Report of the Working Group on Multispecies Assessment Methods (WGSAM)

15–19 October 2007

San Sebastian, Spain

International Council for the Exploration of the Sea

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Executive summary

This is the first report of the newly created Working Group on Multispecies Assessment Methods (WGSAM). The group met at AZTI, San Sebastian (Spain) and reviewed multispecies and ecosystem modelling activities ongoing in each ICES ecoregion (including the North Sea, Mediterranean, Baltic Sea, Bay of Biscay, Iceland, Barents/Norwegian Seas, eastern Canada and USA). It is clear that virtually every ICES ecoregion has been subject to some modelling activity over the past 20 years, and a wide variety of different model types have been applied. The most common model applications have been variants of MSVPA, Ecopath with Ecosim and 'extended single-species' approaches. In many cases these models have been used to provide fisheries management advice.

Stomach content data sets serve as the basis for all multi-species, ecosystem and extended single-species models, and having a solid foundation of food preference data is a prerequisite to successfully implementing an 'ecosystem approach' to fisheries. Stomach sampling programmes and protocols were reviewed in an attempt to evaluate the relative merits of year-on-year but low intensity sampling versus one-off major survey efforts (such as the 'year of the stomach' programme). The group also considered whether or not less-detailed, onboard sampling can complement detailed laboratory-based analyses, and therefore what the most cost-effective ways of gathering useful data on fish feeding preferences might be. A 'feasibility study' for a regional food-web sampling programme was outlined, including a series of 'test cruises' needed to explore sampling methodologies and to fill gaps in European data coverage, also the placement of dedicated staff on existing monitoring cruises. A 'time and motion' study carried out to assess whether additional stomach sampling activity on board NMFS cruises in the US North-west Atlantic imposed any additional and significant burden on survey personnel, revealed that the examination of stomachs added only 5-10 minutes of additional work within the 150 minutes required to sample catches at each station. Existing national and regional diet databases were reviewed, and together these contain more than 1.8 million records of fish stomach contents.

WGSAM considered evidence from across Europe with regard to the possible 'bottom up' effects of low prey availability on predator (seabirds, mammals, and commercial fish) populations. In the North Sea there is strong evidence that recent poor breeding success of seabirds has been linked to a lack of their usual sandeel prey. There is also somewhat controversial evidence that a lack of sandeels may be linked to increased observation of starvation among harbour porpoises and poor body condition in some predatory fish (in particular whiting, plaice and lesser weever). In the Baltic, cod weight-at-age may be related to the availability of sprat and herring, whereas there may be link between hake body condition and blue whiting in the Bay of Biscay and Celtic Sea. In the Barents Sea, cod weight, growth and fecundity has been linked to the availability of capelin, as has growth and migration of harp seals, although the relationship is complex and dependent on the availability of alternative prey types.

Modelling studies have indicated that a lack of 'forage fish' can lead to a displacement of predation mortality (including increased cannibalism) and this can indirectly impact the stocks of commercially-fished predatory fish, even if 'bottom up' effects on weight or body condition are not explicitly included in the models. Multispecies stock-recruitment models were explored by several members of WGSAM, and results suggest that 'bottom up' effects at the pre-recruit level are an important factor in determining recruitment in some stocks.

The group reviewed efforts to compare the outputs of different multispecies and ecosystem model types, including existing comparisons of MSVPA and Ecopath with Ecosim (EwE), as well as EwE with other individual-based, biogeochemical and network analysis approaches. This type of cross-validation exercise appears to be a promising means of evaluating the

robustness of model outputs, when separate validation of marine ecosystem models are difficult to perform. Given the wide variety of different types of models that are potentially available within the ICES region, and the inherent uncertainty associated with model structure, much could be achieved if a larger array of models were used to test the same management scenarios. Discussion during the meeting provided useful insight into the aspirations of different WGSAM members, regarding the purpose of the working group. On the one hand participants clearly stated that they had enjoyed the opportunity to interact with and learn from scientists working in different geographic regions (a clear feature of this reformed and refocused WG in comparison with its geographically focussed predecessors SGMSNS and SGMAB). On the other hand, there was debate concerning whether or not the group should mainly be focussed on answering 'applied' management questions and on comparing model outputs, as opposed to a very detailed 'mechanical' focus on model development and model inputs.

WGSAM was asked by WGECO to provide advice regarding the management action required to meet the Fish Community EcoQO target of *"The proportion (by weight) for fish greater than 40cm in length should be greater than 0.3"*. WGSAM used SMS (the successor to MSVPA) to evaluate the likely time scales involved to reach these targets, and noted that the target set by WGECO can be reached in two ways. Either the stock size of large fish (mainly cod and saithe) can be increased or the stocks of small forage fish decreased. Given the current situation of low sandeel and Norway pout stocks in the North Sea the indicator may not work as intended. In the predictions with F set at $F_{pa,}$ forage fish stocks were predicted to recover, which lead to a decreasing index below the target percentage of 30%. Thus leading to the wrong perception that the situation becomes worse compared to the current situation. The change of F_{pa} by 15% up and down did not lead to substantial differences in the development of the index. In some cases the EcoQO index value was highly dependent on the quarter of the year. In quarters where recruitment takes place (3rd quarter in the model) the indicator value was markedly lower compared to quarters later or earlier in the year.

1 Opening of the meeting

The **Working Group on Multispecies Assessment Methods** (WGSAM]) met at AZTI, San Sebastian, Spain, from 15–19 October 2007. The list of participants and contact details are given in Annex 1.

WGSAM were welcomed to AZTI on the morning of 15 October by Eider Andonegi (AZTI Sukarrieta). The two Co-Chairs, John Pinnegar (Cefas) and Bjarte Bogstad (IMR, Norway) expressed their appreciation for the work done intersessionally by WGSAM members and particularly highlighted the broadened geographic scope of this new working group, encompassing research in the Bay of Biscay, Mediterranean Sea, Barents Sea, Norwegian Sea, Baltic Sea and North Sea as well as the East coast of North America.

The Co-Chairs, particularly welcomed members who had not been part of either of the earlier study groups, SGMSNS (North Sea) or SGMAB (Baltic Sea). WGSAM also recognized the very real contribution made by participants from North America (Canada and USA). 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. The preliminary agenda for the meeting is detailed in Annex 2.

1.1 Acknowledgements

WGSAM would particularly like to thank Eider Andonegi and Marina Santurtun (AZTI Sukarrieta) as well as the staff from AZTI Pasaia for inviting the group to San Sebastian, making everyone feel very welcome, and ensuring that the meeting ran very smoothly.

2 Adoption of the agenda

2.1 Terms of Reference (ToRs):

2006/2/RMC08 The **Working Group on Multispecies Assessment Methods** [WGSAM] (Co-Chairs: John Pinnegar* UK and Bjarte Bogstad* Norway) and will meet at AZTI, San Sebastian, Spain from 15–19 October 2007 to:

a) examine the status of multispecies modelling efforts throughout the ICES region, i.e. Bay of Biscay, Mediterranean Sea, Iceland, Barents Sea, Baltic Sea, North Sea (based on results from EU-funded BECAUSE), and consider the feasibility of using the various methods across regions;

b) evaluate region-specific stomach sampling survey designs and preparation of guidelines and operation manuals;

c) investigate the potential implications of a decline in forage fish for dependent wildlife, and the implications for prey stocks of recovering fish predator populations;

d) investigate the relation between weight at age in the predator species and the abundance of prey species;

e) compare forward projections from ecosystem models such as Ecopath with Ecosim (EwE) and multispecies assessment models;

f) WGSAM are asked to run MSVPA in forecast mode (MSFOR) to complete the matrix below (recognising that numbers at age will need to be translated into numbers at length). This is intended to provide substantive advice regarding the precise management action required to meet the Fish Community EcoQO target of "The proportion (by weight) for fish greater than 40cm in length should be greater than 0.3" (with a ±10% range in target values) and the likely time scales involved to reach these targets.

Fishing mortality averaged across the seven main demersal species (cod, haddock, whiting, saithe, sole, plaice, Norway pout)	EcoQO Indicator Proportion (by weight) of fish > 40cm in length	Time to reach Indicator target
0.85 F_{pa}	0.27	?
	0.30	?
	0.33	?
1.00 F_{pa}	0.27	?
	0.30	?
	0.33	?
1.15 F_{pa}	0.27	?
	0.30	?
	0.33	?

WGSAM will report by 1 December 2007 for the attention of the Resource Management Committee and ACFM.

3   ToR a): Examine the status of multispecies modelling efforts throughout the ICES region

Plagányi (2007) has reviewed models for an ecosystem approach to fisheries. In this overview of ecosystem (including multispecies) models by area, we generally use her classification, but add some categories which she did not consider. Also, some of the model categories she considered were not within the ICES region or descriptions of such models were not made available to WGSAM. Our categories are as follows:

1. Whole ecosystem and dynamic system models

    1.1 Ecopath with ECOSIM (EwE)

    1.2 ERSEM

    1.3 Atlantis

    1.4 APECOSM

    1.5 ECOGOMAG

2. Minimum realistic models (MRMs)

    2.1 ESAM (Extended Single-species Assessment Models)

    2.2 MSVPA models

    2.3 Gadget models (age-length structured)

    2.4 Multispecies statistical models (including SMS)

    2.5 Other age-structured multispecies models

    2.6 Size-spectrum models

    2.7 Multispecies production models

3. Individual-based models.

    3.1 Osmose

    3.2 Biophysical coupled models

4. Bioenergetic models

In the following, we list the models for each area in the order above. An overview over which models are used in the various areas is given in Table 3.1, while Table 3.2 gives the characteristics of each model type. (Annex 5). Figure 3.1 shows the area covered by each eco-region.
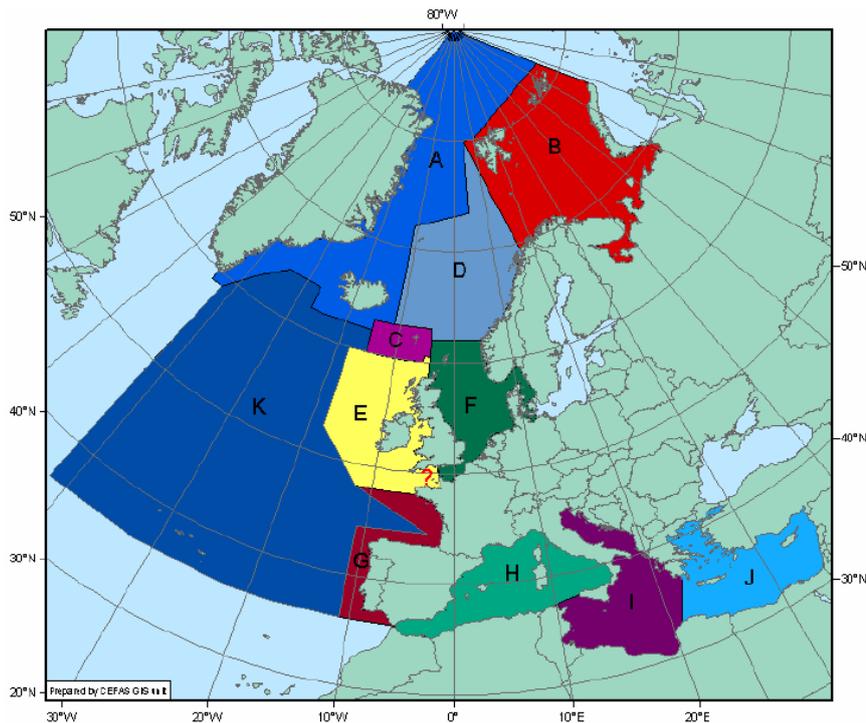
Figure 3.1. ICES Ecoregions.

3.1 Ecoregion A: Greenland and Iceland Seas

Ecopath with Ecosim

With assistance from Drs. Gunnar Stefánsson, Tumi Tomásson, Hreidar Valtýsson, Dr. Heimo Mikkola, Villy Christensen, Alida Bundy, and other staff members of the Marine Research Institute of Iceland, Mendy and Buchary (2001) constructed a model of the Icelandic continental shelf, principally covering ICES area Va. 25 functional groups from marine mammals to plankton were included along with fisheries represented by fourteen fleets. The model summarizes knowledge of the biomass, consumption, production, food web structure and trophic flows in the ecosystem. Of great concern were the recently detected uncertainties in stock assessment results for cod, one of the major commercial species (H. Valtýsson, pers. comm.). If these uncertainties in assessment are borne out, then many, if not all, biomass estimates used in the model for commercial species will have been overestimates.

Gadget models

A Gadget multi-species, multi-area, multi-fleet, cod-shrimp (*Gadus morhua - Pandalus borealis*) model for Icelandic waters has been created (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).

Both species are commercially important in Iceland, and there are known to be strong links between these species, with cod predation forming an important source of mortality on shrimp (Magnússon and Pálsson 1991). The effect of this predation has been incorporated into the routine shrimp assessments. The Gadget model developed considers spatial overlap between cod and shrimp (on a large spatial scale), and prey preference based on the length of both predator and prey. Variants of the model have been used to assess the performance on the model under a number of different spatial and stock structure formulations. For a given model

structure the effects of differing spatial aggregations of the data were considered. Results show that where the model structure is a reasonable representation of the population structure, the spatial aggregation of the likelihood component data is of less importance. Where the model structure does not adequately describe the population structure the format of the likelihood data affects the ability of the model to optimize.

A number of earlier Gadget multi-species models have been developed for Icelandic waters, including e.g. a model for cod-capelin interactions in Icelandic waters (Björnsson 1998).

Other age-structured multispecies models

Several multispecies models were developed for Icelandic waters during the 1990s. A non-exhaustive description is given here. Stefánsson *et al.* (1994) developed a stock-production model for shrimp in Icelandic waters, taking predation by cod into account. Danielsson *et al.* (1998) looked at rational utilisation of the Icelandic cod stock in a multispecies context, taking predation on capelin and shrimp into account. Stefánsson *et al.* (1997) studied the interactions between fish resources (cod, capelin, shrimp) and whales in Icelandic waters. These models were all forward-simulation models, with the population structure being different for the different species. Cod and capelin was age-structured, while a biomass model was used for shrimp and Pella-Tomlinson models for the minke whales. Effects on cod of prey abundance were included.

3.2 Ecoregion B: Barents Sea

Ecopath with Ecosim: Barents Sea

Blanchard *et al.* (2002) developed a EwE model of the Barents Sea. The model has been used to investigate the consequences of alternative functional response formulations on the predictions of responses by marine mammals (Mackinson *et al.*, 2003) and to examine effects of model structure on the robustness of outputs (Pinnegar *et al.*, 2005). A model of the Barents Sea intended to investigate the effects of different management regimes on benthos is under construction (Falk-Petersen *et al.,* in prep.). Falk-Petersen (2004) has also used the approach to investigate the impacts of king-crab invasion in a Norwegian fjord.

Ecopath with Ecosim: Norwegian and Barents Sea

As part of the collaboration between the 'Sea Around Us' project at the University of British Columbia and the 'Ecosystem Norwegian Sea' program of the Institute of Marine Research, Bergen, Dommasnes *et al.* (2001) constructed a model for the combined Norwegian Sea and Barents Sea. The model covers 3,116,000 km^2 of Atlantic, arctic and shelf waters. Thirty functional groups were included, ranging from marine mammals to phytoplankton and detritus. Partly based on the model from 2001, Skaret and Pitcher (2007) constructed a model for the Barents Sea and Norwegian Sea mass balanced for the years 1950 and 2000. They included 58 functional groups, of which 12 were juvenile fish groups. They used Ecosim to simulate the period 1950 to 2000 based on the 1950-model. Catch data on all targeted functional groups were used as forcing functions and the simulated abundance was fitted to 15 abundance time series from VPA, acoustic abundance estimates or CPUE-estimates. A primary production forcing function was added to investigate bottom-up effects in the ecosystem and significantly improved the fit, in particular for the variable capelin abundance. This suggests that bottom-up effects are important in this ecosystem. The model was partly validated using 15 independent time series and stomach data for cod and haddock.

Extended single-species assessment models

SeaStar (Tjelmeland and Lindstrøm 2005) is a herring model, with predation from minke whale included. It is at present used only as single-species model in the assessment of

Norwegian Spring-spawning herring. Cod and harp seals could be included in addition to minke whale as predators on herring. Bifrost/CapTool (Gjøsæter *et al*., 2002, Tjelmeland 2005) is at present used in capelin assessment in order to include predation by cod in a single-species, age-length structured capelin model. Bifrost is also used as a more general multispecies model (see below).

Predation by cod on cod and haddock is also included in the assessment of these two species in an MSVPA-like way by assuming that M=M1+M2, where M2 is the predation mortality induced by cod. The amount of cod and haddock eaten is taken from calculations of the cod stock's total consumption by predator age groups and prey species and length/age groups (Bogstad and Mehl 1997, updated calculations given in ICES, 2007). For cod, an iterative procedure is needed to carry out the calculations.

An extended single-species cod Gadget model (Frøysa *et al*., 2002) is used as an additional assessment model for assessing Northeast Arctic cod. The model includes cod cannibalism, and uses capelin abundance as an exogenous alternate prey for cod.

MSVPA

MSVPA models have been set up for the Barents Sea (Tretyak *et al*., 1999), but this approach has now been abandoned. Up to 7 prey species were included (cod, haddock, capelin, shrimp, polar cod, herring, redfish), with cod the only predator. A major problem when using MSVPA for the Barents Sea is that capelin, which is a key species, has almost total spawning mortality and thus is not suitable for use of VPA-type approaches.

Gadget models

Several models with age-length structure have been set up for the Barents Sea, but at present Gadget is the only one for which model development is continuing (Lindstrøm *et al*., 2007, Howell and Bogstad 2007). The present Gadget model for the Barents Sea includes cod, capelin, herring and minke whale, with plans for also including harp seal. Krill abundance is included as an exogenous prey for whales. The model is age-length structured, with a monthly time step and four spatial areas (the Barents Sea and three subsidiary regions), with hindcast and forecast components. Currently, cod and capelin are modelled as having a fully closed life-cycle, while whales and herring have simpler recruitment functions. Predation by whales on cod, capelin and herring, and by cod on cod and capelin is included within the model, although the effects of prey availability on predator condition/growth are not currently modelled. Prey selection for each fish species is according to the length of the predator and prey, and conditioned to the stomach content data. Work is underway to include uncertainty in the forecast part of the model. Previous models of this kind for which model development has been discontinued include MULTSPEC (Bogstad *et al*., 1997), the 'Scenario' models (Schweder *et al*., 1998; 2000) and Systmod (Hamre, 2003). MULTSPEC was a predecessor of Gadget.

Multispecies statistical models

The Bifrost model (Tjelmeland 2005, www.assessment.imr.no) includes the species cod, capelin, harp seals and herring, and is a forward simulation model which is fitted to observations (survey data, catch data, stomach content data) and which accounts for uncertainty in the observations. It is an age-structured model, and for capelin, length structure is also included, although in a non-dynamic way.

Other age-structured multispecies models

Stocobar (Filin 2005) is an age-structured forward simulation model with growth depending on consumption. Stocobar has cod as the only predator, and cod, haddock, capelin, shrimp, polar cod, herring, redfish and krill as prey species.

3.3 Ecoregion C: Faroes

Ecopath with Ecosim

Zeller and Freire (2001) developed a EwE model of the Faroe Islands marine ecosystem (ICES area Vb), covering the year 1997. The model comprises 19 functional groups, including two marine mammal groups and seabirds. The fisheries component consists of national and foreign fleets, with an emphasis on demersal fisheries. The model has been used to investigate temporal and spatial harvest strategies (Zeller and Reinert 2004) and impacts on human health from the bioaccumulation of mercury (Booth and Zeller 2005).

3.4 Ecoregion D: Norwegian Sea

An Ecopath with Ecosim model for the Norwegian and Barents Sea is described in the Barents Sea section.

3.5 Ecoregion E: Celtic Seas

The Celtic Seas are a relatively under-studied Ecoregion, especially the west of Scotland and Ireland. There is no single assessment working group responsible for the fisheries in the area. These are covered by both northern and southern shelf demersal WGs (WGNSDS, WGSSDS, WGHMM), WGMHSA, HAWG, WGNEPH, WGDEEP as well as WGWIDE (previously WGMHSA and WGNPBW) and WGNEW. This makes the integration of data by eco-region very complex.

Ecopath with Ecosim

As with other parts of the ICES area, the Celtic Seas Ecoregion has benefited from considerable coverage with Ecopath with Ecosim models (Figure 3.2).
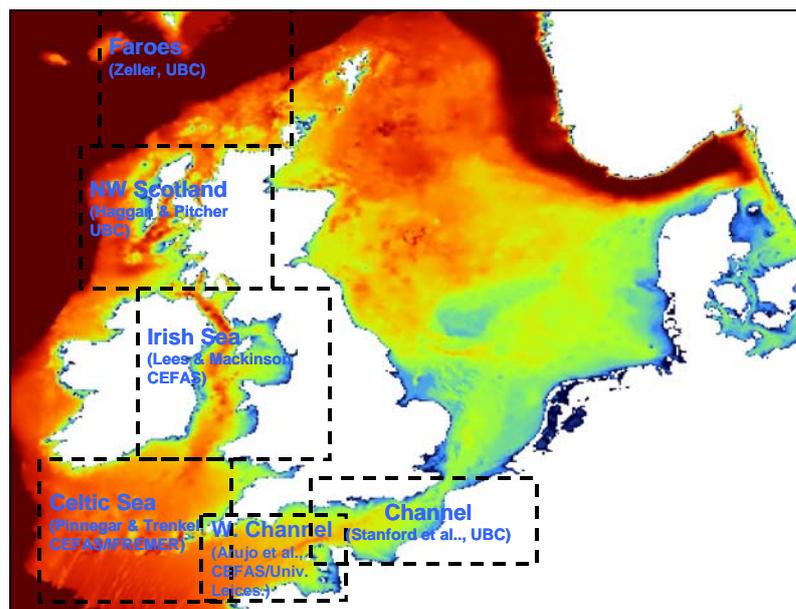

Figure 3.2. Ecopath with Ecosim models in the 'Celtic Seas' ecoregion.

Ecopath with Ecosim: Irish Sea

The Irish Sea (ICES area VIIa) has been modelled by Lees *et al* (2007), who constructed a food-web of 53 functional groups, including 28 fish groups and 9 fishing fleets. The model has been 'tuned' using time-series of fishery and survey data and used to investigate long-term changes in species abundances (Lees and Mackinson, in prep).

Ecopath with Ecosim: West of Scotland

The west of Scotland (ICES area VIa) has been modelled by Haggan and Pitcher (2005), who constructed a food web of 37 functional groups, including 21 fish groups and 8 fishing fleets. This model, which draws heavily on data from adjacent areas, has not been 'tuned' to time-series data, but preliminary spatial simulations (using 'Ecospace') have been conducted in an effort evaluate marine-protected areas (MPAs). Efforts are currently underway (S. Heymans – personal communication) to develop a more detailed Ecopath model for this region, relying more heavily on locally derived survey and diet data.

Ecopath with Ecosim: English Channel (see also North Sea ecoregion for east channel model)

Two EwE models are available, which cover the western English Channel, namely those of Stanford and Pitcher (2004) and Araüjo *et al*. (2005). The former encompasses ICES areas VIId and VIIe, whereas the latter only includes area VIIe. Both models include 50 functional groups and 9 fishing fleets, and both draw on similar literature sources. Stanford and Pitcher (2004) include policy exploration and an examination of possible future climate effects. By contrast, Araüjo *et al*. (2006) has conducted a detailed time-series fitting exercise, whereby the model has been 'tuned' to time-series of zooplankton, fish survey and commercial landings data.

Ecopath with Ecosim: Celtic Sea

For ICES Subdivisions VIIf-j a preliminary EwE model was constructed under the EU DST^2 project in 2003 (J Pinnegar - unpublished). This model included 38 functional groups and was used primarily to obtain semi-realistic values for 'other food' in the Celtic Sea GADGET model (described below). The model drew heavily on diet data from adjacent seas, given that locally-derived data were not available at the time of model construction. A new model currently being developed (Lauria *et al*. in prep), using locally relevant diet information from Pinnegar *et al*. (2003), biomass data from groundfish surveys and invertebrate data from recent epibenthos and infauna surveys (e.g. Ellis *et al*., 2002).

GADGET

The only other multispecies fisheries assessment model that has been applied in the Celtic Seas ecoregion is the three species (cod, whiting, blue whiting) GADGET model developed by Trenkel *et al*. (2004) for the Celtic Sea proper (ICES area VIIe-j). The model was constructed by researchers from CEFAS and IFREMER as part of an EU FP5 project 'DST^2'. Cod was chosen as a species of particular interest to the UK and whiting as a species of interest to France, whereas blue whiting was thought to be an important prey species for these two predators.

Very little was known previously about the functioning of Celtic Sea fish communities, and considerable effort was expended in trying to locate and computerize stomach content records for the region (Pinnegar *et al*., 2003, Trenkel, Pinnegar *et al*., 2005). As an initial step towards a multispecies model, three completely independent single-species GADGET models were developed. For cod and whiting (where sufficient quantities of information was available) 31 parameters were estimated in each single-species model (growth, fleet selectivity, initial population numbers, recruitment). For blue whiting, much less information was available, and

hence the single-species model for this species was highly deterministic and growth parameters were fixed. Predator-prey functions were characterised outside of the model using plots of mean predator length vs. mean prey length. In general, the addition or removal of predator-prey interactions resulted in negligible change to population estimates. This was primarily because the predator species chosen have very broad diets, with blue whiting representing only a small contribution. Hake *Merluccius merluccius* eat large quantities of blue-whiting in the Celtic Sea (Pinnegar *et al*., 2003, Trenkel, Pinnegar *et al*., 2005), as well as small whiting and cod where these are abundant, and hence this species would be a logical candidate for inclusion should the model be expanded further in the future.

Other age-structured multispecies models

In the Irish Sea (ICES area VIIa), cod is the most important predator of Norway lobster (langoustine) *Nephrops norvegicus,* accounting for up to 88% of the total predation mortality in the region (Symonds and Elson 1983; Armstrong 1979). Brander and Bennett (1986) developed a quarterly age-structured yield-per-recruit model which incorporated two fishing fleets (separately targeting cod and *Nephrops*) with selection patterns, bycatch and discarding behaviour. The model was compared with a traditional single-species yield-per-recruit model (e.g. Brander and Bennett 1989), and was found to be robust to changes in assumptions about stock/recruit and functional feeding relationships.

The authors recommended that to increase the joint economic value of the two species, fishing mortality (*F*) should be increased on cod and reduced on *Nephrops*. They predicted this would result in a reduction in the biomass of Irish Sea cod and less predation mortality on high-value *Nephrops.* A reanalysis in 1994 (Bennett and Lawler, 1994) demonstrated that between 1989 and 1992, the *F* on cod did increase and the biomass reached a historically low level – however there was no evidence of a corresponding increase in *Nephrops,* probably because a reduction in predation mortality was masked by an simultaneous increased F on *Nephrops.*

3.6 Ecoregion F: North Sea

Approximately 230 species of fish are known to inhabit the North Sea of which 13 are the targets of major commercial fisheries (cod, haddock, whiting, saithe, plaice, sole, mackerel, herring, Norway pout, sprat, sandeel, Norway lobster, and deep-water prawn). Norway pout, sprat and sandeel are predominantly the targets of industrial fisheries where the catch is converted into fish meal and oil while the other species are the targets of fisheries where the catch is used for direct human consumption. Fish species diversity is low in the shallow southern North Sea and eastern Channel and increases westwards. Species diversity is also higher as the variety of sediment types and spatial niches increases (OSPAR QSR, 2000).

The investigation of species interactions in the context of practical fisheries management has a more than 25 years history in the North Sea through ICES WG and SG's on Multi-species assessments. The main insights from multi-species assessment models of the North Sea (MSVPA, 4M, SMS):

1) a revision of the level of natural mortalities, especially for small fish.
2) a revision of the absolute numbers of recruits as a consequence of 1).
3) a quantitative understanding of the role of fish predation in the ecosystem.
4) a reversal of the single species conclusion on the effects of effort reductions and mesh size increases: reducing effort on predators leads to lower yields in many fisheries if species interactions are taken into account. This also implies that growth overfishing is far less important than previously thought.
5) a quantitative understanding of the role of fish predation on dampening recovery rates of depleted stocks, e.g. North Sea cod.

Few of the results of the multi-species work have so far affected the routine assessments and quota decisions. The revised (higher) values of natural mortality have been exported from MSVPA to the single-species assessments as constant average values. Year to year variations in natural mortalities have not, however been considered so far.

Ecopath with Ecosim: North Sea

A comprehensive model of the North Sea calibrated to time series data and with full spatial representation has recently reached completion after nearly 6 years of construction (Mackinson and Daskalov 2007). With 69 biological groups and 12 fishing fleets, it is one of the most detailed EwE models ever constructed, synthesizing a vast amount of information on the North Sea fauna and fisheries. Briefly, the basic elements and data sources are:

- Fish stock data from ICES single and multispecies assessments and scientific research surveys (IBTS)
- Benthic fauna from international scientific surveys of epifauna (1999 and 2000) and infauna (1985)
- ICES data on seabirds, marine mammals, sharks…
- Phytoplankton, zooplankton and microflora estimates from best available scientific research in the North Sea
- Diet on fish from The 1991 year of the stomach international survey
- Fisheries landings, discards from STCF 1991, UK Trio database
- Information on fleet structure from recent information relating to Data Collection Regulations
- Economic data on vessel costs and fish prices for each fleet from STECF and STCF 1991 database.
- Social information – jobs per vessel
- Time series information from MSVPA, single species assessments and specific papers
- Environmental data – NAOI and GSI indices

The model is currently being used in several projects to explore questions such as the relative roles of climate and fishing on the ecosystem structure and productivity (Mackinson *et al.*, 2007); explore and predict recovery trajectories for depleted fish stocks (in the Uncover project); examining the size, spacing and impacts of MPAs (Pinnegar *et al.*, 2007); exploring tradeoffs in management scenarios aimed to achieve specified objectives (Mackinson in prep); to explore the ecology of the North Sea and help to develop ecosystem indicators of change (e.g. Lees and Mackinson 2007, Daskalov and Mackinson in prep).

Three previous published EwE models exist for the North Sea. Based on 1981 year of the stomach data, Christensen (1995) constructed two models representing the 1981 period; a 24 box model and a 29 box model including more detailed, size based plankton groups. Neither model includes fisheries data. The third was constructed by Mackinson (2002) based on historical records. It gave a detailed representation of the North Sea in the 1880s, which included 49 functional boxes, with catch data from five different fishing fleets.

Ecopath with Ecosim: Eastern English Channel

Under the auspices of the CHARM II Interreg project, a EwE model of the eastern English Channel representing the period the 2004–2005 is currently being constructed by IFREMER (C. Villaneuva and B. Ernand) and Cefas (S. Mackinson). The model structure is somewhat extended in comparison to the Western Channel (Araujo *et al.*, 2005) and Channel (Standford and Pitcher 2004) models, and draws from new regional survey data for benthos (Cabioch data) and fish (CGFS and IBTS). The model description will be published in a joint technical

report (anticipated 2008). After time series fitting, a spatial representation (Ecospace), will be used for examining the impacts of fishing and dredging on fish habitats and food.

Multispecies Virtual Population Analysis: MSVPA/MSFOR/4M

The basic concepts of MSVPA were published in 1979. The first meeting of an ICES multispecies working group took place in 1980 (ad hoc working group on multi species assessment model testing) and during this meeting the stomach-sampling project for the year 1981 was planned. From 1984 the working group was able to run a parameterised version of the MSVPA program. A review of the development and the achievements of the ICES MSAWG until 1990 is given by Pope (1991). This group continued its work up to 1997, after which the group was disbanded. However it was reinstated as a 'study group' in 2002 to update the model runs. Since 2007 the ICES SGMSNS merged into the WGSAM.

The 4M package (Multispecies, Multi-fleet, Multi-area Model-package) (Vinther *et al.*, 2002) has been used to run MSVPA and MSFOR at the ICES multispecies study groups in recent years. The aim of 4M has been to create an integrated-software-system handling model input, the models, and analysis and presentation of output. Basically 4M combines the modules MSVPA and MS-FORECAST written in ANSI C with a SAS environment for data management, analysis and presentation. The various multispecies working groups have mostly been concerned with biological interactions; however, from a management point of view technical interactions between fleets and species are also important. The 4M package handled technical interactions much better than MSVPA/MSFOR. In addition, 4M includes a tuning module enabling single species tuning approaches to be incorporated into the MSVPA (Vinther 2001).

The last official 4M keyrun from the ICES SGMSNS in 2005 covered the period 1963 – 2003. The MSVPA key-run included 10 fish species for which catch-at-age data are available (cod, whiting, saithe, haddock, herring, sprat, Norway pout, sandeel, plaice, and sole), and seven other predators for which stock size at age or length are available (grey seals, North Sea mackerel, Western mackerel, *Raja radiata*, sea birds, grey gurnards and horse mackerel) (ICES SGMSNS 2005, ICES CM 2005/D:06).

Multispecies Virtual Population Analysis: EcoCorP

The EcoCoRP Project (Anon, 2007) was initiated under a directed call, within the European Commission, Directorate-General for Fisheries (DGFish). The consortium (including an economics research institute and a fisheries science laboratory) was tasked with examining the likely economic consequences for different fishing fleet segments resulting from the implementation of effort control regulations in the North Sea, as part of cod recovery measures. The commission specifically referred to earlier multispecies modelling work carried out by the ICES Study Group on Multispecies Assessment in the North Sea (ICES, 2003) which had tested cod recovery assuming different harvest-control-rules (HCRs), and using single and multispecies model formulations. Single and multi species models predicted cod SSB to continue to decline when fished at the current F level and when the proposed HCR for cod was applied, both single and multi species models predicted cod SSB recovery. However, the predicted recovery of cod was slower when taking multi-species interactions into account, and other species were predicted to be adversely affected by the recovery of cod, such that it appeared impossible to 'recover' all species in the North Sea simultaneously.

Hence, the resulting EcoCoRP bioeconomic model was required to include both technical and biological (predator-prey) interactions, and to develop a user-friendly interface, allowing decision makers and analysts to interact with the model in an efficient way, without requiring in-depth knowledge of the underlying equations and complex multispecies dynamics. The project team subcontracted Ventana Systems, a specialist software development and modelling company, to construct this user interface, having worked with the same sub-

contractor to develop tools for the UK Cabinet Office investigation into 'sustainable and profitable' fisheries in the UK.

The biological component of the bioeconomic model was primarily constructed using outputs from ICES SGMSNS in 2005. The model was based on the multi-species VPA programme MSVPA, and in particular the corresponding prediction programme MSFOR (Gislason and Sparre, 1987). 17 species were included in the model (the same as reported by SGMSNS for the North Sea). Predator-prey relationships were projected forward in time using 'suitability' functions and Ricker stock recruitment relationships.

The economic component of the North Sea dynamic bioeconomic model was based on earlier models developed by Pascoe *et al*. (1999), Mardle *et al*. (2000) and Mardle and Pascoe (2002). Fleet structures were based on information obtained from STECF and costs (direct and indirect), revenue, vessel numbers and profits parameterised using data for individual fleets (in Belgium, Denmark, France, Germany, Netherlands, Norway and the UK) contained within the 'Annual Economic Report of Selected European Fishing Fleets' in 2004.

A baseline scenario was constructed (Figure 3.3) to provide model forecasts of cod stocks assuming that fleet sizes and effort levels are maintained at those for 2003. The baseline scenario is a purely deterministic simulation run, with no stochastic variation in recruitment or any of the other model inputs. To test the sensitivity of the key outputs the baseline scenario was re-run in a stochastic mode. The parameters selected for sensitivity impact were:

- Recruitment (by vpa species)
- Natural mortality coefficient M1 (by vpa species and age)
- Predator suitability coefficients (by vpa species, vpa age group 7 predator)
- Predator consumption (by predator)
- Prey mean weight (by vpa species)
- Initial F-values (by vpa species and age).
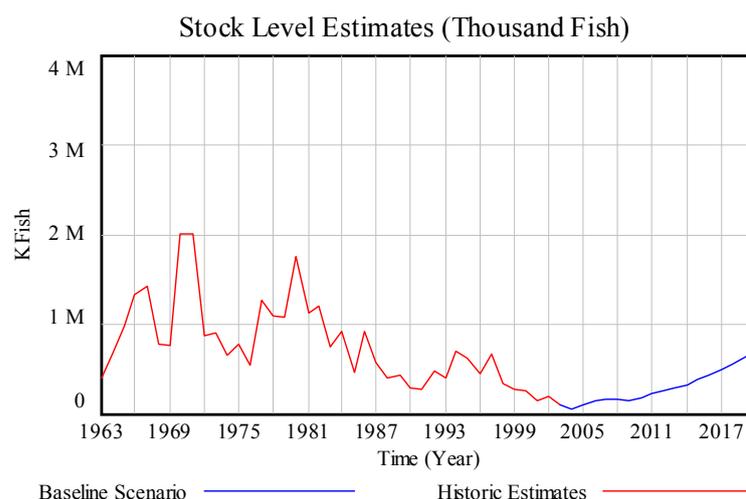
Figure 3.3. Cod stock numbers in the EcoCoRP baseline scenario.

