jones, 1974; dos Santos and Jobling, 1995), while converting from consumption to stomach content requires a feeding model. Since these transformations generally will be non-linear, it must be emphasized to have data from individual stomachs available. Some theory for transformation of consumption rate to a distribution of stomach content has been developed (Magnússon and Aspelund, 1997). This will allow model results to be compared directly to actual untransformed observations.

6.1 Inter- and intra- annual variability in the diet of Celtic Sea fish

Feeding preferences of Celtic Sea fish were investigated by Pinnegar *et al.* (2003) using a database of 26539 stomach content records (18129 individual stomachs), collected by French and UK researchers between 1977 and 1994.

Prey abundance estimates were obtained, based on ICES stock assessments and UK groundfish survey catches. When the proportion of mackerel, horse mackerel and blue whiting in predator stomachs was plotted against the availability of these prey as defined by ICES stock assessments, there were many positive trends, demonstrating that predator diets do track prey availability in the environment, at least for certain species. However, Kendall's tau test indicated that the only significant or near significant correlations were for megrim and hake feeding on blue whiting (*p-value*=0.003 and 0.05 respectively). These data contained many outliers and much variability, largely related to the very limited number of stomachs sampled in some years.

When the proportion of a particular prey represented in stomachs was plotted against the 'availability', as determined by CEFAS spring survey data (1982–1994), there were again many positive relationships. Because of the marked variability in the data, few of these proved to be statistically significant. Despite the relatively large number of whiting stomachs sampled, there were no instances where the proportion in the stomach and availability in the environment were significantly correlated. Megrim appeared to consume significantly more dragonettes and gobies in years when these prey were more abundant (*p-value*=0.036 and 0.009 respectively). Cod consumed more blue whiting when these fish were abundant (*p-value*=0.043) and hake chose more horse mackerel and blue whiting in years when these prey were more abundant (*p-value*=0.053 and 0.053).

In the analyses conducted here, only positive correlations were tested for. There was a clear relationship between consumption of *Trispoterus* spp. by cod, and the abundance of *Trisopterus* spp. in the environment. Because this was a strong negative relationship, however, the test for a positive correlation was rejected (*p-value*=0.958).

It should be acknowledged that the data available has many shortcomings notably that 33% of stomach observations came from a single year (1984) and that trawl survey gears do not necessarily give a true picture of fish abundance in every case. Using the same dataset Trenkel *et al*. (2005) investigated the within-year structure of predator-prey relationships for 4 predator species (cod, hake, megrim, and whiting). Blue whiting were consumed more often during the summer months, whereas mackerel and *Trisopterus* spp. (poor cod *T. minutus*, Norway pout *T. esmarkii*, and bib *T. luscus*) were found more often in predator stomachs during the winter half-year. On a spatial scale, blue whiting was consumed over the shelf edge, in accordance with their higher densities in the environment, while mackerel, horse mackerel and *Trisopterus* spp. were eaten more often on the continental shelf, again in agreement with their depth-related density-distribution patterns. The spatial distribution of whiting closely matched that of a key prey, *Trisopterus* spp. The results of this study suggest spatial and seasonal prey-switching behaviour by cod, hake and whiting. The stomach content datasets reported in these studies have subsequently been made available online within the DAPSTOM data portal (Pinnegar and Stafford 2007).

6.2 Long-term changes in the diet of North Sea fish

Over the past 100 years there have been marked changes in North Sea fish communities, in part due to heavy fishing pressure but also as a result of long-term environmental variability. At the same time dramatic changes in benthic community structure have been observed (e.g. Callaway *et al.*, 2007; Kröncke 1990,1992), and thus it is highly likely that the functioning of marine foodwebs has changed substantially with many predators now feeding on a different portfolio of prey compared to 100 years ago.

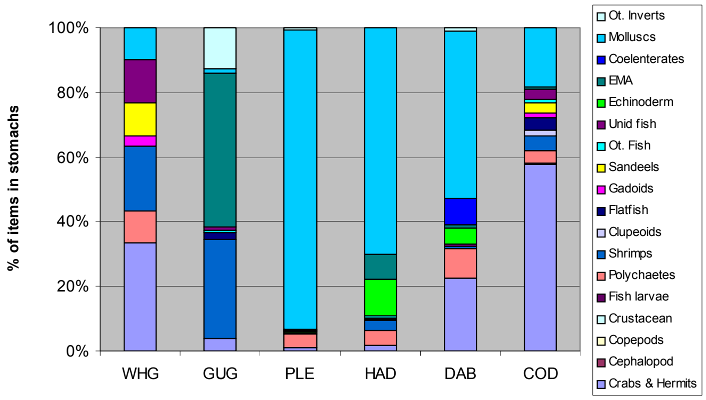
In a preliminary study presented at the ICES ASC in Halifax [ICES CM 2008 F:06] Pinnegar and Blanchard reported on efforts to digitize an extensive dataset of fish stomach content records from the period 1902–1909, and compare these data with records spanning 2004–2006. The RV Huxley was a commercial steam trawler that was requisitioned in 1902 to assist the newly created fisheries laboratory in Lowestoft. The vessel carried out extensive surveys between 1902 and 1909 of the southern and central North Sea. Detailed information was collected on fish abundance, size and movement patterns (Garstang 1905; Anon, 1909; Anon, 1912). Information was also collected on the 'food of fish'. These data were published by Todd in 1905 and 1907 (and 1915). A considerable effort was required in order to 'map' the old data to modern taxonomic schemes (NODC and ITIS TSN codes).

Initial analyses of fish on the Dogger Bank (ICES rectangles 37F0, 37F1, 37F2, 38F0, 38F1, 38F2), where historical and recent data coverage is most extensive, have revealed that species such as cod, grey gurnard, plaice, haddock, dab and whiting previously consumed far fewer prey fish than has been the case in recent years, concentrating on decapod crustaceans (crabs, hermit crabs and shrimps) and polychaetes, rather than species such as sandeels (Figure 6.1) and long-lived molluscs.

Bivalves (in particular *Solen* spp. and *Mactra* spp.) were more important as a prey item 100 years ago compared to recent years, and this coincides with observations on the historical abundance of these particular benthic prey types. Callaway *et al*. (2007) demonstrated that crabs have dramatically increased in abundance since 1902, whereas many slow-growing bivalves have declined. Similarly, Kröncke (1990 and 1992) has demonstrated, specifically for the Dogger Bank, that short-living opportunistic species have increased in number and dominance since the 1950s, whereas a decrease in long-living bivalves (specifically *Ensis ensis*, *Mactra c. cinerea* and *Spisula* *subtruncata*) was found, and these are exactly the same species as those that were observed to have declined as a component of fish stomach contents.

Frid and Hall (1998) also found more bivalves and sandeels in dab stomachs (off the Scottish coast) in historical times (1951–1952) compared to more recent years (1996–1997), and these authors speculated that the apparent increase in scavenging species and a decrease in more sedentary species has largely been the result of trawling pressure. Further analyses of the RV Huxley dataset will focus on a comparison with the more extensive (in terms of spatial coverage) 'ICES year of the stomach' datasets for 1981 and 1991. However there is further corroborative evidence that sandeels may have been less important as a prey item for predators in the past. Stomach content analyses from Scotland in the 1930s and 1940s (Jones, 1954), also suggest that sandeels formed a much smaller part of the diet of haddock and whiting than in the 1980s and 1990s (Hislop, 1996). Andersen and Ursin (1977) suggested that an increase in sandeel stocks may have been associated with the decline of herring and mackerel in the late sixties and this was also reiterated by Cushing (1980).

Dogger Bank 1902 - 1909



Dogger Bank 2004 - 2007

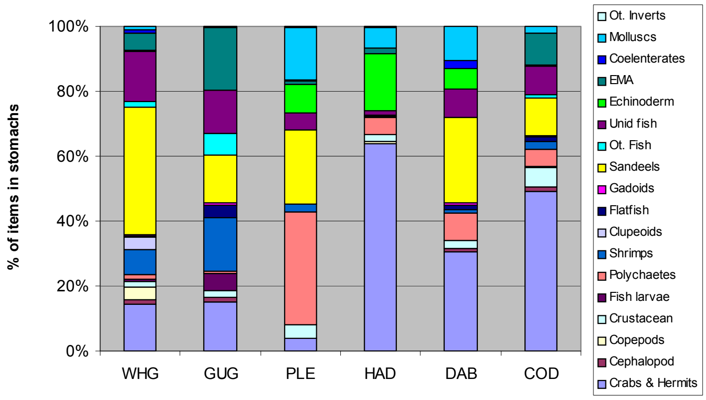


Figure 6.1. Comparison of the diet of fish predators in Dogger Bank at the beginning of the 20th and 21st centuries. The labels in the figure correspond to WHG: whiting, GUG: grey gurnard, PLE: plaice, and HAD: haddock; DAB and COD.

Typically the models (MSVPA and more recently SMS) used by ICES working groups to understand multispecies interactions in the North Sea have only used stomach content data which extend back to 1981. However, some of the most important and interesting changes are thought to have occurred in the late 1960s and early 1970s, during a period which has come to be known as the 'gadoid outburst' (Hislop 1996; Cushing 1980). At this time, herring and mackerel were reduced to levels unprecedented in the 20th Century, whereas gadoids (cod, haddock, whiting) and possibly sandeels increased.

'DAPSTOM' is a searchable database of historical fish stomach content records developed in the UK (Pinnegar and Stafford 2007), which is now freely available over the Internet (www.cefas.co.uk/dapstom). The existing online dataset includes ~103,000 records spanning 1960 – 2007. One of the main incentives for developing this database and digitizing information contained in paper records was to explore events that occurred prior to the 1981 ICES 'Years of the Stomach'. The database is dominated by records from the North Sea (82%) and includes 15,527 records (9,960 stomachs) from the North Sea for the period 1968–1978.

Predator-prey overlap induced Holling type III functional feeding response in the North Sea fish assemblage

The data available from the 'years of the stomach' in 1981,1985,1986,1987 and 1991 were analysed in a study by Kempf *et al.* (2008a) to evaluate the influence of changes in predator-prey spatial overlap on the observed diet composition of North Sea cod (*Gadus morhua*) and whiting (*Merlangius merlangus*). Previous analyses on the large-scale feeding response of predator populations resulted in unrealistic results for the North Sea. The observed feeding response types (e.g. negative prey switching) would tend to lead to the extinction of prey populations within the resulting models. However, past analyses did not take changes in predator-prey overlap into account.

The large-scale response of North Sea cod and whiting populations to varying prey fields was analyzed using Generalized Additive Models (GAMs). The composition of the prey field and changes in predator-prey overlap had a significant *effect on* the diet composition in the final GAMs explaining 65.6% of the variance (Figure 6.2). The existence of a large-scale prey refuge at low prey abundances as proposed by the Holling type III functional response was demonstrated from field data for the first time. The refuge was not only caused by an active prey switching behaviour of the predators. It was also a result, to a large extent, caused by a passive change in the availability of prey due to changes in predator-prey overlap associated with changes in the prey abundance. The relative stomach content only dropped down when the prey became low in abundance and the spatial predator-prey overlap was low (Figure 6.3).

It was demonstrated that juvenile cod contract their area of distribution towards the outflow region of the Skagerrak when at low stock levels (Figure 6.3). Therefore, they were less available to larger cod in the other regions of the North Sea leading to a prey refuge for small cod at low abundance. This study demonstrated that the predictive power of current diet selection models can be improved if changes in predator-prey overlap are explicitly taken into account.

Changes in predator-prey overlap are key mechanisms determining the diet composition of predators especially at low prey abundances. Therefore, the utility of the current parameterization of the diet selection models inside MSVPA and SMS assuming constant predator-prey overlap has to be questioned. Important dynamics of predator-prey interactions are ignored due to this assumption. Further details can be found in Kempf *et al.* 2008a.

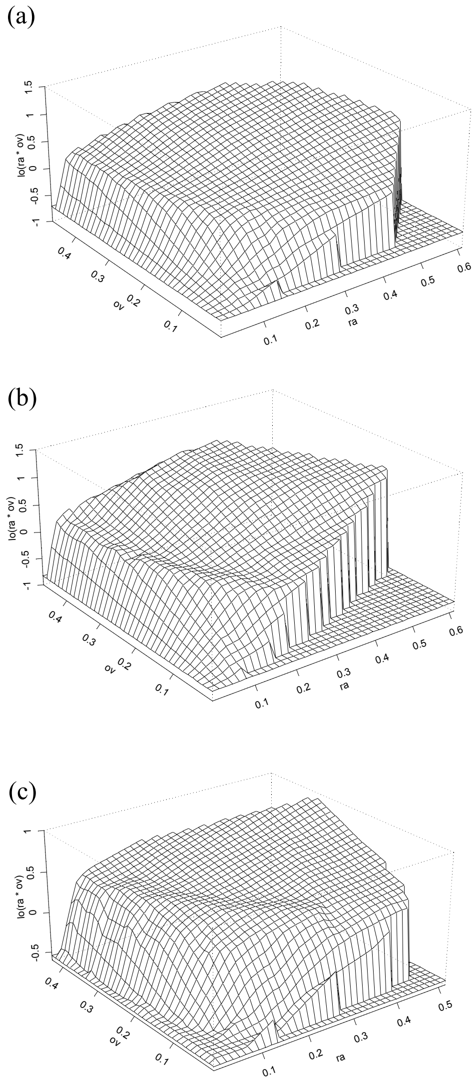


Figure 6.2. Fitted relative stomach contents as a function of the interaction between relative prey abundance (ra) and predator-prey overlap (ov) as well as the predator-prey interaction specific factor (C, not displayed). The relationships are demonstrated for all analysed predator-prey interactions (a) but also separately for cod as predator (b) and whiting as predator (c). The span argument for the LOESS smoother (lo) was 0.5.