The model predicted that the cod stock will start to recover, and by 2020 be back around the level achieved in early 1993. Results from a number of scenarios were examined. Scenarios included effort reduction, harvest control rules, fleet decommissioning and a no cod fishing simulation. Generally speaking, all scenarios suggested a larger stock level in 2020 in comparison with the baseline, however results of the analysis also suggest that the effort

controls imposed in 2003 had a substantial negative impact on the profitability of certain fleets.

Stochastic Multi Species model (SMS)

SMS (Stochastic Multi Species model) (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a parameterised 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. Once the parameters have been estimated, the model can be run in projection mode, using recruitments from stock recruitment relations and fishery mortality derived from an array of Harvest Control Rules.

SMS is, in contrast to MSVPA, a stochastic model where the uncertainties on fishery, survey and stomach contents data are included. The parameters are estimated using maximum likelihood (ML) and the confidence limits of the estimated values are calculated by the inverse Hessian matrix or from the posterior distribution from Markov Chain Monte Carlo simulations. The approach contains sub-models for stock recruitment, food selection, predation mortality, fishing mortality and survey catchabilities. Further, in contrast to the fully age-structured MSVPA, SMS is a semi age-length structured model where the stomach content observations and the food selection model are length based. This allows for more realistic food selection models and the use of the originally sampled length based stomach data. Catch data models are kept age-structured as length-structured data are not available for the cases considered.

In the EU BECAUSE project a first SMS keyrun was established covering the period 1975–2005. Using this keyrun as the basis several strategic scenario model runs were conducted assessing multispecies and climate effects on future stock projections.

In the present SMS analysis for the North Sea (ICES area IV) the following predator and prey stocks are included: predators and prey (cod, whiting, haddock), prey only (herring, sandeel, Norway pout), predator only (saithe), 'external predators' (8 seabirds, starry ray, grey gurnard, grey seal, western mackerel, North Sea mackerel, North Sea horse-mackerel, western horse-mackerel).

Due to problems in the assessment of North Sea sprat (ICES, 2004, 2006b) and fitting problems for this stock inside SMS, it was decided to leave this prey species out. Sprat was treated as 'Other Food'. The relative stomach content of sprat was added to the observed relative stomach contents for 'Other Food'. Therefore, sprat was still available as prey for the model predators in an indirect way. Plaice and Sole were included for single-species assessment. In the multi-species version of SMS both species have no influence on model results since they are neither predator nor prey species in the model.

Size-spectrum models

In contrast to the species-based approach used in an Ecopath ecosystem model, a size-based model assumes that the size rather than the species most heavily influences the role of an individual in an ecosystem. The approach relies on the principle that the distribution of body mass follows regular patterns and changes to this pattern can occur by fishing affecting the largest individuals and climate etc. affecting the smallest individuals. Size-based models are simpler and less data-demanding compared to conventional multi-species and ecosystem models. They provide a useful tool for answering questions related to the effects of fishing on the structure of ecosystems and can complement traditional single-species, multi-species and more complex modelling approaches for addressing ecosystem-based fisheries management questions.

Two size spectrum models of the North Sea have been developed by J. Blanchard (Cefas); (i) a dynamic size-spectrum model for the pelagic fish community based on Benoît and Rochet (2004) (Blanchard *et al*. in prep) and (ii) a new dynamic size spectrum model allowing for coupling between benthic and pelagic communities, incorporating the effects of high and low quality prey (Blanchard *et al*. in prep). The models are used to represent the seasonal flux of energy from plankton to large fish predators and the effects of fishing on different parts of the size-spectrum. Broadly, similar to the Ecopath model, they can eventually be used to contrast the historical changes that have occurred in the North Sea over time, either in a descriptive sense by scenario testing, or by implementing time-series data for production and exploitation patterns. Work is underway on developing spatially resolved models (Castle *et al*. in prep)

OSMOSE

Shin and Cury (2004) have developed a multi-species individual-based model known as OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation) where predation is a size-based opportunistic process. The 'individual-based' approach is receiving increasing attention among ecologists (Grimm 1999) and involves tracking the fate of all individuals through their life cycle by assigning to them specific features and behavioural rules. Shin *et al*. (2004) developes 'OSMOSE' for the southern Benguela ecosystem, and explored different fishing scenarios, previously examined using Ecosim (Shin *et al*., 2004). A version for the North Sea is currently being developed by Travers and Shin (Ifremer) in collaboration with Cefas.

3.7 Ecoregion G: South European Atlantic Shelf

Ecopath with Ecosim: Bay of Biscay

Ainsworth *et al*. (2001) from University of British Columbia, Canada developed two models of ICES Division VIIIa, b, Bay of Biscay. Over 200 species of fish, invertebrates, birds, marine mammals and primary producers were considered. Parameters and diet matrices were determined from the literature, while catch information was obtained from the ICES STATLANT database. The initial model was submitted to French experts, and their suggestions were included in subsequent revisions of the model.

Ecopath with Ecosim: Cantabrian Sea

To understand the effects of the different fisheries that operate in the Cantabrian Sea shelf, Sanchez and Olaso (2004) parameterised a EwE model based on a database of bottom trawl surveys, ICES stock assessment working groups, stomach analyses and information from literature. The model had 28 trophic groups corresponding to pelagic, demersal and benthic domains, also including detritus and fishery discards. Results indicated that the biomass and production of some groups would be unrealistic if they were independently estimated by single-species assessment approaches. Strong relationships existed between the pelagic, demersal and benthic domains due to key groups, like suprabenthic zooplankton and horse mackerel that transferred the flow from primary production to the upper trophic levels. Feeding pressure on phytoplankton was low and detritivorous species were an important component of the ecosystem. Fisheries impact level in the Cantabrian Sea was comparable to that in the most intensively exploited temperate shelf ecosystems of the world. Trawlers had the strongest negative impact. Purse seine was the only gear that did not result in a negative impact on fish feeders and elasmobranchs. The mean trophic level of Cantabrian Sea fisheries declined from 1983 to 1993 but has remained steady since then (Sanchez *et al*., 2005).

GADGET: Bay of Biscay

A preliminary GADGET multispecies model has been implemented in the Bay of Biscay, a minimum realistic model (Plagányi, 2007) where European hake (*Merluccius merluccius*), as

the main predator, feeds on anchovy (*Engraulius encrasicolus*), as the main prey. This is the first length-based model available in the Bay of Biscay and, due to the ageing problems already known, especially for hake; it should provide a good alternative to the age-based models used by the current assessment Working Groups. This first multispecies GADGET model is based on strong assumptions, which makes it somewhat unrealistic and not ready to be used as a multispecies assessment evaluation tool yet. However, this work has shown real difficulties and necessities to go deeper, with these kinds of models in the area. For example, new information in consumption available from recent studies (Mahe, 2007; Velasco, 2007) will be implemented into this preliminary model in order to see how this improves its reliability.

GADGET: Iberian Peninsula

Preliminary work has begun on developing a Southern hake cannibalistic model with GADGET in the Iberian Peninsula, and this was presented during WGSAM 2007 (Cerviño *et al.*, 2007). The model is size and age structured covering the same area than the present ICES official assessment for Southern Hake, i.e. the Atlantic coast of the Iberian Peninsula without the Gulf of Cadiz. The model is structured by quarter from 1990 to 2005. The trophic link was implemented as a constant proportion of hake in hake stomachs, independently of size, seasons or area. The base model provides consistent results compared with the ICES assessment. Comparison of the base model with the one including cannibal shows differences regarding age structure and predictive trajectories for yield and SSB although this work should be considered preliminary.

3.8 Ecoregion H: Western Mediterranean Sea

Ecopath with Ecosim

Coll *et al*. (2006) developed a model comprised 40 functional groups including primary producers, the main species of benthic, demersal and pelagic invertebrates, fishes and non-fish vertebrates (cetaceans, birds etc,) and three detritus groups. In addition, trawling, purse seine, longline and troll bait fishing fleets were included. Results showed that the functional groups were organized into four trophic levels with the highest levels corresponding to anglerfish, dolphins, large pelagic fishes and adult hake. The system was dominated by the pelagic fraction, where sardine and anchovy prevailed in terms of fish biomasses and catches. Detritus and detritivorous groups also played key roles in the ecosystem and important coupled pelagic-demersal interactions were described. Considering Odum's theory of ecosystem development, the ecosystem was placed on an intermediate-low developmental stage due, at least partially, to the impact of fishing activity. This highlighted the high intensity of fishing in the ecosystem, in accordance with the general assessment of western Mediterranean marine resources, and fishing fleets were ranked as top predators of the system. The low trophic level of the catch was in line with the long history of exploitation in the area.

Pinnegar (2000) constructed a EwE model for the coastal shelf area in the Bay of Calvi, Corsica (~ 2200 ha). This model included 27 functional groups plus one artisanal fishing fleet. The model drew extensively on locally-relevant but unpublished data sources, including information on local fisheries catches and discarding practices. The model has subsequently been used (by Pinnegar and Polunin, 2004) to examine possible indirect 'trophic cascades' which might result when fishing is halted inside marine protected areas. Several instances of indirect fishing effects have been proposed from anecdotal evidence in the western Mediterranean. Model outcomes provided little support for the widely accepted paradigm that fishing, by removing invertebrate-feeding fish, allows increases in the biomass of sea urchins and as a consequence the formation of overgrazed 'barrens' of bare substrate. Simulated harvesting of sea urchins by humans did, however, results in an increase of macroalgal biomass as reported previously. Intensified fishing pressure on 'macrocarnivorous' fish

resulted in a 'release' of small fish species (e.g. blennies), and as a consequence a decline in the biomass of some small invertebrates on which they feed (e.g. amphipods). Increased fishing on large 'piscivores' resulted in increases in other small fish groups and consequential effects on other benthic invertebrate groups (e.g. polychaetes).

GADGET

During the EU project BECAUSE, the GADGET model was chosen for the development of a multispecies model including hake in the Mediterranean. Although the trophic interactions between hake and its prey have been analysed and quantified, the lack of systematic data collection on small pelagic fish in the area (no acoustic or pelagic surveys) did not allow the authors to build dynamic models for sardine and anchovy. Single species models for prey are needed in GADGET to evaluate prey-predator interaction in a dynamic fishery context. Thus, the available data were used to develop a GADGET single-species model for hake including cannibalism, ready to be connected with new models for small pelagic fish, assuming that such biological data will become accessible in the future.

The basic hake model has a quarterly time step and time span of 11 years (1994–2004). It includes two stock components; small and large hake separately. The whole fish population included five year classes with age 4 as a plus-group, and 1 cm length groups. Maturation takes place at a fixed length of 40 cm. A certain number of assumptions were necessary because not enough data were available to properly model some biological processes. The values of the von Bertalanffy equation assumed a fast-growth hypothesis: L_{inf} = 95.4 cm and k=0.21.

A natural mortality vector was applied to model higher mortality for younger individuals (Figure 1). Caddy's equation simulates natural mortality as a reciprocal function of age (Caddy, 1991):

$$M_t = A + \frac{B}{t}$$

A single recruitment event was modelled in the second quarter of the year.

Fisheries effect was simulated through two fleets: the main one represented commercial trawlers and was controlled by a gamma suitability function, the second and less important was governed by a constant function. The first fleet fished the small fish component (fish < 40 cm) i.e. most of total landings (Abella *et al*., 1997; Colloca *et al*., 2000), while the second fleet caught only large hake (fish >40 cm) and represented a multitude of actual gears (the tail of trawlers selectivity on large hake, gillnets of different mesh size).

Likelihood functions were fitted to the following data: 1 cm length distributions from the summer and autumn surveys, 2 cm length distribution from commercial landings, indices of abundance for three length groups from both summer and autumn trawl surveys, total landings from IREPA.

3.9 Ecoregion I: Adriatic-Ionian Seas

Ecopath with Ecosim

Coll *et al*. (2006) developed a model to characterise the food web structure and functioning of the Northern and Central Adriatic Sea and to quantify the ecosystem impacts of fishing during the 1990s. Forty functional groups were described, including target and non-target fish and invertebrate groups, and three detritus groups (natural detritus, discards and by-catch of cetaceans and marine turtles). Results highlighted that there was an important coupling between pelagic–benthic production of plankton, benthic invertebrates and detritus. Organisms located at low and medium trophic levels, (i.e. benthic invertebrates, zooplankton

and anchovy), as well as dolphins, were identified as keystone groups of the ecosystem. Jellyfish were an important element in terms of consumption and production of trophic flows within the ecosystem. The analysis of trophic flows of zooplankton and detritus groups indirectly underlined the importance of the microbial food web in the Adriatic Sea. Fishing activities inflicted notable impacts on the ecosystem during the 1990s, with a high gross efficiency of the fishery, a high consumption of fishable production, high exploitation rates for various target and non target species, a low trophic level of the catch and medium values of primary production required to sustain the fishery. Moreover, the analysis of Odum's ecological indicators highlighted that the ecosystem was in a low-medium developmental stage. Bottom trawling (Strascico), mid-water trawling (Volante) and beam trawling (Rapido) fleets had the highest impacts on both target and non target ecological groups. Purse seining (Lampara) showed medium to low impacts on the ecosystem; cetaceans, marine turtles and sea birds were not significantly involved in competition with fishing activity.

Under the auspices of the INCOFISH project, further modelling work of the Adriatic Sea is being undertaken by the University of Palermo (Dr. Luca Palmeri).

GADGET

During the EU project BECAUSE a GADGET model of the Aegean-Ionian Sea was constructed with hake as predator and cannibalism as a trophic process was included. Several predictive scenarios were investigated, including technical measures (i.e. limiting fishing effort, increasing trawl mesh size).

3.10 Ecoregion J: Aegean-Levantine

Nothing submitted for this Ecoregion.

3.11 Ecoregion K: Oceanic northeast Atlantic

Ecopath with Ecosim

Vasconcellos (2002) discussed the general problems and consideration required to model open-ocean systems. EwE was used to construct six models representing oceanic ecosystems of the North, Central and South Atlantic for the late 1990s (1997–1998) and 1950. The report characterizes some of the fundamental characteristics of oceanic ecosystems which were captured in a model 'template' for oceanic areas, and describes the parameterisation of individual functional groups.

A EwE model also exists for the Azores Archipelago (Guenette and Morato, 2001), a small shelf surrounded by a large component of deep oceanic waters dotted with seamounts. The model is structured by depth and constitutes a first step in applying the Ecopath modeling approach to Atlantic seamounts. It is the result of a collaborative effort with several researchers of the University of the Azores. The model is composed of 43 functional groups including 26 groups of fish classified according to their size and their preferred depth range. Fisheries are represented by 13 fleets. Suggestions for future developments are presented.

APECOSM

APECOSM (Apex Predators ECOSystem Model) is a model of the oceanic pelagic ecosystem that is currently being developed by the IRD (Maury *et al.* in press). The model represents the basin-wide spatial dynamics of open ocean pelagic ecosystems from phytoplankton production up to fishing with a special emphasis on top predators. It integrates various physiological, behavioural and ecological processes acting on a variety of scales. Physical forcing (wind, temperature and current fields from the OPA OGCM), biogeochemical forcing (primary production, light and oxygen fields from the PISCES or the ESSIC biogeochemical model) and the effects of fishing are explicitly taken into account. It has been specifically developed

to represent the dynamics of tuna, integrating the demography of four tuna populations (bigeye, skipjack, yellowfin and albacore) with their physiology and main life history traits (growth, reproduction, metabolism, starvation mortality, ageing mortality and life span, and size at maturity) in a bioenergetics framework. The model also describes the horizontal movements and migrations of tunas as well as their small scale vertical movements, and, together, these movements determine trophic interactions with meso-pelagic preys and the internal temperatures of tunas. The size-structured nature of predation is explicit. The model represents the energy fluxes through the ecosystem with a size-structured mass-balanced energy flux equation in four explicit dimensions (time, 2D space, and the weight of organisms). The epipelagic prey community is distinguished from its mesopelagic migratory counterpart. The tuna species interact trophically with the open ocean pelagic ecosystem (OOPE) and are represented with a DEB-based (Dynamic Energy Budget) physiologically structured advection-diffusion flux equation which describes the status of individuals in six dimensions (2D space, time, energy reserves in the body, the body itself, and gonads). The behaviour of a tuna is related to its physiological status. The model produces a large range of outputs that can be compared with observed data such as size-structured prey fields, fishery catches and size-frequencies, tagging data, size-structured tuna stomach contents for both the epipelagic and mesopelagic prey communities, δ15N ratios of tunas and of the ecosystem, and growth and maturity schedules. The OOPE component is now operational in the Indian Ocean, and various climatological runs have been conducted. Retrospective runs will be conducted in the next few months in the Indian Ocean from 1950 to 2003. The tuna spatial distribution component is operational but not yet fully coupled with the physiology and the vertical behaviour of tunas.

3.12 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 in 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.

Ecopath with Ecosim

To evaluate interactions between fisheries and the food web from 1974 to 2000, Harvey *et al.* (2003) created a food-web 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 chief 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 food web and may ultimately provide a basis for estimating community responses to management actions.

MSVPA/MSFOR

The Baltic multispecies assessment process started about 20 years ago and presently the following data (catch, mean weight, proportion mature and food ration) by age group, quarter and year are available for the Baltic Sea.

Baltic Main Basin combined subdivisions: Years 1974–2005

- cod in Subdivisions 25–29+32
- sprat in Subdivisions 25–32,
- herring in Subdivisions 25–29+32,
- a total of 55000 cod stomachs sampled in the period 1977–1994

Baltic Main Basin: Years 1976–2003, area dis-aggregated analysis:

- cod in Subdivisions 25, 26 and 28
- sprat in Subdivisions 25, 26 and 28
- herring in Subdivisions 25, 26 and 28

Western Baltic: Data: Years 1977–2001,

- cod in Subdivisions 22+24 (Subdivision 23 included in 1996–1997),
- sprat in Subdivisions 22–24,
- herring in Subdivisions 22–24 including Division IIIa.

The 4M software package (Vinther *et al.,* 2001), which contains MSVPA/MSFOR (Sparre, 1991), and a tuning module (Vinther, 2001), have been run for several years. Analyses and results have been presented in reports from the ICES Study group report on multispecies assessment in the Baltic Sea (e.g. ICES CM 2004/H:06, ICES CM 2005/H:06)

Stochastic Multispecies Models (SMS)

As part of the BECAUSE project, a Stochastic Multispecies Models (SMS) (Lewy and Vinther, 2004) has been configured for the Baltic Main Basin. Input data to SMS are given by quarter of the year. This time step is also used by ICES SGMAB (ICES, CM 2005/H:06) and input including catch numbers, mean weight at age, proportion mature and food rations were as far as possible copied from this SG. Survey CPUE data were copied from ICES single species assessment data. Stomach content data, 1977–1994 have previously been compiled for use in the age-based MSVPA and are used by SGMAB. SMS uses stomach data by size classes, however, and a recompilation of the "raw" stomach data are now available on the standard ICES format. During the re-compilation of data, errors were spotted in the old data compilations and some of the methods previously used were rejected.

SMS can fit the catch at age, survey CPUE and recruitment sub-models reasonably well, but the model has limited ability to predict the stomach contents. Further analysis of the residuals from the stomach contents observations showed a distribution of residuals for the named prey species, with an excess of large positive residuals (higher observed than expected stomach contents). The distribution of "other food" residuals has an overrepresentation of negative residuals. The residuals of named prey species seem independent of the predator-prey size ratio, indicating a good fit to the size model. When the residuals are plotted against the size of the prey, there seems however to be an overweight of positive residuals for the smallest prey of all the prey species. This indicates that more small preys are found in the stomachs than expected from the model. The results from SMS are quite similar to the results from the deterministic 4M model.

Other age-structured multispecies models

Horbowy (2005) applied his multispecies stock production model to simulate stock dynamics and species interactions of cod, herring, and sprat in the Baltic from 1982 to 2001. Using the extended stock-production model, the relative changes in stock biomass were similar to the changes derived using the age-structured multispecies model, the multispecies virtual population analysis (MSVPA). However, the production model estimates of the average predation mortality of young cod and young sprat are much lower than those derived from MSVPA, although the estimates for young and adult herring and adult sprat are similar in both

approaches. The estimates of food suitability show that the preferred food of adult cod is adult sprat and young herring, while the suitability of young sprat, young cod, and adult herring is much smaller. The simulations show that the multispecies production model, which is less data-demanding than age-structured MSVPA, can provide estimates of stock dynamics and species interactions that are largely consistent with those estimated by MSVPA.

3.13 Ecoregion M: Black Sea

Ecopath with Ecosim

In conjunction with literature reviews and empirical analyses, Daskalov (2002) used a model of the Black Sea to investigate the role of fishing in community changes. The model has 15 ecological groups including bacteria, phytoplankton, zooplankton, protozoa, ctenophores, medusae, chaetognaths, fishes and dolphins. Ecosystem dynamics were simulated over 30 years, assuming alternative scenarios of increasing fishing pressure and eutrophication. The changes in simulated biomass are similar in direction and magnitude to observed data from long-term monitoring. A 'trophic cascade' is anticipated, following the removal of predators, while the inclusion of eutrophication effects leads to biomass increase in all groups. The study demonstrates that the combination of uncontrolled fisheries and eutrophication can cause important alterations in the structure and dynamics of a large marine ecosystem. Recent work (Daskalov *et al*.,) has highlighted the importance of cascades to changes in jellyfish (*Mnemiopsis*).

3.14 Ecoregion: Canadian Northwest Atlantic

Ecosystem modelling of Atlantic ecosystems in Canada has mainly been done at DFO, within the Ecopath with Ecosim framework. This work includes Ecopath models, and in some cases Ecosim simulations, for the northern Gulf of St. Lawrence, southern Gulf of St. Lawrence, Eastern Scotian Shelf and Labrador and Newfoundland Shelf. Most models were developed within the envelope provided by the CDEENA project (Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic). Some of the mass-balance models were build using the Ecopath master equations but balanced using an inverse modelling approach. The CDEENA website (http://www.osl.gc.ca/cdeena/en/accueil.shtml) provides detailed information on the structure of the models, key results, publications, etc.

Ecopath with Ecosim: Newfoundland-Labrador shelf

Bundy (2000) constructed a EwE model for the southern Labrador Shelf, Northeast Newfoundland Shelf and Grand Bank in Northwest Atlantic Fisheries Organisation (NAFO) Divisions 2J+3KLNO for the period 1985–1987. The paucity of data on biomass and diet of many groups was emphasised. Information on productivity of lower trophic levels was especially weak. Major imbalances were found in the original model. Biomass estimates of some prey species were increased substantially to meet the food requirements of predators. Hooded seals were at the top of the food web. Other high level predators included Greenland halibut, harp seals, Atlantic cod and skates. The major predators in the area were harp seals and Atlantic cod. The dominant planktivorous fish was capelin, but Arctic cod and sand lance were also important. The model has been applied to investigation on the dynamics of fish and fisheries (Bundy 2001). Historical reconstructions of past ecosystems have also been made (Pitcher *et al*., 2002, Heymans 2003).

Ecopath with Ecosim: Eastern Scotian Shelf

Under the auspices of a DFO project, 'Comparative Dynamics of Exploited Ecosystems in the Northwest Atlantic' (CDEENA), Bundy (2004) developed two detailed models of the eastern Scotian Shelf, Nova Scotia for 1980–1985 and 1995–2000. The models represent the eastern Scotian Shelf before and after the collapse of cod and other groundfish and were developed to

explore how the ecosystem has changed, in terms of its structure, function and the role of key species (Bundy (2005). Analysis was conducted to examine the effects of the uncertainty on model estimates. A comparison of the two Ecopath models demonstrates that though total productivity and total biomass of the ecosystem remains similar, there have been changes in predators, trophic structure and flow; the ecosystem has changed from a demersal dominated system to a pelagic dominated system. With the exception of the average trophic level of the catch, there is no effect of the groundfish collapse on the emergent properties of the ecosystem. The eastern Scotian Shelf ecosystem is profoundly altered and it exhibits a classic case of "fishing down the foodweb", although system properties are generally conserved.

Ecopath with Ecosim: Northern and Southern Gulf of St Lawrence

Morisette *et al*. (2003) and Savenkoff *et al*. (2004) developed a model of the Northern Gulf of St. Lawrence ecosystem for the period 1985–1987, prior to the collapse of commercially exploited demersal fish stocks in the area. Marine mammal trophic levels were estimated by the model. Different seal species preyed on different levels of the food chain. Harp seals preyed on most trophic groups, whereas larger seals, such as gray seals and hooded seals, mainly consumed higher trophic levels. The model suggested that apex predators had a negative effect on their dominant prey, but an indirect positive feedback on the prey of their preferred prey, mainly American plaice (*Hippoglossoides platessoides*), flounders, skates, and benthic invertebrates. The results suggest that both marine mammals and fisheries had an impact on the trophic structure. The model has been used to investigate trophic role of marine mammals (Morissette *et al*., 2006) and in comparison with the Southern Gulf. Savenkoff *et al*. (2004) developed a model for the Southern Gulf of St. Lawrence ecosystem and used it to compare in periods before and after the collapse of groundfish stocks (Savenkoff *et al*., 2007).

Bioenergetic models

In addition to the work on EwE models, current work is underway to implement multispecies bioenergetic-allometric models following the framework developed by Yodzis and Innes (1992) and later expanded by Vasseur and McCann (2005) to incorporate temperature dependence. This work builds upon the experience gained by modelling other systems (Yodzis 1998; Yodzis 2000; Koen-Alonso and Yodzis 2005) and currently involves models for the Eastern Scotian Shelf and the Labrador and Newfoundland shelf. In contrast with the EwE models, these models only include key components of the two systems and can be regarded as 'minimum realistic models'. Both are aimed at describing the full dynamics of the species under consideration and they are currently at an implementation stage. They are based on numerically integrated ODE systems and their parameterization involves both allometric-derived parameters and parameters estimated by fitting the models to time series. Current fitting exercises rely on simulated annealing methods.

Seal-fish models

Additional modelling work specifically directed to explore the impact of seals on cod is also ongoing in different DFO laboratories. A workshop directed to evaluate the impact of seals on fish stocks will take place in November 2007. All models described above, plus the targeted modelling work, will be discussed in this workshop. The targeted modelling work has involved single species models with additional mortality terms, statistical modelling, and single species bioenergetic-modelling with explicit predation components.

3.15 Ecoregion: US Northwest Atlantic

Ecopath with Ecosim

As part of work developing EMAX (see below), 4 Ecopath models were developed covering the Gulf of Maine, Georges Bank, Southern New England and Middle Atlantic Bight (Link *et al*., 2006).

EMAX

The Energy Modelling and Analysis eXercise (EMAX) is a network analysis model (i.e. a more nuanced energy budget) of the entire food web. It includes the entire NE US continental shelf, broken into 4 subregions with 36 network "nodes" or biomass state variables across a broad range of biology. The emphasis is on the role of small pelagics, with some pseudo-dynamic scenarios executed. Interactions among targeted and protected species are explicitly included. This work is highly interdisciplinary and involves personnel from most of the NEFSC's organizational structure.

The primary work has been to calculate a balanced energy budget for the four regions- MAB, SNE, GB, and GoM. Once these networks were balanced, a suite of network analyses and outputs were executed. This work has not gone through a formal model review process; however there has been an interdisciplinary team meeting regularly in workshops to review and revise the work as it has progressed. The rigor and degree of quantitative data used to input and balance these networks has been atypical to much of the published literature on the subject. This modelling approach was designed to compile and catalogue information, identify data gaps, and serve as the basis for future dynamical system modelling. As such it was a research tool. But the model was also designed to evaluate the relative role of specified nodes in the ecosystem; as such it provides contextual and strategic management advice.

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. We estimated biomass, production, consumption, respiration, and diet composition for all nodes. Additionally, for some nodes we also estimated other sources of removals- namely fisheries.

The positives of this approach are its exclusivity of a wide range of biota and associated processes. Being able to holistically examine an ecosystem to ascertain the relative importance of processes simultaneously is a major positive. Also positive is the ability to examine tradeoffs in biology and fishing in an integrated fashion. Negatives include the data intensiveness for the many nodes, the lack of clarity on detrital dynamics, and the complexity of possible dynamics given the myriad pathways in the full system.

ATLANTIS

ATLANTIS (Fulton *et al*., 2004) 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 bio-

physical processes are realistic. A second level calibration is nearing completion to ensure fishing processes are reasonable. Future scenarios of different management strategies are planned to follow completion of the second 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 in other contexts (not yet at the NEFSC) to provide multispecies fishery advice and multi-sector ocean-use advice. The NEUS rendition of ATLANTIS has not been through a formal model review.

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 further improvement.

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 fishes to zooplankton), and trophic reference points (i.e. marine mammal biomass to pelagic fish biomass) 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.

Extended single-species models

A suite of 'minimum realistic' models have been developed and, these models seek to add in predation removals of a stock into a single species assessment model. These have been both age/stage structured and bulk biomass/production models. These have ranged from providing context of stock biomass, tuning indices, sources of other mortality, to explicit estimates of additional (i.e. predation or M2) mortality.

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 amenable to calculating BRPs, 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 be missing a suite of complex interactions and non-linear responses from not including the full suite of interactions in an ecosystem. They also have the potential to be controversial, by producing more conservative BRPs 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.

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 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 and research or else have been calculated as part of predatory removals of forage stocks (noted above).

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 they are relatively simple conceptually and operationally, they use extant data, they are implemented in a familiar assessment and management context, 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 minimum-realistic models, namely that they may be missing a suite of complex interactions and non-linear responses from not including the full suite of interactions in an ecosystem. They also have the potential to be controversial by emphasizing the potential for competition between stocks and fleets that target their prey without having a fuller modelling capability to fully address these trade-off issues.

Single Species Add-ons: Environmental Considerations

NMFS have begun to incorporate environmental considerations into population models, but not yet in a fully operational mode. These include changes in carrying capacity (K), growth rates (r), stock-recruitment relationships, or stock distribution relative to environmental conditions.

These have been done or are being done for a wide range of fish, mammal and invertebrate species. Currently none of these models have been through a formal stock assessment review nor explicitly incorporated into a review process that directly informs management. All remain active areas of research and development.

In addition to the standard stock assessment data needs, these approaches require appropriately (spatio-temporal) scaled environmental data such as temperature, depth, salinity from various monitoring sources.

The positives of this approach are that the environmental data are usually available and relating them to stock dynamics typically utilizes commonly established statistical methods. These approaches also improve the biological realism of assessment models and allow for dynamics driven by factors typically outside of usual assessment considerations. The chief negative of this approach is that the data are often autocorrelative without definitive causal mechanisms; the data may also usually be collinear, and short of exhaustive multivariate analysis are difficult to parse out into factorial weightings useful in stock projection.

MSVPA-X

This 'extended' multi-species 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. The model has the ability to provide short-term forecasts. Most typically the model examines the stock dynamics of multiple species that are both predators and prey of one another, particularly exploring the role of predatory removals of stocks relative to fishery removals.

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 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 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 biomass (i.e. not age structured) predators.

Other age-structured models: MSYPR

A multispecies YPR model was developed to model technological interactions in the New England groundfish fishery. The impact of fishing by a single fleet and multiple fleets on a complex of fish was studied with an YPR analysis. The model was designed to measure the simultaneous impact of effort and mesh changes for groundfish on Georges Bank. Data requirements include aggregated fishing effort, catchability coefficients, mean weight data, and mesh selection data for the set of fish species being modelled. For Georges Bank these species included cod, haddock, yellowtail flounder, and winter flounder. Equilibrium yields were estimated as a function of aggregate effort and mesh selectivity. Outputs included total and individual species yields, exploitation rates, and individual fish weights. The model was used to study growth under-fishing and over-fishing by using total yield as the measure of optimality.

MS Bioeconomics

Two related models that explore the bioeconomics of multiple species have been developed. One is a portfolio approach, while the other is an age structured multispecies model that incorporates a market evaluation of the stocks. Both are research tools/products and not generally used in providing management advice or in the stock assessment review process. However, the multispecies model was used to develop advice for a groundfish amendment for the New England groundfish fishery. The former is a RandD tool; the latter is now a software package. Neither are actively being pursued at this point. These models have not been through a formal model review.

The multispecies bioeconomic model was designed to evaluate management strategies and scenarios. The model uses age-structured data for a multispecies complex of fishes and is driven with aggregate fishing effort apportioned to stock areas. The original application was developed to investigate selected biological and economic implications of effort control on groundfish in New England. A variety of biological and economic performance measures were used to assess the impact of effort reductions in a benefit-cost framework. Increases in catch, SSB, and CPUE were projected when aggregate fishing effort was reduced. Increases in consumer surplus, net present value of revenue, and average fish prices due to size increases were also suggested. The model was also used to evaluate how management strategies with time horizon interventions would impact revenue and consumer surplus.

Multispecies production models: MSPROD

A multi-species 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 that can then explore sensitivities and scenarios for different considerations. Right now this is a research tool and will not be used in a management advice context until we develop the capacity to fit to time-series data. 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 MS models, it is parameter intensive but less so than many other MS models given the simplicity of the model equation structure.

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. The data needs, pros, and cons are the same as MS-PROD, with the amalgamation of parameters across groups a notable caveat.

Biophysical Coupled Models

As part of the synthesis phase of GLOBEC, in collaboration with colleagues at the Institute of Marine Research, Bergen, comparative biophysical coupled model studies are being developed for transport and growth of larval and early juvenile fish in the two marine ecosystems Georges Bank and the Norwegian shelf/Barents Sea (the northern and southern extremes of the distribution of Atlantic cod). These studies will contribute to basic understanding of the interactions between fish populations and zooplankton and how these interactions are influenced by climate variability and change. Realistic physical conditions are being developed to hindcast selected years using the Regional Ocean Modelling System (ROMS) forced by a common set of variables with increased resolution within the regional domains. Lagrangian (particle tracking) models and Individual-based trophodynamic models for larval and early juvenile fish growth are embedded in the regional circulation models.

The core of the trophodynamic model is the standard bioenergetic supply-demand function, in which growth is represented as the difference between the amount of food absorbed by a larva and the metabolic costs of its daily activities. The formulation includes: (i) variable composition of prey fields; (ii) effect of turbulence, swimming behaviour and satiation on encounters and ingestion of larval fish and their prey; (iii) light limitation on ingestion rates at low and at high light intensities and (iv) effects of temperature on metabolic costs, ingestion rates and growth.

Data collected during selected years will be used to examine the space-time variability of the larval fish feeding environment. The distribution and evolution of the zooplankton fields will be specified based on the observed structures. If available, evolving prey (zooplankton) fields will be computed from NPZ models.

Comparative basin-scale, spatially explicit simulations can be made (NAO high vs. low years), but full model implementation requires extensive data fields. ROMS forced with CORE or ERA data sets have significant spin-up time before good solutions are realized. This model has not been through a formal model review. This remains a research tool and has not been used for management purposes.

4   ToR b): Evaluate region-specific stomach sampling designs

Stomach content data serve as the basis for a plethora of multi-species, extended single-species, and ecosystem models. Having a solid foundation of food preference data is a pre-requisite for implementing the ecosystem approaches to fisheries. In this section, we first give an overview of existing data bases and survey designs. Then possible improvements and simplifications to the data collection procedures are considered, and finally a possible regional European food web sampling program is discussed.

4.1   Overview over existing databases and survey designs

Annex 4 contains an overview of the main eco-region-specific stomach content databases. The data have been collected by ICES member institutes and are available after contacting ICES or the persons listed. By far the largest and most integrated datasets in Europe are those originally collected under the auspices of ICES itself, during coordinated programmes in the 1980s and 1990s (including the two 'Years of the Stomach'). **Concern was voiced within WGSAM** that these datasets, although available indirectly through ICES, are not held centrally, securely and in an easily downloadable and standardized form. These datasets are the common property of all partner institutes and it was felt that they should be made available through the ICES data centre (in a similar way to oceanographic and catch data), and in a form that is well documented, and 'version controlled'. At present various versions are in circulation and/or are held by persons across Europe.