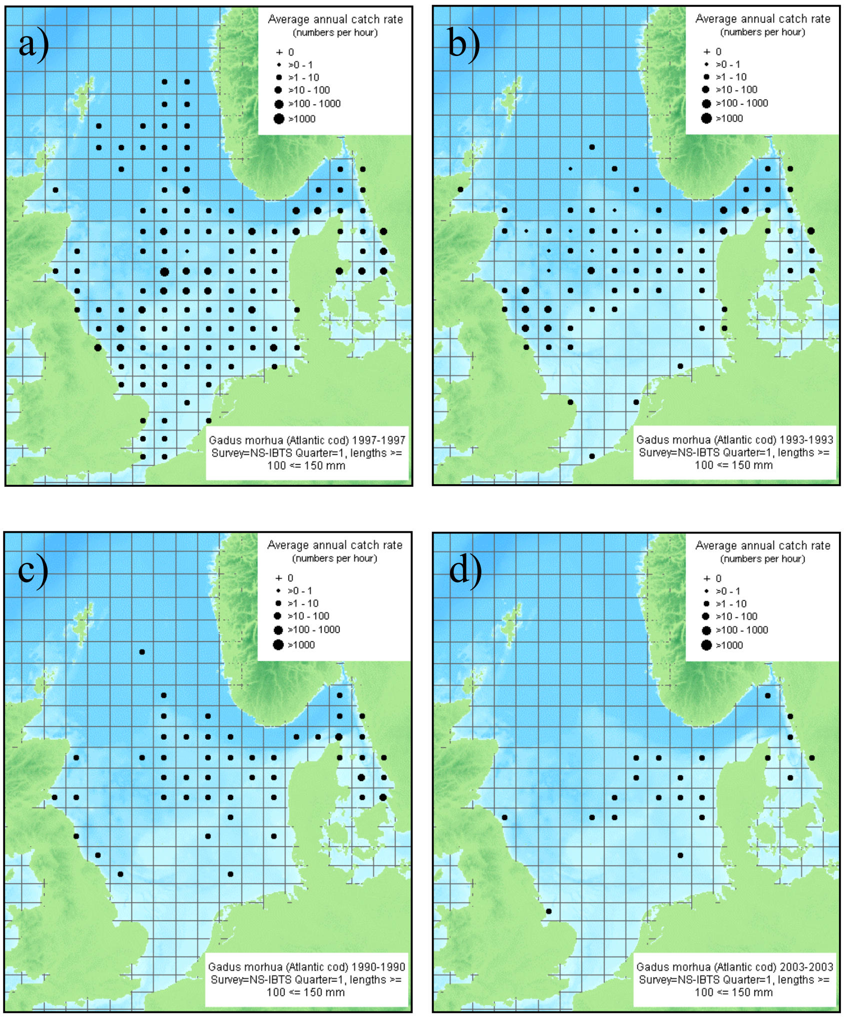


Figure 6.3. Distribution of 10–15 cm cod catches in the IBTS quarter 1 survey. The distributions are demonstrated for 1997 and an abundance index of 4097 for cod between 10 and 15cm (a), for 1993 and an abundance index of 804 for cod between 10 and 15cm (b), for 1990 and an abundance index of 397 for cod between 10 and 15cm and for 2003 and an abundance index of 46 for cod between 10 and 15cm (d). The maps were created with ICES fishmap (http://www.ices.dk/marineworld/ ices-fishmap.asp).

6.3 Modeling prey preference and vulnerability in multispecies models: the Baltic SMS implementation

Stomach content data are a cornerstone of modelling and assessment of predatory species interactions. However, there are problems: lacking information on the time of ingestion of prey items found in stomachs, or information on the prey field available to individual predators at the time of ingestion might be reasons, and there is no well established methodology for the application of these data.

We used SMS to check to what extent to which the information from stomach content data fits to other sources of information. Details are given in the WG document 'Modeling prey preference and vulnerability in multispecies models: the Baltic SMS implementation'.

Figure 6.4 presents the stomach content observations in a plot using the predator size on the x-axis (log-scale) and predator size/prey size on the y-axis (log-scale). Figure 6.5 is the frequency plot of the same data. The basic idea that there is a preferred predator-prey size ratio which can be described by a normal distribution seems plausible for sprat and herring, while the size distribution of cod prey is more uniform. Both plots only present the stomach content observations, which is a function of size selection and the available amount of that particular size. As the available amount is not included, the plots only give a rough indication of the size selection.

The size spread (related to the σ_{pred} parameter) in general increases with increasing predator size (

Figure 6.6.4) i.e. big animals tend to continue to eat small prey items. For sprat however, the spread seems relatively constant over all cod sizes (except for the very small cod), which is likely to be due to the limited size range of sprat. The regression lines have similar parameter values for prey cod and herring while the sprat regression has a higher intercept and slope parameter. This may again be an effect of the limited size range of sprat in the sea or prey specific size selection.

Exploratory SMS runs were made with different versions of the prey size selection model:

$$\exp\left(-\frac{(\log\frac{\textbf{pred size}}{\textbf{prey size}} - (\eta_{pred} * \tau_{prey} + \upsilon_{pred} * \log(\textbf{pred size}))^2}{2\sigma^2_{pred}}\right)$$

a) Equal size selection (=1) within the observed predator/prey size range and 0 outside the observed size range

b) Simple size selection, parameter τ fixed to 1.0 and parameter υ fixed to 0.0

c) Size selection with predator size adjustment; as b but estimation of parameter υ

d) Size selection with predator size and prey species adjustment; estimation of all parameters.

Configuration (a) assumes a fixed size ratio for each predator-prey combination. This seems to be the case for sprat (

Figure 6.6.4), while increasing size range with increasing predator size is observed for cod and herring. Configuration (b) uses a lognormal distributed size preference. The same is used in (c), but this configuration does also take the apparent size dependent size preference into account (related to the slope value in Figure 6.4). Configuration (d) adds a possible prey specific size selection (related to the intercept values in Figure 6.4).

From the results we can conclude that there is large temporal variation in the proportion of "other food" and that the model has a limited ability to predict the stomach contents (Figure 6.6). The relation between the two measures is very weak, with r-squares in the range of 0.02 to 0.09 for the named prey species.

The SMS model has, as well as MSVPA, a limited ability to predict the stomach contents. Overall, the fit of predicted stomach contents to observed stomach contents for the 5 subsets of stomach data has to be considered very poor.

For the Bornholm Basin of the Baltic Sea, the fraction of the cod population's habitat volume where sprat and herring co-occur has been shown to vary substantially from year to year (Neuenfeldt and Beyer 2006). In consequence, the average cod stomach content of herring and sprat is related to this overlap fraction. The larger the fraction of the cod habitat where sprat occurs as the only available fish prey for cod, the larger the predation on sprat, even if sprat abundance remains constant. This variable predator-prey overlap is, not accounted for in the present multispecies models for the Baltic Sea.

Knowledge on the actual predator-prey overlap is still very limited, and will have to be collected in other regions and during the full annual cycle. Afterwards the hypothesis can be tested, that account for spatial heterogeneity, and this will significantly improve the predictive power of the model, and its ability to account for observed long-term trends in stomach content composition.

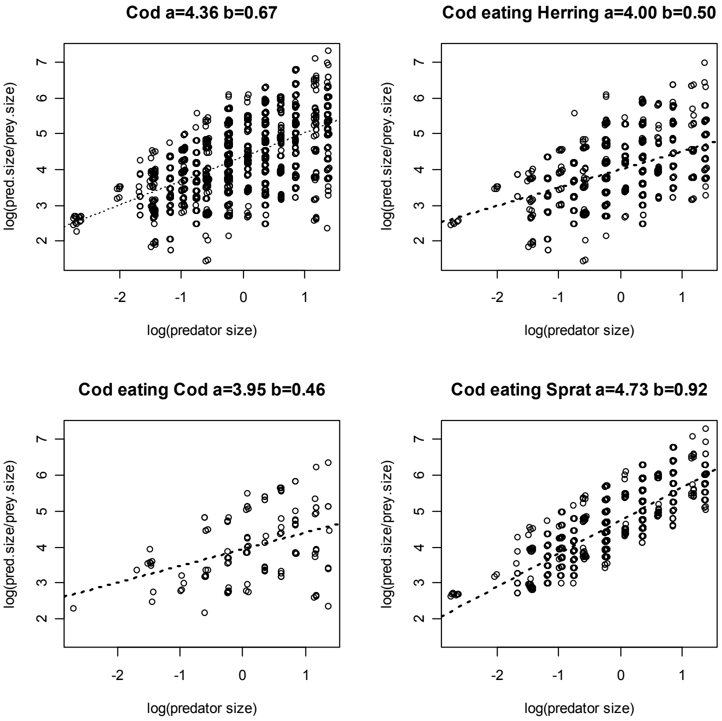


Figure 6.4. Stomach contents observations. Each observation has equal weight in calculating the regression line.

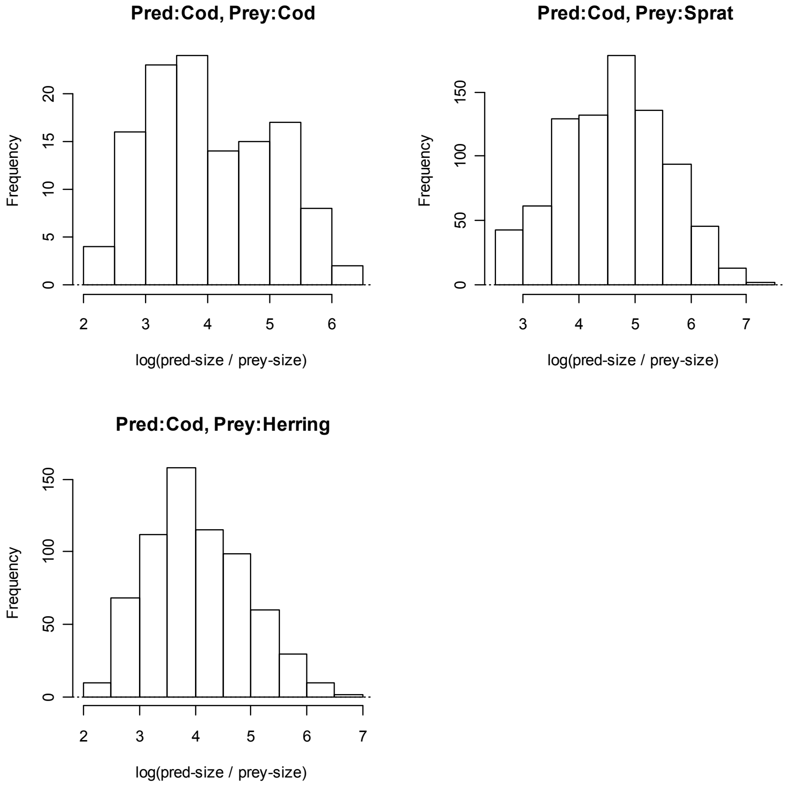


Figure 6.5. Frequency plot of stomach contents observations.

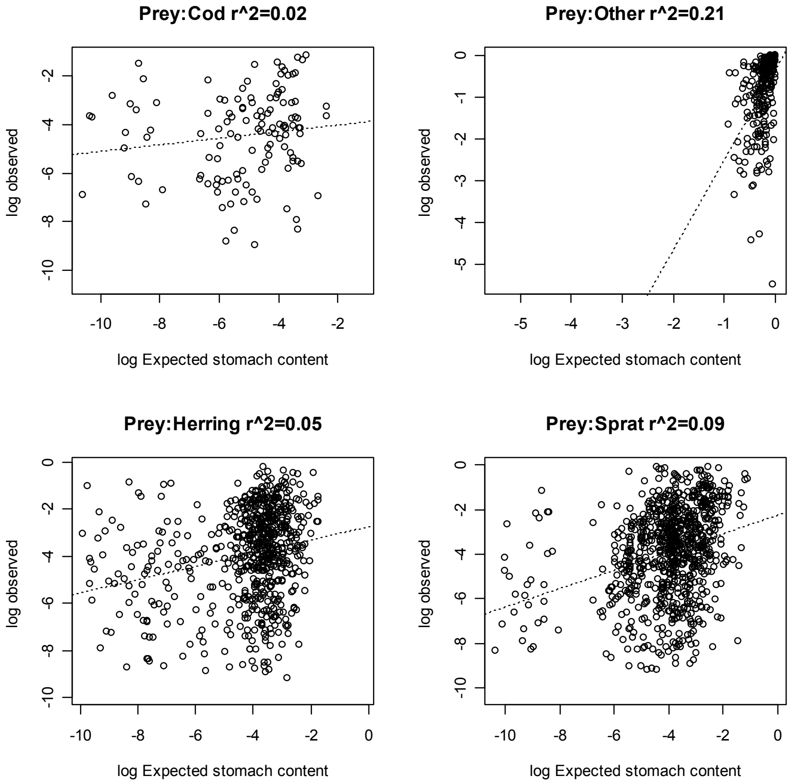


Figure 6.6. The logarithm of observed and expected stomach content. Time series 1974–1994.