4.1.1 Icelandic waters

The Marine Research Institute (MRI) in Iceland has collected stomach data regularly since 1975, mainly from demersal fish surveys. The data base contains data from 50 predator species, but only for 10 of these are stomach data collected regularly. In addition to the regular collection of stomach content data, there was a special 'Multispecies research program in 1992–1995' where data on the diet of both pelagic fish, demersal fish, seabirds and marine mammals were collected (MRI, 1997). 60% of the data collected are from cod, the main predator in the ecosystem in Icelandic waters. Data have been analysed for 280 000 predators.

4.1.2 Barents Sea

IMR, Bergen, Norway and PINRO; Murmansk, Russia have a joint data base for stomach content data. Stomach sampling protocols and the database format are described in Mehl and Yaragina (1992). Norwegian and Russian stomach data are currently recorded in the institutes' data bases for trawl data, and then converted to the (old) joint data base format. The IMR data base for trawl data is described by Mjanger *et al*. (2006). An overview of the stomach sampling carried out in the Barents Sea is given by Dolgov *et al*. (2007). The data base at present contains about data from 366 000 thousand stomachs, 2/3 of which are from cod.

A total of 470 harp seal stomachs/intestines have been sampled, in the period 1990–2006 in various parts of the Barents Sea. Additionally, 94 faeces samples were collected on the ice in the northern Barents Sea in the period 2004–2006. All stomach/intestine contents in the northern part of the Barents Sea have been collected exclusively along the ice edge whereas the seal stomach/intestine samples in the southern Barents Sea is mainly from gillnet by-catches. Additionally, there is stomach/intestine samples from seals caught in gillnet during the seal invasion in 1986–1988. A total of 623 minke whale stomachs have been sampled in the Northeast Atlantic in the period 1992–2004. The whales were collected in three areas (North Sea, Norwegian Sea and Barents Sea); 24 whale stomachs were collected in the North Sea in 2001–2003, 17 in the Norwegian Sea in 2002 and 2004 and 583 in the Barents Sea in 1992–2004.

4.1.3 North Sea

Stomach content data for North Sea fish predators, are available from the ICES 'years of the stomach' in 1981, 1985–1987 and 1991 (Anon, 1988; Daan, 1989; Hislop *et al*., 1997). Stomach data sets are available for two full years, 1981 and 1991 where 7 predator species were sampled in all quarters and for three incomplete years, 1985, 1986 and 1987 only two predator species were sampled in two quarters. The total stomach content database contains about 200.000 analysed stomach contents.

For eight of the most important sea bird species in the North Sea (Tasker and Furness 1996) quarterly dietary data were provided by the Working Group on Sea Bird Ecology (WGSE). These data were revised in 2006 in the EU BECAUSE project and described in ICES SGMSNS (2006).

In the UK a project is currently underway, under the name DAPSTOM (Pinnegar and Stafford 2007), to digitise historic and recent stomach content data, and to make this data generally available over the internet (see www.cefas.co.uk/dapstom). The DAPSTOM project has received initial funding under the 'data rescue' programme of the EU Network 'Euroceans'. In terms of geographic coverage, the database (which currently uses MS Access) includes information from the North Sea (ICES area IV), the Celtic Sea (area VIIe-j) and the Irish Sea (area VIIa). Data is available from the 1960s, 70s, 80s, and the past 5 years (2002–2006). 82 predator species are represented, and the database includes information on larval feeding preferences (cod, haddock and whiting) from the recent EU LIFECO project. It is hoped that the database will eventually include even earlier information concerning fish feeding

preferences in the 1900s – 1950s (see inventory in SGMSNS 2006), and that it might be used to examine long-term changes in the functioning of ecosystems. Currently the database includes 103,827 records from 59,181 predator stomachs.

4.1.4   Bay of Biscay

The 'trophic relationships' team at IEO have analyzed food habits data for 25 demersal fish species in the ICES Division VIIIc since 1988. These species represent 90% of the demersal fish biomass in the region and they are ecologically and commercially very important. Stomach contents of these demersal species were analyzed at sea, aboard standard scientific surveys. These surveys were carried out using random sampling stratified by depth, 30 – 500 m, and geographical area, following the methodology explained in Sánchez (1993). The sampling unit is an individual tow. Data come from bottom trawl surveys conducted every autumn for demersal fishery assessment in the Cantabrian Sea (ICES Division VIIIc) and some years commercial vessels.

The protocols have been standardized since 1988. For each haul, a minimum of 10 stomachs from each age class were selected by size range in the commercially important species. For each predator, length to the cm below was measured. In addition, state of the gall bladder (Robb, 1992) was examined in all fish. Stomachs containing food that had been ingested during the haul itself (i.e. the gall bladder was not used) were considered empty.

The data collected from each predator were: length (cm), sex, sexual maturity, stomach state (with food, empty, regurgitated), total volume (cc) of stomach content. The total volume (cc) of fish with food groups in the stomach was measured using a "trophometer", a calibrated measuring instrument, consisting of several different sized half-cylinders built into a tray, in such a way that they form horizontal cylindrical-moulds (Olaso, 1990). Stomach content weight was derived from a regression equation using the estimated volume and actual weight of the contents (Olaso *et al*, 1998).

The data collected for each prey specimen were: lowest possible taxon (species) in the case of decapod crustaceans and fish, percentage contribution to the total stomach content volume (cc), digestion state, total length of the prey (given that the state of prey permitted the measurement). With this method, in each survey IEO can analyse about 8000 stomach contents. The method is well suited to identify feeding in the trawl due to the gall bladder examination that reveals regurgitated stomachs.

The food habits database of IEO contains more than 180,000 stomachs from over 25 predators. All stomach analyses are contained in a DBASEIII-database. These data serve as basis for single-species feeding investigations (hake – Velasco and Olaso, 1998, anglerfish – Preciado *et al.*, 2006 -, etc) as well as the benthic community studies (Serrano *et al*, 2003), and serve as input for ecosystem models (Sanchez and Olaso, 2004).

4.1.5   Baltic Sea

Cod is the top piscivore predator in the Baltic Sea ecosystem. The international database of Baltic cod stomach contents contains data from 62 427 cod collected during 1977–1994. The collation of national stomach content data set into one set for multispecies assessment has mainly been done 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.

4.1.6   Northwest Atlantic – Canada

The collection of stomach contents is not a standard activity in the multispecies surveys carried out by Fisheries and Oceans Canada (DFO). Nonetheless, regional programs have collected stomach content information over the years, most often directed to the main

commercial species. Although not to be considered a thorough review, some details of these activities are given below.

In the Newfoundland and Labrador Region of DFO, a multi-year program collected Atlantic cod stomachs during the period 1978–1999. This information has served as basis for many analyses (e.g. Lilly and Fleming 1981, Lilly 1991, Lilly 1994, Steel and Lilly 1999, Lilly *et al.*, 2000). Greenland halibut is another species for which stomach contents have been collected and analysed (Bowering and Lilly 1992, Pederson and Riget 1993, Pederson 1994, Orr and Bowering 1997). Beside directed stomach content analysis programmes like these, semi-quantitative information on stomach fullness and the identity of the two main prey in the stomachs is also recorded for those commercial species for which otolith sampling is regularly conducted. These basic data are currently stored in flat files, but a migration project is currently underway to move these and other survey-based data into a relational database. This necessary update in archival procedures should streamline the access to these data. In addition to this and over the last few years, stomach contents of capelin have also been collected and analysed (F. Mowbray, personal communication). At the present time a stomach content sampling program is being designed and implemented in the Newfoundland and Labrador Region as part of the regional implementation of a nationally-driven Ecosystem Research Initiative. This diet program will be carried out during the annual autumn multispecies survey (NAFO divisions 2J3KLNO) and will collect stomach contents for a small set of species (a tentative list includes Atlantic cod, Greenland halibut, American plaice, Yellowtail flounder, redfish, capelin, Arctic [Polar] cod, and sand lance [sandeel]). The program will combine full stomach content analyses with information from at-sea semi-quantitative information on main prey in the stomachs (further details are provided below).

In the Maritimes Region of DFO, the stomach contents database for the Scotian Shelf and Bay of Fundy area contains data on over 100,000 fish stomachs covering 51 of the species found in the region. The data come from a variety of groundfish and pelagic commercial and research surveys conducted between 1958 and the present. The protocols for collection have recently been standardized through the use of an "Enhanced Sampling Program", which has been implemented in the: groundfish researchs surveys, herring research (pelagic) surveys, area 4VsW sentinel survey, halibut industry surveys, and commercial onboard observer and dockside sampling. The details of the sources and quantity of the data, the collection methodologies, and the Oracle database in which the data are stored are described in Laurinolli *et al* (2004).

There is also an ongoing multiregional diet program for seals, mainly harp, gray and hooded seals. This seal diet program started in the late 1970s early 1980s and relies on stomach contents, fatty-acid and stable isotopes analyses. This program covers the Newfoundland and Labrador shelf, the Scotian Shelf and the Gulf of St. Lawrence.

4.1.7 Northwest Atlantic – US

The Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service (NMFS) has had the Food Web Dynamics Program (FWDP) in one form or another since 1953. The FWDP is responsible for designing the collection of, sampling, processing samples, quality control and data auditing, database management, and analyzing food habits data for the major fish species in the northwest Atlantic. There have been changes in protocols over the extent of the program, but effectively the core of what is collected has remained generally consistent for multiple decades. For further details of the history, sampling protocol, and philosophies of the FWDP food habits database, see Link and Almeida (2000).

The stomachs are collected and mostly processed at-sea as part of the NEFSC bottom trawl survey. Select subsamples of stomachs are brought back to the lab for processing and quality control purposes. The bottom trawl survey carries out tows in a stratified random design, with

the number of tows per strata dependent upon strata area. Although we track the number of stomachs, strictly speaking in a statistical sense, our sampling unit is an individual tow. For further details of the NEFSC bottom trawl survey, see Grosslein (1969), Azarovitz 1981, NEFC (1988) and Reid *et al.* (1999).

These data serve as the basis for a plethora of multi-species, single-species add-ons, and ecosystem models. Having a solid foundation of food habits data such as that maintained by the FWDP places the NEFSC in a good position to begin implementing ecosystem approaches to fisheries.

Metadata

The food habits database (FHDBS) contains more than 500,000 stomachs from over 130 predators and has more than 1,300 different prey items. For most fish species, diet can be adequately characterized with the examination of 500 – 1000 stomachs, which is the case for the 40–50 main species. The data have been collected quantitatively since 1973 to present (at the time of this report, 2007). The data have been routinely collected in the two principal seasons of the bottom trawl survey, both during spring and during autumn. Additional stomachs have been collected in other seasons (namely winter), on other surveys (e.g. some scallop survey goosefish stomachs), and on process-oriented cruises.

Common Metrics and Output

There are a plethora of statistics and metrics that can be presented (e.g. Hyslop 1980, Cortes 1997) to describe, model and analyze fish food habits data and trophic ecology. For a broad range of examples for a suite of northwest Atlantic species there are copious examples (e.g. Brodziak and Link in press, Garrison and Link 2000a, b, c; Link and Almeida 2000, Link and Garrison 2002a, b; Link *et al.*, 2002a, b, 2006, Overholtz and Link, 2007).

Generally speaking, NMFS present appropriately weighted (taking into account survey design and various size, seasonal, yearly, or geographic factors) estimates of mean stomach contents (g), percent diet composition of major or specified (i.e. prey species of interest) prey, percent frequency of occurrence of major or specified prey, number of stomachs, number of tows with stomach collected, number or percent of empty stomachs, percent daily ration (stomach content / body mass), and various derived estimates of consumption rates (both on an individual and population basis).

4.2 Matching data collection with management questions

Regardless of the specific details about how ecosystem approaches can be implemented; there is very little argument about the need to develop some operational understanding on the functioning of the ecosystems under exploitation. This understanding needs to be informative, at the very least, on the basic dynamics of the core species of the exploited community. Hence, it minimally requires identifying the main pathways and interactions in the system and tracking how they change over time (and in many cases spatially, too). Developing a knowledge base on trophic interactions is certainly an important part of this process.

Although this development could be achieved using many different sampling strategies and analytical techniques, given the scale of fisheries systems and the more or less conventional logistics and budgetary constraints, this knowledge base is often based on stomach content sampling and analysis programs. In order to be useful, these programs should be developed to ensure a capability for addressing relevant management questions. These questions are the drivers that will define the type of program required, the quality of the data needed, its sampling strategy, etc.

Different management questions will most likely require different sampling programs. However, based on current and past experiences, it is fair to state that most (if not all) trophic-related management questions will require reliable information on diet variability over time. This type of long term data is seldom collected under a single program over the years; time-series are often assembled from a wide variety of sources. Furthermore, most current management questions are addressed using trophic information collected under programs which did not have these questions as objectives. This highlights two general issues, 1) new management questions will always emerge after the design and implementation of any sampling program, and 2) managers always have the initial expectation that these new questions can be answered with the information of the programs currently in place.

Even though addressing the above observations is beyond the scope of WGSAM, they suggest that sampling programs need to be scoped under two different frameworks. One involves standard long term sampling programs intended to capture the time-series nature of trophic interactions. These programs would likely be generalist, trying to provide reliable but not necessarily finely-detailed information. The other would involve targeting sunset programs intended to provide fine-scale details and more specific answers to more narrowly stated questions.

Implementing stomach content sampling programs has different considerations under each one of these frameworks. Long term sampling programs are well suited for becoming standard components in regular fishery surveys. Dealing with this type of sampling in this way facilitates processes to be streamlined and, more importantly, allows a better control and standardization of procedures. Ensuring that samples are consistently collected and processed is vital to make this type of time-series a reliable source of information, especially if these programs are intended to span over the years and where scientists and technicians would likely change over time. On the other hand, detailed studies can be implemented as a special request in standard surveys or built around a dedicated survey targeting the particular issue of interest. In this type of sampling, standardization across programs is an asset but in most cases only internal consistency is really required to achieve its objectives.

4.3 Can less detailed, onboard sampling complement detailed laboratory based analyses?

There has been much discussion regarding the relative merits of somewhat less refined, ship-based analyses of stomach contents versus detailed examination of preserved stomachs in the laboratory. Several institutes (notably NMFS-NEFSC, CEFAS) have conducted comparative exercises, to see whether the data which results from onboard analysis differs appreciably from data that emerges from more rigorous examination of stomachs in the laboratory. In some instances, comparative exercises have demonstrated that ship-borne programmes yield high-quality, very usable data which closely matches information from the more rigorous laboratory studies, in other cases – clear discrepancies have been highlighted with the different approaches emphasising different prey types as being important. In broadest terms, taxonomic resolution is usually the main difference between ship-based and in lab stomach processing, more than accuracy of taxonomy or stomach amount.

In the US North-west Atlantic, scientists from the NEFSC regularly carry out stomach content analyses as a routine part of annual bottom trawl surveys. Stomachs are examined onboard as a subsample of all individuals processed (although fewer stomachs are examined in comparison with biological sampling for maturity and age determination (otolith extractions)). High frequency, low intensity sampling is carried out for ~50–60 main predator species (~30–50 stomachs per haul) and key prey types are identified with the aid of printed identification keys. The total volume of stomach contents is quickly assessed using graduated measurement dowels (graduated trays are used in the Bay of Biscay), as is the volume and percentage

represented by individual prey types. These are later converted into weights using standard conversion rates, and in some instances individual prey length (for commercially important prey) is also recorded. For 1 in 20–25 stations (out of a total 350–400) all stomachs are retained and brought back to the laboratory in order to validate the ship-borne assessments, to check for measurement error (including more detailed mass and gravimetric measurements) and to explore taxonomic identification errors, etc. The ship-based data is subsequently 'cleaned' in accordance with a rigorous auditing process (to ensure that prey proportions add to 100%, prey names are consistent, measured lengths of prey are consistent with lengths of predators etc.) and the data is then uploaded to the FHDBS database. A 'time and motion' study carried out to assess whether the additional (stomach) sampling activity imposed an additional and significant burden on survey personnel revealed that the examination of stomachs added only 5–10 minutes of additional work within the 150 minutes required to sample catches at each station.

A recent sampling exercise carried out as part of a fishery-science partnership project in the North Sea, involved both ship-based assessment of whiting stomach contents and the retention and preservation of stomachs for analysis in the laboratory (see report by Stafford *et al.*, 2006). Many more stomachs were examined whilst onboard the commercial vessel, using a simple 'tick sheet') compared to the quantity examined in the laboratory. Where stomachs were not empty, the main contents were small crustaceans. However, unlike the onboard assessment, the detailed stomach analysis revealed significant seasonal differences in the diet. This difference between the data sets largely resulted from differences in the processing of samples, since the detailed analysis was performed by weight of prey and the onboard analysis simply by presence or absence.

Scientists from Fisheries and Oceans Canada (DFO), Newfoundland Region, are currently engaged in the design of an ecosystem research program aimed to develop capacity towards addressing ecosystem questions in their region. One component of this program is the enhancement of the current multispecies survey by incorporating and/or consolidating activities which are relevant for characterizing basic ecosystem processes. Basic diet analysis of key species is one of these activities.

As part of the design of this program, scientists have recently begun to evaluate whether simple dietary information routinely collected as part of the multispecies survey broadly agrees with more detailed diet information obtained from targeted stomach content analysis studies. For example, research into the diet of Greenland Halibut along the coasts of Newfoundland (and in particular NAFO divisions 2J, 3K and 3L) began in 1973. This work, which currently is not part of the core survey activities, relies on stomach contents brought back to the lab for analysis and constitutes the basis for our current understanding on the feeding habits of this species. As part of the regular multispecies survey a parallel stream of coarser diet data is also being collected in this region. Information on stomach fullness and the identity of the 1 or 2 main prey species in the Greenland halibut stomachs is recorded for those fishes that are being sampled for ageing (note: this protocol is in place for all commercial species for which otoliths are collected but the consistency and quality of this information has not been assessed yet). In this context, a preliminary comparative analysis of data from the autumn of 1985 (Mariano Koen-Alonso, personal communication), has revealed that in terms of identifying broad patterns in the frequency-of-occurrence, simple recording of the dominant prey can yield results which are consistent with the ones obtained from more expensive and time consuming laboratory studies. However, assessing prey biomass and abundance in the diet would still likely require some level of detailed stomach content analysis. What is currently under consideration is the development of a dual sampling scheme, combining both detailed stomach analysis and coarse on-board sampling.

Scientists from the same DFO institute (Northwest Atlantic Fisheries Centre, St. John's) have also begun to evaluate the feasibility of using basic information about the dominant prey in

biomass, in combination with average weights of prey in the stomachs, to generate biomass diet composition estimates. In this case, they are using harp seals diet as a test case for this idea. This approach relies on multicategory logit models which are based on qualitative information on the most dominant prey types and render probabilities of any given prey type to be a dominant prey in a stomach (Buren *et al.*, 2006). These probabilities were multiplied by an average weight for each prey type and this yielded a diet composition which was surprisingly similar to that obtained from analysing the stomach contents in the traditional way. The key message emerging from this preliminary exploration is that, given a sufficiently large sample size, high-quality diet composition information can be reconstructed from very simple input data.

4.4 Low frequency-high intensity vs. high intensity low frequency sampling

The Study Group on Multi Species Assessment in the North Sea concluded that the sampling intensity for future stomach sampling cannot be substantially lower than sampling intensity in the North Sea 'years of the stomach' surveys in 1981 and 1991 (ICES, 2006). The probability of detecting a specific interaction decreases with a reduction in sampling intensity. A reduction in the number of sampling stations of more than 25% leads to substantial decreases in detection probabilities. In addition, the full aerial distribution of predators has to be covered to get an unbiased overview of the diet composition of the predator populations. What can be reduced compared to 1981 and 1991, however, is the number of stomachs samples per haul and predator type. Intra-haul correlation points to a little gain in sampling a large number of stomachs at a station.

Ideally, stomach sampling should be part of a standard routine carried out every year on available surveys (e.g. IBTS). Under limited time and money resources, it has been preferable to concentrate the sampling effort to some years than to have an insufficient sampling intensity each year. The frequency of stomach samples, however, should at least ensure that important changes in the food web will be detected (sampling every 3–5 years). This will allow for process studies on the evolution of predator-prey interactions over time and a proper parameterisation of improved multi species assessment models.

4.5 Statistical precision: more stomachs or more stations?

The study group on multi species assessment in the North Sea (SGMSNS; ICES, 2006) analysed the precision of average diet estimates for North Sea species and linked precision to sampling level. This section gives a quick review of the main conclusions:

- Species and size distribution of prey tend to be more similar at a local scale, than in the general population. Such intra-haul correlation points to a little gain in sampling a larger number of stomachs at a station. If the number of the stations is not a limiting factor, it is much more cost effective to sample only a few fish at each station but increase the number of sampling stations.

- Analytical results indicate that sampling procedures that base the analysis on the contents of individual stomachs are preferable to those based on combining the contents of several stomachs into aggregate samples. Given a relatively small sample size per haul, the time saved of pooling stomachs is limited.

- By nature the precision of stomach data can be low. Even though several thousand stomachs are analysed, each diet entity (combination of quarter, predator species, predator length group, prey species and prey length group) is often based on rather few hauls. However, the gain to increase the sample size from 50 to 100 hauls is much higher than an increase from 500 to 1000 hauls. Therefore, the number of hauls conducted in standard surveys (e.g. IBTS) is often sufficient to give a reasonable precision of diet data.

- Standard surveys do not cover all biotopes (e.g. stone reefs, shallow water regions) and are not designed to quantify very localised predation events (e.g.

intense feeding aggregations). Additional studies could correct for the associated bias in existing sampling programs.

- The geographical coverage of a stomach sampling program should match the spatial units used in modelling.

4.6 Feasibility study for a regional food web sampling program

In the 2006 report of the report of the Study Group on multispecies assessments in the North Sea the reasons why food web dynamics need to be taken into account in fisheries and ecosystem management were described in greater depth, including European as well as regional political and scientific requirements (SGMSNS, ICES CM 2006/RMC:02).

Following discussion concerning the possible design of a new stomach sampling programme in the North Sea, SGMSNS proposed that a North Sea programme should consist of two separate components:

- A 'core/integral programme' including IBTS focussed sampling and some gap-plugging *ad-hoc* sampling aboard research and commercial vessels (for example to increase the sample size of under-represented species or to gain sample coverage in quarters 2 and 4).
- An 'extra programme' involving smaller-scale, targeted research aimed at exploring known biases in the 'core/integral programme'. For example specific exercises aimed at exploring the implications of using different sampling gears (pelagic vs. demersal trawls), day-night sampling.

In the EU BECAUSE project regional summaries of available food web data were established for the North Sea, Baltic Sea, Bay of Biscay / Iberian Peninsula and the Mediterranean Sea. Subsequently the shortcomings of the existing models and currently available data were identified and coarse characteristics of future stomach regional sampling programs were drafted, similar as SGMSNS did for the North Sea.

The suggestion from the SGMSNS and BECAUSE consortium, which includes most of the EU fisheries centres, was that the EU Commission should incorporate a rolling stomach sampling program in the revised EU Data Collection Regulations (DCR), and WGSAM continues to pursue that aim. However, it is acknowledged that before such a food web sampling can be included in a revised DCR, first a feasibility study should be conducted in order to establish the most efficient sampling strategy while harmonizing the stakeholder demands (in terms of resources and 'man-power') on the European level.

In the following an outline of such a feasibility study is presented. Hereby especially the input from North American colleagues attending the first WGSAM meeting proved highly valuable, since the Northeast Fisheries Science Center (NEFSC) of the National Marine Fisheries Service (NMFS) has had a 'Food Web Dynamics Program' (FWDP) since 1953 (see above). WGSAM greatly appreciates the input from North American colleagues, whose experience in designing multi-purpose ecosystem surveys should prove highly valuable in terms of 'knowledge transfer'.

4.7 The structure of the feasibility study

WGSAM suggests that a feasibility study is initiated at the EU level (with the support from EFFARO and national institutes), which aims at the identification of food web data requirements for multi-species assessment and ecosystem modelling in the various ICES eco-regions including **an analysis of the most cost effective** means of data acquisition. Such a study should address the following main points:

Identification of the data requirements

A meta-database would need to be compiled in order to give an overview of the existing data from various sources. As a major task recent applications of multi-species models will be analysed with emphasis on the specific problems that have been encountered, due to limited availability of recent (or historical) stomach datasets.

From this exercise the main gaps in data coverage should become obvious. The study needs to separate the data needs for multi-species assessment models, where the required taxonomic resolution often is limited to a subset of the fish community, from the requirements of 'whole ecosystem' models, where smaller amounts of data are required on individual species, but the whole food web must be covered. As a major outcome, the research and management questions, together with the required specific data will be compiled.

Comparison of temporal and financial efforts of different sampling schemes

Concern has been voiced about the additional cost of any extra stomach sampling, which relate in the most part to the way that sampling exercises where performed in the past, i.e. the highly intensive and expensive "years of the stomach" in 1981 and 1991. There are, however, alternative approaches of routine sampling schemes which work with comparatively little effort. We are referring here to the protocols adopted by the 'Food Web Dynamics Program' (FWDP) of the National Marine Fisheries Service (NMFS), where all samples are processed onboard the research vessels, applying simple volumetric methods in combination with a paperless computerised data acquisition system. It is planned to carefully investigate the FWDP approach and opportunities to implement a similar scheme into EU waters. A similar volumetric onboard analysis approach, which was inspired by the FWDP is currently applied onboard Spanish vessels in the Cantabrian Sea.

NMFS has made detailed analysis of the time cost of individual activities during the processing of a haul on their research vessel. Examination of stomachs added only 5–10 minutes of additional work within the 150 minutes required to sample catches at each station. This offers a valuable starting point for a comparable analysis on European research vessels. The following alternative sampling schemes will be explored:

Taking samples on research vessels
- onboard cutting of fish stomachs and storage in formalin
- onboard cutting of fish stomachs and storage in freezer
- onboard opening of stomachs and immediate analysis
- using paper records
- using electronic recording
- analysing only fish and storing invertebrates
- taking additional samples for validation of onboard analysis

Taking samples on commercial vessels
- inventory of seasonal and spatial coverage of commercial fishing activities in respective eco-regions that can be used to sample stomachs of the various target species
- Analysis of the cost and the logistic problems associated with the extra sampling on commercial vessels, taking into consideration the above options.

Analysing stomachs
- all material analysed in fisheries laboratories with trained technicians
- all material analysed in subcontracted sorting centers
- all material analysed onboard

- a mixture of the above

Test cruises

It is hoped that any 'feasibility study' might include a number test cruises on chartered research vessels to test the performance of the potentially optimal schemes of sample analysis and to establish and harmonize methods, also the **placement of dedicated staff on existing monitoring cruises**. The test cruises will be located and scheduled in such a way, that they also generate relevant information on predator prey interactions, which are currently of concern in fisheries management.

The field-testing might comprise a visit to the NMFS in Woods Hole to explore the FWDP methods and especially the electronic data acquisition techniques under real conditions.

Exploring the best way of inclusion of stomach samples into the DCR

The main end product of the feasibility study should be optimised schemes for future stomach sampling and sample analysis in relation to specific fisheries- and ecosystem management and monitoring tasks, which will be presented to the involved national fisheries centres. After discussions and feedbacks a consensus version would be generated as a guideline to the EU.

4.8 The IBTSWG Chair's perspective - Existing surveys as a backbone for stomach sampling

Information on feeding behaviour is essential for performing valuable multispecies assessments studies. Instead of developing a complete new stomach sampling survey, it is most likely less complicated to collect stomachs during existing survey programs that are under the umbrella of ICES. Though not on a seasonal basis, all areas mentioned in this report are at least annually monitored by different type of surveys, ranging from acoustic to trawl surveys that are designed to provide data for stock assessments. Therefore, the feasibility of such surveys to serve as a backbone for a proper stomach sampling program should be explored. Within this section, the International Bottom Trawl Survey is being taken as an example, since it covers a large part of the ICES coastal areas, from Portugal to Norway, including the British and Irish Seas.

The core task of the International Bottom Trawl Surveys (IBTS) is to provide information to several assessment working groups on the distribution, relative abundance, and biology of commercial fish stocks. In addition, data on the abundance and length-frequency distributions of all other fish species, and some invertebrates are being collected. At each trawled station, a CTD-cast is carried out in order to monitor hydrographic features such as profiles of temperature, salinity (conductivity) and depth (pressure). From 2007 onwards, additional biological sampling for age and maturity of several non-target species was incorporated in the regular program according to Annex XVI of the DCR (Commission Regulation 1581/2004) (ICES, 2006).

It has been discussed whether the IBTS surveys can be used routinely as a platform for collection of data on other ecosystem components. At the IBTSWG meeting in 2006, the working group held a joint session together with representatives from the ICES REGNS Study Group to discuss additional sampling. In the report, an overview is given of all additional biological investigations that are already carried out by individual countries during the regular surveys (ICES, 2006, Table 12.1), ranging from nutrient and egg sampling up to bird watching. The issue of collecting stomach samples was not discussed.

At the IBTSWG meeting in 2006 it was concluded that since all surveys are programmed according to a tight financial and time schedule, none of the countries will be able to expand their standard program if sticking to the current techniques. For example, specific tows for plankton or benthos data are expensive additions in terms of time and effort. Also, the lack of

specific expertise may be a limiting factor, for example for monitoring seabirds. Some observations could be made at night (e.g. towed CTD, acoustic survey of seabed) but it should be highlighted that none of the additional sampling should cause any disruption to the core IBTS effort. All issues mentioned will also apply for incorporation of routine collection of stomach samples. It should however be emphasized that the IBTS-participants have voiced that they are willing to perform additional samplings.

The increasing demand from the scientific and management bodies to include ecosystems aspects into routine survey platforms is acknowledged. A great potential is seen in the establishment of modern, more efficient, methods and techniques for fulfilling the classical survey tasks. This includes the full adoption of a paper-less lab, by e.g. direct digital recording of all measured parameters of the routine sampling procedure by the use of, e.g. size measurement boards and digital balances which are directly connected to the ships data server. Such efficient procedures are already established on the other side of the Atlantic. On the broader scale, there are more ways to make the IBTS protocols more efficient, e.g. varying the effort put into the sampling of different ecosystem components between years. This could mean e.g. adopting a rolling program for the additional ecosystem sampling in the DCR where benthos, plankton and food web sampling is conducted every third year.

5 'Bottom up' effects of prey abundance on predators

This section covers Terms of Reference c) and d), both of which consider 'bottom up' effects of prey abundance on predators. Section 5.1–5.4 gives examples from the North Sea, Baltic, Barents Sea and Bay of Biscay respectively, while section 5.5 considers multispecies stock-recruitment models. It should be noted that such effects have been considered previously e.g. by SGGROMAT (ICES, 2003, 2004) and in the report of SGMSNS in 2006 but not in any great detail. These ToRs emerged as a consequence of concerns in the North Sea that both major 'forage fish' species (sandeel and Norway pout) appear to be at an all time low, and the worry that this might have "bottom up" consequences for predators such as seabirds, marine mammals, but also commercially important fish species such as cod and whiting (changes in 'condition' or weight-at-age).

5.1 North Sea

5.1.1 'Bottom up' effects of sandeel availability on seabirds

The structure and function of marine ecosystems may be regulated through 'bottom-up' effects, where the amount of primary production, often thought to be under climatic control, determines the abundance at higher trophic levels, or through 'top-down' effects of predators on lower trophic levels (Cury *et al.*, 2001). Recently, there has been strong interest in when and where each of these mechanisms is most important (Hunt *et al.,* 2002; Worm and Myers 2003; Duarte and García 2004; Munch *et al.,* 2005; Ware and Thomson 2005). The dominant type of regulation in a specific ecosystem clearly has major implications for resource management and for inferring causes of observed changes in ecosystem components (Cury and Shannon 2004).

Most species of seabirds in the North Sea suffered widespread reproductive failures in 2003, 2004, 2005 and 2006 (Mavor *et al.,* 2005, 2006, 2007). The most severe problems, including total failures of some species, occurred in Shetland and Orkney in the northernmost part of the North Sea, but in 2004 exceptionally low breeding success was also observed in colonies along the E coast of Britain (Harris *et al.,* 2004; Mavor *et al.,* 2005). Although bad weather during the chick-rearing period was partly to blame at some colonies, the main proximate cause of the breeding failures was a lack of high-quality food (Davis *et al.*, 2005; Wanless *et al.,* 2005). Most seabirds in the North Sea feed mainly on sandeels *Ammodytes marinus* during the breeding season (Wanless *et al.,* 1998; Furness and Tasker 2000; Furness 2002). Since the

1970s, sandeels have been the dominant mid-trophic pelagic fish in the North Sea, and around Shetland no other high-lipid prey fish occur in sufficient densities to support successful breeding of most piscivorous seabirds (Furness and Tasker, 2000). There is thus little doubt that the observed seabird breeding failures were linked to low availability of sandeel prey. Further evidence for the bad state of North Sea sandeel stocks comes from the large-scale industrial fishery: during the 1990s annual landings were 600,000–1,100,000 t, but in 2003 and 2004 they fell to around 300,000 t (ICES, 2004b), and the fishery was closed completely by the European Commission from 15 July 2005 (Anon, 2005).

Recruitment to sandeel stocks in the southern North Sea has been shown to be negatively affected by high winter sea temperature (Arnott and Ruxton, 2002). Recruitment was extremely low in 2002 and in most subsequent years. It thus seems obvious to link the problems associated with sandeel stocks, and the problems breeding seabirds have experienced since 2003 to global climate change, and such a connection has indeed been made, and widely publicized (Royal Commission on Environmental Pollution 2004; RSPB 2004; BBC 2005). However, there is as yet no published evidence to show that high sea temperatures caused the observed sandeel recruitment failures since 2002, and the exact mechanism through which climate affects sandeel recruitment remains unclear. While climate-driven 'bottom-up' control of sandeel abundance is a plausible scenario, other explanations are possible and should be considered. Specifically, a 'new' source of possible top-down control has reappeared in the North Sea since 2000. Herring *Clupea harengus* stocks have increased from less than 100,000 t in the late 1970s to 2 million t in 2004, a level not seen since they were reduced dramatically by overfishing in the 1960s (ICES, 2004b). Little effort has so far been put into evaluating the possible top-down impact of predatory fish that consume sandeel larvae, but see Frederiksen *et al.* (2007).

In recent decades, sandeels have been the only common high-lipid schooling fish around Shetland, and unsurprisingly the breeding success of most species of seabirds is closely related to sandeel abundance in that region (Hamer *et al.,* 1993; Davis *et al.,* 2005). This dependence is clearly illustrated by data on breeding success of Arctic skuas *Stercorarius parasiticus* and black-legged kittiwakes *Rissa tridactyla* on the island of Foula, which show a close correlation with each other across the years (Figure 5.1), and strong correlation with Shetland sandeel total stock biomass (Figures 5.2 and 5.3). The total stock biomass of sandeels around Shetland declined at the same time as the spawning stock biomass (SSB) of herring in the North Sea increased, and both showed remarkable deviations from the long-term trends during the 1990s (Figure 5.4). Such a mirror-image pattern may indicate a top-down effect of herring predation on sandeel biomass, and it has long been known that sandeel larvae form an important part of herring diet in spring (Hardy 1924; Last 1989). Herring predation has previously been shown to affect stocks of another small pelagic, the capelin *Mallotus villosus* in the Barents Sea (Gjøsæter and Bogstad 1998). However, other factors are also known to influence the abundance of Shetland sandeels. The extremely low sandeel biomass in 1987–1990, and by implication the seabird breeding failures observed during those years (Hamer *et al.,* 1993), was thought possibly to be caused by few sandeel larvae drifting in from spawning grounds around Orkney due to failure of the Fair Isle current, rather than due to effects of sandeel fishing at Shetland (Proctor *et al*., 1998).