6.4 Interannual variability in feeding patterns of the Barents Sea cod

Qualitative data (i.e. frequency of occurrence of main prey species) of the diet of cod and other species in the Barents Sea have been collected annually by PINRO, Murmansk since 1947 (Ponomarenko *et al.*, 1978, Ponomarenko and Yaragina 1978, 1984). Also, quantitative data on stomach content (weight, number of prey, size of prey etc.) have been collected by IMR, Bergen and PINRO, Murmansk since 1984 (see review in Dolgov *et al.*, 2007). These data show short-term variability as well as long-term trends in feeding patterns. Figures 6.7–6.9 show the variation in diet composition of age 1–2, 3–6 and 7+ cod, respectively, in 1984–2007 (adapted from ICES 2008a, using the method described by Bogstad and Mehl (1997). Among the features that can be seen, are:

- The proportion of capelin in the diet fluctuating strongly, being very low during the first capelin collapse in 1987–1988 and less affected during the other collapses. Capelin is replaced by krill and amphipods in the diet, particularly during the first capelin collapse.
- Redfish is an important part of the diet in the 1980s, but then disappears gradually during the 1990s and is almost absent from the diet since the late 1990s. This is consistent with the collapse of the redfish observed during the 1990s (ICES, 2008a).
- Blue whiting becomes a significant part of the diet of older cod during the 2000s, consistent with the increased abundance of blue whiting in the Barents Sea (ICES, 2008b).
- Cod cannibalism is high during the mid-1990s, related both to high abundance of young cod and low capelin abundance (see Yaragina *et al.*, 2009).

Figure 6.10 shows the frequency of occurrence of cod and capelin in cod stomachs for the period 1947-present (Yaragina *et al.*, 2009). These seem to be inverse related in some periods, but not in others, and for the whole time-series there is no correlation. Furthermore, abundant cod year classes such as 1975 and 1983 only show up to a small extent in the cod diet. It is also interesting that the proportion of herring in the cod diet was lower in the 1980s and 1990s than in the 1950s–1960s, although the herring abundance seems to have been comparable (Gjøsæter and Bogstad 1998).

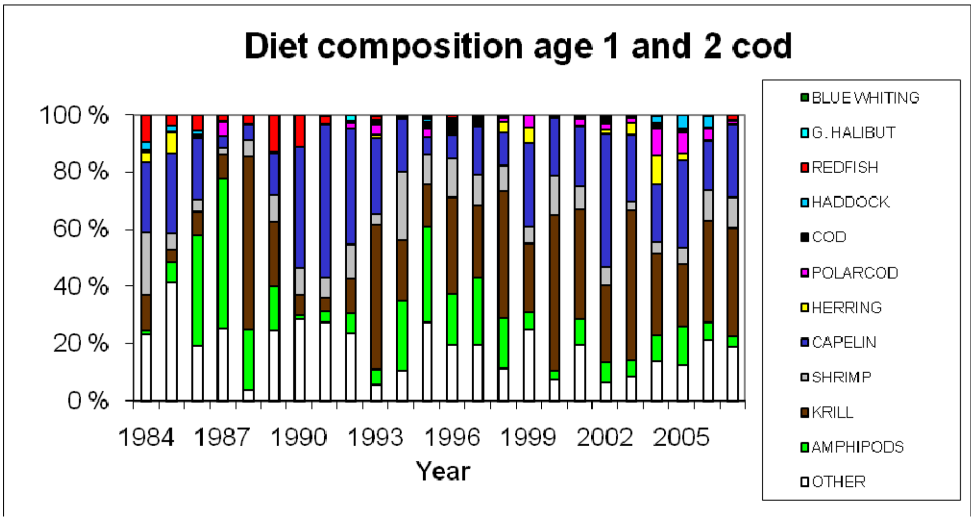


Figure 6.7. Diet composition of age 1–2 cod in the Barents Sea in 1984–2007.

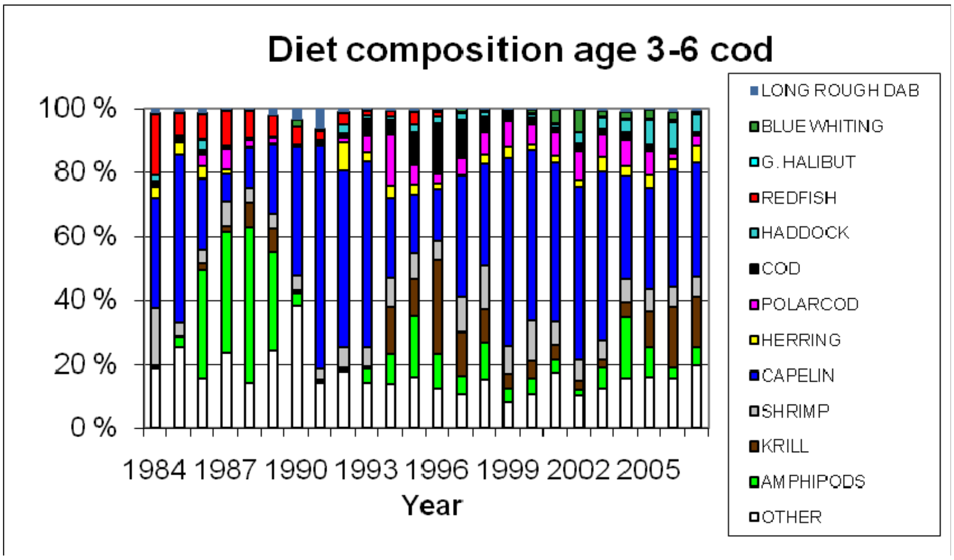


Figure 6.8. Diet composition of age 3–6 cod in the Barents Sea in 1984–2007.

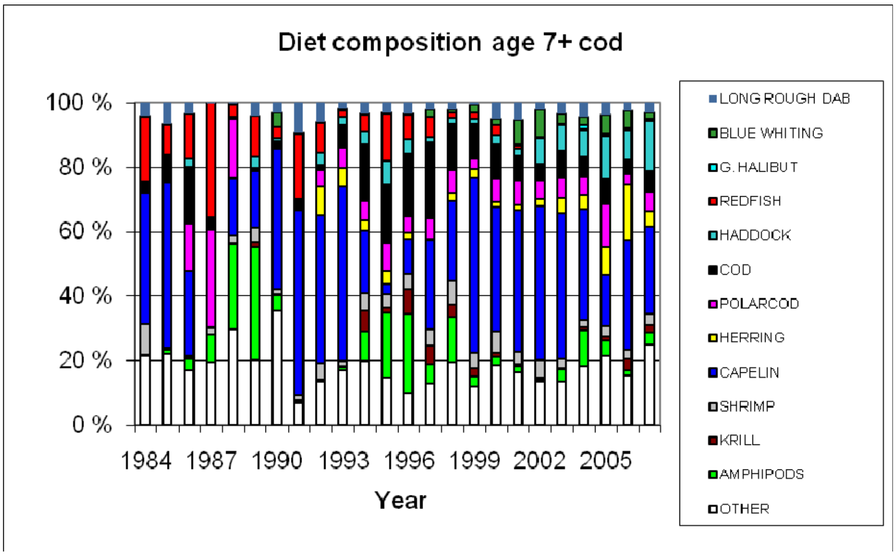


Figure 6.9. Diet composition of age 7+ cod in the Barents Sea in 1984–2007.

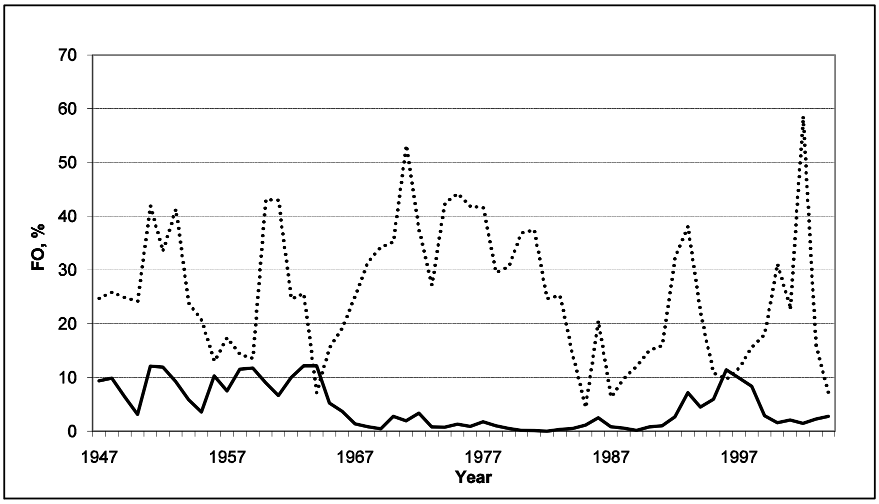


Figure 6.10. Frequency of occurrence (FO) of capelin (dotted line) and cod (solid line) in cod stomachs in the Barents Sea 1947–2005.

6.5 Newfoundland Shelf – progress in the study of the diet of marine predators with emphasis on diet interannual variability

Although the diet of many predators of the Newfoundland Shelf and Grand Bank, Northwest Atlantic, have received considerable attention over the years (Lilly and Fleming 1981, Lilly 1991, Bowering and Lilly 1992, Pedersen and Riget 1993, Pedersen 1994, Orr and Bowering 1997, Lilly 1994, Stenson *et al.*, 1997, Lilly *et al.*, 2000, Stenson and Perry 2001, Stenson and Hammill 2006), there are a surprisingly few studies attempting comparative analyses among them.

Given the importance that diet changes can have on the estimations of consumption by predators, as well as their impact in the parameterization of multispecies and ecosystem models, studies on the diet of several predators have been re-initiated and/or enhanced in the Newfoundland and Labrador Region of Fisheries and Oceans Canada (DFO). This work is being carried out as part of a national DFO Ecosystem Research Initiative (ERI), implemented in this region through the ERI-NEREUS program.

In collaboration with other initiatives and DFO Centres of Expertise (www.dfo-mpo.gc.ca/science/coe/index_e.htm) like the Centre of Expertise in Marine Mammals (CEMAM), a series of studies involving the re-analysis and modelling of archived diet data, as well as collection and analysis are currently underway. As part of this process, some preliminary results on a novel approach to model diet data (Buren *et al.*, 2008a) and a comparative diet analysis among cod, turbot and harp seals (Buren *et al.*, 2008b) have been recently presented at the ICES-NAFO-NAMMCO Symposium on "The Role of Marine Mammals in the Ecosystem in the 21st Century" held in Dartmouth, Canada, on Sep 29–Oct 1 2008.

The first of these aforementioned papers describes a new method to model diet composition by weight (Buren *et al.*, 2008a). This approach is based on the fact that the classical calculation of proportion by weight in the diet can also be represented in terms of probability of finding a given prey in a stomach and the mean weight of that prey in the stomach when it is present.

For example, if N is the total number of predators in a sample, n_x is the number that actually contains a given prey x, and B_x is the total biomass of x in the collection, then the relative proportion of x in the diet (w_x) can be calculated as:

$$w_x = \frac{B_x}{\sum_I B_i} = \frac{(B_x/N)}{\sum_I (B_i/N)} = \frac{[(n_x/N)(B_x/n_x)]}{\sum_I [(n_i/N)(B_i/n_i)]} = \frac{p_x m_x}{\sum_I p_i m_i}$$

with

$$p_i = n_i / N \quad \text{and} \quad m_i = B_i / n_i$$

and where p_x is the probability of finding prey x in a stomach and m_x is the mean weight of x in a stomach when x is actually present. The usefulness of this reparameterization is that allows for estimating p_i and m_i independently.

Under the assumption that each prey species in a stomach is consumed independently, using the above parameterization when considering all prey species in a stomach or just one of them should render similar results if the sample size is large enough. Buren *et al.* (2008) tested this concept using harp seal diet data by comparing the classical diet analysis with the proportions obtained by only considering the most important prey in biomass in each stomach. Of course, the p_i and m_i calculated were adjusted accordingly (i.e. p_i was defined as the probability of being a main prey while m_i was calculated as the mean weight of prey when it is a main prey). The results obtained indicated that the approach was sensible (Figure 6.11).