Further south in the North Sea, off SE Scotland and NE England, sandeels are also the main prey of most seabird species (Wanless *et al.,* 1998). In contrast to Shetland, other fish prey are also available, and in particular young clupeids (mainly sprat *Sprattus sprattus*) are taken in some years by seabirds (Bull *et al.,* 2004; Harris *et al.,* 2004; Wilson *et al*., 2004). There are no long-term data on sandeel abundance in this area, but during the 1990s local sandeel biomass was reduced by an industrial fishery, and this was associated with low breeding success of black-legged kittiwakes on the Isle of May in the Firth of Forth (Rindorf *et al*., 2000). Frederiksen *et al*. (2005a) used Continuous Plankton Recorder data to develop an index

of sandeel larval abundance, and this index was positively correlated with breeding success of four seabird species in the following year. The sandeel larval index was also strongly positively related to the abundance of phyto- and zooplankton, suggesting strong bottom-up control (Frederiksen *et al.,* 2005a). In 2004, breeding success was exceptionally low for most seabird species on the Isle of May, despite sandeel larvae being abundant in the spring of 2003. Detailed studies showed that the energy content of both sandeels and sprat fed to seabird chicks in 2004 was extremely low, indicating poor food availability for the fish (Wanless *et al.,* 2005). Data from chick-feeding puffins and CPR samples also indicate that the size-at-date of both larval, 0 group and older sandeels has declined substantially since 1973, although it is unclear the exact cause of this decline might be (Wanless *et al.,* 2004).There is thus evidence that both abundance and quality of seabird prey is under bottom-up control in this region, and this is likely to have affected seabird breeding success.

It is noteworthy that the recent decline in sandeel abundance in the North Sea shows a very strong regional patterning, with the greatest decrease in sandeel abundance at Shetland and off southern Norway, but with much smaller decreases towards the southern North Sea. This change is clearly evident in fishing activity too – catches of sandeels have been drastically reduced on the Norwegian grounds in the northern North Sea, but much less reduced on the Dogger Bank for example. Ecosystem control of the North Sea food web is likely to be complex and this is illustrated in Frederiksen *et al.* (2007) where the authors suggest relationships that may drive sandeel abundances in different parts of the North Sea. While there is some evidence of a top-down effect of herring on sandeels, herring abundance may itself be influenced by several factors, including top-down, bottom-up and direct climatic effects.

Seabirds are long-lived animals with a low reproductive output. Life history theory predicts that seabirds should buffer their adult survival rates against fluctuations in their food supply (Boyd *et al.,* 2006), and since food-fish are short-lived animals with high but also variable recruitment rates (Jennings *et al.,* 2001, Browman and Stergiou 2004), it is inevitable that seabirds will experience large changes in the abundance of the food fish on which they depend. They must, therefore, have evolved the ability to cope with variation in food abundance. The literature indicates that, seabird breeding success does show a close correlation with food fish abundance (Furness and Tasker 2000, Rindorf *et al.,* 2000, Davis *et al.,* 2005, Frederiksen *et al.,* 2005), whereas breeding numbers and adult survival may not track these short-term fluctuations (Boyd *et al.,* 2006). Nevertheless, several recent studies do show a trade-off between adult survival rate and reproductive performance, as a result of adults increasing investment when food supply declines and so incurring costs (e.g. Davis *et al.,* 2005). But variation in breeding success is much greater, and easier to measure, and so is likely to provide a much clearer signal of food shortage (Furness 2002, Mitchell *et al.,* 2004, Mavor *et al.,* 2006).

Furness and Tasker (2000) reviewed the ecological characteristics of seabirds in the North Sea and ranked species from highly sensitive (e.g. terns, kittiwake *Rissa tridactyla*, Arctic skua *Stercorarius parasiticus*) to insensitive (e.g. northern gannet *Morus bassanus*) to reductions in sandeel abundance. They argued that the most sensitive seabirds would be those with high foraging costs, little ability to dive below the sea surface, little 'spare' time in their daily activity budget, short foraging range from the breeding site, and little ability to switch diet. This prediction was supported by empirical data from studies at Shetland (Furness and Tasker, 2000).

Arctic skuas in Shetland feed almost exclusively on sandeels, although they obtain these by stealing them from terns, kittiwakes and auks, and so the link between their breeding success and sandeel stock size is indirect (Furness 1987, Pennington *et al.,* 2004, Davis *et al.,* 2005). We can estimate the amount of sandeels consumed by Arctic skuas from data on the numbers and energy requirements of these birds. The annual consumption of sandeels by Arctic skuas

at Shetland in the period 1980–2000 is estimated to have been around 65 tonnes per year. This contrasts strongly with the observation from Figure 5.3 that Arctic skua breeding success at Shetland fell to less than half of the level seen in years of high sandeel abundance when the sandeel stock biomass was below about 30,000 tonnes. The data indicate that Arctic skuas require a sandeel stock biomass about 460 times greater than the amount that they consume, in order to be able to gain energy at a rate sufficient to sustain a good level of breeding success.
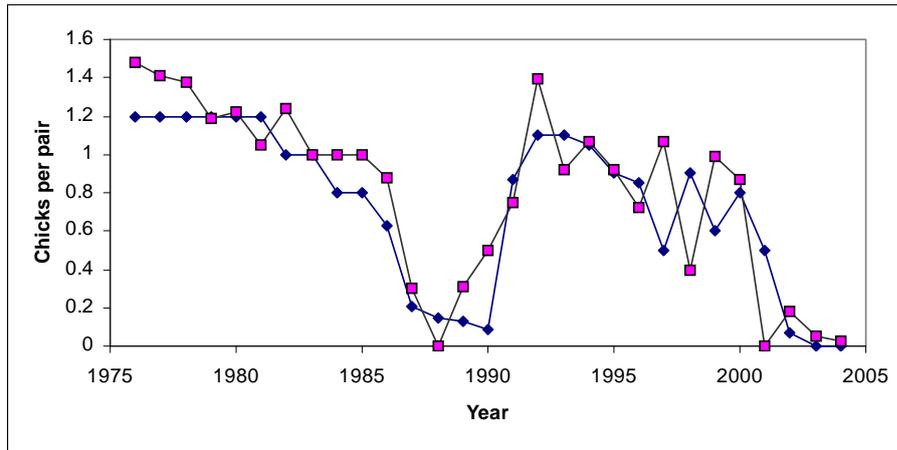
Figure 5.1. Breeding success of black-legged kittiwakes (pink) and Arctic skuas (blue) at Foula, Shetland, during 1976–2004, showing a close correlation between the success of the two species in this time series, and periods of particularly low success in 1987–1990 and in 2001–2004.
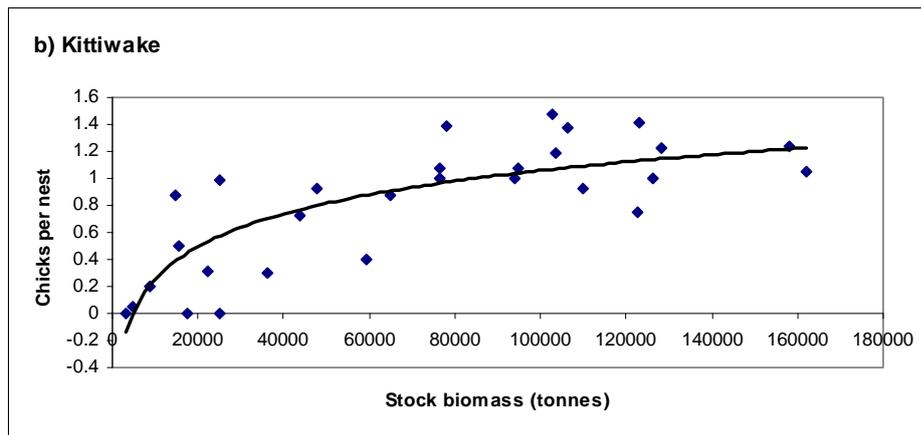

Figure 5.2. Breeding success of Kittiwakes at Foula in relation to the estimated total stock biomass of Shetland sandeels (see Furness 2006, 2007).

$$y = 0.2119Ln(x) - 1.5151$$
$$R^2 = 0.418$$
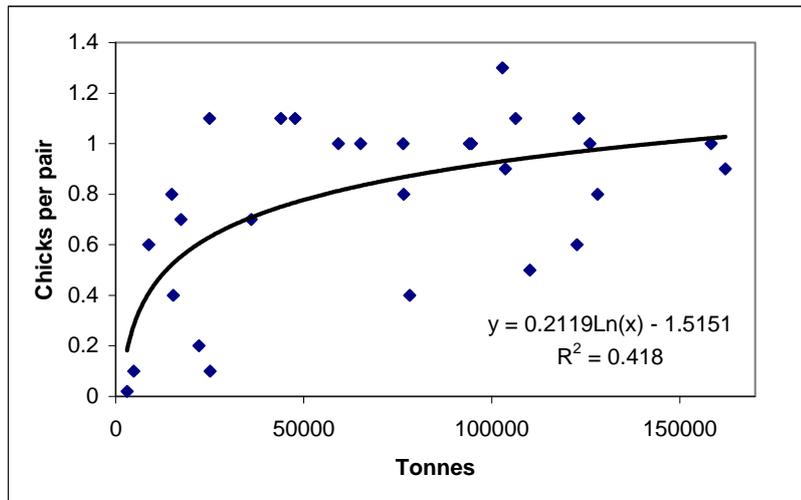
Figure 5.3. Breeding success of great skuas Stercorarius skua at Foula, Shetland, from 1976–2004 in relation to the estimated biomass of sandeels in the Shetland area.
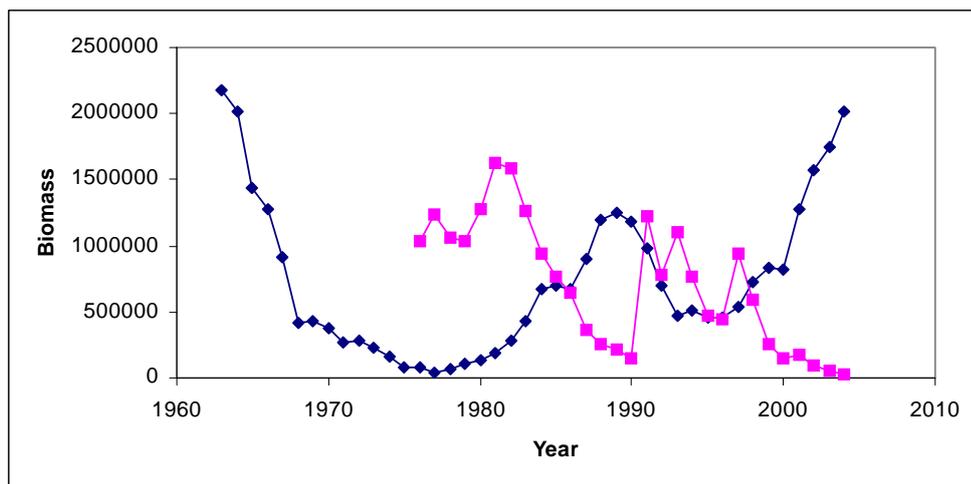
Figure 5.4. Plot of Shetland sandeel TSB (blue) in relation to North Sea herring SSB (pink) in the same year. See Frederiksen *et al*. (2007) for further details.

In the case of seabirds that feed extensively by scavenging at fishing vessels (especially great skuas, fulmars *Fulmarus glacialis*, great black-backed gulls *Larus marinus*) part of the impact on their breeding success may be due to reduced amounts of fishery discards and offal in recent years (Votier *et al*., 2004, 2007, Käkelä *et al*., 2005, 2007, Furness *et al*., 2006, 2007). Although these seabirds appear to feed by preference on sandeels when those are available, they turn to fishery offal and discards as an alternative food, and in the last few years there have been large reductions in amounts of discards and offal provided to seabirds in the northwest North Sea at a time when sandeels have also been depleted. Great skuas have attempted to mitigate this situation by increasingly killing other seabirds, but have also suffered breeding failures due to food shortage, part of which results from the fact that great skuas will kill chicks of neighbouring skua pairs. The depredations on other seabirds will also reduce their breeding success, as the chances of chicks surviving if a parent has been killed during the breeding season will be much reduced.

Since 2003 there has been a much-reported influx of snake pipefish (*Entelurus aequoreus*) into the waters of Europe, with several authors now publishing on this phenomenon in the

scientific literature (e.g. Harris *et al.,* 2007; Kloppmann and Ulleweit 2007; Lindley *et al*., 2006; van Damme and Couperus, 2006). It has been suggested that this influx might pose a threat to certain marine predators, notably seabirds (Harris *et al.,* 2007), but they have also been reported as occurring in the stomach contents of important commercial fish species (Stafford *et al*., 2007), possibly associated with a lack of 'usual' prey types such as sandeels. These fish may represent a food of "last resort" since they are a poor quality resource; low in lipid, bony and difficult to digest. The fact that seabirds did not feed snake pipefish to chicks in large numbers prior to 2002 may reflect the fact that abundances of preferred fish prey, such as sandeels, were much higher than they have been in the last few years or that snake pipefish have increased in availability. It is unclear why snake pipefish numbers have apparently increased, Kirby *et al*. (2006) speculate that the increased abundance of larval and juvenile *E. aequoreus* in CPR plankton samples as far west as the Mid-Atlantic Ridge may coincide with a rise in winter, spring and summer sea temperatures (January–September), when the eggs, which are brooded by the male, are developing and the larvae are growing in the plankton. van Damme and Couperus (2006) put forward the alternative hypothesis that the sudden appearance of this species is a result of changes in zooplankton availability which in turn has been caused by changes in the hydroclimatic environment.

5.1.2 'Bottom up' effects of sandeels on marine mammals and predatory fish

The magnitude of the sandeel fishery and the importance of sandeels to marine predators (predatory fish and marine mammals) have led to considerable concern over the potential impact of sandeel harvesting on the North Sea ecosystem (Monaghan, 1992). UK trawlermen have accused the Danish sandeel fishery of driving them out of business by depriving predatory species such as cod of their natural diet (Anon, 2003).

Indeed, in 1998 when the sandeel fishery was at its peak, an estimated 42% (>1million tonnes) of sandeel removals were taken by the fishery, compared to 58% by natural predators. In 2003, when the fishery was tightly regulated, 12% (310,000 tonnes) of sandeel 'removals' were taken by the industrial fishery and 88% by natural predators.MacLeod *et al*. (2007a) examined the diet of harbour porpoises (*Phocoena phocoena*) in the North Sea between 1993 and 2001. The authors focussed their attention on the diet of stranded individuals in spring (March–May), a critical time of year for survival when sandeels are usually an important prey. Stomach contents were examined from 1993 to 2001 when sandeels were abundant in the North Sea, and compared with data from spring 2002 and 2003 when sandeel stocks were at very low levels. The diet of porpoises in these two periods was found to be substantially different, with a significantly smaller proportion of sandeels being consumed in recent years, compared to the past. There were also differences in the number of porpoises reported as starving between the two time periods (33% in spring 2002 and 2003 died of starvation, but only 5% in the baseline period). This suggested to the authors that a lower proportion of sandeels in the diet of porpoises in spring increases the likelihood of starvation.

In the Shetland Islands (north Scotland), declines in porpoise numbers were observed between 1982 and 1990, followed by an increase, at least in the southern part of Shetland between 1990 and 1995 (Evans *et al*., 1997). Changes in harbour porpoise abundance were related to annual variation in sandeel populations. Sandeel spawning stock biomass declined markedly from 1984–1992, when coastal summer porpoise populations also apparently declined. During 1993 and 1994, sandeel spawning stock biomass was relatively high and harbour porpoise abundance was also higher (Evans *et al*., 1997).

Thompson *et al*. (2007) refuted the main findings of MacLeod *et al*. (2007a) and argued that small sample sizes and uncertainty over biases in these data could cast doubt on the study's evidence. The central claim that the percentage of porpoises that starved increased from 5 to 33% was based on only 11 starved individuals. Furthermore, the central tenet of MacLeod *et al*.'s (2007a) paper is that North Sea sandeel abundance has declined. While true for the North

Sea as a whole, since 2000 stock monitoring cruises along the east coast of Scotland (MacLeod *et al*.'s study area), showed a large increase in sandeel biomass.

Thompson *et al*. (2007) go on to suggest that assessments of relationships between diet and starvation require more detailed analyses, ideally based on full datasets from other North Sea coasts (Jepson 2006). In a reply to this criticism, MacLeod *et al*. (2007b) stood by their core finding that there appears to be a link between sandeel consumption and the likelihood of starvation for porpoises in the Scottish North Sea in spring. They agree that there has been an increase in sandeel biomass in the Firth of Forth since the closure of the industrial fishery in 2000 (Greenstreet *et al*., 2006), although other sandeel aggregations remain depleted particularly in the northern North Sea (Anon, 2006). It has also been suggested that there is a link between climatic conditions and the size and energy content of sandeels in the Scottish North Sea (Wanless *et al*., 2004), and this could contribute to an increased likelihood of starvation even if the overall biomass has increased.

In 2006 SGMSNS reasoned that whiting, which is the most piscivorous of the species for which diet data are available, will probably be little affected by a decline in Norway pout since recent survey results reveal that whiting distribution has largely contracted into Roundfish Area 4 along the north English coast (i.e. away from Norway pout). Whiting might be affected to some extent by a decline in sandeel availability, however they might also switch prey to consume greater quantities of herring and sprat, since populations of these species have increased in recent years, as has the apparent spatial overlap between whiting and sprat distributions. Two sources of recent data are available to test this hypothesis, research carried out in the Firth of Forth region as part of the EU FP6 IMPRESS project (1997–2003), and research carried out on western Dogger Bank by UK scientists ('MF0323' project; 2004–2006).

Three gadoid populations (cod haddock, whiting) were sampled at 19 evenly spaced stations in the Firth of Forth (including Wee Bankie and Marr Bank) on 7 research cruises. The contribution of sandeels to the diet of the three gadoid predators varied markedly from year to year, although the importance of sandeels in particular years was consistent accross all three species (Figure 5.5). No evidence of any beneficial effect of the sandeel fishery closure in 2000 on the abundance or biomass of any of the three gadoid predators was apparent, however, there was some suggestion that fish condition was greater in years when the proportion of sandeel prey in the diet of each predator was higher (Figure 5.6). Fish condition varied significantly from year to year and this variation was consistent between species. Fish condition was not strongly related to gadoid food intake rates, although for all three gadoid predators, fish condition was positively correlated with water temperature near the seabed.
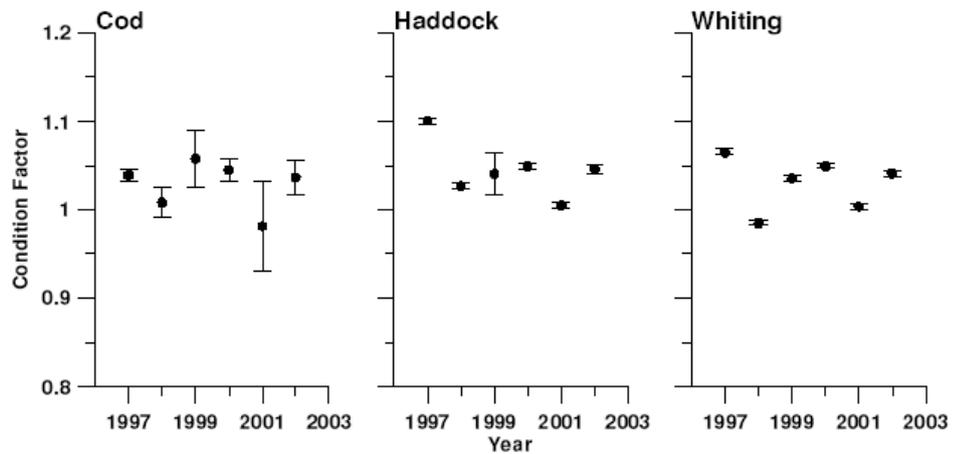
Figure 5.5. Inter-annual variability in the condition of gadoid predators in the Firth of Forth (from Greenstreet *et al*., 2006).
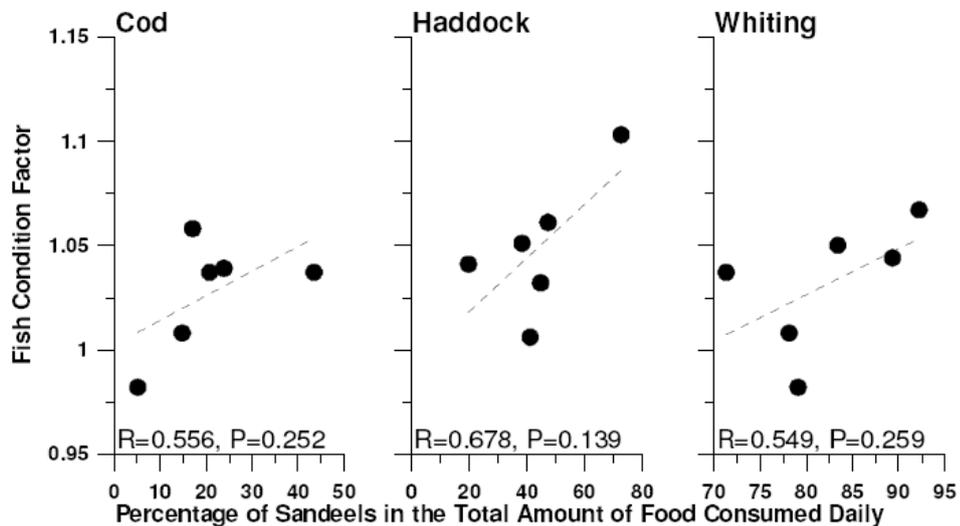
Figure 5.6. Relationship between the body condition of gadoid predators in the Firth of Forth, and the quantity of sandeels consumed (from Greenstreet *et al*., 2006).

Between 2004 and 2006 CEFAS conducted investigations into sandeels and their predators on the Dogger Bank, in the central North Sea ('MF0323' project). Two survey grids were sampled each containing 48 stations, the grids were separated by 28 km. The northernmost survey grid ('grid 1'), on an area known as the 'North-West Riff', was characterised as having high sandeel abundance and was an important area for the Danish sandeel fishing fleet. The southernmost grid ('grid 2') on an area known as 'The Hills' was characterised by much lower sandeel abundance, and was less important to the industrial sandeel fishery. Predator stomachs (mostly whiting, plaice, lesser weeverfish, grey gurnard, haddock, and mackerel) were sampled on 6 research cruises. The diets of all species were found to vary markedly and consistently between the two sampling grids (Pinnegar *et al.,* 2006). Sandeels were much more important to predators (especially for whiting and lesser weeverfish) at grid 1, as compared to at grid 2, and this coincides with the greater abundance of sandeels at the northern grid (Grid 1), as determined by dredge survey during the night when sandeels bury themselves in the sediment. At grid 2, the apparent 'shortfall' in the availability of sandeels

seems to be made up by sprat in whiting, and pelagic crustaceans (hyperiid amphipods) plus shrimps in weeverfish.

Clear seasonal differences were observed in predator diets for all species. Diets were much more diverse during autumn as compared to those in spring. Whiting ate substantially more crabs and sprat during the autumn period as well as hyperid amphipods ('EMA') and much less sandeel at both sampling grids. Sandeels bury themselves in the sediment during autumn/winter months and are thus less accessible to predators, even though they were more abundant in real terms than was the case during the spring.

Preliminary analyses (G. Engelhard, unpublished data) suggests that for some predators, most notably lesser weeverfish *Echiichthys vipera*, body 'condition' was slightly better at the high-sandeel site (grid 1) compared to the low-sandeel site (grid 2) (Figure 5.7). An examination of interannual variability in fish body condition (Figure 5.8) revealed that plaice and weever condition was better in sandeel-rich years and at the sandeel-rich survey grid. Whiting and haddock condition was better in sandeel-rich years, but no site difference was apparent in these mobile species which forage over a large area. Grey gurnard and greater sandeel (*Hyperoplus lanceolatus*) condition appeared not to be significantly linked to sandeel numbers, but positively linked to per-capita sandeel consumption (condition was better when more sandeels were observed to have been consumed).
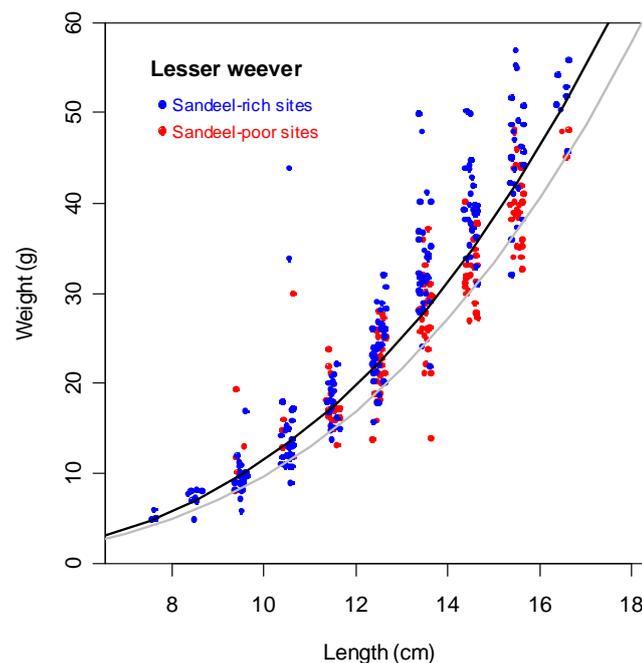
Figure 5.7. Le Cren's condition index. Plot of L with W for Lesser weever in 2 areas, grey line indicating the North Sea-wide relationship (G. Engelhard, unpublished data).

Thus it was concluded that various predatory fish species do have better condition in years/sites where sandeels are more abundant. It would appear that sandeels are a crucial prey for predatory fishes, including some species which support important demersal fisheries for human consumption. In a parallel study carried out in August and October 2006, whiting were sampled aboard commercial fishing vessels all along the North East coast of England (from Flamborough to the Firth of Forth, including the Dogger Bank). It was noted by the crew that the fish caught over areas of hard ground with empty stomachs during the August survey were very thin and of poor condition (Stafford *et al.*, 2006). Where stomachs were not empty, the main contents were small crustaceans in August and fish in October. Fish consumed were

often non-commercial prey species such as pipefish or hagfish, although gadoids and clupeoids were also consumed. The data show changes from the 1981 and 1991 ICES 'year of the stomach' sampling exercises, when far more sandeel and clupeoids and far less crustaceans were consumed. The authors of this study (Stafford *et al.*, 2006) speculate that the limited availability of sandeels in 2006 may have been responsible for the poor body condition of the fish in that year and the selection of nutritionally poor prey items such as snake pipefish.

In 2006 SGMSNS suggested that cod is a more flexible feeder in comparison with whiting, consuming large quantities of benthic invertebrates as well as fish. Given a shortage of sandeel and Norway pout, cod might switch diet towards non-target fish, as well as sprat, other gadoids, crabs, shrimps and invertebrates. The availability of some benthic invertebrate groups is thought to have increased substantially in recent decades (Heath, 2005). Equally, haddock might be impacted by a decline in Norway pout and sandeel but this species consumes even larger quantities of 'other food', the majority of the diet consisting of invertebrates with very few fish prey. Norway pout is a major prey of saithe in the North Sea and hence this species may be affected by a reduction in prey abundance although the availability of diet information for this species is much more limited compared to that of other gadoid species. The distribution of saithe extends beyond the boundaries of the North Sea (and hence beyond the available stomach database) in addition, juvenile saithe tend to aggregate in fjords and hence they have been very poorly sampled in the past.
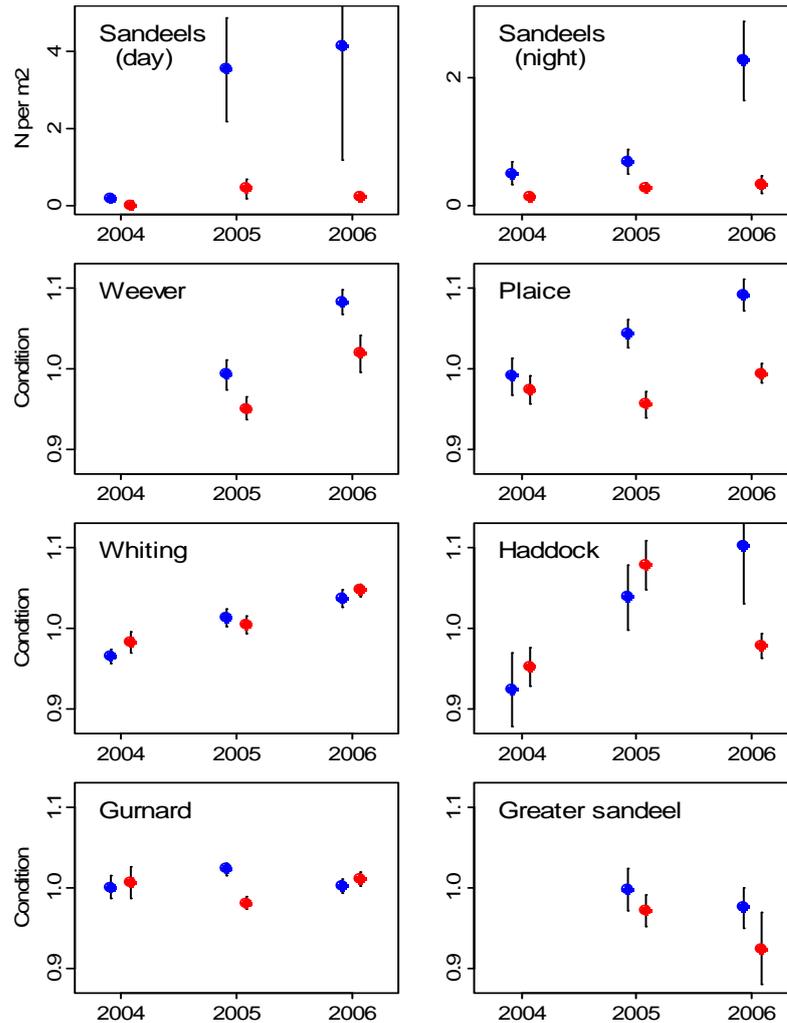
Figure 5.8. Sandeel abundance during spring surveys in 2004, 2005 and 2006 in the day (top left), and night (top right). Condition factor in lesser weever, plaice, whiting, haddock, grey gurnard and greater sandeel; survey grid 1 (blue), grid 2 (red).

5.1.3 Predicting 'bottom up' effects in multispecies models

MSVPA/MSFOR allows predator abundance to modify prey abundance 'top down' through predation mortality. Food intake and growth are assumed to be constant and changes in biomass of prey will therefore not affect the growth or weight-at-age of their predators through 'bottom up' processes. This is also true of the successor to MSVPA known as SMS (Lewey and Vinter, 2004) but not Gadget, which can (but rarely does) include prey-dependent growth (Begley and Howell, 2004).

It should be recognised however, that such models are able to capture the consequences of a shortage of 'forage fish' prey resource indirectly in the sense that this will result in a shift in the diet to other prey resources, with consequences for their populations. Therefore, in such models, a lack of forage-fishes might result in a notable impact on predator populations (such as cod or whiting) when a shift in the diet results in more juveniles of the particular predator are consumed, either through cannibalism or by other (larger) predators. This is not a 'bottom up' effect in the traditional sense but is worth considering nonetheless.

In 1992 the EC convened a special group to assess the effects of industrial fishing in the North Sea, and specifically, to 'predict' the effects a 40% reduction in industrial fisheries might have on predatory species which are dependent on sandeels and Norway pout as a food, or accidentally in the fishery (reported in Gislason and Kirkegaard, 1998). Using MSVPA it was

found that a 40 % decrease in industrial fisheries, would lead to small increases in SSB and landings of cod, haddock and whiting. The results were however, complex, on the one hand reducing the industrial fisheries resulted in increases in Norway pout, which resulted in saithe preying more on Norway pout than on cod and other demersal species. On the other hand reducing the industrial fishery led to high whiting stocks (because of less bycatch), which predated on other demersal species including juvenile cod.

Similar analyses have been carried out more recently, using the SMS model as part of the EU FP6 project BECAUSE (EU BECAUSE final report Contract n° SSP8-CT-2003-502482). The authors of this study simulated how the future stock development of cod, whiting and haddock could be affected if the 3 forage fish stocks (herring, sandeel and Norway pout) were exposed to higher levels of fishing pressure. Fishing mortality was doubled relative to the $F_{status\ quo}$ in 2006 to greatly reduce the stock numbers of the forage fish. Due to problems in the assessment of North Sea sprat (ICES, 2004, 2006b) and fitting problems for this stock inside SMS, it was decided to leave this prey species out. Sprat was treated as 'other food'.

The average F values in the baseline scenario were taken from the respective assessment reports for the year 2006 (ICES, 2007 a,b) and set constant for the forecast time period (from 2006 to 2015). The increase in fishing mortality on herring, sandeel and Norway pout had a clear negative impact on stocks of these species. When fished at double the current fishing mortality rate, the sandeel spawning stock biomass was reduced to around 500,00t compared to an increase up to 1 million t in the baseline scenario. Similarly, Norway pout was predicted to go extinct when fished at double the fishing mortality, but maintained at an SSB of around 180,000t under the baseline scenario. Herring SSB was predicated to increase to ~800,000t under the baseline scenario, but to decrease to 250,000t when fishing mortality was doubled

The decrease in forage fish stocks altered the future stock development of the three gadoid species (cod, whiting and haddock). The fewer forage fish remaining in the system, the worse the situation became for the gadoid stocks due to higher displaced predation mortalities. The largest impact was observed for haddock. In the baseline scenario haddock was predicted to stay above B_{pa} with a 60% probability in 2015. In the scenario where the forage fish stocks suffered from a doubling of fishing mortality, this probability was below 40%. Cod and whiting stocks were similarly affected. In the scenario with double the fishing mortality on forage fish, cod SSB remained constant at around 50 thousand tonnes and the whiting stock decreased to below 100 thousand tonnes, as compared to a marked increase in SSB (to ~70,000t and ~180,000t respectively) under the baseline scenario. As none of the 8 seabird species (fulmar, guillemot, herring gull, kittiwake, great-black-backed gull, gannet, puffin, razorbill) included in the SMS model were consumed as prey (they were all 'external predators') the reduction in forage-fish availability was not able to influence their population numbers.

5.2 Baltic Sea

The Baltic International Trawl Surveys Working Group (WGBIFS) regularly collates information on weight-at-age in the Baltic cod stock, based on 1st quarter and 4th quarter bottom trawl surveys. Weight-at-age in eastern Baltic cod increased with decreasing stock size throughout the 1980s, and decreased throughout the 1990s (Figure 5.9) (WGMAB 2006).
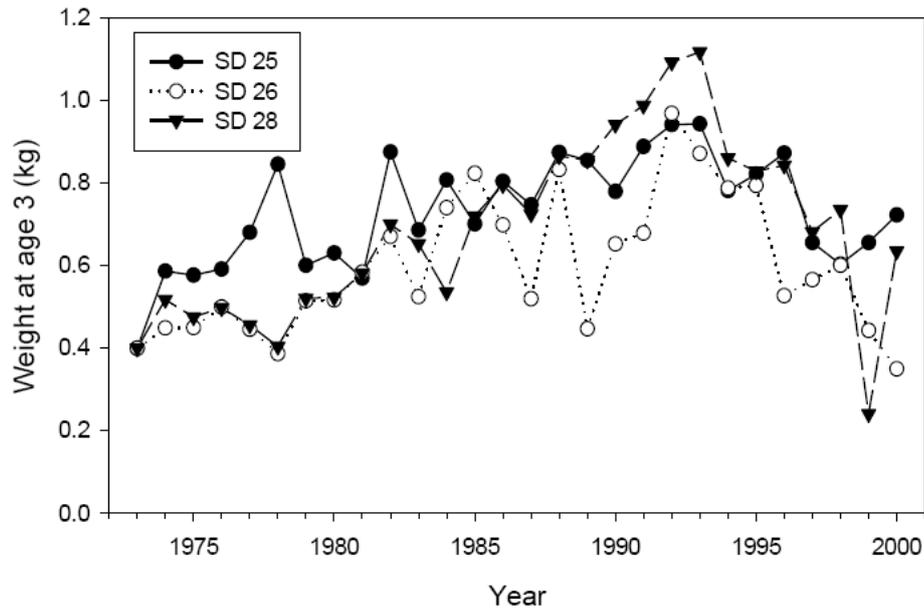
Figure 5.9. Average weight at age 3 of cod (1.quarter) in different Subdivisions of the Baltic, as obtained from sampling the commercial fishery.

The decline in weight at age during most recent years may be explained by a successive shift in main spawning activity from spring to summer months (Wieland *et al.*, 2000), reducing the length of the first growth season and thereby size at first over-wintering. This has lead to the hypothesis that these late spawned juveniles are unable to catch up in size compared to earlier born cohort affecting the entire individual growth history (Larsson and Eriksson, 1996). Associated with this, weight-at-age might also be linked to the availability of particular prey resources, as suggested in earlier studies (Baranova and Uzars 1986, Baranova, 1992).

Weight at age 3 was modelled in relation to clupeid (herring and sprat) availability as part of the BECAUSE project (and reported in WGMAB 2006). Weight at age 3 was modelled using individual weight in the catch data but also MSPVA-abundances of age 3 cod and the aggregated clupeid abundances.

A simple model was fitted to the cod weight at age 3 data:

$$w(3) = \frac{w(3,\max)}{1+\exp(\gamma(CLU-CLU_{0.5})}$$

In this model, w(3,max) is the asymptotic weight at age 3, w(3) where a further increase of CLU (the number of clupeids per cod) will not lead to an increase in cod age 3 weight. $CLU_{0.5}$ is the half-saturation constant, and γ encompasses all processes involved in the conversion from prey availability per cod to weight.

For the 'early spawning' scenario, the weights in the period when the cod had spawned late were scaled up according to the average weight during the period when cod had been spawned early. Vice versa, for the 'late spawning' scenario, the weight in the periods when the cod had spawned early were scaled down to the average weight during the period when the cod had been spawned late.

The model explained 82% of the variability of w(3) for both scenarios (Figure 5.10) and was highly significant (P<0.001). The residuals for both scenario models were normally distributed (Shapiro-Wilk test, P>>0.05).
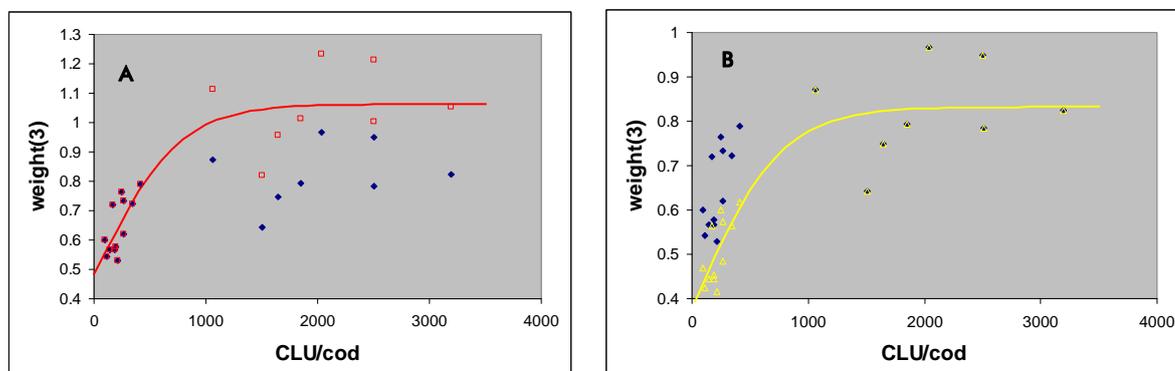
Figure 5.10. Weight at age 3 (weight(3)) versus clupeids available per cod (CLU/cod) for the early spawned scenario (A) and the late spawned scenario (B). The solid points represent the raw weight in the catch data. In A the late spawned cod weight has been scaled up, and in B the early spawned cod weight has been scaled down.

For both scenarios, γ was estimated to be -0.002819 ± 0.001264 (s.e.) and $CLU_{0.5}$ was estimated to be 65.03931 ± 72.3974 (s.e.). The maximum weight at age 3 for the 'early spawning' scenario was estimated at 1.063 ± 0.043 kg, and for the 'late spawning' scenario to 0.833 ± 0.034 kg. Thus the conclusion of this work is that using the number of clupeids per cod as a measure for prey availability, weight at age 3 in the first quarter of the year can be predicted based on the above mentioned relations (WGMAB, 2006).

Gislason (1999) used single and multi-species models to estimate and compare a few of the commonly used reference points for cod, herring, and sprat in the central Baltic. The models consisted of a single-species VPA, a multi-species VPA (MSVPA), and an extended multi-species VPA (MSGVPA) in which cod growth and maturity were modelled as a function of available food.

In the MSGVPA model, cod growth was dependent on the amount of available food. Weight-at-age was assumed to equal weight-at-age in the cohort during the preceding year plus a growth term. The growth term was dependent on whether the amount of available food in a particular year was above or below the average. Growth was faster than average in years where there was more than average food available. In years with less food available growth was assumed to be slower.

In the two multispecies models, F_{MSY} was dependent 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} was higher in MSGVPA than in MSVPA. In MSGVPA, a higher fishing mortality and lower stock size will be counteracted by increases in cod growth

When total catch value was considered, the single-species model predicted that cod effort should be reduced by 30% and that pelagic effort should be increased by 26%, while both multispecies models suggest that effort should be increased. In MSGVPA the maximum was found at a combination of cod and pelagic fishing efforts corresponding to a 86% increase of the fishery for cod and an 82% increase in the fishery for herring and sprat. This suggests that F_{MSY} could be a dangerous reference point to use in a multispecies context, particularly when prey-dependent growth is taken into account.

5.3 Barents Sea

5.3.1 Previous studies on effects of capelin

In 1991 and 1992, following a special meeting (in Bergen) to consider multispecies work in 'boreal' systems, the ICES Multispecies Assessment Working Group (MAWG) engaged in a series of comparative studies (using GLMs), contrasting 6 "cod-rich ecosystems" namely –the Baltic Sea, North Sea, Barents Sea, Iceland, Newfoundland-Labrador Shelf, and Georges Bank / Gulf of Maine. The group considered whether cod growth and weight-at-age is influenced by changes in prey availability and concluded that "boreal systems are functionally different from highly-networked feeding webs such as the North Sea". The working group found that cod growth in 'boreal' systems (e.g. Barents Sea and Iceland) was influenced by the availability of capelin, since there is little potential for cod to compensate for low capelin abundance with any other alternate prey type. In more diverse systems such as the North Sea and Baltic, where there are many alternative prey types, the working group found less variability in cod growth and weight-at-age and hence little evidence that these are influenced by the availability of any particular prey type (ICES, 1992, 1991).

As shown below, newer data for the Barents Sea show that cod in some periods have the potential to compensate for low capelin abundance by preying on other food. Also, in Iceland, a regression between capelin abundance and cod growth, which from 1991–2003 was used in short-term predictions, is no longer used (ICES NWWG 2007). Thus, the effect of capelin on cod growth may not be as clear-cut as previously assumed.

5.3.2 Capelin effects on predator (cod, harp seal) population dynamics in the Barents Sea

Capelin is a key forage fish in the Barents Sea. This stock has shown large fluctuations (Figure 5.11), ranging from 0.1 to 7 million t. It has collapsed (i.e. fallen below 1 million t.) three times during the last 25 years. These collapses are thought to be closely connected to the occurrence of strong year classes of young herring in the Barents Sea (Gjøsæter and Bogstad 1998).

The fluctuations of the Barents Sea capelin stock have had strong effects on the population dynamics of its main predators, such as cod and harp seal. For cod, effects were observed on growth, maturation, fecundity and cannibalism, while for harp seal, effects on condition, reproduction, mortality and migration were seen. The overall picture is that the first capelin collapse in the late 1980s affected the predators to a much larger extent than the second and third collapse (Gjøsæter *et al*., 2007). One important reason for this is probably that more alternative fish prey was available to the predators during the second and third capelin collapses.

The fluctuations in growth, maturation, fecundity and cannibalism in cod are shown together with the fluctuations in the capelin stock size in Figures 5.12–5.15 (data from ICES 2007 for growth, maturation, cannibalism, Figure 5.14 from Marshall *et al*., 2004 (Figure 8 in that paper). The variations in cod growth during the first collapse were discussed by Mehl and Sunnanå (1991), and the fluctuations in cod cannibalism and how they relate to variations in capelin abundance have been analysed by Yaragina *et al*. (2007). Capelin stock biomass is significantly positively correlated with both liver condition index (liver weight expressed as a % of total weight) and liver weight (expressed in g) (Marshall *et al*., 2004). In gadoids liver weight is indicative of the magnitude of stored energy available for reproduction (Yaragina and Marshall 2000). Interannual variation in fecundity has been attributed to variation in liver condition (Marteinsdottir and Begg 2002). Thus, variability in capelin which results in variation in condition (sensu energy reserves) will affect individual fecundity (Thorsen *et al*., 2006) and stock reproductive potential (Marshall *et al*., 1999, 2006).

The effects on the Barents Sea stock of harp seals of the first capelin collapse were studied by Haug and Nilssen (1995). During the first capelin collapse, large numbers of harp seals invaded the Norwegian coast, particularly the coast of North Norway, where they were incidentally caught in gillnets (Figure 5.16). The poor food availability in these years (1986–1988) resulted in poor growth, recruitment and high natural mortality of pups (Nilssen 1995). More recent studies indicate that the Barents Sea stock of harp seals have reached or is close to the carrying capacity; age at maturity has increased from 5–6 years in the 1960s to c. 8 years in the 1990s (e.g. Frie *et al.*, 2003).
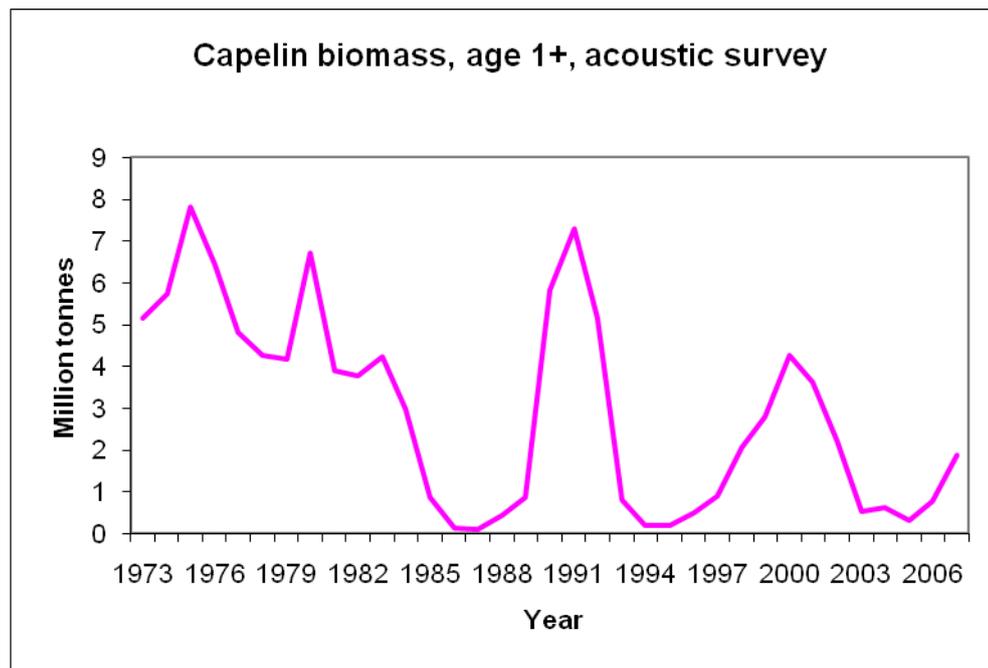
Figure 5.11. Fluctuations in stock size of Barents Sea capelin.
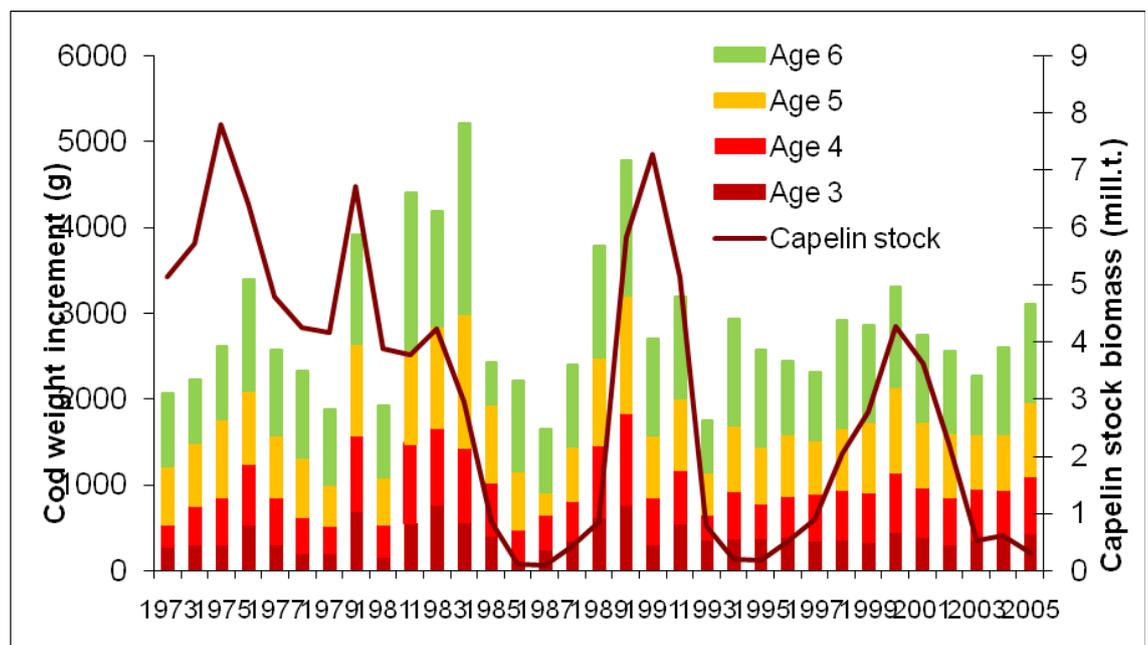
Figure 5.12. Growth (annual weight increment) of cod in various age groups, and the standing stock of capelin.
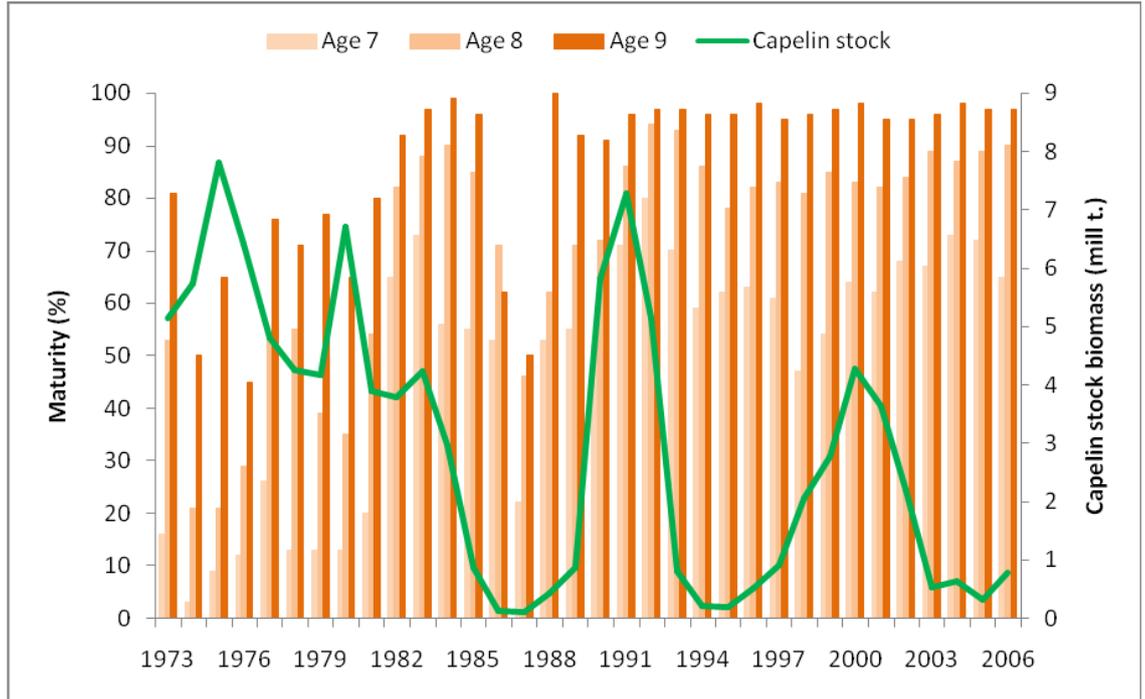
Figure 5.13. Maturity rate (%) of some age groups of cod.
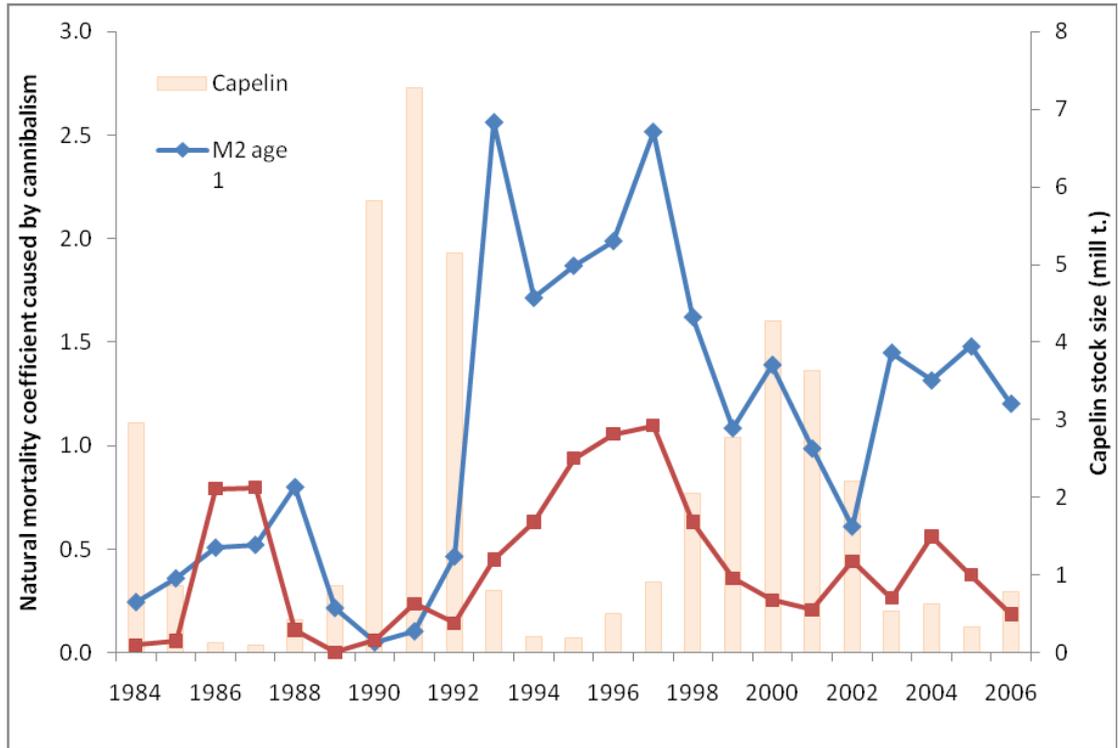
Figure 5.14. Natural mortality coefficients caused by cannibalism, estimated from cod stomach samples.
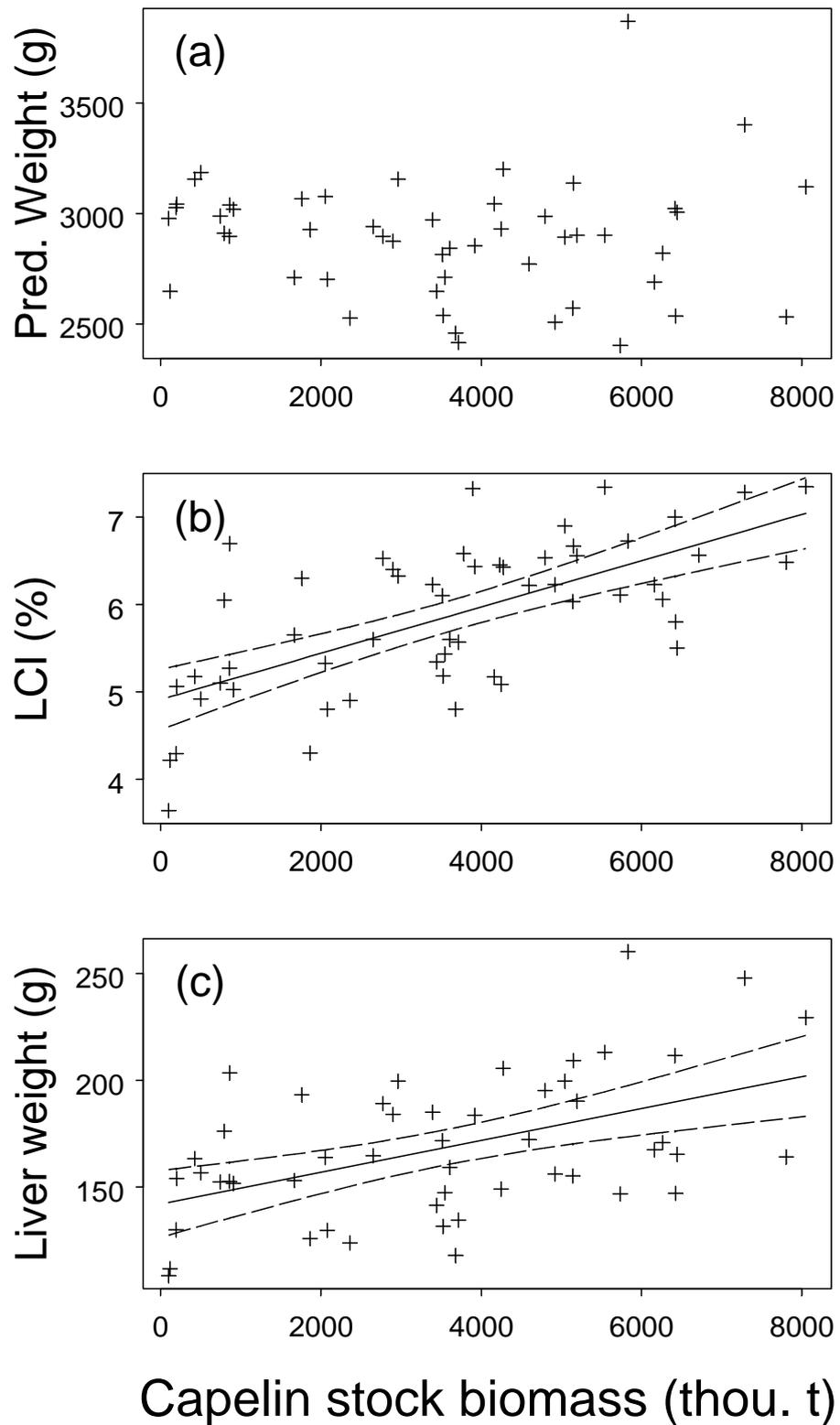
Figure 5.15. The bivariate relationships between capelin stock biomass (thousand t) and (a) predicted weight at 70 cm; (b) liver condition index of the 61–70 cm length class; and (c) estimated liver weight at 70 cm. Observations are denoted by year. Solid line indicates the least squares model fit and dashed lines indicate approximate 95% confidence intervals for the estimate. The model fit is not shown in (a) because the correlation was not significant. (From Marshall *et al.*, 2004).
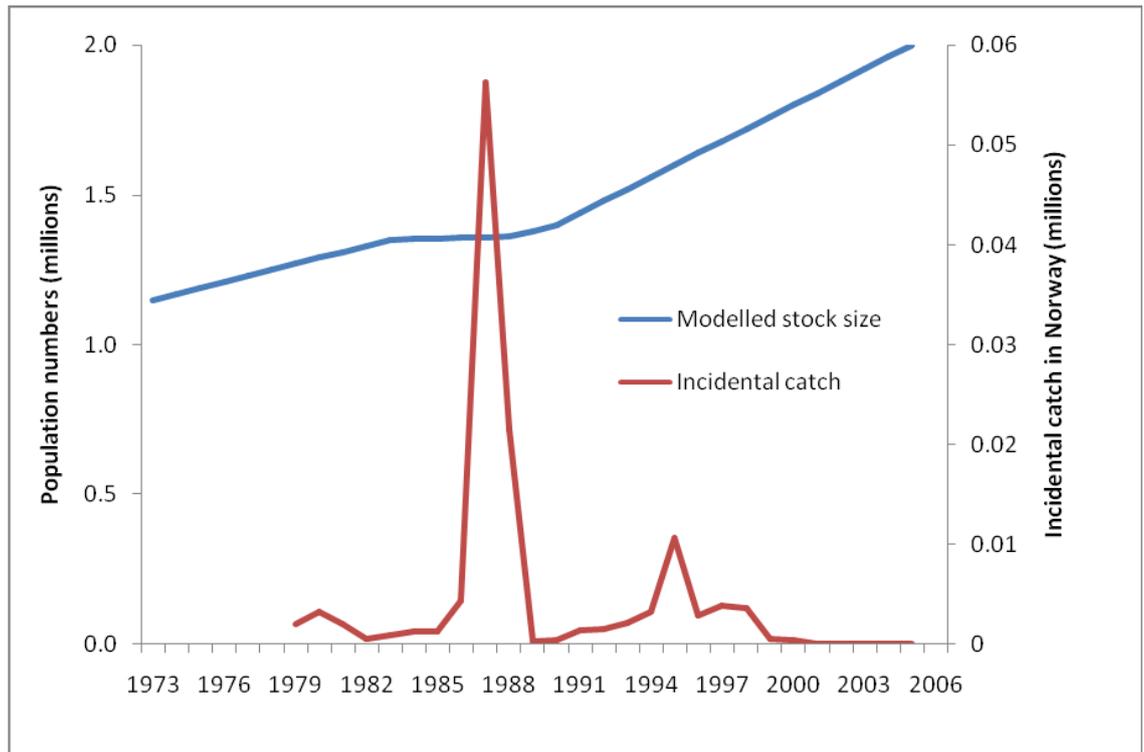
Figure 5.16. Modelled standing stock of harp seals in the Barents Sea, and number of incidental catches on the Norwegian coast.

5.4 Bay of Biscay

5.4.1 Relation between weight at age in the Hake and the abundance of prey species

A quick analysis has been completed looking for any kind of relationship between the weight-at-age of predators and the abundance of particular preys in the Bay of Biscay area. The main predator in this analysis is the European hake (*Merluccius merluccius*) and the preys are blue whiting (*Micromesistius poutassou*), horse mackerel (*Trachurus trachurus*), sardine (*Sardina pilchardus*) and anchovy (*Engraulius encrasicolus*).

Data sets were extracted from ICES Working Group Reports (WGHMM, WGMHSA, WGNPBW). Note that abundance data have been manipulated to achieve a similar order of magnitude as the weight-at-age data (Figure 5.17).

Wage0

Wage1

Wage2

Wage3
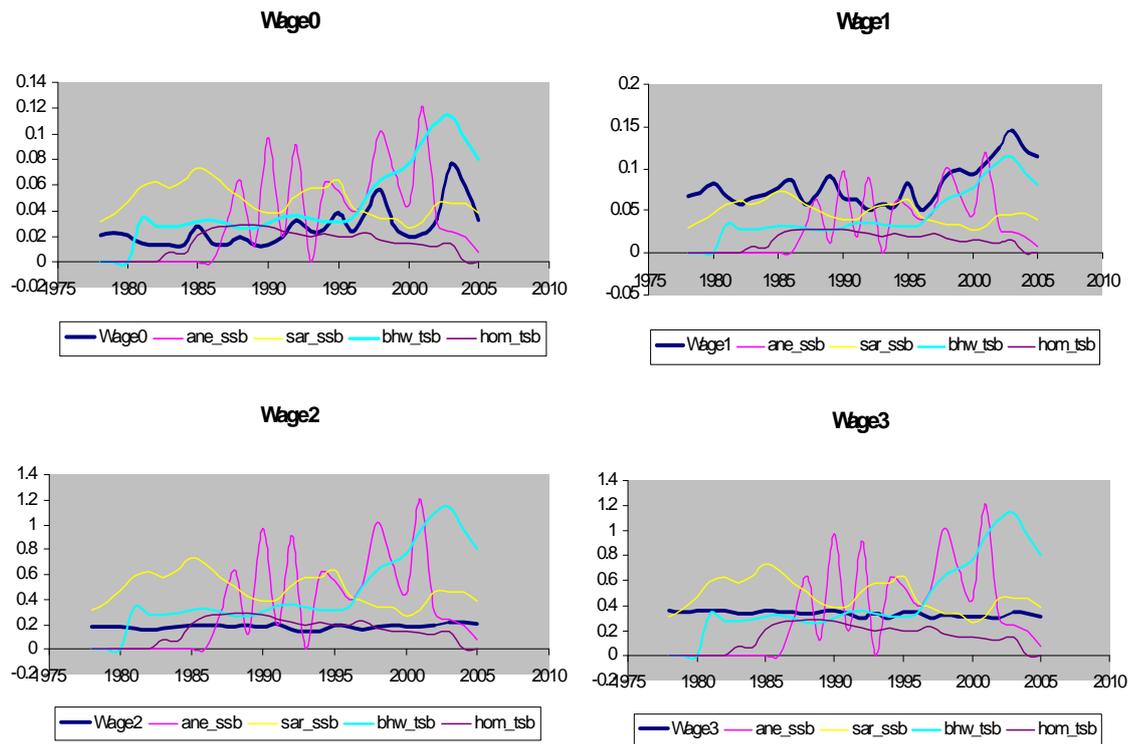
Figure 5.17. Weight-at-age of hake *Merluccius merluccius* (dark blue), in relation to the biomass of different prey species: anchovy (pink), blue whiting (light blue), horse mackerel (purple), sardine (yellow).

One preliminary observation from these analyses is an apparent correlation between the trends of weight-at-age in small hake (ages 0 and 1) and blue whiting abundance. However an increase of blue whiting abundance in the total stock (encompassing ICES Subareas I IX, XII, and XIV) was not reflected in the local abundance of blue whiting in the Bay of Biscay (ICES Division VIII). Furthermore, small hake were not thought to feed on blue whiting in this region (Velasco and Olaso 1998), although they form a significant part of the diet of hake in the Celtic Sea (ICES Divisions VIIf-j) and are consumed by larger animals (>30cm). Pinnegar *et al*. (2003) suggested that horse-mackerel and clupeoids (sardine *Sardina pilchardus*) were targeted by larger hake (>50 cm) in the Celtic Sea, whilst blue-whiting, *Argentina* spp., *Trisopterus* spp., and small clupeoids (mostly sprat *Sprattus sprattus*) were exploited by smaller hake (<50 cm). The average occurrence of blue whiting in the stomachs of hake and megrim was positively related to blue whiting stock abundance, as determined from ICES stock assessments. Furthermore, the average proportion of blue whiting in cod and hake stomachs was also positively related to the average proportion of blue whiting in scientific trawl surveys (Pinnegar *et al*., 2003).

No clear relationship with the abundance trends of the other main preys (horse mackerel, sardine and anchovy) was apparent in the Bay of Biscay. Trenkel *et al* (2005) have suggested that the Celtic Sea fish community is characterised by opportunistic predators and general independence between predator and prey distributions. This study suggests spatial and seasonal prey-switching behaviour by cod, hake and whiting. Blue whiting *Micromesistius poutassou* were consumed more often during the summer months, whereas mackerel *Scomber scombrus* 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 *Trachurus trachurus* and

Trisopterus spp. were eaten more often on the continental shelf, again in agreement with their depth-related density-distribution patterns.

5.5 Multispecies stock-recruitment models

5.5.1 Exploration of a multispecies stock-recruitment model

Classical stock-recruitment models are derived by assuming that the mortality pattern of a cohort can be described by a differential equation of the form $\dfrac{dN}{dt} = -ZN$ with Z being the total mortality rate and N being the pre-recruits density, and by considering that the initial cohort density is directly proportional to the spawning stock S ($No=cS$). Depending on the specific representation of Z this basic model can render both the Beverton-Holt stock-recruitment model ($Z=a+bN$; mortality of pre-recruits is density-dependent) and the Ricker model ($Z=a+bS$; mortality is a function of spawning stock, implying cannibalism).

Following a similar rationale, a model incorporating bottom-up and top-down effects on recruitment was introduced. This model assumes that total mortality can be represented as the product of two factors, one being the susceptibility of the pre-recruits to sources of mortality and the other one being that actual sources of mortality ($Z=s*m$). The susceptibility factor s captures bottom up effects by assuming that it is an inverse function of the food consumption by the pre-recruits. This food consumption is represented by the pre-recruit's functional responses for each of its prey (i.e. food consumption by the pre-recruits is a function of the prey field available to them; a bottom-up effect). The model structure determines that when pre-recruits have enough food available, and hence, they forage at their maximum consumption rate, then the susceptibility to sources of mortality reaches its minimum possible value. On the other hand, if prey availability to the pre-recruits tends to zero, then susceptibility will tend to positive infinity; ensuring the death of all pre-recruits regardless of how small the sources of predation are. In the absence of availability information for the pre-recruit's prey, susceptibility can be expressed as an inverse function of pre-recruits condition by making the additional assumption that condition is a direct function of food consumption.

The sources of mortality represented by the factor m captures the top-down predatory effects on the pre-recruits. This factor is modelled as a summation of mortality terms. One term is predator-independent and corresponds to sources of mortality other than predation (e.g. diseases). The remaining terms correspond to the consumption on those pre-recruits by all its predators.

The full conceptual representation of this model is structurally similar to the differential equation written above, but with a more complex function describing Z. Practical applications of this model require further assumptions depending on each case. One example was provided using the NAFO Divisions' 2J3K American plaice stock in the Northwest Atlantic. This specific application assumed that mean length-at-age was a reasonable proxy for condition (bottom-up effects) and that the variability in the predation terms can be captured by simple linear functions of the predator's abundances. By further assuming average effects during the pre-recruit period, a closed solution of the model could be obtained. This closed form resembles very much a standard extension of the Ricker closed form, but instead of having condition as one more term in the exponent, condition appears as a common denominator of the exponent. The results make sense; poor condition inflates the overall mortality, while the opposite happens with high condition values.

Besides condition, the model considered cod, seals and American plaice (i.e. cannibalism) as sources of mortality for the American plaice pre-recruits. Preliminary evaluations using likelihood ratio tests indicated that condition was a very significant factor in determining recruitment of American plaice, suggesting bottom-up effects. Cod was also a significant

factor but seals and American plaice were not. For comparative purposes, a similar approach was followed but using a standard extension of the Ricker model with the same factors (i.e. condition, cod and seals; plus the core cannibalistic effect). The exploration of this extended Ricker model using likelihood ratio tests indicated that only condition was a significant factor, also pointing to the importance of bottom-up effects. Interestingly enough, both 'best' models had very similar fits but they imply different ecological processes. The multispecies models discarded cannibalism as an important factor but retained cod predation, while the Ricker model assumes cannibalism and discarded the cod effect. Although there are not a lot of diet studies on this stock, the available diet information indicates that cannibalism doesn't appear to be an important factor. This suggests that despite the high similarity in model fits, the multispecies stock-recruitment model appears to be more in sync with current knowledge of this stock.

Overall, and despite the preliminary nature of these analysis, it is fair to conclude that condition had a significant impact of recruitment, and if the assumption that it is directly related to prey availability actually holds, then this results suggest that bottom-up effects at the pre-recruit level are an important factor in determining recruitment in this stock.

5.5.2   Meta-analytical approach

A common approach to investigate the relationship between spawner biomass and the number of recruits is to fit a stock-recruitment curve (commonly a Ricker, Schaefer or Beverton-Holt curve). These fits are often characterized by high variability and generally result in a poorly defined relationship and parameters (Myers *et al.*, 1994). An alternative is to use methods which "borrow strength", from other populations to obtain better parameter estimates for a given population (Efron and Morris, 1977). One such method is meta-analysis (Myers *et al.*, 2001). A first step in a meta-analytical approach is to correctly standardize the units of spawners and recruits so as to make the data comparable across ecosystems. Once completed, it is possible to run empirical Bayes (mixed effects) analysis to obtain overall estimates and Best Linear Unbiased Predictors (BLUPS) parameter values for each population.

Predation upon pre-recruits, generally clupeid predation upon groundfish eggs and larvae, has been documented in a number of ecoregions. Köster and Möllmann (2000) and Pepin (2006) describe this predation, whereas Swain and Sinclair (2000), Köster *et al.* (2001), and Garrison *et al.* (2002) investigate the potential implications for recruitment. Including potentially interacting species into the stock-recruit relationship is an example of the direct incorporation of pertinent multispecies interactions into stock assessment. Embedding this approach in a meta-analytical framework, as outlined above, will allow for comparisons of processes between regions and better parameter estimation in a given region. The idea is to collate available data on the spawning stock biomass and recruitment of the species of interest and also the abundance or biomass of potentially interacting species. Once the units are standardized, the analysis of each area can be run simultaneously in an empirical Bayes approach. In this way we can obtain estimates of how the systems differ in the capacity of predation/competition to affect recruitment but will also obtain better estimates of the parameters of interaction for any given population. This is the approach currently being investigated, particularly in terms of parameter estimation, by Coilin Minto using the global stock-recruit database (http://fish.dal.ca/~myers/welcome.html) at the Myers' Lab, Dalhousie University, Nova Scotia. It is hoped that such an approach will provide useful input to more comprehensive ecosystem/multispecies models (Myers *et al.*, 2001).