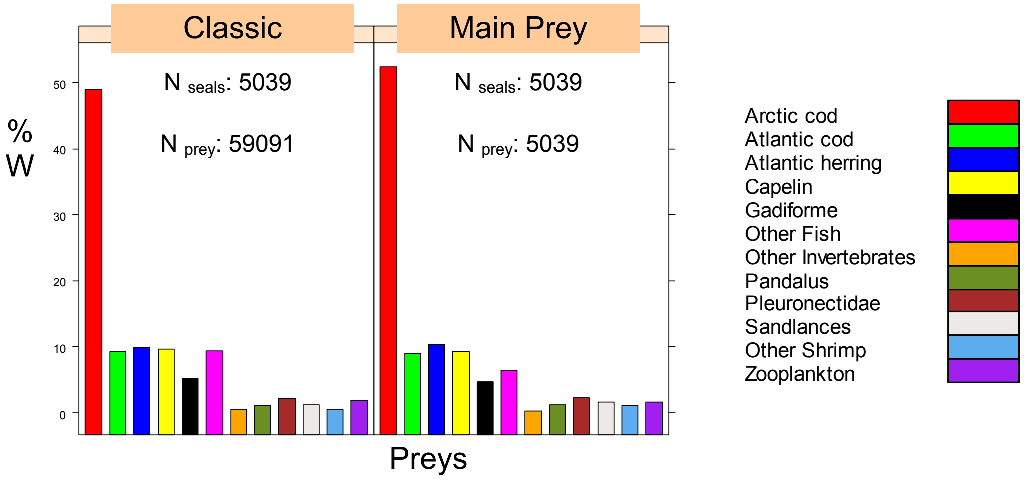


Figure 6.11. Comparison between the prey proportions by weight in the diet of harp seal from Newfoundland, Canada, using classical diet analysis and using only the main prey (see text for details).

Considering only main prey in the stomach allows for a more credible support for the assumption that individual data are statistically independent. Furthermore, individual stomachs can be thought as the realization of a multinomial experiment (one prey species is selected as main prey from a finite set of potential prey), and hence, the probability p_i can be estimated using multinomial regression models (a.k.a. multicategory logit models) (Agresti 2002). These probabilities, in conjunction with estimated (or reasonably approximated) m_i values can be used to reconstruct the predator diet. If time is one of the significant factors in these regressions, then the expected changes in diet over time can be visualized (Figure 6.12).

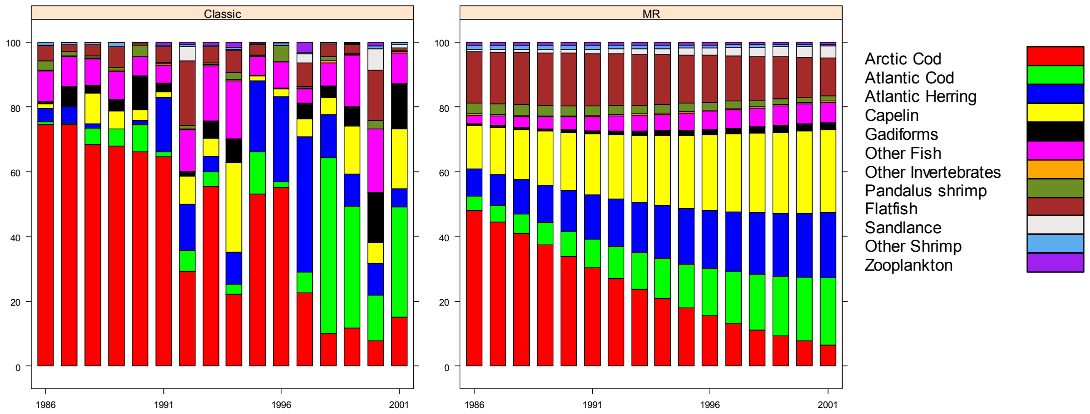


Figure 6.12. Predicted change over time for adult harp seals in the inshore waters of Newfoundland as estimated using the multinomial regression approach (MR) compared with the classic diet analysis.

This approach was then applied to cod (*Gadus morhua*), turbot (*Reinhardtius hippoglossoides*), and harp seals (*Pagophilus groenlandicus*) diet data to compare the predicted diets for these three top predators in the offshore of the Southern Labrador and Northern Newfoundland Shelf (NAFO Divisions 2J3KL) before and after the collapse of groundfish stocks (Figure 6.13) (Buren *et al.*, 2008b).

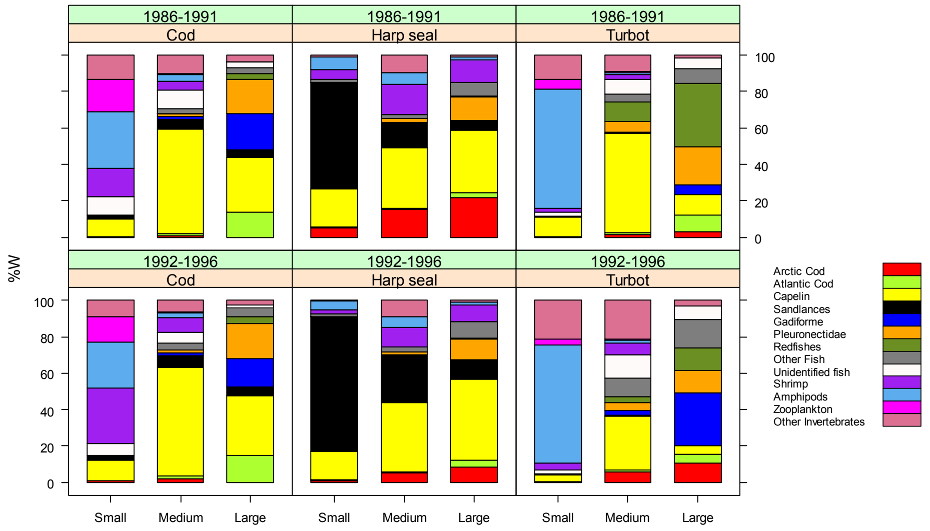


Figure 6.13. Modelled diet for cod, turbot, and harp seals in the offshore waters of NAFO divisions 2J3KL during 1986–1996. Years are grouped in two periods (1986–1991 and 1991–1996) associated with the pre and post groundfish stock collapses (most notably, but not exclusively, cod).

This analysis indicated that the diet of cod was the most stable among all three predators, while the diet of both harp seals and turbot showed a higher variability over time (Figure 6.13). Turbot was the predator that had the highest trophic plasticity, showing an important reduction of capelin and redfish (*Sebastes* sp.) in the diet and an increase of invertebrates (Figure 6.13). Harp seals, on the other side, showed a decrease in Arctic cod (*Boreogadus saida*) and an increase in sandlance (*Ammodytes dubius*) (Figure 6.13).

7 ToR e) – Review further progress in multispecies and ecosystem modelling throughout the ICES region

In 2007 the working group provided a broad overview of the multispecies models currently used within each ICES Ecoregion. This chapter of the WGSAM 2008 report offers an update on further developments and progress made within the different geographic areas:

7.1 Ecoregion A: Greenland and Iceland Seas

Multispecies models used in Icelandic waters were described in last year's report. The incorporation of predator-prey interactions in the routine shrimp assessment was, however, not described. The assessment has for a number of years been carried out using a GADGET model, initially including several species and three geographic areas, but later by a simpler model with only 2 species: cod and shrimp. In this simpler model the cod dynamics are not modelled explicitly but cod predation on shrimp is assumed to be proportional to abundance of cod in the shrimp survey. The reason for this change in formulation was that the abundance of cod in the shrimp survey does not correlate with abundance from any other survey nor from stock assessment but does explain the dynamics of the shrimp stock much better than any other measure of the cod stock. In summary the amount of cod caught in the shrimp survey has been an order of magnitude higher in the period 1997–2008 than from 1987–1996 while the cod stock was of similar size or larger in the earlier period. Evidence does therefore indicate increased, though variable, migration into the area after 1996. Modelling this in a fully multispecies model would be a very complicated task.

7.2 Ecoregion B: Barents Sea

7.2.1 Species interactions as a background for multispecies modelling

The Barents Sea capelin stock has collapsed three times during the last 25 years (Figure 7.1). The first collapse in the 1980s seemed to have both clear causes and clear effects (Hamre 1994, Gjøsæter *et al.,* 2009): High abundance of young herring in the Barents Sea preying on capelin larvae led to capelin recruitment failure (Gjøsæter and Bogstad 1998). Predators were affected in various ways. Cod experienced increased cannibalism, growth was reduced and maturation delayed. Sea birds experienced increased rates of mortality and total recruitment failures, and breeding colonies were abandoned for several years. Harp seals experienced food shortage, recruitment failures and increased mortality because they invaded the coastal areas and were caught in fishing gears. These interactions, in particular those between cod, capelin and herring, have been crucial in most multispecies models set up for the Barents Sea. Figure 7.2 illustrates the interactions between the most important species.

However, the second and third capelin collapse has provided us updated knowledge of the species interactions. This knowledge should be taken into account in the construction of future multispecies models for the Barents Sea. We can conclude that our recent knowledge of species interactions in the Barents Sea indicates that these relations are less straight forward than they appeared to be a decade ago:

- It has been observed that high abundance of herring does not necessarily cause recruitment failure for capelin
- The effects on predators such as cod and harp seals were most serious during the 1985–1989 collapse and can hardly be traced during the third collapse. These differences likely result from increased availability of

alternative food sources during the two last periods of collapse (Gjøsæter *et al.*, 2009).

- Since the mid-1990s, the recruitment of cod and herring seems to be less correlated than observed in previous years. Temperature and cod and herring recruitment also seems to be less correlated than in previous periods (Figure 7.3).

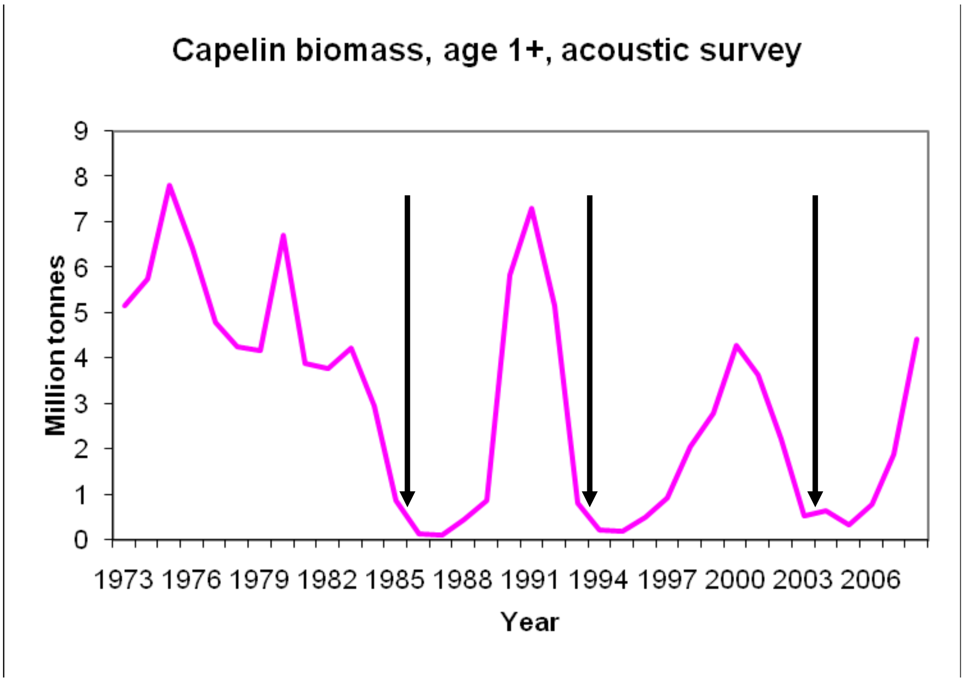


Figure 7.1. Capelin biomass (age 1 and older in September, acoustic survey). From ICES 2008a, with results from the 2008 survey added. Black arrows indicate the main three stock collapses of capelin in the Barents Sea over the past decades.

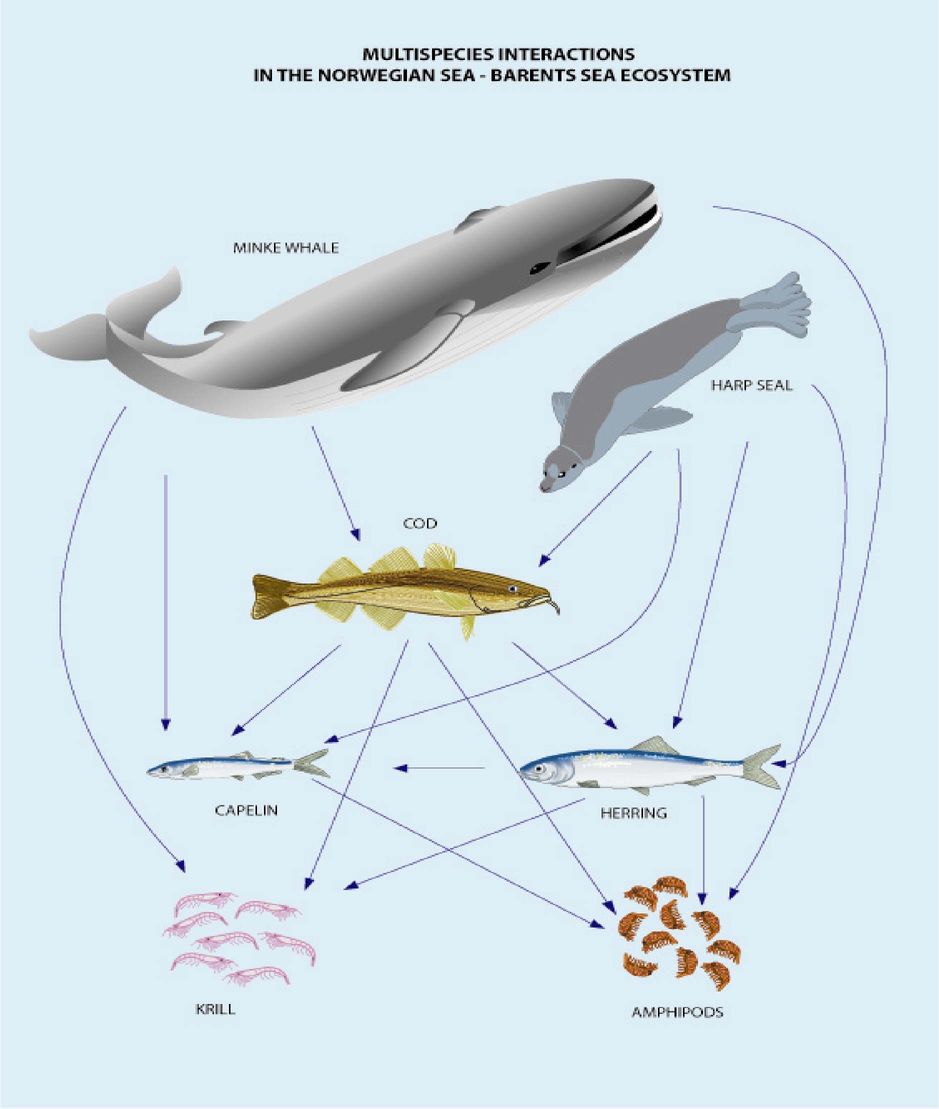


Figure 7.2. Species interactions in the Barents Sea.

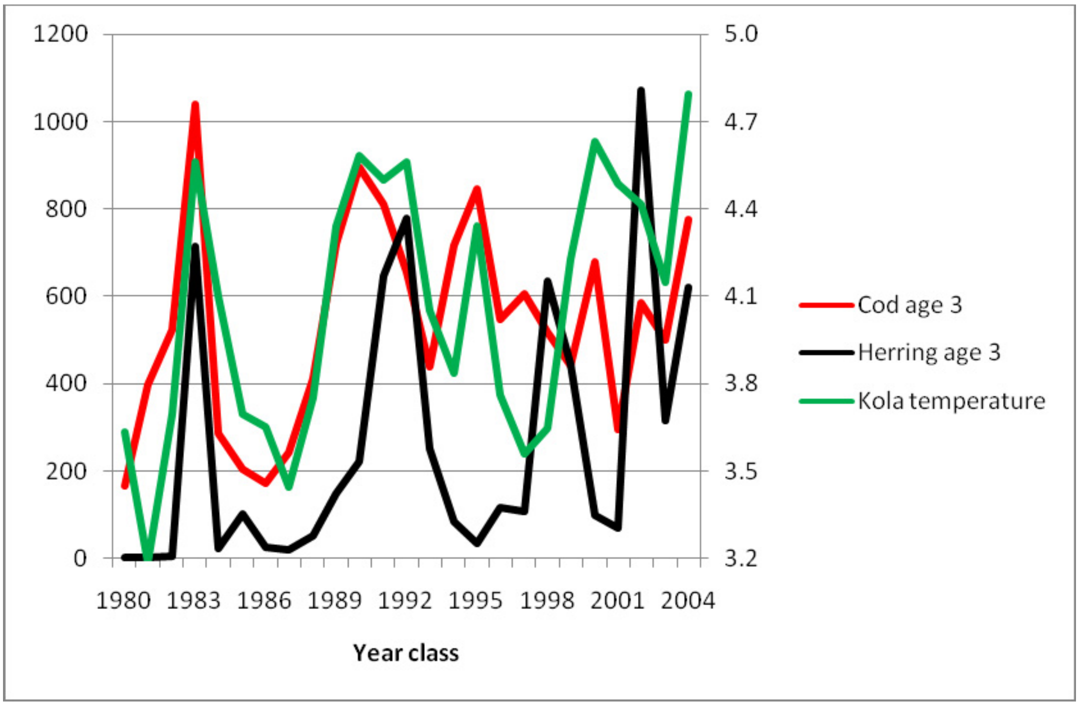


Figure 7.3. Cod and herring recruitment vs. temperature in Kola section. Recruitment on the left axis, temperature on the right axis. Data from 2008 assessment (ICES 2008a, b) and PINRO, Murmansk (Tereshchenko 1996, www.pinro.ru). Recruitments are scaled to fit to the same scale by dividing the number of herring recruits by 33.3.

7.2.2 Modelling

7.2.2.1 Gadget models

The existing Barents Sea Gadget model includes minke whales, cod, capelin and herring and is described in the 2007 WGSAM report. The model has now been expanded to include the full herring life cycle and its predation on capelin larvae. Herring spawn along the Norwegian coast after which the larvae move to the Barents Sea where they recruit as one fish. The young herring grow in the Barents Sea, being a prey for minke whales, cod and predate on capelin larvae. They migrate back to the Norwegian Sea at-age three and after that they are found in the Norwegian Sea and along the Norwegian coast. Processes as fishing, growth, maturation and spawning of herring are modelled in the Norwegian Sea/Norwegian coast area. However, their interactions with other fish or whales are not included into the model. Capelin larval and 0-group numbers are modelled from spawning to recruitment as age 1 fish the following year. A density-dependent natural mortality has been estimated outside the model, and is applied to the larvae. Juvenile herring predate on the capelin larvae, producing an important source of mortality prior to the recruitment of one capelin. This version of the model was presented at the ‘Linking Herring’ symposium at Galway, Ireland in August 2008.

7.2.2.2 STOCOBAR

The STOCOBAR (STOck of COd in the BARents Sea) is a cod-ecosystem coupled model that describes stock dynamics of cod in the Barents Sea, taking trophic interactions and environmental influence into accounts (Filin, 2007). It is designed as a tool for prediction and exploration of cod stock development as well as for evaluation of harvest strategies and recovery plans under different ecosystem scenarios. STOCOBAR is an age-structured, single-area and single-fleet model with one year time-step. It includes cod as predator and up to eight of its prey items: capelin, shrimp, polar cod, herring, krill, haddock, own young and other food. Species structure of the model is not fixed and it can be reduced from the current seven-species version to a simpler version, which includes cod and capelin only. The recruitment function is used for cod only. The stochastic nature of recruitment is realized within the model by including residuals in the simulated data.

The model parameters are estimated by fitting the simulated data to observed data on cod body weight and length in the stock, mean annual weight of cod in catch, cod maturation ogive and fatness (hepatosomatic index) as well as cod diet.Impact assessment of ecosystem factors on cod stock dynamics are based on "what if " scenarios. The model is programmed in Delphi and has a comprehensive windows-oriented user interface that makes selection of options and viewing of data and results easy. The first version of STOCOBAR was created at PINRO in 2001 and development of this model is continuing. The work on the development of the STOCOBAR model is part of the Barents Sea Case Study within the EU project UNCOVER (2006–2010) and the joint PINRO-IMR project (2004–2013) Optimal long-term harvest in the Barents Sea.

The last updating of the model was created to explore the implications of skipped spawning in cod. Skipped spawning could have important implications for an estimation of spawning-stock biomass and egg production because a significant part of mature cod may fail to spawn. The model parameterization was updated using new data.

7.3 Ecoregion C: Faroes

Nothing submitted for this Ecoregion

7.4 Ecoregion D: Norwegian Sea

In the recent years there has been a record high amount of pelagic fish in the Norwegian Sea. There has been strong recruitment of Norwegian spring-spawning herring and blue whiting, together with a stable Northeast Atlantic mackerel stock. At the same time the zooplankton biomass in the Norwegian Sea has decreased. This has raised the question whether there are species interactions that have negatively affected individual growth, mediated through depletion of their common zooplankton resource. The main goal of the new INFERNO project is to quantify the amount and degree of interactions between the major planktivorous species in the area. The project is a collaboration between scientists at IMR (Norway), PINRO (Russia), MRI (Iceland), FFL (Faroe Islands) and OSU (USA).

Work done during the project includes diet analysis, improved quality of historical acoustic data, statistical analyses and individual based modelling (IBM). A major part of the project aims to develop IBM's for NSS herring, blue whiting and NEA mackerel. The focus is on modelling the annual migration pattern and their plankton consumption. The IBM is run over one year, and focuses on the period when the species are located in the Norwegian Sea. The model domain is mainly the Norwegian Sea, excluding the adjoining Barents Sea and the North Sea. The years 1995–2007 will be modelled, assuming that proper validation data for all these years will be provided. Oceanographic features and phytoplankton fields are provided from a NORWECOM-ROMS model. This model system has now been coupled to an individual based model for *C. finmarchicus* that will be used to simulate the prey field of the pelagic fish. The plan is to link all these models early in 2009. Feeding is simulated from simple functional response models, and the half saturation constant is adjusted to a level which gives reasonable annual growth. Predation mortality on the pelagic fish is set to a fixed rate for the entire year. Thus, the model will not include any detailed specification of predators although this can rather easily be implemented if required. The IBM for each stock will be coupled together, and run in parallel to investigate the impact from the pelagic fish on the zooplankton resource. How extensively the species use the same areas, either directly or indirectly will also be investigated.

7.5 Ecoregion E: Celtic Seas

7.5.1 Modelling Seal Predation in ICES Division VIa

At the ICES ASC in Halifax, Pope and Holmes presented a paper describing 'length-based approaches to determine the significance of seal feeding on cod in ICES Division VIa (NW Scotland) [ICES CM 2008 F:08]. Studies of grey seal feeding in ICES Division VIa, based on scat sampling, have indicated that consumption of commercially exploited fish species is increasing, and that in the case of cod, estimated annual consumption by seals is comparable to single-species estimates for the total cod biomass thought to exist in the region (Hammond and Harris 2006). Insufficient data exist to deduce natural mortality estimates based on a full multispecies VPA. Specifically, the seal feeding data are only available for two years (1985 and 2002) and time-series do not exist of sandeel, the dominant food item of grey seals. Thus simpler predation models are required.

This paper outlined results from two approaches that are better suited to the limited data available. The first method was a length-based delay difference method characterized by the authors as 'proto-moments' modelling. The second method used ANOVA techniques to interpolate seal feeding data to provide estimates of the consumption of each age of cod in non-sampled years. These seal consumption-at-age estimates were then added to the fishery catch-at-age data to provide inputs into the Time Series Analysis (TSA) model used by the ICES working group for the current assessment.

Thomas and Harwood (2007) estimate that grey seal numbers in the west of Scotland area have increased through time. Hence, it is likely that the natural mortality rates of cod have also increased through time. Agreement between the proto-moment and TSA model estimates of total-stock biomass was generally reasonable, both in respect to absolute values and to trend through time. However, the proto-moment model typically suggested a steeper decline in recent years. Both models give higher values than the WGNSDS assessment which does not take account of seal predation.

The results of the TSA model showed at best slow recovery of total cod stock biomass and spawning-stock biomass in the period up to 2015 at current harvest rates. More future options are considered with the proto-moment model. Where the lower Density Dependent Survival (DDS) grey seal population estimates were used, these indicated that fishing mortality rate is the main constraint on cod spawning-stock biomass recovery. If no change occurs in either fishing effort or seal populations then as with the TSA model the spawning-stock biomass was predicted to show little recovery. Progressively reducing either fishing effort or seal populations progressively enhanced recovery of the spawning-stock biomass but the influence of reducing fishing effort by 50% or 100% was greater than equivalent reductions in seal numbers.

If the higher Density-Dependent Fecundity (DDF) grey seal population estimates were used in the analysis, then grey seal harvest rates become approximately equal to human harvest rates. Again maintaining the status quo resulted in rather little recovery of spawning-stock biomass but equivalent reductions in either factor had similar effects on the recovery of the spawning-stock biomass. Thus, reducing either human harvest or grey seal harvest by 50% has a similar effect and increased SSB to above 10,000 t by 2015.

7.5.2 An Ecopath Model for Rockall Trough region

Work has recently begun at the Scottish Association for Marine Science (SAMS), together with Plymouth University and FRS to create an Ecopath with Ecosim (EwE) of the Rockall Trough region (ICES area VIa,b and VIIb,c,k,j), in order to evaluate the potential impact of deep-water fisheries.

The modelling framework will be used to, in particular, predict the effect of current fishing pressure on the target fish species but also predict other ecosystem components over time (20 years, 50 years, 100 years etc), and to predict the effect of banning certain fishing gears within the region. This project is known as 'Deepfish' and was funded by the Esmee Fairbairn Foundation.