6   ToR e): Compare projections from ecosystem models and multispecies assessment models

6.1   Existing comparisons of EwE with other models

Shin and Cury (2004) have developed a multi-species individual-based model known as OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation) where predation is a size-based opportunistic process. The 'individual-based' approach is receiving increasing attention among ecologists (Grimm 1999) and involves tracking the fate of all individuals through their life cycle by assigning to them specific features and behavioural rules. Shin *et al.* (2004) have constructed an OSMOSE model for the southern Benguela ecosystem, and explored different fishing scenarios, previously examined using ECOSIM (by Shannon *et al.*, 2000). Simulation results were generally consistent with those obtained using ECOSIM. This type of cross-validation exercise appears to be a promising means of evaluating the robustness of model outputs, when separate validation of marine ecosystem models are still difficult to perform. Given the wide variety of different types of models that are potentially available within the ICES region (Section 2), and the inherent uncertainty associated with model structure, much could be achieved if a larger array of models were used to test the same management scenarios. The OSMOSE model, has now been parameterised for the North Sea and further comparative efforts (with dynamic-size spectra models and Ecosim) are planned as part of a UK research programme starting in 2008. OSMOSE has also been compared (in a more qualitative sense) with another size-structured ecosystem model known as APECOSM (see outputs reported in Shin and Cury 2004; Maury *et al.*, 2004).

Fulton and Smith (2004) have carried out comparisons of three ecosystem simulation models (ECOSIM, Bay Model 2 [BM2] and the Integrated Generic Bay Ecosystem Model [IGBEM]), tuned to data from Port Phillip Bay, Australia. Whilst ECOSIM is a dynamic biomass model, the other two are biogeochemical ecosystem models. Scenarios of environmental change (altered nutrient loading) and alternative fisheries management strategies (economically and ecologically motivated policies) were run for each model. A comparison of the predictions made by the models for these runs led to several general conclusions, first that large, shallow and enclosed bays, with many fish groups dependent on spawning stocks from outside the immediate area, may react more strongly to eutrophication than to fishing. The second conclusion was that a selected set of indicator groups (in this case, sharks, seagrass and chlorophyll a) seems to capture the major ecosystem impacts of alternative management scenarios. The third conclusion was that multispecies or ecosystem models can identify potential impacts that a series of single-species models cannot (such as non-intuitive changes in biomass when species interactions outweigh fishery-induced pressures). Finally, policies focusing on the protection of species or groups at higher trophic levels can fail to achieve sensible ecosystem objectives and may push systems into states that are far from pristine. These four findings have important ramifications for sustainable multiple-use management of shallow marine ecosystems.

There has been a long-held aspiration to compare Ecopath with MSVPA in the North Sea, since these are the two main tools used by fisheries scientists to investigate predator-prey dynamics. In 2003, scientists began the process of model comparison (Christensen *et al.*, 2003). It was the authors intention to see whether EwE, given output data from MSVPA, and a model structure inherited from a previously published Ecopath model region (Christensen 1995), could yield similar results and predictions in comparison with the predictive version of MSVPA, known as MSFOR. The EwE model included a total of 32 functional groups, with 17 fish groups (of which 4 were juvenile gadoids). Using information from the time period 1963–1999 the authors ran Ecosim simulations to see if EwE could replicate the results from the MSVPA. In doing so, they mainly had to modify the vulnerability settings, and overall it was concluded that it <u>was</u> possible to achieve a fair agreement between the two time series. There

were several discrepancies that became apparent in the comparisons. For instance, the authors did not succeed in using EwE to replicate the marked increase and subsequent decline in herring and horse mackerel that the MSVPA suggested. This may be because the North Sea model did not adequacy characterize the recruitment of these species. Whatever the reason, the authors thought the problem sufficiently interesting to plan further comparisons (Christensen *et al.*, 2003). However this study was never completed, although output images have been widely reproduced and cited on the internet (e.g. Figure 6.1).
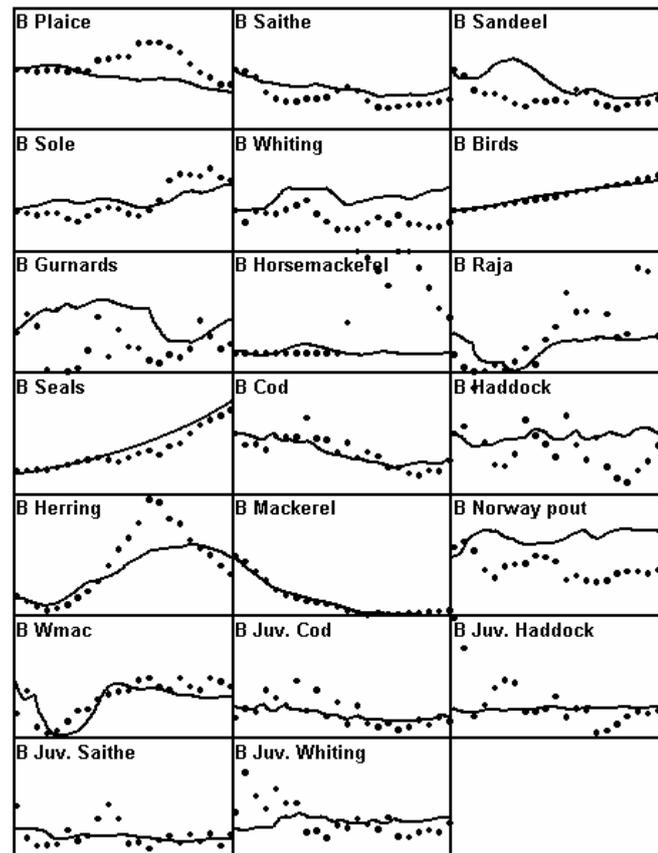
Figure 6.1. Output image from the 'original' EwE/MSVPA comparison exercise (described by Christensen *et al.*, 2003) in the North Sea. 'Tuned' stock biomasses for each fish group.

A similar exercise was carried out in the Baltic Sea by Harvey *et al.* (2003). A food web model for the Baltic Sea was created using the Ecopath with Ecosim software, to evaluate interactions between fisheries and the food web from 1974 to 2000. The model was based largely on values generated by multispecies virtual population analysis (MSVPA). Ecosim outputs closely reproduced MSVPA 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 and clupeids: cod exhibited top-down control on sprat biomass, but had little influence on herring. Fishing, the chief source of mortality for cod and herring, and cod reproduction, was driven by oceanographic conditions as well as unexplained variability. The model generated many hypotheses about relationships between key biota in the Baltic Sea food web and may ultimately provide a basis for estimating community responses to management actions.

A number of software packages are available to construct food-webs and to compute ecosystem variables. These include NETWRK and ECOPATH. A flow model of the northern Benguela ecosystem was used by Heymans and Baird (2000) to compare the outputs from these two packages. The food web used in this study consisted of 24 compartments.

NETWRK is a DOS-based package constructed in 'FORTRAN' by R.E. Ulanowicz, in the late 1980s (updated in 1999), while ECOPATH is a Windows-based package written in 'Visual Basic' that uses the same methodologies as NETWRK but whose algorithms have been programmed based on the original descriptions with some differences in interpretation. There are fundamental differences between the input methodologies of the two packages, which leads to differences in their output. NETWRK takes the respiration of primary producers into consideration, while ECOPATH does not. This leads to various discrepancies in the calculation of throughput and all the parameters related to it, such as the 'ascendancy' and 'development capacity'. In most cases, the differences are small enough that the interpretation of the results would bring the modeller to the same qualitative conclusion whether using ECOPATH or NETWRK. However, the mixed-trophic-impacts, Lindeman-spine, primary-production-required and Finn-Cycling-Index, are markedly different for the two models. It was concluded that consolidating these approaches would be of enormous value to ecosystem analysis.

Link *et al*. (2006) also compared the outputs of Ecopath with those of 'Econetwrk' another name for NETWRK (above). Both approaches were applied to a model for Georges Bank comprising 33 nodes based on ecosystem monitoring programs of the Northeast Fisheries Science Center (NEFSC). A full description of data sources and analytical methods used to derive estimates of biomass, production, consumption and respiration is provided by Link *et al*. (2006). There is a subtle difference in the underlying philosophy and numerical solutions between the two programs. The benefit of using the two packages instead of choosing one is that their strengths and weaknesses can be played off against one another. The detritus box is the main weakness of Ecopath, while in EcoNetwrk it is egestion. Ecopath includes an optimization program, whereas EcoNetwrk incorporates a minimization procedure. These programs use two different methods to arrive at working, balanced solutions: Ecopath emphasizes P, while EcoNetwrk emphasizes R. Both use convergence of values with repeated (auto) balancing as the main way to verify model finalization. Even though the two models have a conceptually different approach (Ecopath is more top-down while EcoNetwrk is more bottom-up), both highlighted the same deficiencies in data sets for the Georges Bank. A positive outcome of using both software packages is that the comparison encourages closer examination of input data and provides greater understanding than would be possible using one package alone. It also provides reassurances that results are robust to model choice and structural error.

There have been many comparisons between related multi and single species model formulations (see review by Hollowed *et al*., 2000) but not many inter-comparisons between different multispecies model types, largely because individual institutes tend to favour a particular modelling 'culture' and less frequently employ people from a number of multispecies modelling 'traditions'. Several authors have attempted to provide guidance with regard to which multispecies modelling approaches are appropriate for answering which types of scientific or management question. Hollowed *et al*. (2006) identified four types of model: descriptive multispecies, dynamic multispecies, aggregate system, and dynamic system models. The strengths and weaknesses of multispecies models and their ability to evaluate the causal mechanisms underlying shifts in production were examined. This comparison provides a basis for assessing the benefits of each modelling approach and a tool for evaluating likely impacts of fishing in marine ecosystems.

It is important to note that EwE and MSVPA (or other assessment type models such as Gadget) were not created for the same purposes; hence a comparison between these very disparate types of models may not be wholly appropriate or fair. The models should be thought of as complimentary rather than being in competition, EwE provides better coverage at the 'whole system' level and is mainly aimed at addressing longer-term 'strategic' questions

whereas MSVPA typically provides detailed, age-based outputs for individual species and can be used to answer shorter-term 'tactical' questions (such as setting quotas).

Plagányi (2007) has recently provided a critical analysis of the advantages, disadvantages and limitations of each modelling approach. Short descriptions are given of model parameters, assumptions and data requirements. The report concludes with recommendations for moving forward in the development of multi-species and ecosystem models and for the prudent use of the currently available modelling tools for provision of scientific information on fisheries in an ecosystem context. Faced with incomplete knowledge of ecosystem functioning, there has been increasing recognition that definitive conclusions cannot be drawn from a single model structure. There has thus been a parallel increase in efforts to modularize models so that different components can be easily substituted.

Discussion among WGSAM participants indicated a clear dichotomy in people's aspirations for comparative work, the two approaches can be summarised as: (1) detailed comparisons using identical input data, and highlighting mechanical differences in the way each model works; (2) simple comparisons of model outputs – when applied to the same fisheries question (e.g. the relative magnitude of predation mortality M2 in relation to levels of fishing mortality *F*, expectations regarding MSY etc).

Both types of comparison are clearly needed, but the former is probably not achievable within the context of a 1 week working group meeting (with other ToRs to address). Such an analysis is however, possible within the context of existing EU projects where sufficient time and resources <u>is</u> currently available (see below).

For more 'applied' model comparison exercises (number 2 above), modal exploration might be possible within the working-group (see suggested ToRs for next year's meeting), however some participants questioned the utility given potentially disparate input datasets, and it was suggested that 'uninformed' comparisons with little regard to data consistency might actually undermine confidence in the models overall.

Such questions provided useful insight into the aspirations of different WGSAM members, regarding the purpose of the working group. On the one hand participants clearly stated that they had enjoyed the opportunity to interact with and learn from scientists working in different geographic regions (a clear feature of this reformed and refocused WG in comparison with its geographically focussed predecessors SGMSNS and SGMAB). On the other hand, there was discussion concerning whether or not the group should mainly be focussed on answering 'applied' management questions and on comparing model outputs, as opposed to a very detailed 'mechanical' focus on model development and model inputs. A mixture of both is probably desirable.

6.2 Planned future comparison work

Time did not allow WGSAM to conduct actual model comparisons during the meeting; however, during the meeting the technical details of the model comparisons were discussed and planned in detail. The model comparisons will be conducted during November 2007 at a meeting of the EU FP6 project UNCOVER.

The plan is to compare the North Sea 4M (MSVPA), SMS and EwE model formulations. To do so, it is necessary to aggregate the 4M/SMS model output on levels comparable to the EwE output. Therefore the EwE species group definitions (used in the EwE model developed by Mackinson and Daskalov in press) will be applied:

- cod juveniles age 0-2, adults age 3-oldest age
- whiting juveniles age 0–1, adults age 2- oldest age
- haddock juveniles age 0–1, adults age 2- oldest age

- saithe juveniles age 0–3, adults age 4- oldest age
- herring juveniles age 0–1, adults age 2- oldest age

EwE usually runs on a monthly time step but the output is annually, thus the 4M/SMS results will be aggregated as the annual mean values. The North Sea EwE model has been calibrated to the 2005 4M keyrun annual F values, thus for the hindcast model comparison this 2005 4M keyrun will be used as the baseline. Both models cover the period 1973–2003, so the 4M model period will be truncated in the beginning, i.e. omitting 1963–1972.

EwE uses the 1991 year of the stomach data set to parameterize the diet composition matrix, therefore the 4M/SMS models will be parameterized equally. For additional comparison SMS will be parameterized with the full diet data set from 1981, 1985–1987 and 1991. Model comparisons will carried out for the hindcast period as well as for strategic (forward projecting) scenario simulations. The latter will mimic a mesh size increase by reducing the F for old ages and mimic a nursery closure by reducing the F for juveniles. Model results will be compared by scatter plots of biomass vs. time and the time to reach B_{lim} and/or B_{pa}.

Further model comparison (involving EwE, size-structured ecosystem models and multispecies fisheries assessment models) will also be conducted as part of the UK MF12-2 Project 'STEEM' (A Strategic Evaluation of Ecosystem Models in Support of Fisheries Management) and as part of the EU FP7 project MEECE.

Table 6.1. Planned model runs for the North Sea EwE, 4M, SMS comparisons.

MODEL RUN	DIET DATA 4M/SMS	DIET DATA ECOPATH	PERIOD	F
Hindcast 1	1991	1991	1973–2003	F at age from 2005 keyrun
Hindcast 2	1981, 1985–1987, 1991	1991	1973–2003	F at age from 2005 keyrun
Forecast 1	1991	1991	2004–2020	Fpa at group pattern from 4M/SMS
Forecast 2	1981, 1985–1987, 1991	1991	2004–2020	Fpa at group pattern from 4M/SMS
Mesh Size 1	1991	1991	2004–2020	0.50* F_{2004} age 2+ ??
Mesh Size 2	1981, 1985–1987, 1991	1991	2004–2020	0.50* F_{2004} age 2+ ??
Nursery 1	1991	1991	2004–2020	0.25* F_{2004} age 0and1
Nursery 2	1981, 1985–1987, 1991	1991	2004–2020	0.25* F_{2004} age 0and1

7   ToR f): The proportion of fish greater than 40cm in length

7.1   Background

WGSAM was asked by WGECO to run MSVPA in forecast mode for the North Sea to evaluate the management action required to meet the Fish Community EcoQO target *"The proportion (by weight) for fish greater than 40cm in length should be greater than 0.3"*, taking multi-species interactions into account.

The modelling approach previously used by WGECO was incomplete, because it did not account for dynamic interactions (predator-prey, competitive) among species and within populations. Consequently, it was recognised that the models used may have predicted the times required to reach these targets in a wrong way, because of their failure to take account of the reduction in the numbers of small fish caused by increasing predation mortality. Reductions in the numbers of small fish would tend to drive both the proportion of large fish and the mean weight of fish up. On the other hand, MSVPA-like models also often create larger estimates of recruiting year class sizes, to account for young fish lost to the population through predation before any catches from the year-classes are taken. The effect of the two processes on the size-based indicators requires exploration.

In this section WGSAM provides advice regarding the management action required to meet the Fish Community EcoQO target of "The proportion (by weight) for fish greater than 40cm in length should be greater than 0.3" (with a ±10% range in target values). The likely time scales involved to reach these targets in a multi species modelling environment was analysed using SMS (stochastic version of MSFOR) to fill the following table:

Table 7.1. Table provided by WGECO for completion by WGSAM.

Fishing mortality averaged across the seven main demersal species (cod, haddock, whiting, saithe, sole, plaice, Norway pout)	EcoQO Indicator Proportion (by weight) of fish > 40cm in length	Time to reach Indicator target
0.85Fpa	0.27	?
	0.30	?
	0.33	?
1.00Fpa	0.27	?
	0.30	?
	0.33	?
1.15Fpa	0.27	?
	0.30	?
	0.33	?

SMS was used instead of the requested MSFOR model (the forecast version of MSVPA) because the conversion from age to weight to size is much more direct in the age-size based SMS model than in the pure age –based MSVPA – 4M model.

7.2   Model configuration

In the present SMS analysis for the North Sea (ICES area IV) following predator and prey stocks were included:

Table 7.2. Species included in the SMS model of the North Sea.

PREDATOR ONLY	PREDATOR AND PREY	PREY ONLY	'EXTERNAL' PREDATORS
Saithe	Cod	Herring	Fulmar
	Whiting	Sandeel	Guillemot
	Haddock	Norway pout	Herring Gull
			Kittiwake
			Great black-backed Gull
			Gannet
			Puffin
			Razorbil
			Raja_radiata
			Grey gurnards
			Western mackerel
			North Sea mackerel
			Western horse mackerel
			North Sea horse mackerel

Due to problems in the assessment of North Sea sprat (ICES, 2004, 2006b) and fitting problems for this stock inside SMS, it was decided to leave this prey species out. Sprat was treated as "Other Food". The relative stomach content of sprat was added to the observed relative stomach contents for Other Food. Therefore, sprat was still available as prey for the model predators, but in an indirect way.

All configurations and input data for the SMS hindcast to derive parameter estimates for the forecast (e.g. stock-recruitment relationships, predator-prey specific vulnerabilities) were identical to the North Sea key-run used in the BECAUSE project (502482, final project report)

The following forecast settings were used for all scenario runs:

- First forecast year was 2006
- The forecast time period was from 2006 to 2015
- 100 MCMC simulations were carried out.
- Mean weight in the sea and food rations as average for 2000 to 2005.

Recruitment estimates were drawn assuming a log-normal distributed error with standard deviation as estimated by the SMS hindcast keyrun and with a noise truncation default at -2 and 2 (95% confidence interval). The following stock recruitment types and average parameter estimates were used:

Table 7.3. Types and average parameter estimates of the stock recruitment relationships.

SPECIES	TYPE OF SRR	ALPHA	BETA
Cod	Hockey stick	15.08	1.5E5 (inflection point)
Whiting	Ricker	63.22	1.82E-6
Haddock	Geom. mean	9.49E6	
Saithe	Ricker	4.29	7.55E-6
Herring	Ricker	53.28	9.57E-7
Sandeel	Ricker	736.76	6.43E-7
Norway pout	Ricker	1257.91	3.36E-6

The F_{pa} values were taken from the assessment reports (ICES, 2007a,b) when available and kept constant for the forecast time period. The following F_{pa} values were assumed:

Table 7.4. Precautionary reference points (Fpa) assumed within simulations.

SPECIES	F_{PA}
Cod	0.65
Whiting	0.65
Haddock	0.70
Herring	0.25
Sandeel	0.40
Saithe	0.40
Norway pout	0.35

As requested, the F_{pa} values were modified by assuming a 15% decrease and increase. The effect on the time needed to reach the WGECO index was analysed.

As it turned out that only few species in the model contribute to the % above 40cm, also a 25cm and a 30cm threshold was explored in the Fpa scenario forecast.

7.3 Calculation of the proportion of fish larger than x cm

SMS is primarily an age based model. To carry out analyses of the WGECO index the age based output had to be transformed into a size based output. The transformation was done by giving each age group a mean weight for each of the 4 quarters of the year. This mean weight-at-age was transferred into mean length by applying length-weight relationships (L=alpha*weight**beta) with following alpha and beta parameters:

- Raja sp.   4.09E-08   2.896
- Grey gurnard   6.2E-9   3.1
- Western Mackerel   3.8E-09   3.210
- North Sea Mackerel   3.8E-09   3.210
- Western Horse Mackerel   7.2E-09   3.033
- North Sea Horse Mackerel   7.2E-09   3.033
- Cod   2.0475E-08   2.8571
- Whiting   1.0509E-08   2.9456
- Haddock   1.8212E-08   2.8268
- Saithe   2.8322E-08   2.7374
- Herring   6.03E-09   3.0904
- Sandeel   1.243E-09   3.32
- Norway Pout   9.2E-09   3.0265
- Plaice   1.1E-08   3.009
- Sole   9.0E-09   3.000

Examples of mean weight per species and age-group are presented below:

Table 7.5. Mean weight (kg) at age group, 2005 quarter 1 as used by SMS.

	0	1	2	3	4	5	6	7	8	9	10
Cod	.	0.052	0.576	1.735	3.205	4.831	7.422	9.521	10.959	11.940	12.451
G. gurnards	0.004	0.044	0.124	0.347	.	.	.	.	.	.	.
Haddock	.	0.055	0.191	0.369	0.501	0.613	0.648	1.092	1.084	1.755	2.489
Herring	.	0.012	0.075	0.117	0.141	0.159	0.165	0.184	.	.	.
N. mackerel	.	0.078	0.164	0.241	0.342	0.390	0.486	.	.	.	.
N.horse mac	0.032	0.104	0.249	.	.	.	.	.	.	.	.
Nor. pout	.	0.008	0.024	0.042	.	.	.	.	.	.	.
Plaice	.	0.150	0.200	0.236	0.290	0.409	0.468	0.687	0.742	0.707	0.864
R. radiata	.	0.030	0.135	0.585	.	.	.	.	.	.	.
Saithe	.	0.026	0.200	1.026	1.127	1.539	1.685	2.592	3.088	4.742	8.927
Sandeel	.	0.004	0.010	0.015	0.020	.	.	.	.	.	.
Sole	.	0.050	0.140	0.198	0.226	0.261	0.267	0.301	0.336	0.377	0.280
W. mackerel	0.164	0.376	.	.	.	.	.	.	.	.	.
W.horse mac	.	0.120	0.210	.	.	.	.	.	.	.	.
Whiting	.	0.039	0.125	0.238	0.288	0.287	0.277	0.277	0.327	.	.

Using the mean weight and the length-weight relation given, length-per-species and age-group are presented below:

Table 7.6. Mean length (cm) at age group, 2005 quarter 1 as used by SMS.

	0	1	2	3	4	5	6	7	8	9	10
Cod	.	17	40	60	74	85	99	108	114	117	119
G. gurnards	8	16	23	32	.	.	.	.	.	.	.
Haddock	.	20	30	38	43	46	47	56	56	67	76
Herring	.	11	20	23	24	25	25	26	.	.	.
N. mackerel	.	19	24	27	30	31	34	.	.	.	.
N.horse mac	16	23	31	.	.	.	.	.	.	.	.
Nor. pout	.	9	13	16	.	.	.	.	.	.	.
Plaice	.	25	27	29	31	34	36	40	41	41	44
R. radiata	.	11	18	30	.	.	.	.	.	.	.
Saithe	.	15	32	58	60	67	69	81	86	101	127
Sandeel	.	9	12	14	15	.	.	.	.	.	.
Sole	.	16	23	26	27	28	28	30	31	32	29
W. mackerel	24	31	.	.	.	.	.	.	.	.	.
W.horse mac	.	24	29	.	.	.	.	.	.	.	.
Whiting	.	17	25	31	34	33	33	33	35	.	.

The age groups for *R. radiata,* grey gurnards, horse mackerel and western mackerel do not reflect real age-groups, but groups of ages or sizes. To test the sensitivity of the WGECO index the weight proportion of fish larger than 25, 30 and 40cm was calculated. Stock numbers in the beginning of the first quarter of the year were used.

7.4 Results
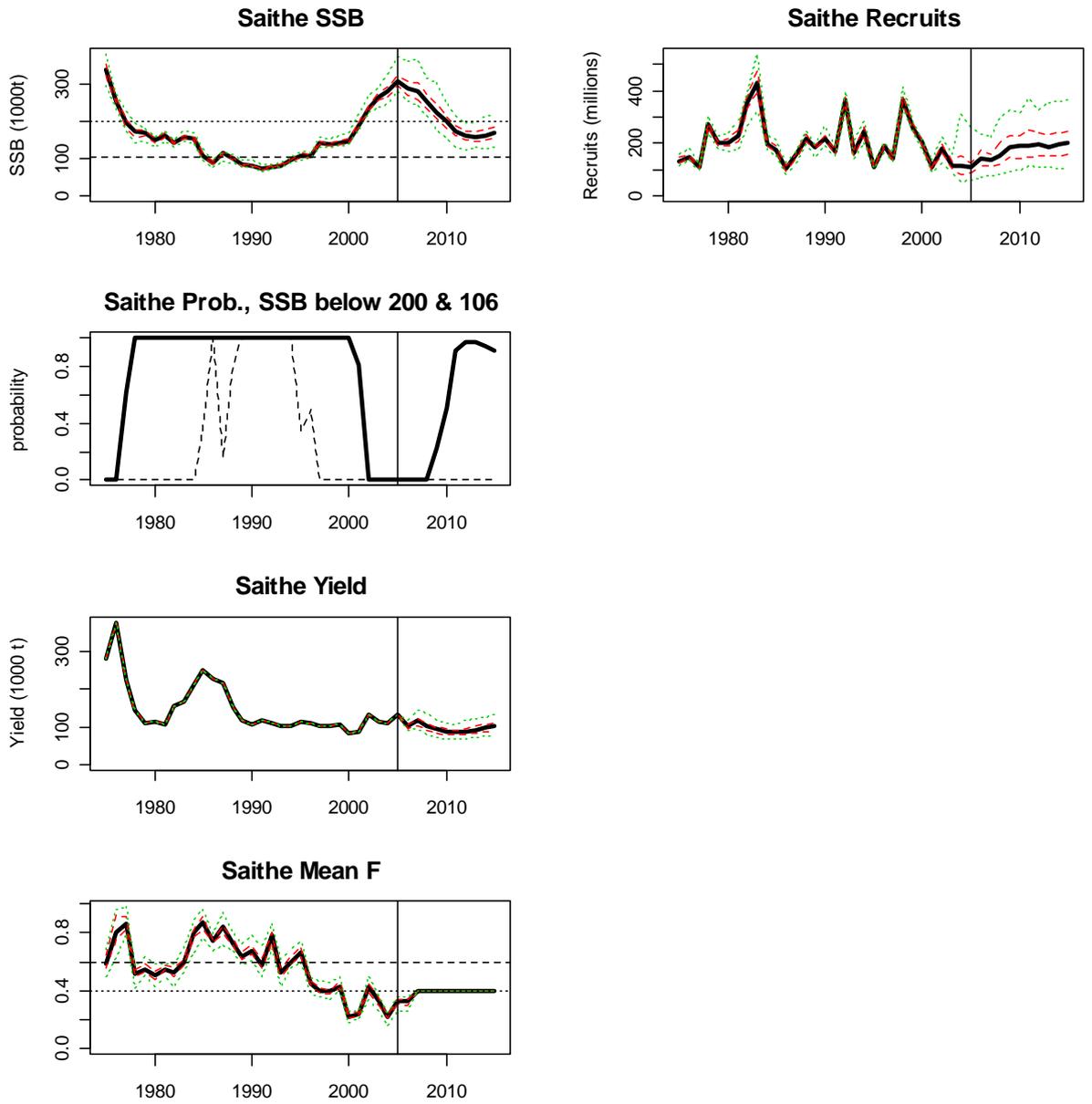
Figure 7.1. SMS model output for run with Fpa.
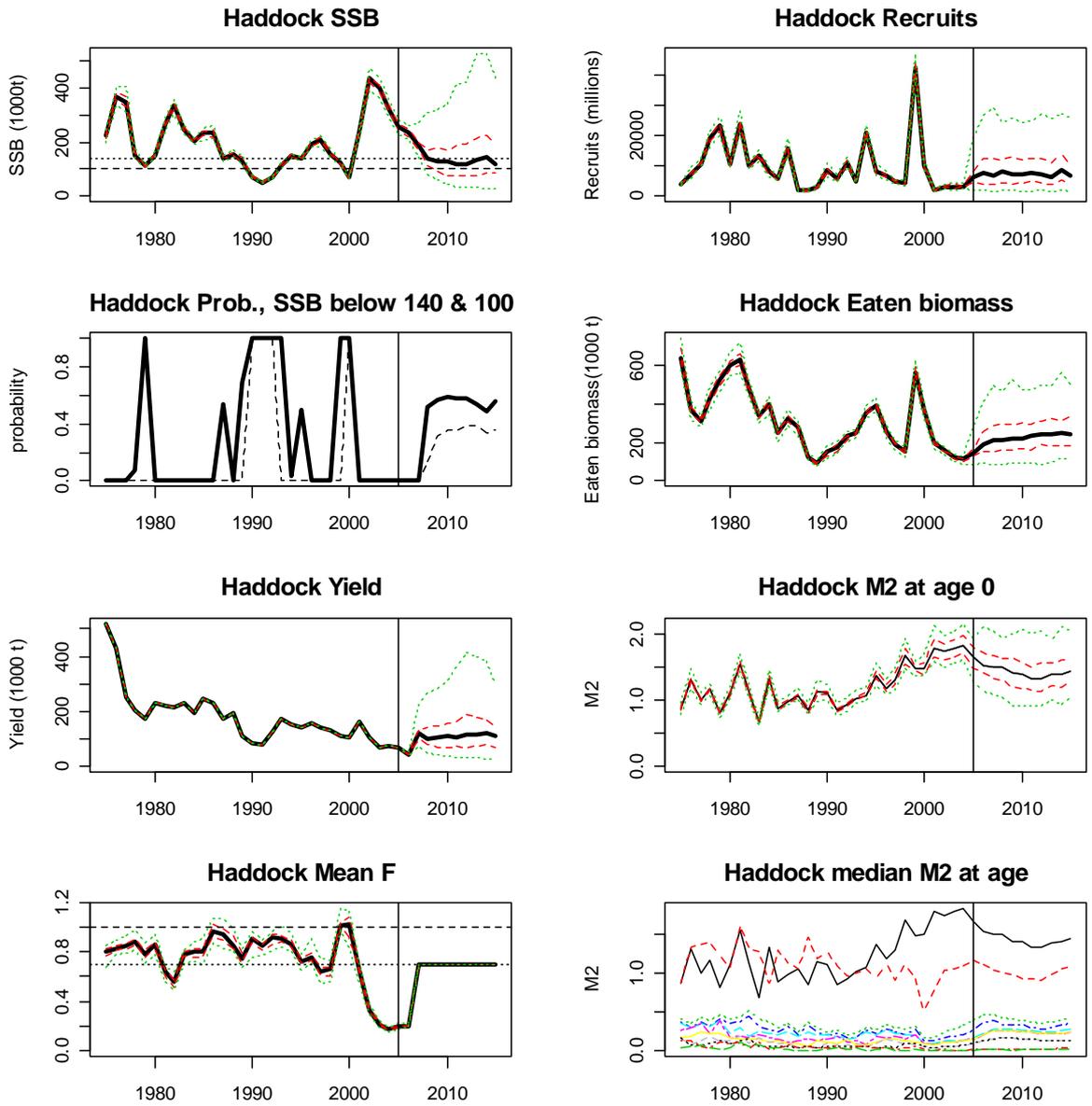
Figure 7.1. SMS model output for run with Fpa (continued).
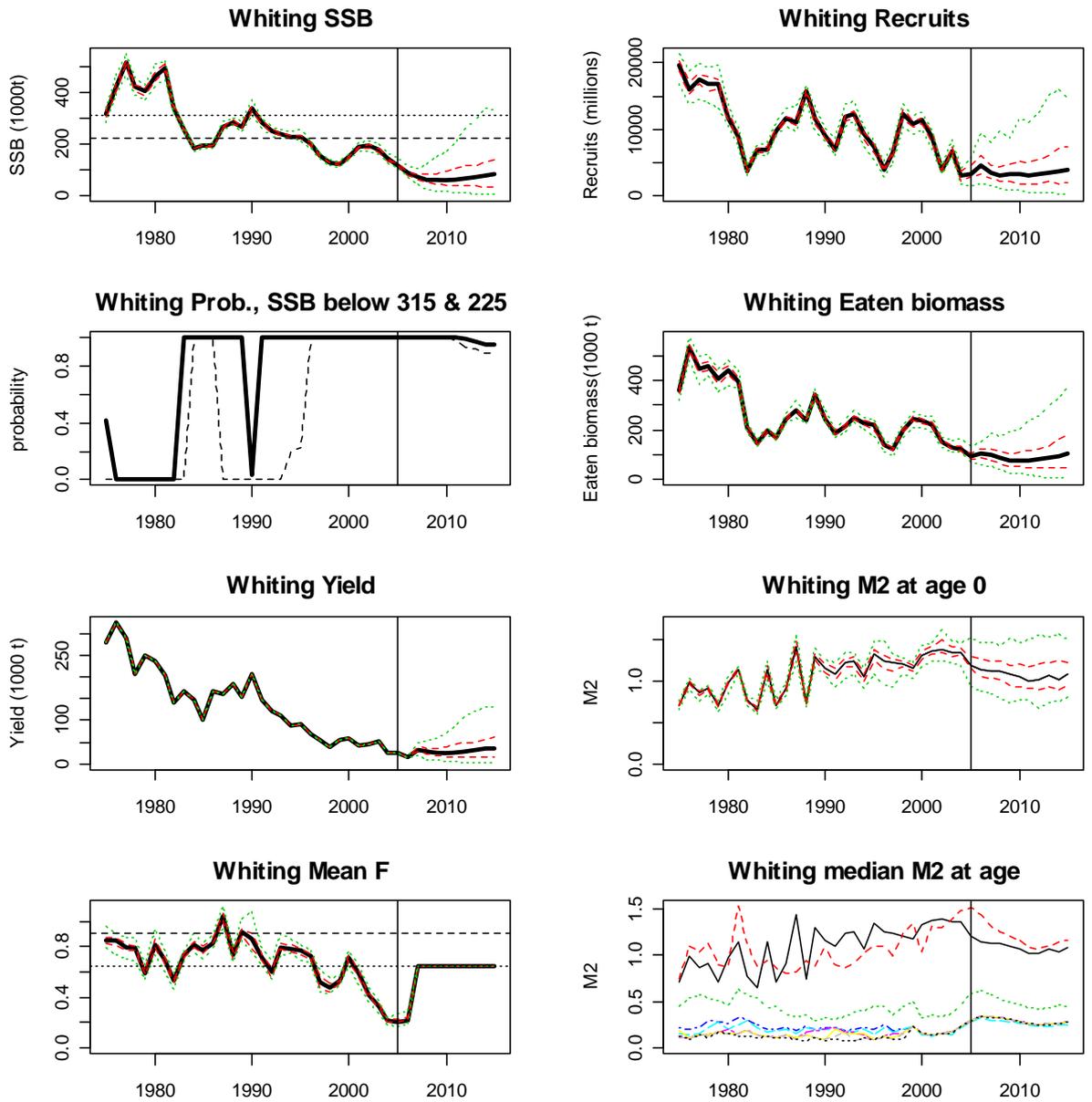
Figure 7.1. SMS model output for run with Fpa (continued).
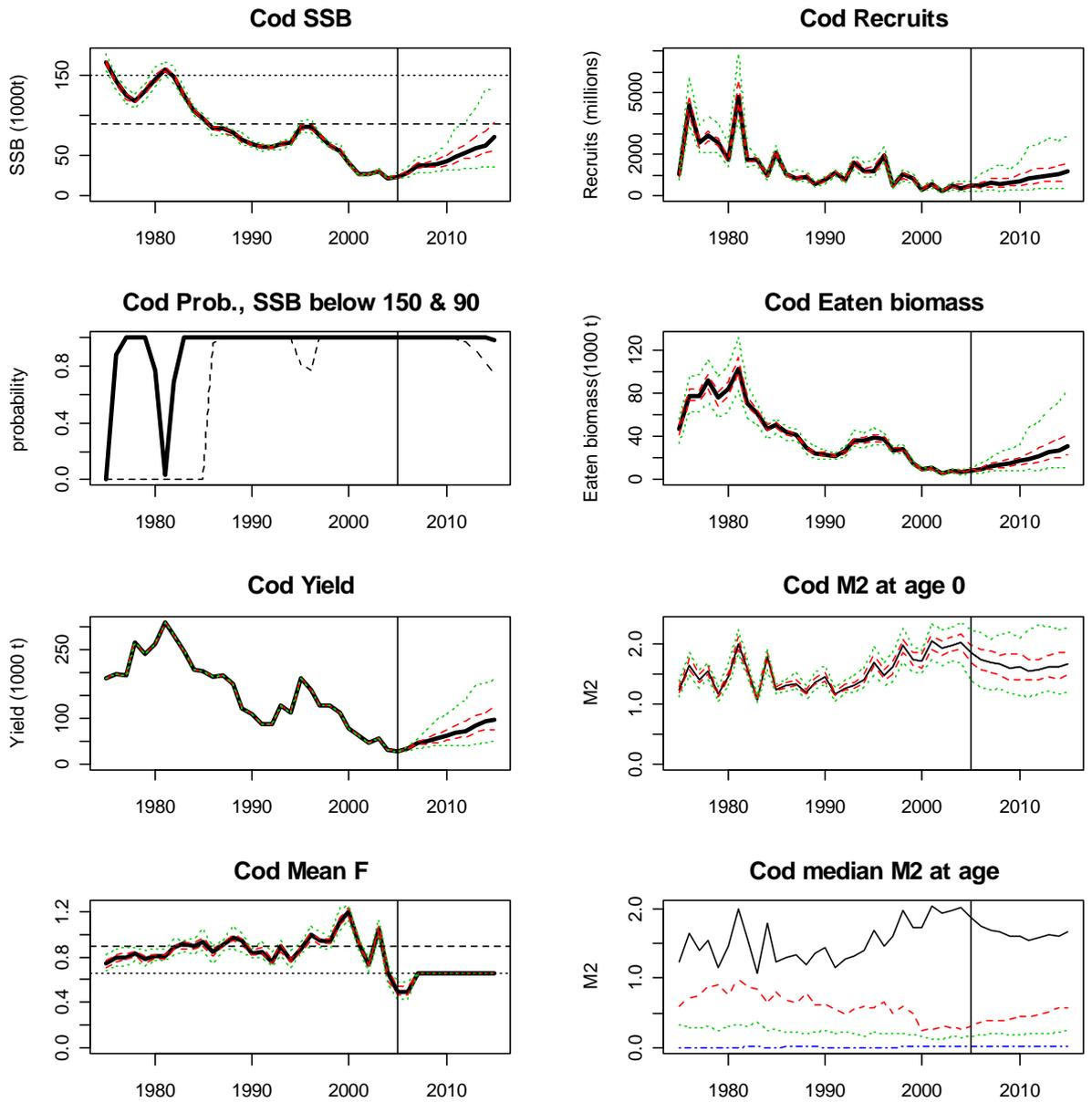
Figure 7.1. SMS model output for run with F$_{pa}$ (continued).
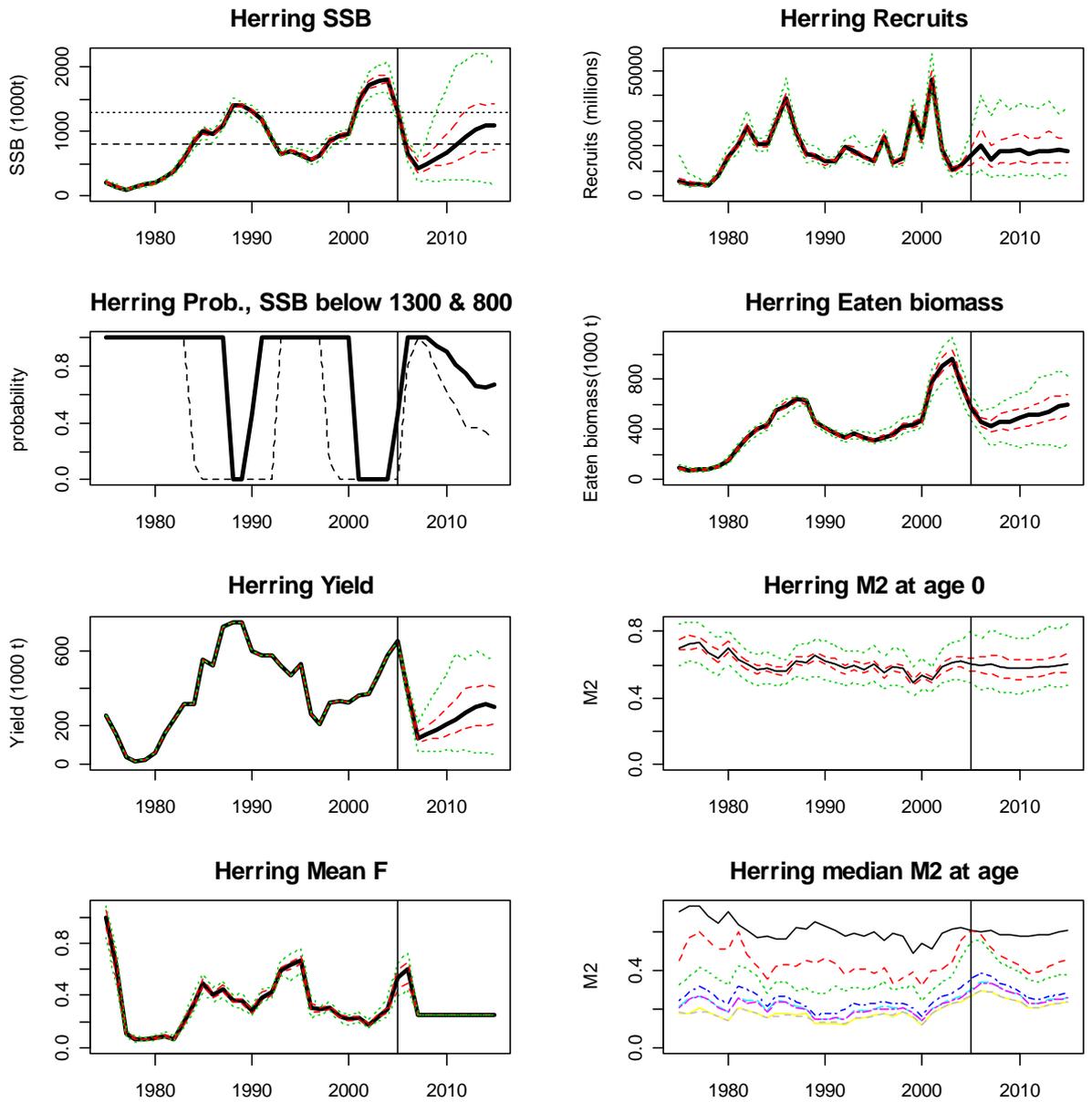
Figure 7.1. SMS model output for run with F_{pa} (continued).
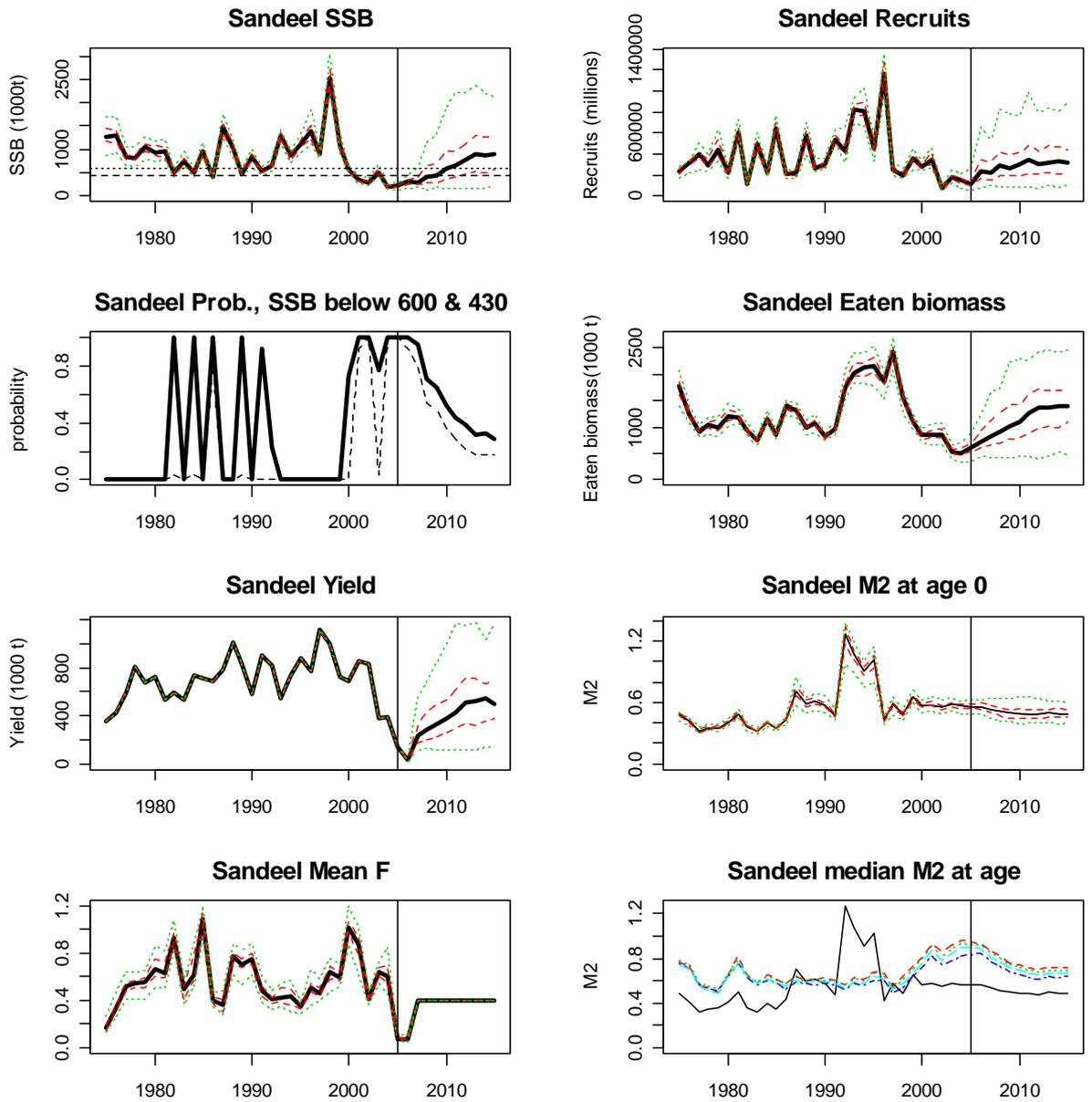
Figure 7.1. SMS model output for run with F$_{pa}$ (continued).
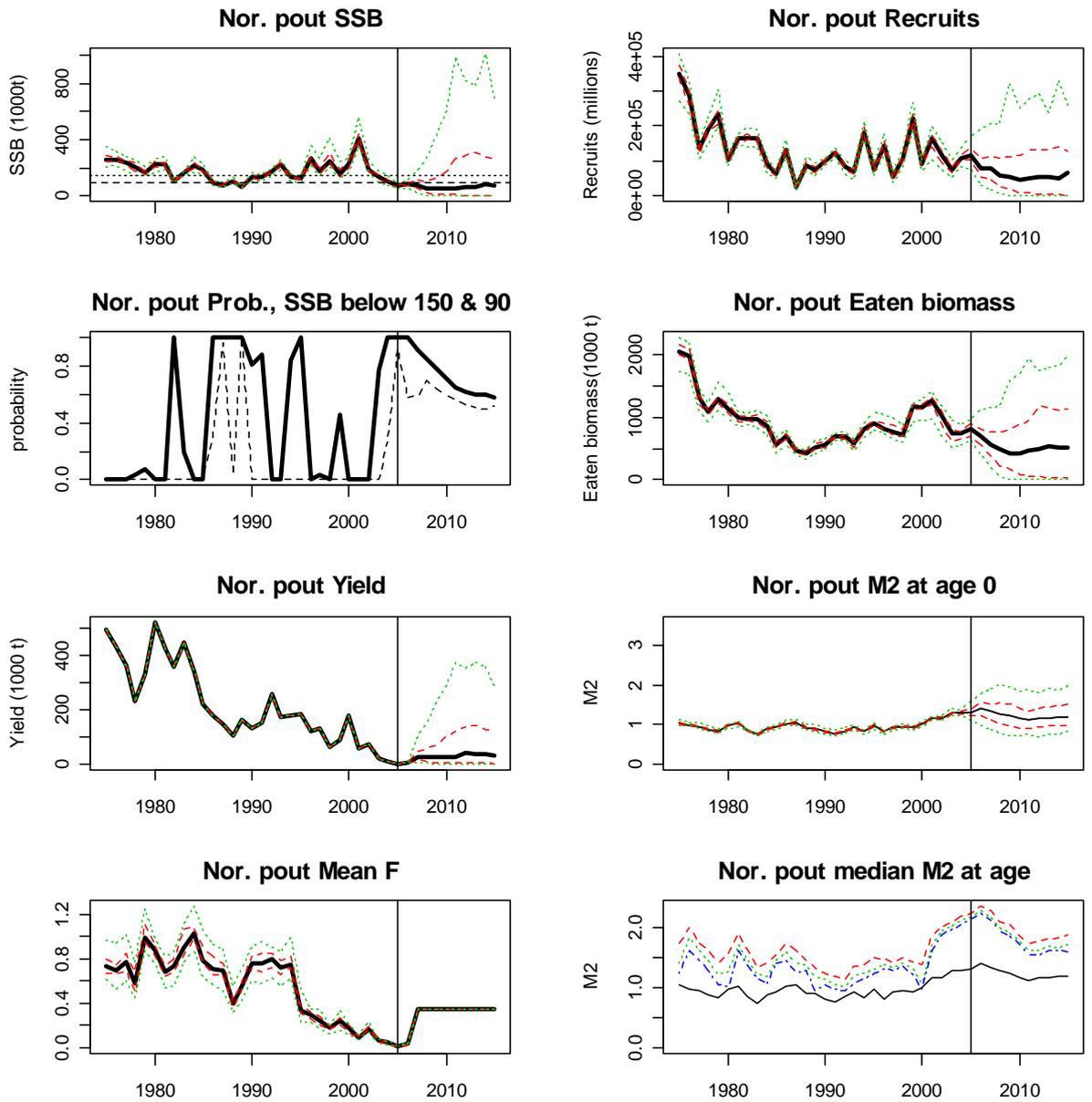
Figure 7.1. SMS model output for run with F$_{pa}$ (continued).
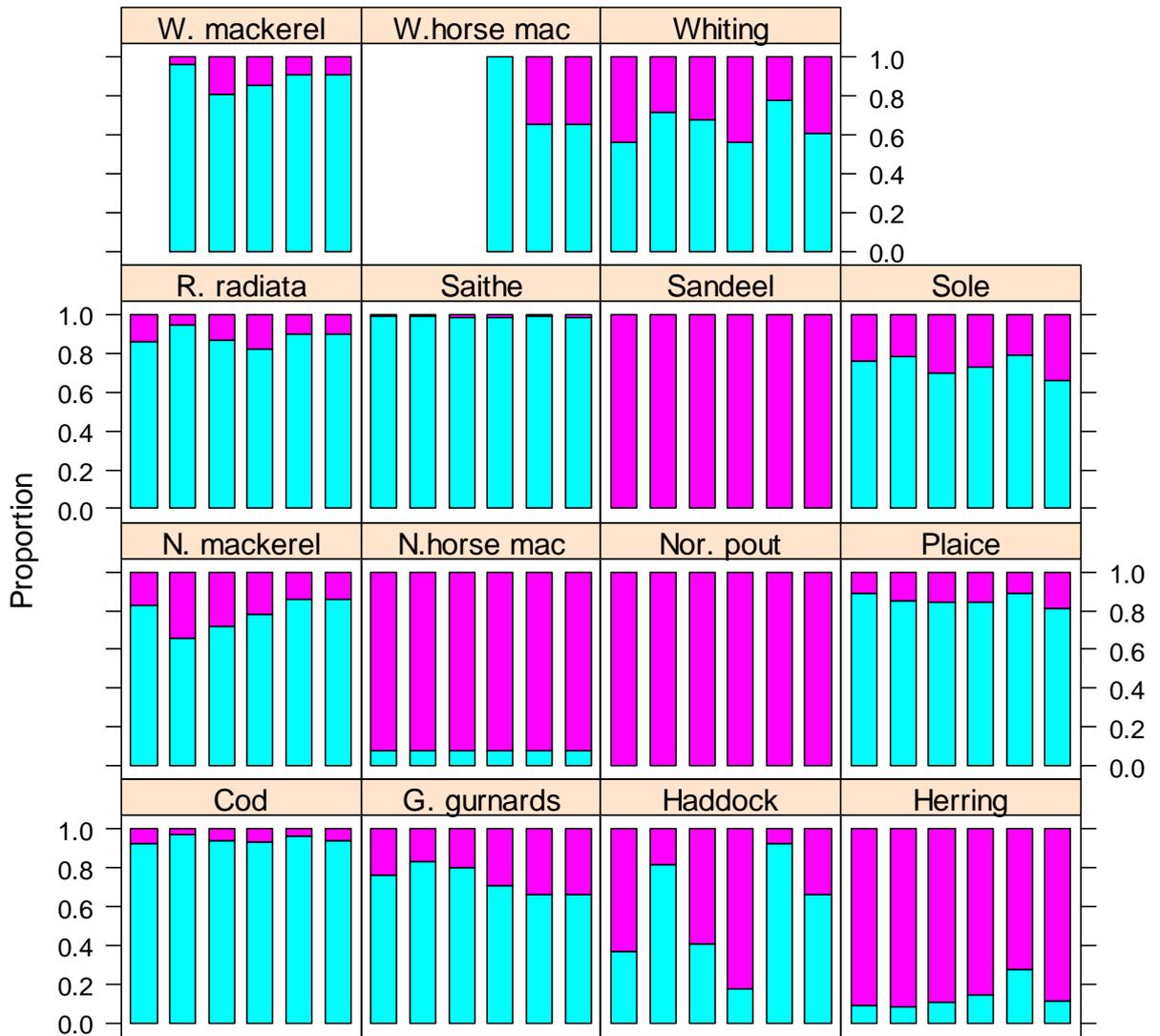
Figure 7.2. Proportion by weight of fish larger than 25 cm (cyan, lower) in the North Sea, quarter one, for selected years (1975, 1985, 1990, 2000, 2005 and 2010) as estimated by SMS. Fishing mortality at F_{pa} is assumed for projection.
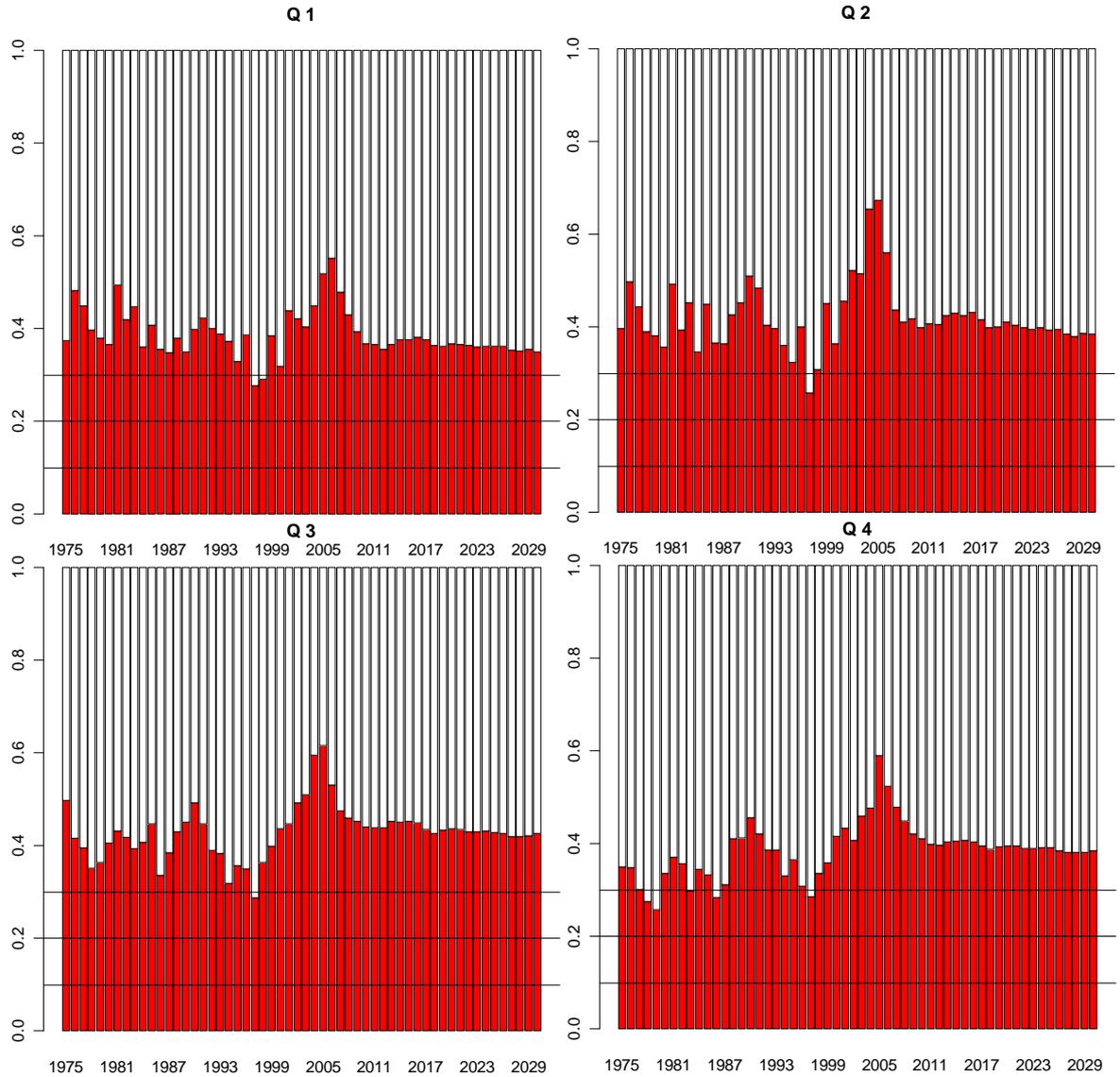
Figure 7.3. Proportion by weight of fish larger than 25 cm (red) in the North Sea by quarter of the year as estimated by SMS. Fishing mortality at F$_{pa}$ is assumed for projection. The species includes *R. radiata*, grey gurnards, western mackerel, North Sea mackerel, western horse mackerel, North Sea horse mackerel, cod, whiting, haddock, saithe, herring, sandeel, Norway pout, plaice and sole.
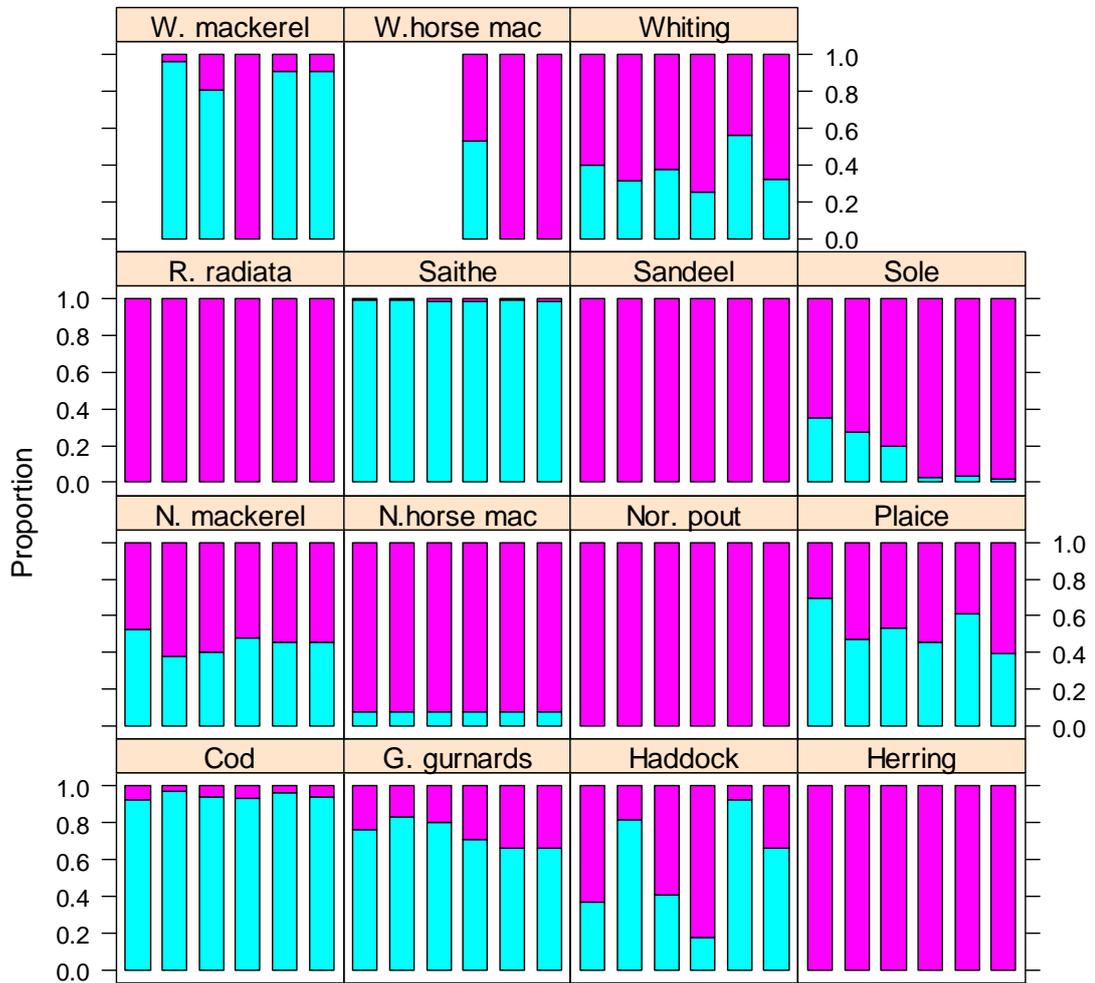
Figure 7.4. Proportion by weight of fish larger than 30 cm (cyan, lower) in the North Sea, quarter one, for selected years (1975, 1985, 1990, 2000, 2005 and 2010) as estimated by SMS. Fishing mortality at F_{pa} is assumed for projection.
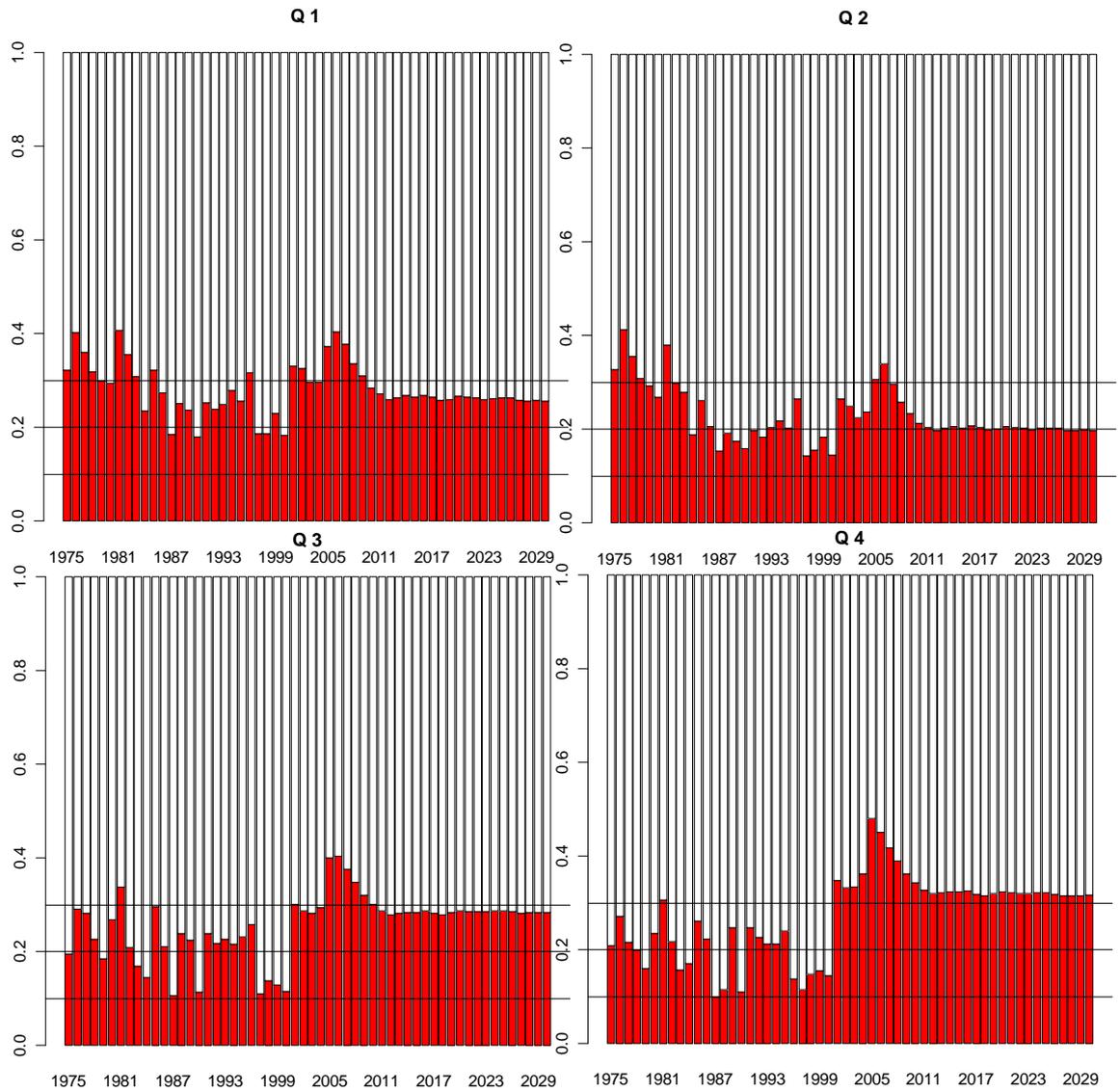
Figure 7.5. Proportion by weight of fish larger than 30 cm (red) in the North Sea by quarter of the year as estimated by SMS. Fishing mortality at F_{pa} is assumed for projection. The species includes *R. radiata,* grey gurnards, western mackerel, North Sea mackerel, western horse mackerel, North Sea horse mackerel, cod, whiting, haddock, saithe, herring, sandeel, Norway pout, plaice and sole.
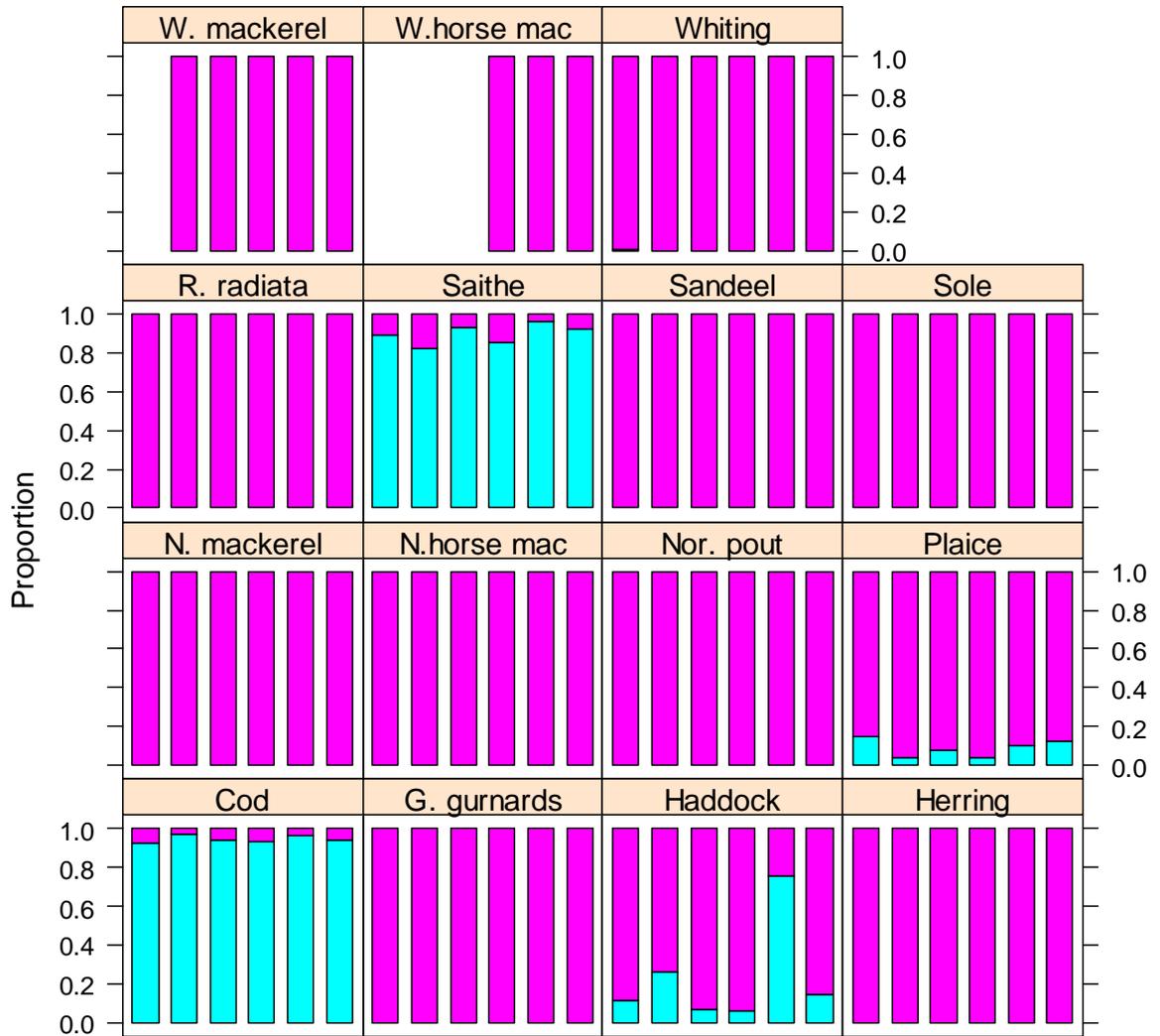
Figure 7.6. Proportion by weight of fish larger than 40 cm (cyan, lower) in the North Sea, quarter one, for selected years (1975, 1985, 1990, 2000, 2005 and 2010) as estimated by SMS. Fishing mortality at F$_{pa}$ is assumed for projection.
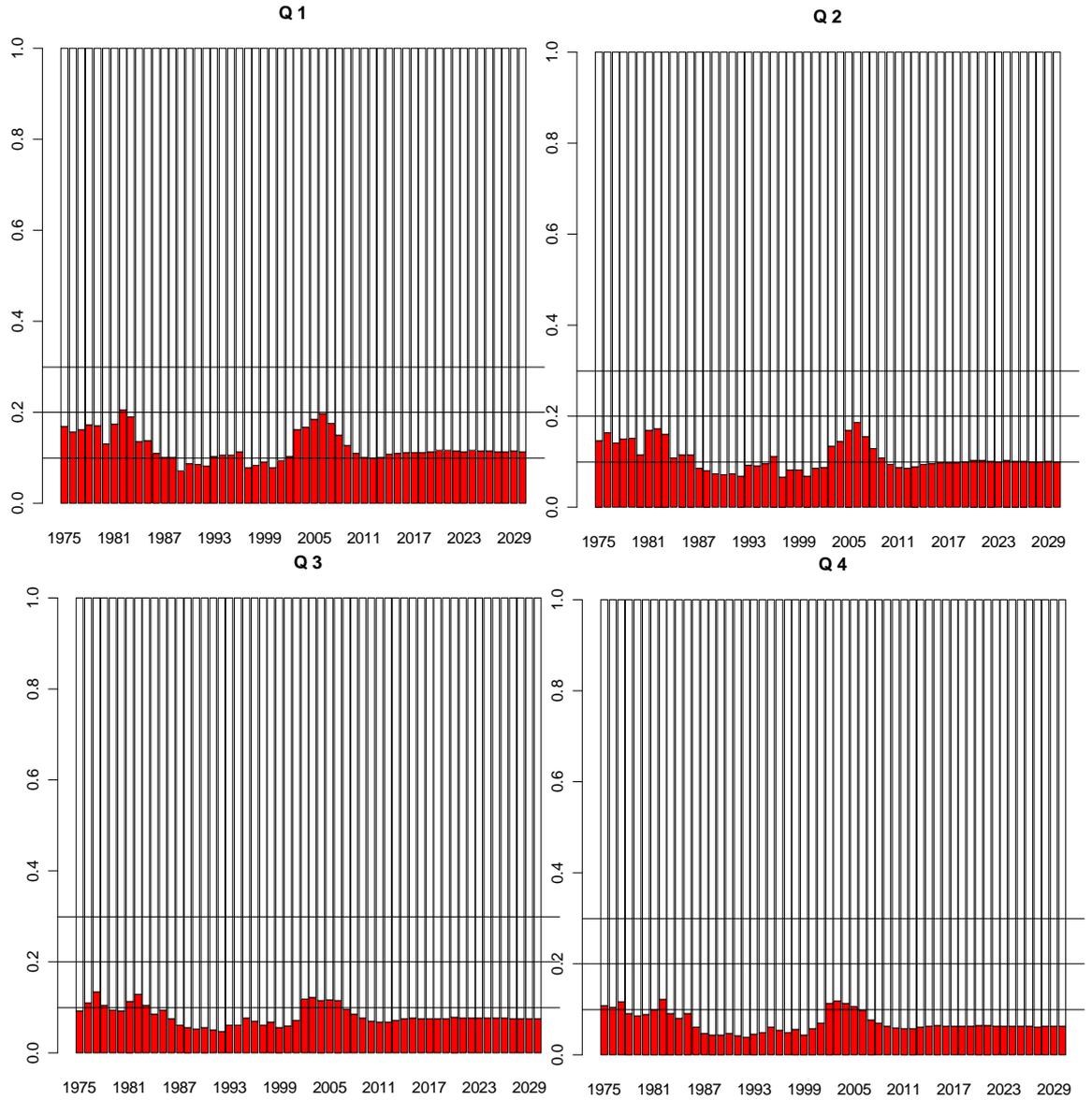
Figure 7.7. Proportion by weight of fish larger than 40 cm (red) in the North Sea by quarter of the year as estimated by SMS. Fishing mortality at F$_{pa}$ is assumed for projection. The species includes *R. radiata,* grey gurnards, western mackerel, North Sea mackerel, western horse mackerel, North Sea horse mackerel, cod, whiting, haddock, saithe, herring, sandeel, Norway pout, plaice and sole.
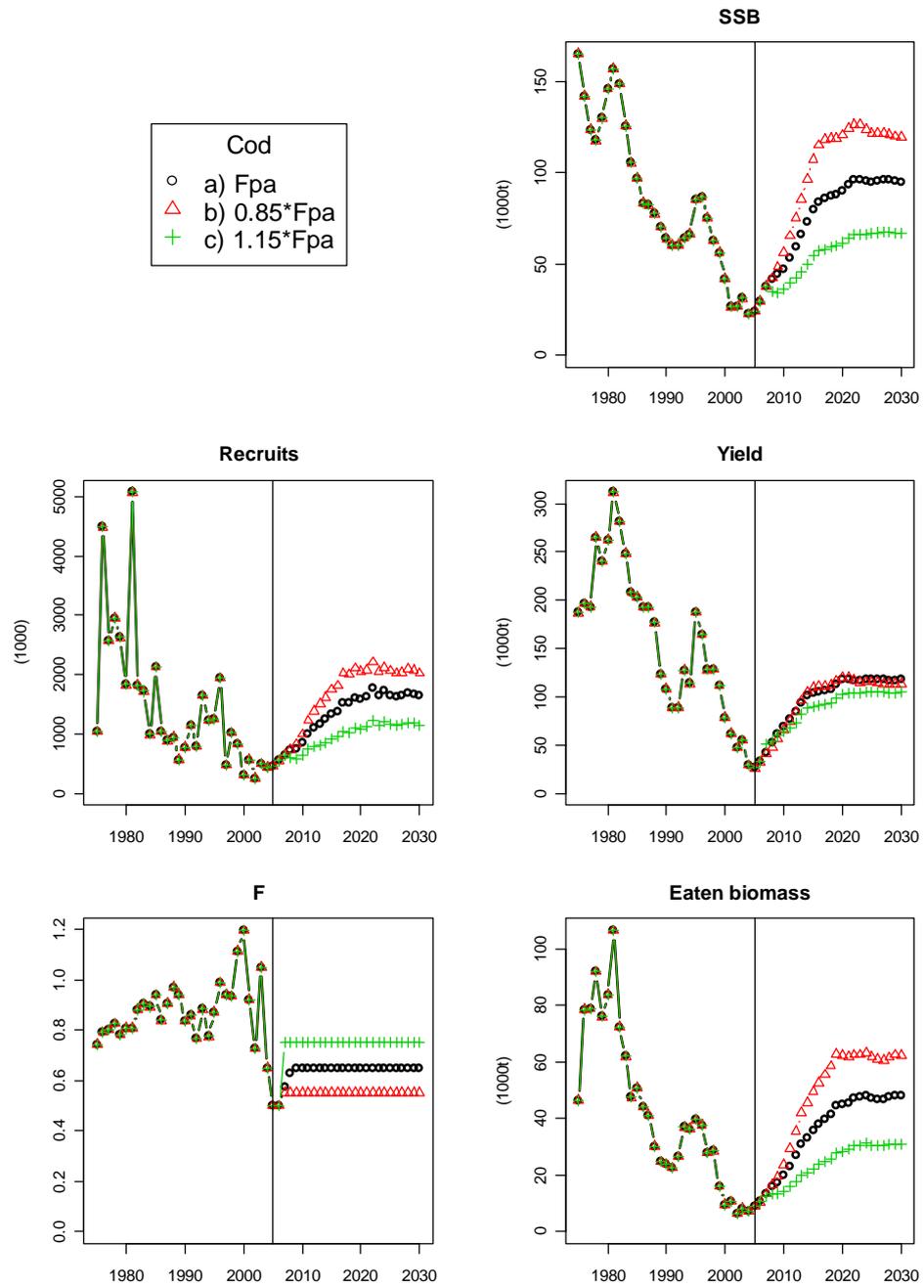
Figure 7.8. SMS model output for run with 3 levels of F (cod).
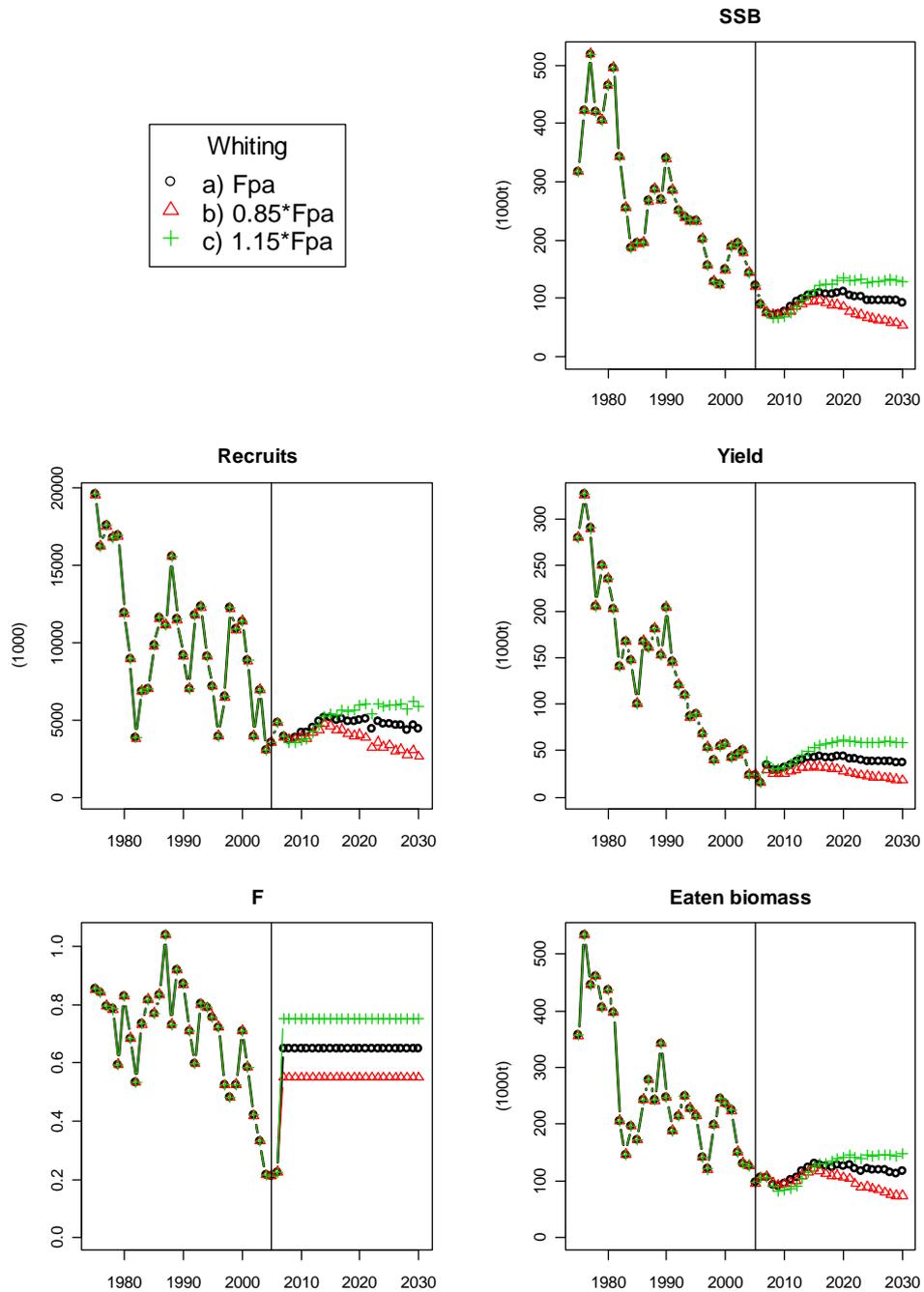
Figure 7.8 Continued. SMS model output for run with 3 levels of F (whiting).
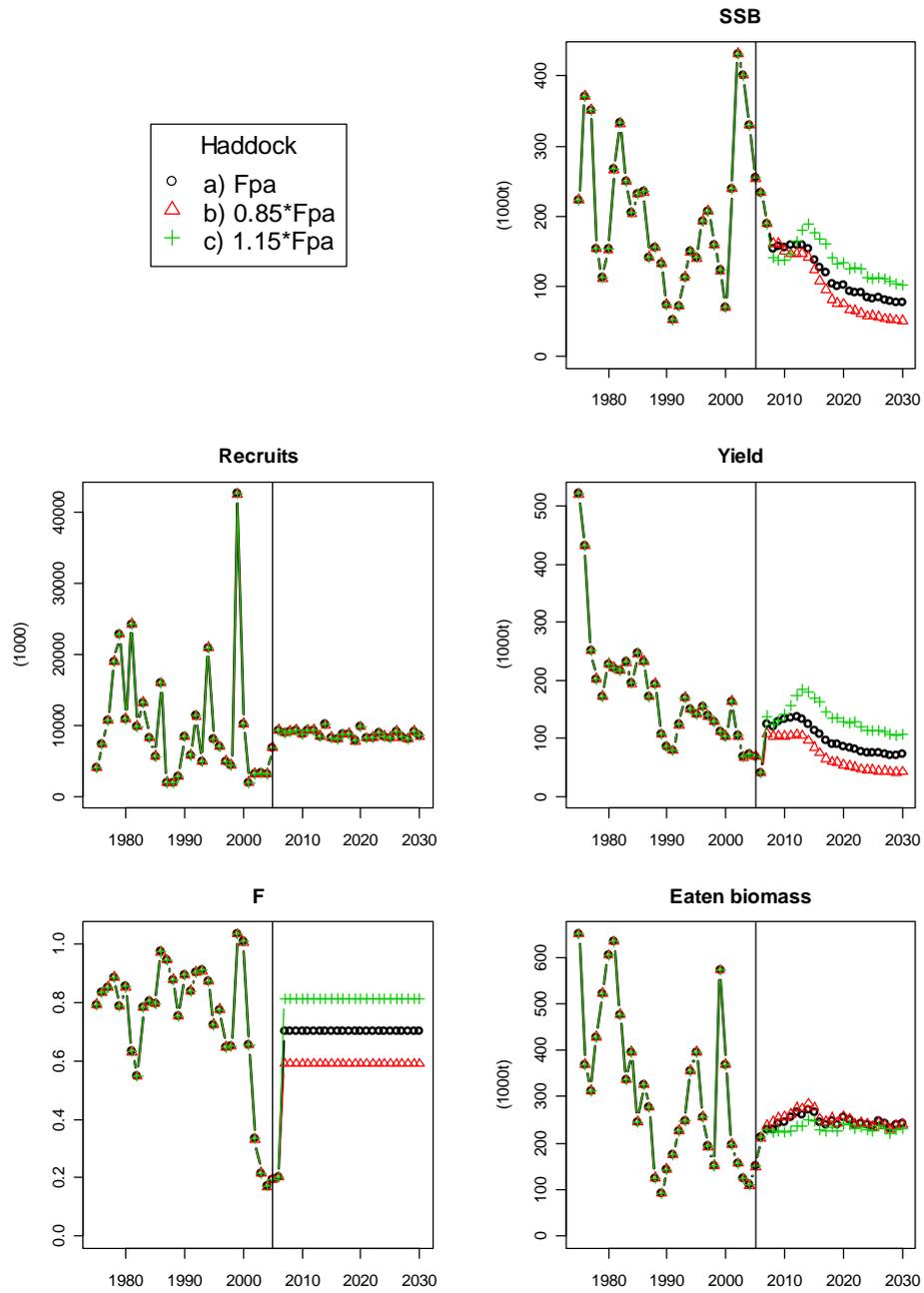
Figure 7.8 Continued. SMS model output for run with 3 levels of F (haddock).