7.5.3 The 'PREDATE' project in the Irish Sea

Most multispecies models do not take account of predation on the eggs and larvae. Juveniles simply recruit into the model at-age-1, with little regard for what might have happened during the previous year. Predation mortality is thought to be substantial during this first year (Segers *et al.,* 2007; Daan *et al.,* 1985), and WGSAM have a long-term aspiration to try to incorporate prerecruitment processes into existing multispecies models. The PREDATE project at Cefas (UK), aims to develop molecular tools for detecting the presence of eggs and larvae (which can be difficult to identify) of several commercial species in the stomachs of predators; to test the reliability of these methods via laboratory experiments; and to employ the methods in the field to identify the range of predators responsible for egg and larval mortality. The first research cruise of this project was carried out in February 2008, in the Irish Sea. Pelagic predators were particularly targeted (herring and sprat), and stomachs were examined both visually and using genetic probes to test for the presence of plaice, cod and haddock. Initial results in herring, suggest that ~20% had been consuming plaice over the past 24–48 hours.

7.6 Ecoregion F: North Sea

A comprehensive Ecopath with Ecosim (EwE) model of the North Sea, calibrated to time-series data has now been completed and fully documented after nearly 6 years of work (see Mackinson and Daskalov 2007, www.cefas.co.uk/publications/techrep/tech142.pdf). A full technical description is now available for this model, which includes data sources, assumptions and detailed outputs of sensitivity testing. The various chapters concerning particular functional groups are co-authored and have been peer-reviewed by international experts. The model has subsequently been used to evaluate Maximum Sustainable Yield (MSY) within a multispecies context, on behalf of the North Sea Regional Advisory Council *(see Section 3),* in a paper submitted by Mackinson *et al.* to the Canadian Journal of Fisheries & Aquatic Science. The model comprises 68 functional groups and 12 fishing fleets. Preliminary spatial analyses have also been undertaken with this model in order to evaluate the efficacy of planned and existing marine protected areas in the North Sea.

As stated in Section 6, the stomach data from the ICES 'years of the stomach' were reanalysed in a new study by Kempf *et al.* (2008a) in order to evaluate the influence of changes in predator-prey spatial overlap on the diet of North Sea cod and whiting. The large-scale response of North Sea cod and whiting populations to varying prey fields was analysed using Generalised Additive Models (GAMs). The composition of the prey field and changes in predator-prey overlap had a significant effect on the diet composition in the final GAMs explaining 65.6% of the variance. The existence of a large-scale prey refuge at low prey abundances as proposed by the Holling type III functional response was demonstrated for the first time.

The detailed understanding gained by analysing the influence of changes in spatial predator-prey overlap has been used to evaluate the interplay between temperature related processes and predation in determining age 1 recruitment strength for North Sea cod and Norway pout (Kempf *et al.*, 2008b). For this purpose an index of predation impact (PI) on 0-group juveniles was calculated out of survey data. PI was assumed to depend on the abundance of the predators as well as on the spatial overlap between predator and prey populations. Generalized Additive Models (GAMs) were created with the spawning-stock biomass (SSB), the sea surface temperature (SST) during the 1st, 2nd and 3rd quarter of the year in the respective spawning and nursery areas and PI as explanatory variables. SSB had no significant impact on recruitment strength for both species, i.e. there was no stock-recruitment relationship. By contrast, SSTs during the 2nd quarter and PI explained the interannual variability in age 1 recruitment to a large extent. The resulting GAMs explained 88% of the total variance for cod and 68% for Norway pout (Figures 7.4 and 7.5). The SST during the 2nd quarter determined thereby the overall level of recruitment strength. Above certain SSTs, however, the effect on recruitment strength was no longer significant. In these temperature ranges, predation was the dominant effect. The fate of North Sea cod and Norway pout stocks under global warming conditions will be therefore strongly influenced by the status of the North Sea foodweb and to a greater extent than in previous colder periods where temperature related processes ensured higher survival rates during egg and larval stages.

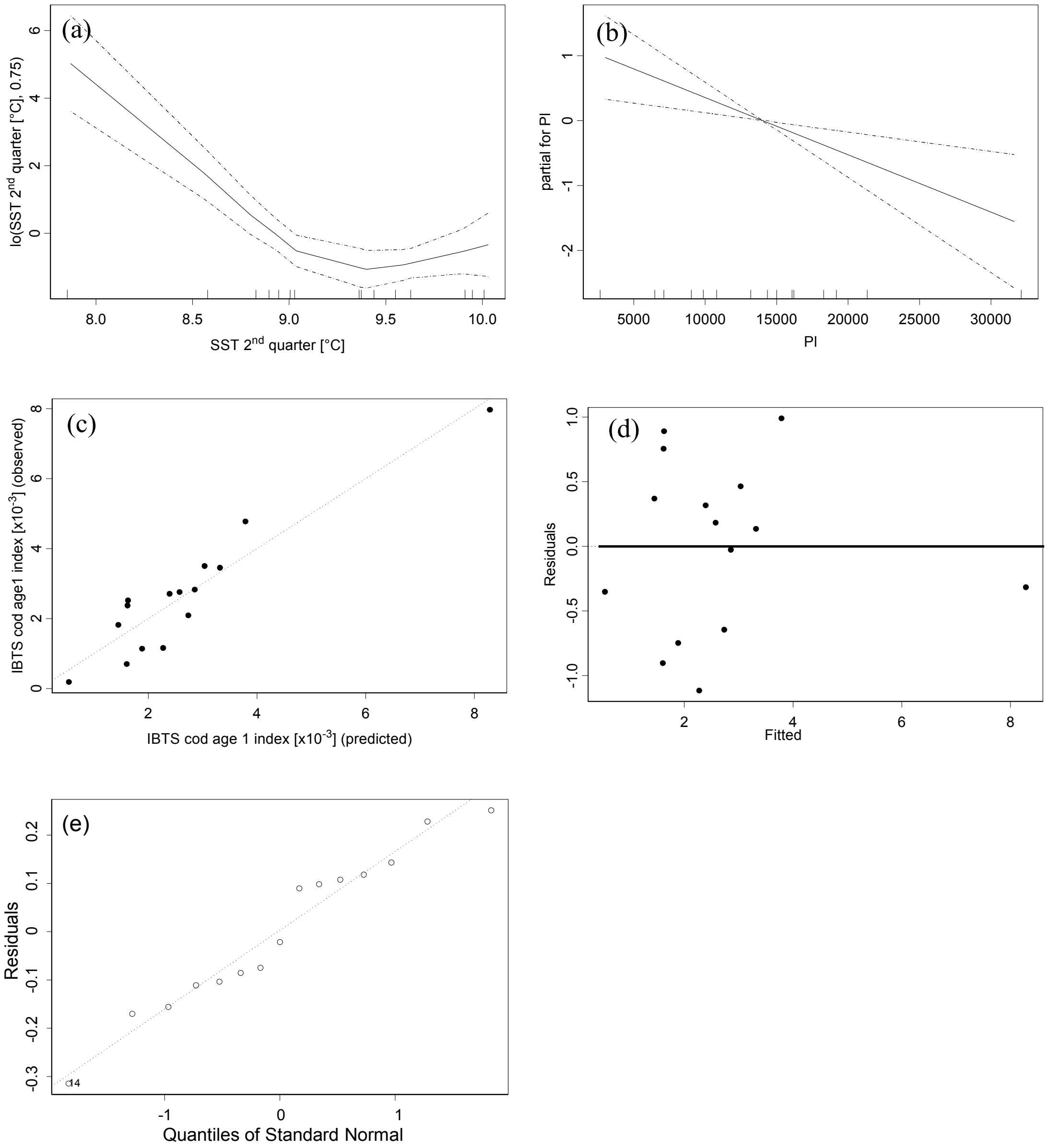


Figure 7.4. Fitted cod age 1 recruitment index as a function of the North Sea sea surface temperature (SST) during the 2nd quarter north of 55° latitude and the predation index (PI). (a) represents the contribution of SST and (b) the contribution of PI.(c) shows the relationship between predicted and observed IBTS cod age 1 index, (d) the residuals in dependence of the predicted model values and (e) a Q-Q plot for the residuals. Striped bars and dashed lines indicate the twice standard error. Bars on the x-axis indicate observations. The span argument for the loess smoother (lo) was 0.75.

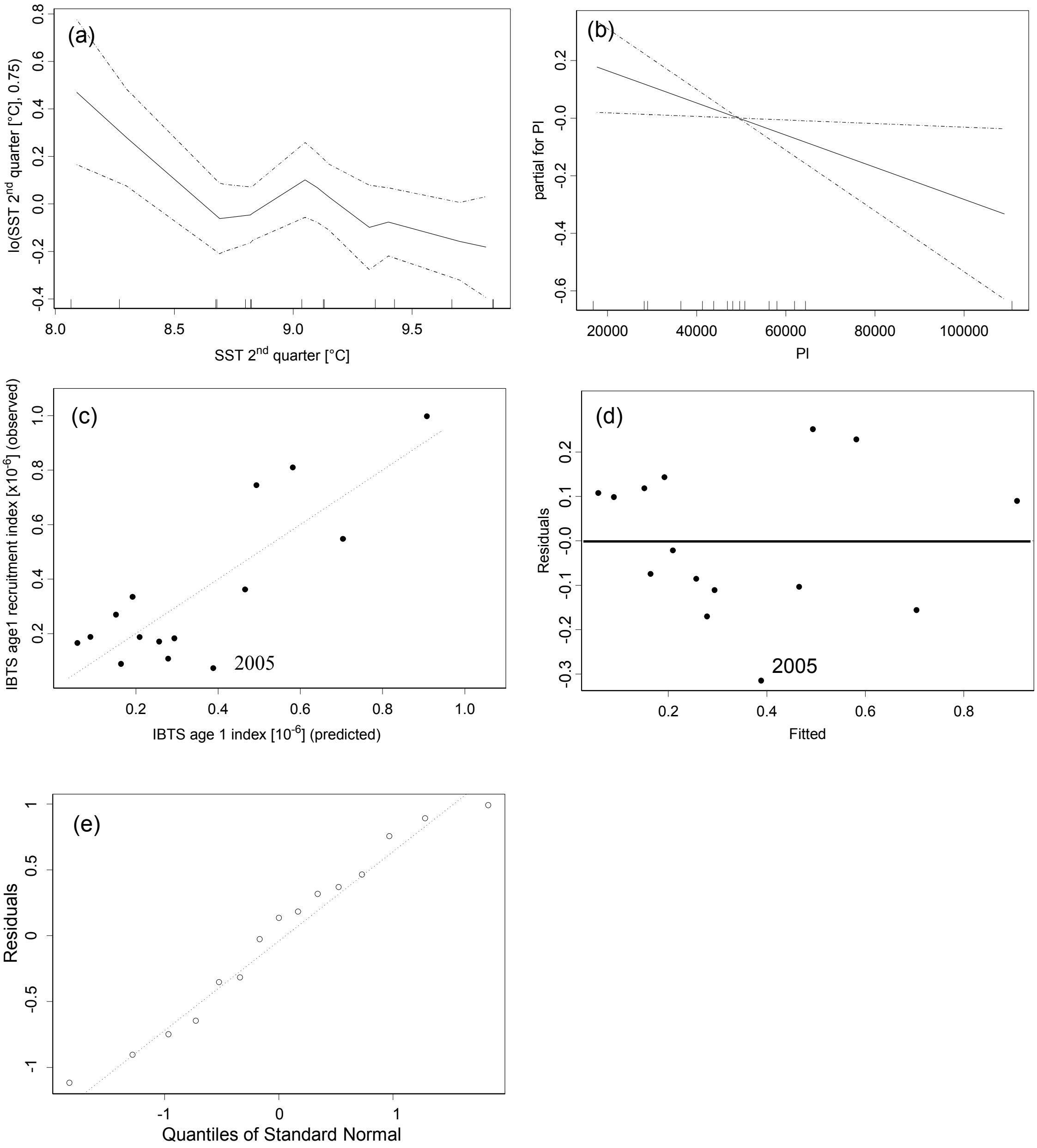


Figure 7.5. Fitted Norway pout age 1 recruitment index as a function of the North Sea surface temperature (SST) during the 2nd quarter north of 58° latitude and the predation index (PI). (a) presents the contribution of SST and (b) the contribution of PI. (c) shows the relationship between predicted and observed IBTS Norway pout age 1 index, (d) the residuals in dependence of the predicted model values and (e) the Q-Q plot for the residuals. Striped bars and dashed lines indicate the twice standard error. Bars on the x-axis indicate observations. The span argument for the loess smoother (lo) was 0.75.

7.7 Ecoregion G: South European Atlantic Shelf

7.7.1 Trophic data

A stomach data sampling program developed by IEO started in 1988 and continues during the annual demersal survey on-board the RV "Cornide de Saavedra". The survey covers Cantabrian Sea and Galician waters. The survey is performed every autumn and stomachs are analysed quantitatively on-board using a trophometer to measure the volume of the stomach content. Prey species in the stomachs are determined to the lowest possible taxonomic level. Decapod crustaceans and molluscs are measured individually while the rest of the invertebrates are counted and maximum and minimum sizes are recorded (if possible). Hence, approximately 10 000 stomachs are analyzed every year for the main fish predators. These data were used to define trophic processes in GADGET and ECOPATH models for Atlantic areas around the Iberian Peninsula.

7.7.2 Gadget models

Several GADGET models exist for this area. Two separate hake models, one for southern hake and another for northern hake, and a separate anchovy model are under development.

7.7.3 Gadget in the Bay of Biscay for southern European hake

The southern hake model includes a cannibalistic trophic relationship. It was presented in the 2008 ICES WGHMM (Cerviño *et al.*, 2008). The model covers the same area as the present ICES official assessment for Southern Hake. At the beginning of WGSAM 2008 the South hake cannibal model progress was presented and some critical problems were identified (see *Section 4.4*). A subgroup of WGSAM was commissioned to deal with some of these problems during the meeting.

7.7.4 Gadget in the Bay of Biscay for anchovy

A Gadget model for the Bay of Biscay anchovy (*Engraulis encrasicolus*) is also under development. This model is intended to form a part of a hake-anchovy multi species model, with the hake eating both small hake and anchovy. The anchovy model was reviewed during the WGSAM 2008 meeting (see *Section 4.4)*. The model is capable of producing trends in biomass and fishing mortality which are similar to those presented in the assessment working group (WGHMSA). However the absolute levels of modelled biomass (and hence fishing mortality) do not appear to be realistic. Further development work on the model will continue during 2008 and 2009.

7.7.5 Gadget in the Bay of Biscay for northern European hake

Following the results published in Mahe, K. (2007) and Velasco, F. (2007) recent work has been directed to include the cannibalism of hake into the previous multispecies model for hake predating on anchovy. This model is still at a preliminary stage and more work is necessary to solve the problems of fitting it to data. Progress on this model was not presented at the WGSAM 2008 meeting. Some work has been carried out in updating data to both the hake submodel and the anchovy model. However, this work cannot be continued without the collaboration of the French partners, since there is a clear need for French data, mainly for anchovy, in the study area. New work has also been done in data processing, checking the availability of data of other relevant species in the area, in order to be included in this multispecies approach (e.g. horse mackerel and blue whiting).

7.7.6 ECOPATH and ECOSIM

An ECOPATH with ECOSIM model based on a database of bottom-trawl surveys, ICES stock assessment estimates, stomach analyses and information from literature was parameterized with 1994 data. This model has 28 trophic groups corresponding to pelagic, demersal and benthic domains, as well as detritus and fishery discards (Sanchez and Olaso, 2004; Sanchez *et al.*, 2005). A new ECOPATH with ECOSIM model for the Cantabrian Sea was recently developed with 2004 information. It considers 42 functional groups and 8 fisheries. The main improvement with respect to the past model is the inclusion of low level trophic groups (in the past model these were estimated from predator requirement) from benthic surveys (infrabenthos, benthos, suprabenthos and zooplankton).

7.8 Ecoregion H: Western Mediterranean Sea

Nothing submitted for this Ecoregion

7.9 Ecoregion I: Adriatic-Ionian Seas

Nothing submitted for this Ecoregion

7.10 Ecoregion J: Aegean-Levantine

Nothing submitted for this Ecoregion

7.11 Ecoregion K: Oceanic Northeast Atlantic

Nothing submitted for this Ecoregion

7.12 Ecoregion L: Baltic Sea

In the Baltic Sea, the interacting fish community in the open sea is dominated by three species namely cod, herring, and sprat. Cod is known to feed on herring and sprat and in addition juvenile cod. The biomass of cod has varied by a factor of around 5 with the highest biomass during the beginning of the 1980s and the lowest in the most recent period. There seems to be a clear link between the biomass of the predator and the biomass of the prey species, especially sprat. The Baltic Sea is heavily influenced by environmental driving forces, which impact reproduction, survival and species interactions. Especially eutrophication, hypoxia and water inflow from the North Sea play a key role.

7.12.1 Ecopath with Ecosim

To evaluate interactions between fisheries and the foodweb from 1974 to 2000, Harvey *et al.* (2003) created a foodweb model for the Baltic Sea proper, using EwE. Model parameters were derived mainly from multispecies virtual population analysis (MSVPA). Ecosim outputs closely reproduced MSVPA biomass estimates and catch data for sprat (*Sprattus sprattus*), herring (*Clupea harengus*), and cod (*Gadus morhua*), but only after making adjustments to cod recruitment, to vulnerability to predation of specific species, and to foraging times. Cod was shown to exhibit top-down control on sprat biomass, but had little influence on herring. Fishing, the main source of mortality for cod and herring, and cod reproduction, as driven by oceanographic conditions as well as unexplained variability, were also key structuring forces. The model generated many hypotheses about relationships between key biota in the Baltic Sea foodweb and may ultimately provide a basis for estimating community responses to management actions.

The Harvey *et al.* (2003) model, with some modification, has been used as a foodweb component in Baltic NEST platform (www.balticnest.org). Based on the Harvey *et al.* model Hansson *et al.* (2007) explored possible effects of different management scenarios for the Baltic Sea. The scenarios include an oligotrophication of the system, a drastic increase in the number of seals, and changes in the fishery management. From these simulations the authors concluded that fisheries, seals, and eutrophication all have strong and interacting impacts on the ecosystem. These interactions call for integrated management. The modelling highlights the potential for conflicts among management mandates such as flourishing fisheries, rebuilt seal populations, and substantially reduced nutrient inputs. The results also suggest that fisheries management reference points have to be adjusted in response to changes in the presence of natural predators or ecosystem productivity.

Österblom *et al.* (2003) used a EwE NEST model to investigate reduced top-down control (seal predation) and increased bottom-up forcing (eutrophication) which can largely explain the historical dynamics of the main fish stocks (cod, herring and sprat) in the Baltic Sea between 1900 and 1980. Based on these results and the historical fish stock development two major ecological transitions are apparent. A shift from seal to cod domination and a shift from cod to clupeid domination in the late 1980s. Authors argue that the shifts in the Baltic Sea are a consequence of human impacts, although variations in climate may have influenced their timing, magnitude and persistence.

Another EwE model of Baltic foodweb (Niiranen *et al.,* 2008) was presented during ICES ASC 2008 in Halifax by Susa Niiranen from the Finnish Institute of Marine Research. The authors used a 30 functional groups model to investigate the impact of the changing of nutrient conditions on a Baltic foodweb as well as the propagation of tracers in the foodweb.

For five Baltic costal ecosystems (Puck Bay, Curonian lagoon, Lithuanian Open Baltic coast, Gulf of Riga coast and Pärnu Bay) Ecopath models have been built to investigate trophic networks and carbon flows (Tomczak *et al.,* in press). Authors compared the models using 12 common functional groups. The studied systems ranged from the hypertrophic Curonian Lagoon to the mesotrophic Gulf of Riga coast. Interestingly, authors found that macrophytes were not consumed by grazers, but rather channelled into the detritus food chain. In all ecosystems fisheries had far reaching impacts on their target species and on the foodweb in general.

The ICES working Group on Integrated Assessment of the Baltic Sea (ICES WGIAB 2008) investigated 7 systems within the Baltic Sea ecoregions: the Sound (ÖS), the Central Baltic Sea (CBS), the Gulf of Riga (GOR), the Gulf of Finland (GOF), the Bothnian Sea (BOS), a coastal area (COAST). The Integrated Assessments (IAs) approach adopted by WGIAB considered physical-chemical and trophic interactions including biodiversity and socio-economic parameters as a basis for ecosystem-based management.

7.13 Ecoregion M: Black Sea

Nothing submitted for this Ecoregion

7.14 Ecoregion: Canadian Northwest Atlantic

Ecosystem modelling plays an important role in the implementation of ecosystem-based management approaches. However, the development and implementation of these models is often a time consuming and data demanding proposition. In this context, choosing the proper modelling approach for the specific goals in mind, as well as ensuring that the necessary data are available (or will be collected) requires advance planning and organization. Since the last WGSAM meeting, several activities at Fisheries and Oceans Canada (DFO) have taken place towards addressing these types of issues. Instead of a detailed report of all activities, progress can be better illustrated by providing some details on key activities and programs.

Regarding modelling approaches, many of the currently available frameworks were reviewed at a DFO national workshop held in Victoria, British Columbia, in October 2007 (DFO 2008). The goal of this meeting was to compare different approaches, as well as assess their relevance and utility in the Canadian context. Invited experts on different modelling approaches gave keynote lectures discussing the advantages, disadvantages and limitations of each of the models or family of models. Among the general conclusions it was recognized the existence of a continuum in model complexity as well as in their applications, going from heuristic/conceptual, strategic and tactical that can be applied in the Canadian context. The importance of using multiple modelling approaches of different complexity was emphasized, and multispecies and ecosystem models were envisioned as operating models within management strategy evaluation frameworks.

Also in 2007, DFO launched its Ecosystem Research Initiative (ERI), which is a national program intended to facilitate the development of regional research priorities in the area of ecosystem science. There are 6 regional ERI programs underway (Pacific region focused on the Strait of Georgia, Central and Arctic region focused on the Beaufort Sea, Quebec region focused on the St. Lawrence Estuary, Gulf region focused on the Northumberland Strait, Maritimes region focused on the Gulf of Maine, and Newfoundland and Labrador Region focused on the Newfoundland Shelf). Each one of these programs is tailored to regional needs and goals, and builds upon existing knowledge and ongoing activities in each region.

For example, in the Newfoundland and Labrador (NL) region the ERI program is called NEREUS (NL's Expanded Research on Ecosystem-relevant but Under-surveyed Splicers). It is designed to enhance the capability of NL surveys for providing information on ecosystem status and main trends by improving monitoring on forage fish, non-commercial species, major benthic components and trophic interactions. It also aims to identify and track main pathways of energy in the NL system by integrating results from trophodynamic and statistical models with trends and patterns in ecosystem indicators.

7.15 Ecoregion: US Northwest Atlantic

7.15.1 Ecopath with Ecosim

As part of work developing The Energy Modeling and Analysis eXercise (EMAX), 4 Ecopath models were developed covering the Gulf of Maine, Georges Bank, Southern New England and Middle Atlantic Bight (Link *et al.,* 2006). EMAX used two energy budget software packages: Econetwrk and Ecopath. There were five main elements critical to the construction of each node for the four NE US regional networks. Biomass, production, consumption, respiration, and diet composition were estimated for all nodes. Additionally, for some nodes other sources of removals- namely fisheries were estimated.

These models are being used in various virtual perturbation experiments. They provided context in the GARM III process. The use of these models remains an area of research.

7.15.2 ATLANTIS

ATLANTIS (Fulton *et al.,* 2005) is by far the largest, most complicated model NMFS are using. It was developed by colleagues at CSIRO of Australia and includes a modelling environment with: "A virtual ocean with all its complex dynamics, a virtual monitoring and assessment process, a virtual set of ocean-uses (namely fishing), and a virtual management process”. The dynamics range from solar radiation to hydrodynamics, to nutrient processes, to growth (with age structure, to feeding to settling, to sinking, to migration, to fishery capture, to fleet dynamics, to market valuation, to regulation, then feeding back into the various libraries of the model as appropriate. NMFS have developed ATLANTIS for the NE US continental shelf ecosystem with 30 boxes, 5 depth layers per box, 12 hour time-steps for 50 years, 45 biological groups, and 16 fisheries. The parameterization and initialization has required over 60,000 parameters and 140,000 initial values to estimate. A first level of calibration has been completed to ensure basic biophysical processes are realistic. A second level calibration is also now complete to ensure fishing processes are reasonable. A final, third level validation is currently underway. Future scenarios of different management strategies are planned to follow completion of the third level calibration.

Although parameterized, initialized and loosely tuned to empirical values, ATLANTIS is too complex and was not designed to provide specific tactical management advice for a particular stock (e.g. a quota or effort limit). Rather, ATLANTIS is not only a research tool but a simulator to guide strategic management decisions and broader concerns. For instance, it has been used to provide multispecies fishery advice and multi-sector ocean-use advice. The NEUS rendition of ATLANTIS has not been through a formal model review. Scientists are currently in the process of documenting this parameterization and model calibration set of efforts.

The advantage of ATLANTIS is that it can incorporate multiple forms of a myriad processes, it can emphasize those considerations and processes most appropriate for a given system, and it can virtually evaluate management decisions without having to actually implement them in a real system. Another positive is that it covers a wide range of biota and is quite flexible or adaptive to a range of key factors. The chief negative of ATLANTIS is that it is unwieldy in its complexity, takes an inordinate amount of time to parameterize, initialize, calibrate, and run any particular application. Additionally, the validation routines and capabilities of ATLANTIS are minimal at best, requiring much improvement.

7.15.3 ECOGOMAG

NMFS are currently constructing a model of the Gulf of Maine (GOM) ecosystem based on results from Ecopath modelling exercises. The authors have structured the system based on 16 aggregated biomass nodes spanning the entire trophic scale from primary production to seabirds and marine mammals. Parameters from the Ecopath model of the GOM system were used to construct a simulation model using recipient controlled equations to model the flow of biomass and the biomass update equation used in Ecosim to model the annual biomass transition. Various performance measures and metrics such as throughput, total flow, biomass ratios (i.e. pelagic fish to zooplankton), and trophic reference points can be monitored over the simulated time horizon. The model will be used to evaluate how the GOM ecosystem responds to large and small-scale changes to the trophic components and system drivers. Specifically events such as climate change, various fishing scenarios, and system response to changes in the biomass of lower and upper trophic levels could be evaluated. ECOGOMAG has not been through a formal model review. This remains a research tool and has not been used for management purposes.

7.15.4 Extended single-species models

A suite of ‘minimum realistic’ models have been developed and, these models seek to add predation removals of a stock into a single species assessment model. These have been both age/stage structured and bulk biomass/production models. Examples of species where this has occurred are predominately forage stocks, including Atlantic herring, Atlantic mackerel, longfin squid, and Northern shrimp. One model has been through a formal stock assessment review; the others are in various stages of development and research. Mostly the way predation is added into these models is to treat it as an additional fleet, explicitly as another source of removals. The data required are abundance of predators that eat the stock of interest, stomach contents, consumption estimates, and diet composition estimates (in addition to the usual survey and fisheries catch data).

The positives of this approach are that such models are relatively simple conceptually and operationally, they use extant data, they are implemented in a familiar assessment and management context, they provide familiar (albeit modified) model outputs, they improve the biological realism of assessment models, and they help to inform and improve stock assessments for species that may have had modelling challenges. The negatives of this approach are that they run the risk common to all MRMs, namely that they may neglect complex interactions and non-linear responses. They also have the potential of being controversial, by producing more conservative biomass reference points and emphasizing the potential for competition between predators and fleets that target these stocks without having a fuller modelling capability to fully address these trade-off issues.

7.15.5 Single Species Add-ons: Ecological Footprints

These models attempt to account for the amount of food eaten by a stock. These estimates of energetic requirements (i.e. consumptive demands) at a given abundance level are then contrasted to estimates of the amount of food known to be available in the ecosystem from surveys and mass-balance system models. In many ways this is the same calculation as noted above for predatory removals; the difference here is that instead of summing across all predators of a stock, here we sum across all prey for a specific stock.

These 'footprints' have been calculated for a wide range of groundfish, elasmobranch, and pelagic fish species. One set of stocks (the skate complex) has had these estimates go through a formal stock assessment review; the others are in various stages of development. The data required are abundance of predators that eat the stock of interest, stomach contents, consumption matrices, and diet composition estimates (in addition to the usual survey and fisheries catch data).

7.15.6 MSVPA-X

This 'extended' multispecies virtual population analysis is an expanded version of the ICES MSVPA model applied in Europe, which is in effect a series of single species VPAs linked together via a feeding model. MSVPA-X has been applied to two-subsystems in this region. One is in conjunction with colleagues in the SEFSC and emphasizes menhaden as prey with three main predators in the mid-Atlantic region. The other is for the Southern New England-Georges Bank-Gulf of Maine ecosystem, has 19 species, and emphasizes herring and mackerel as the major prey. The mid-Atlantic MSVPA-X has gone through extensive peer review in the ASMFC and SARC context. Outputs from that model have informed the single species assessments, particularly by providing time-series of M2s for the assessment of menhaden. The NEUS MSVPA-X is still in research and development, with results anticipated to inform single species assessments for herring and mackerel.

The positives of this approach effectively mirror those of the SS Add-on with predation; namely it uses extant data, it is implemented in a familiar assessment and management context, it improves the biological realism of assessment models, and it helps to inform and improve stock assessment outputs. The key negative of this approach is that it is quite data intensive, with many factors required for each species to parameterize the model. Other limitations of MSVPA are being addressed in the MSVPA-X version (software continually being updated), particularly adding in 'external' (i.e. not age structured) predators.

7.15.7 Multispecies production models: MSPROD

A multispecies extension of the Schaeffer production model has been developed to include predation and competition terms. The software development is ongoing, with a GUI and mathematical simulation engine available. This model seeks to simulate the relative importance of predation, intra-guild competition, between guild competition, and fisheries removals. The model has been parameterized for 25 species from the Georges Bank region. The model has not been through a formal review. The model currently does not fit or tune to time-series of survey or catch data; the model currently is a simulator, parameterized with empirically based values, which can then explore sensitivities and scenarios for different considerations. The data required are initial biomass estimates, carrying capacities, predation and competition interaction terms, growth-rates, and fishery removals.

The positives of this approach are that it explicitly accounts for ecological processes in addition to fisheries effects and that lower trophic level processes can be directly linked to estimates of carrying capacity. The negatives are that some of the parameters, although empirically derived, are difficult to estimate. The other negative is that it does not currently fit to time-series data. Like most multispecies models, it is parameter intensive but less so than many other multispecies models given the simplicity of the model equation structure.

7.15.8 Multispecies production models: Agg-PROD

This is effectively the same as the MS-PROD model noted above, but initialized for aggregate groups of species. These groups have been parameterized both as functional guilds and taxonomically related species. The one distinction is that the model simulates BRPs and a more systemic level production at a group, rather than species, level. This will be useful for considering a two-tier quota system.

8 Year of the Stomach – securing and making the data available

8.1 Background to request

In a response to the call for WGDIM to work closely to address the needs of end-users and empower the ICES Data Centre to deliver meaningful services, WGSAM suggested (through a communication from John Pinnegar, drafted at the Halifax ASC) the following ToR for WGDIM in 2009:

"WGSAM requests that WGDIM work towards making the ICES 'Year of the Stomach' datasets for North Sea and Baltic more readily available to the ICES community. This will require the creation of a standardized and quality-controlled version of the data including an updated look-up key for prey codes".

8.2 Year of the Stomach

The first 'year of the stomach' in the North Sea occurred in 1981 and covered a handful of species in the North Sea. There was some follow up data collection performed in 1985–1986 and a decade later in 1991 a larger number of species were sampled, i.e. the 2nd year of the stomach. The data were collected as part of an ICES initiative and the results and analyses were presented in two cooperative reports (CRR 164 and CRR 219). The datasets are currently in the hands of the individual scientists (many of whom have now retired) and there are potential discrepancies in the different copies, as well as difficulties in translating prey identification codes (which use the now defunct NODC notation).

8.3 End product

WGDIM should work with the ICES Data Centre and the various contributors to original 'year of the stomach' sampling programmes (as well as WGSAM), to:

- Collate the dataset(s) into one location
- Standardize references and format
- Create an online, downloadable dataset
- Make the research reports available online (with the data)
- Secure the dataset for future use by the scientific community

8.4 Actions

DESCRIPTION	RESPONSIBLE	COMMENTS
Convert CRR's into electronic format	ICES Librarian	Will be done by 20/10/2008
Issue request for North Sea dataset(s)	WGDIM	There may or may not be a 'master dataset'. This action would involve contacting Niels Daan, Henk Heesen, Morten Vinther and Henrik Gislason to determine what they have
Comparison of North Sea datasets	ICES Data Centre/WGDIM	Create a master set from assembled datasets
Request for Baltic dataset(s) and interim year datasets	WGDIM	Contact Henrik Gislason, Fritz Köster to determine what they have or identify who might have the complete/additional set
Comparison of Baltic datasets	ICES Data Centre/WGDIM	Create a master set from assembled datasets
Creation of master datasets	ICES Data Centre	Merge Baltic and North Sea datasets
Conversion/Mapping of codes to ICES/Standard Units	ICES Data Centre	
Make data available through EcoSystemData front-end	ICES Data Centre	The dataset is really one table but it could be shown, graphed and mapped in EcoSystemData

The Bureau has subsequently accepted a request for funding (submitted by Neil Holdsworth) to support a workshop of 4–5 people for 1.5 or 2 days to complete this task.

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Annex 1: WGSAM List of Participants 6–10 October 2008

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Annex 2: WGSAM Terms of Reference for the next meeting.

The Working Group on Multispecies Assessment Methods [WGSAM] (Co-Chairs: John Pinnegar, UK and Bjarte Bogstad, Norway) will meet at ICES headquarters, Copenhagen from 5–9 October 2009 to:

a) Review further progress in multispecies and ecosystem modelling throughout the ICES region;
b) Report on the development of key-runs (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies fisheries models for different ICES regions;
c) Determine a standardized format for reporting Ecopath key-runs;
d) Review current process-knowledge, data requirements, and data available to model predation on pre-settlement life stages by pelagic predators;
e) Work towards the inclusion of spatial overlap in existing multispecies models;
f) Review methods for estimating consumption and diet composition in multispecies models;
g) Work towards implementing new stomach sampling programmes in the ICES area in 2011 by reviewing protocols and estimating costs;

Longer-term aspirations (possible ToRs for future years)

- Investigate alternative ways to present multispecies advice to decision-makers;
- Explore the possibility of developing 'virtual datasets' which might be used in multiple models, for comparison and sensitivity testing.

Supporting information

PRIORITY:	Multispecies assessment modelling is essential to the development of viable long-term management strategies.
SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:	The increased emphasis on ecosystem management, and the move away from advising on single-stocks in isolation, necessitate considering interactions between fish stocks and the ecosystems of which they are part. Historically the ICES multispecies working and study groups have acted as a useful conduit within the ICES system, drawing together advice and quantitative outputs from many different assessment working groups and combining these into an integrated product of direct use to managers and researchers. The 2007 meeting of WGSAM showed that there is much ongoing work within this field of research, and that there is a need for a pan-European forum for reviewing progress within this important field (ToR a). Stomach content data serve as the basis for a plethora of multispecies, extended single-species, and ecosystem models. Having a solid foundation of adequate stomach content data are a prerequisite for implementing the ecosystem approaches to fisheries. Stomach sampling has been annual in some areas, while in other areas (e.g. the North Sea) a large effort ('Year of the Stomach') has been made sporadically. At the 2009 WGSAM meeting the group will work towards implementing new stomach sampling programmes throughout the ICES area in 2011 by reviewing protocols and estimating costs. Multispecies models have often been used to provide updates of natural mortality *M* for inclusion in conventional single-species stock assess-

	ments. Consequently it is considered useful to have occasional 'key-runs' for each region, whereby time-series are updated and mode configurations are agreed by a number of regional experts. WGSAM will continue to work towards key-runs in the Barents Sea, Bay of Biscay and Iceland as well as devising the reporting formats necessary for key-runs using Ecopath with Ecosim (ToRs b and c). At the WGSAM 2008 meeting it became apparent that little is known with respect to the role that herring and sprat (and other pelagic fish) play as predators of demersal fish eggs and larvae. Research in several sea areas (e.g. the North Sea, Iceland, NW Atlantic) suggest that herring may constrain the recovery of commercial species when they are at high abundance, and conversely when herring are removed other species seem to experience enhanced recruitment success. In 2009 WGSAM will review the evidence-base on this topic (ToR d) and this may influence future stomach sampling exercises, and species included as predators in multispecies models.
RESOURCE REQUIREMENTS:	–
PARTICIPANTS:	Approx 20. Expertise in ecosystem, modelling and fish stock assessment from across the whole ICES region.
SECRETARIAT FACILITIES:	None
FINANCIAL:	No financial implications
LINKAGE TO ADVISORY COMMITTEES:	ACOM
LINKAGE TO OTHER COMITIES OR GROUPS:	AMAWGC, WGRED, WGECO, SGMAS, WKEFA, SGMIXMAN, most assessment Expert Groups
LINKAGES TO OTHER ORGANIZATIONS:	–

Annex 3: Requests for other groups

BEWG:

Produce a digitalized map of average benthos production and biomass by quarter and area for the North Sea

Explanation

Benthic food plays a large role in the diet of several North Sea predators. Among these are haddock and grey gurnard, two species which are important predators of sandeel (haddock), cod and whiting (grey gurnard). Unfortunately, the WGSAM does not have any information on the yearly variation in benthos production and biomass and is therefore forced to assume these as constant. However, future developments of the SMS will likely be able to include spatial differences in biomass and production of prey and the BEWG should be able to describe these to WGSAM. With these data, the model can take account of whether e.g. northern areas differ from southern in the amount of benthos present.

WGWIDE:

Report on the proportion of horse mackerel and mackerel stock which are present in the North Sea in each quarter of the year.

Explanation

Mackerel and horse mackerel are responsible for virtually all of the predation on 0-group herring as well as a large part of the consumption of 0-group Norway pout and all ages of sandeel in the North Sea. The WGSAM does not have updated information on the proportion of the stock which enters the North Sea and the amount of time they spend in this area. The uncertainty about this parameter renders estimates of natural mortality of herring, Norway pout and sandeel extremely uncertain. All these species have experienced a suite of poor recruitment years and to determine whether mackerel and horse mackerel predation has contributed to this, new information on the stock size of these predators in the North Sea is needed.

ACOM:

ACOM should reconsider the following paragraph in the standard 'Single Stock Summary template': "Fishing mortalities between $F_{0.1}$ and F_{max} can be considered as candidate target reference points, which are consistent with taking high long-term yields and achieving a low risk of depleting the productive potential."

Explanation

The standardized ICES single-species advice on long-term F could be problematic, because if followed, low F values might for some stocks be expected to result in very large stock sizes if species are treated in isolation, but this could have knock-on impacts in a multispecies context, in terms of reduced productivity due to increased predation pressure and density-dependent growth reduction, such that these high yields are never attained. In the 2008 WGSAM report (Section 3.3), this is exemplified for a number of cod stocks.