Figure 7.8 Continued. SMS model output for run with 3 levels of F (saithe).
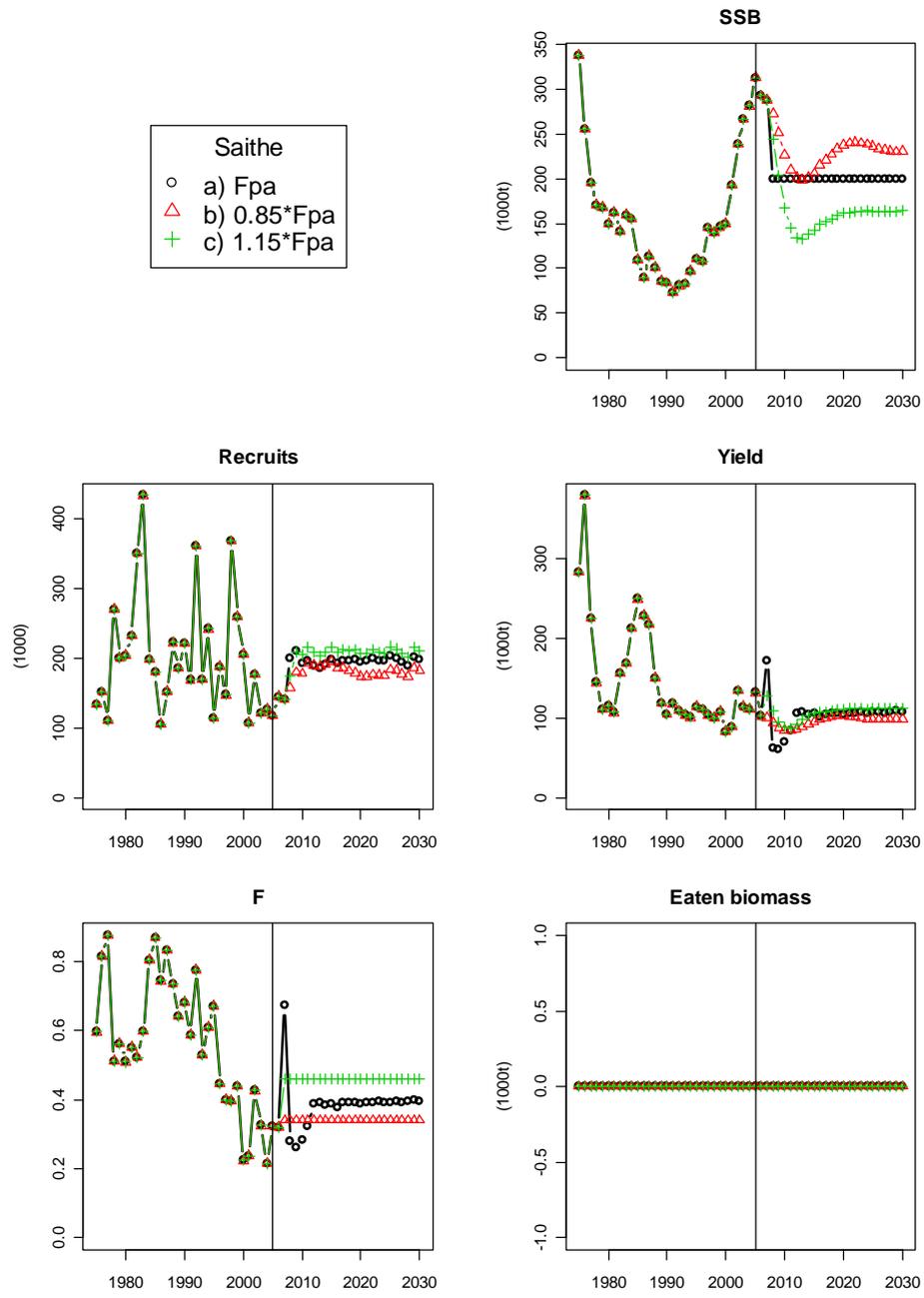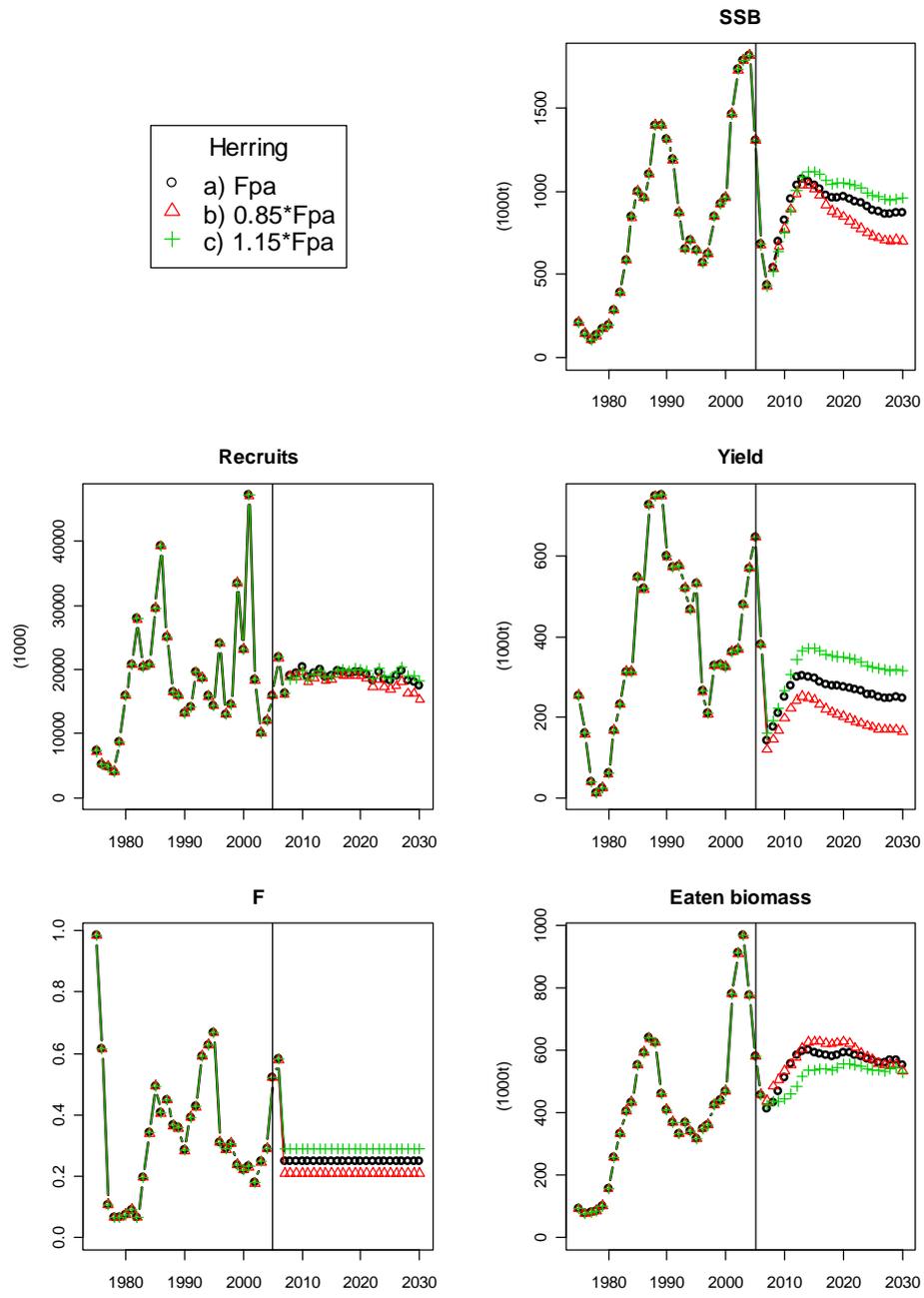
Figure 7.8 Continued. SMS model output for run with 3 levels of F (herring).

Figure 7.8 Continued. SMS model output for run with 3 levels of F (Norway pout).
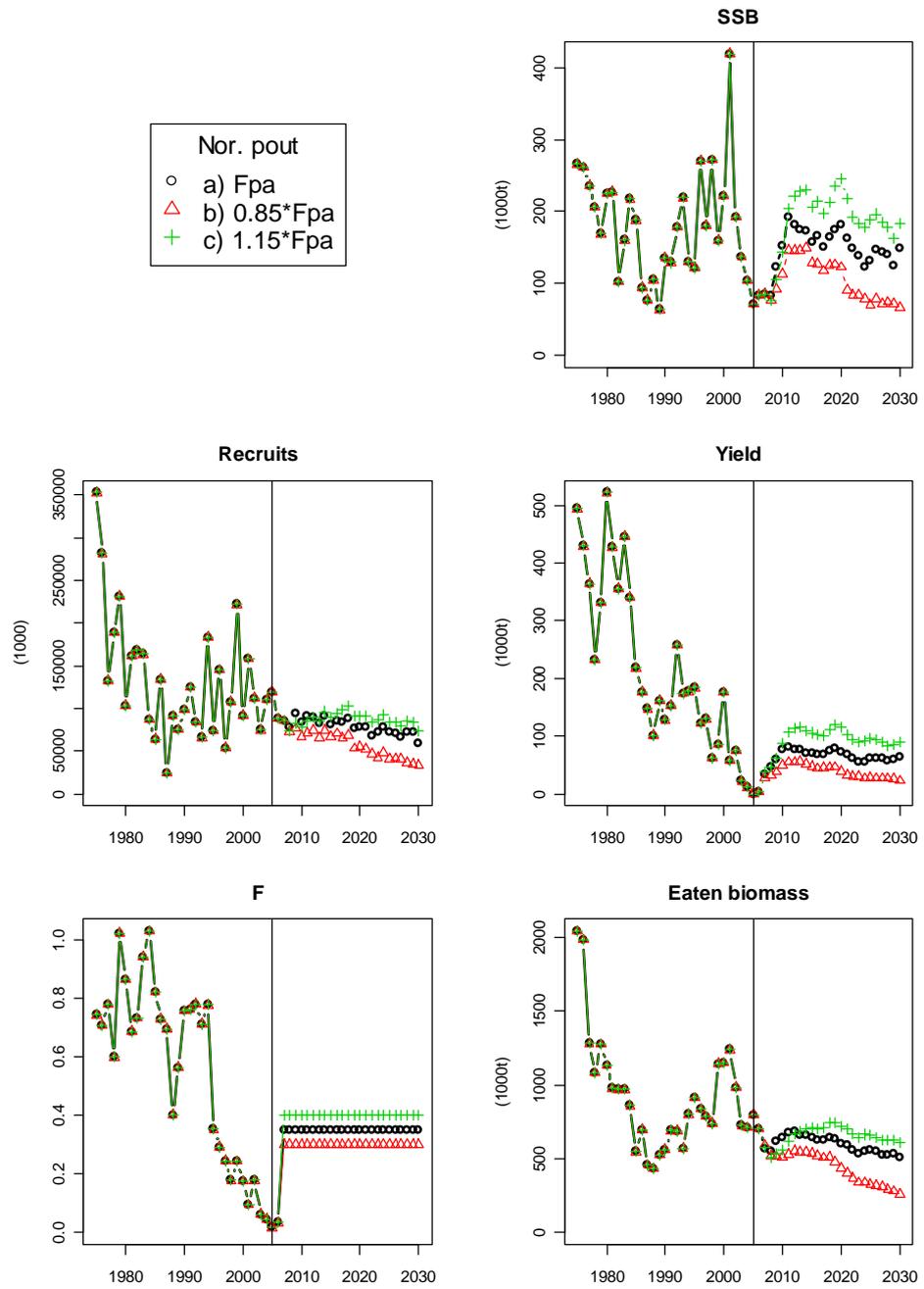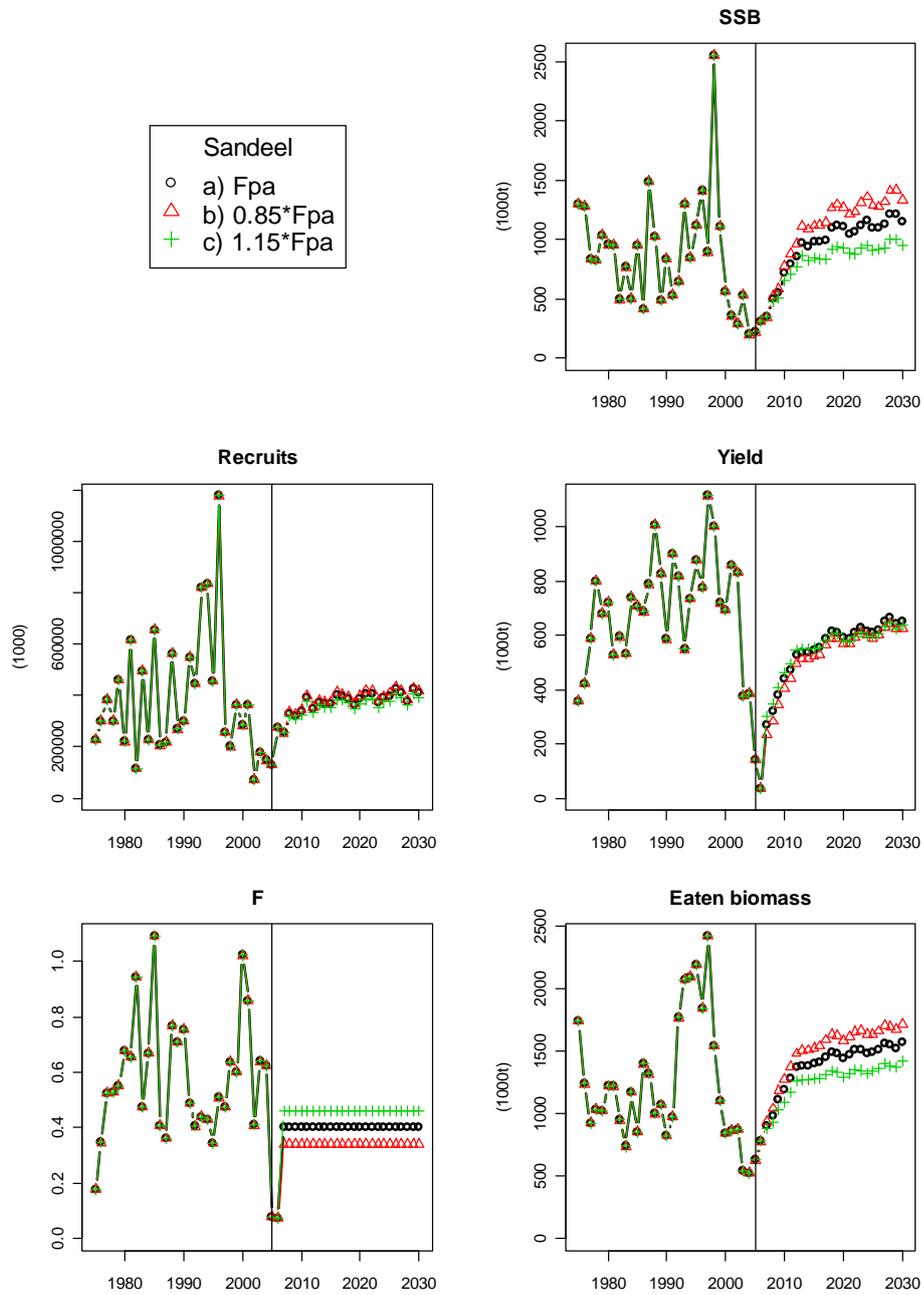
Figure 7.8 Continued. SMS model output for run with 3 levels of F (sandeel).

Figure 7.8 Continued. SMS model output for run with 3 levels of F (plaice).
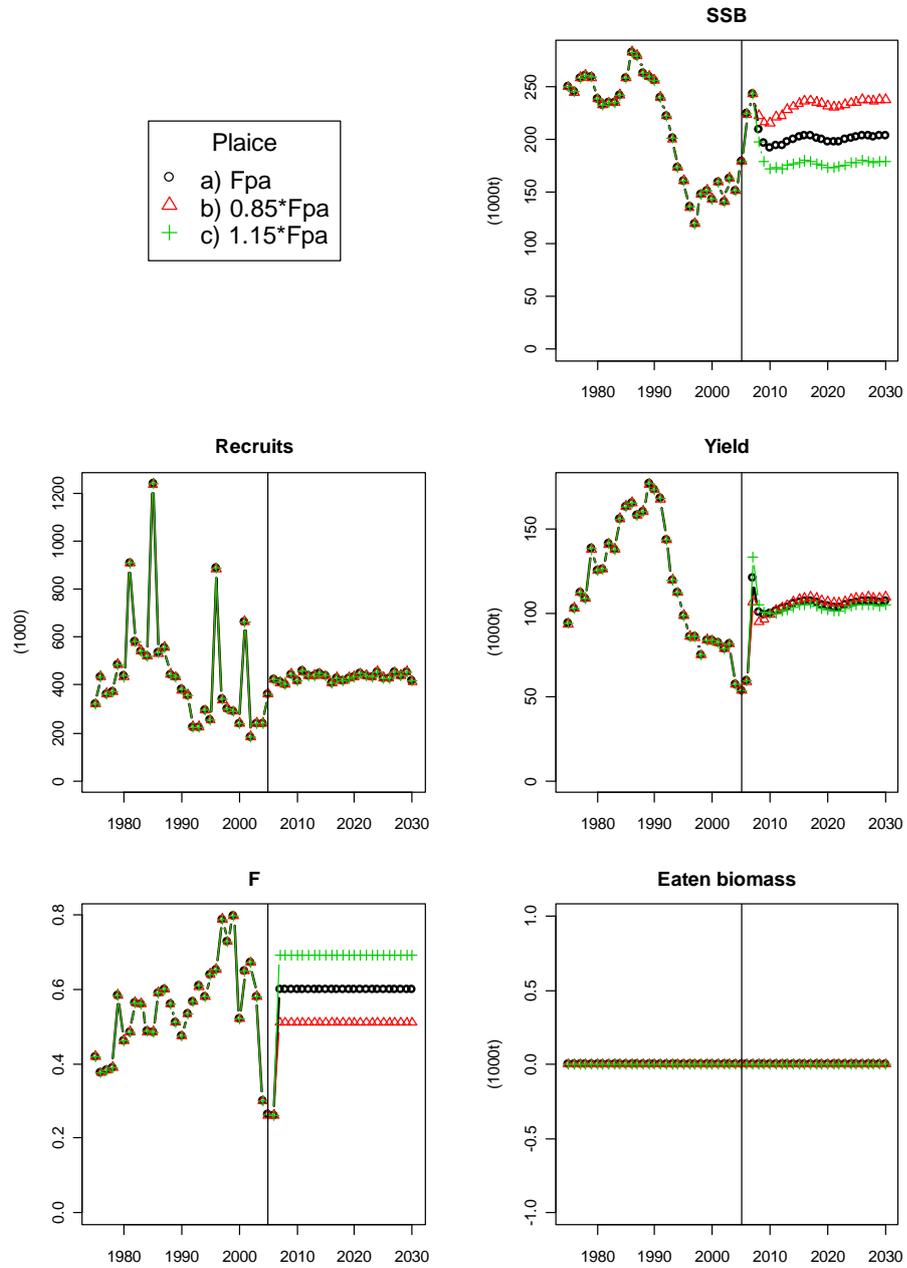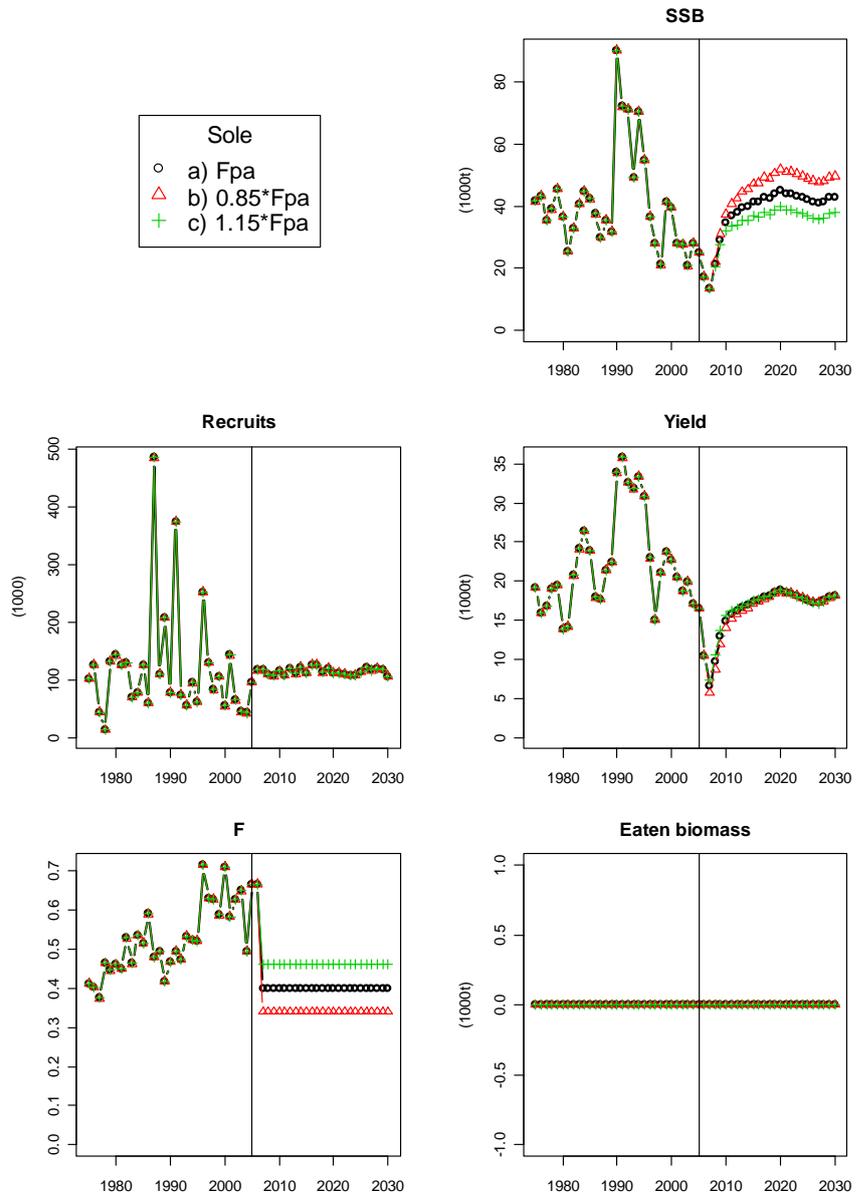
Figure 7.8 Continued. SMS model output for run with 3 levels of F (sole).

Figure 7.9. Proportion by weight of fish larger than 40 cm (cyan, lower) in the North Sea quarter one, for selected years (1975, 1985, 1990, 2000, 2005 and 2010) as estimated by SMS. Fishing mortality at 85% F_{pa} is assumed for projection.
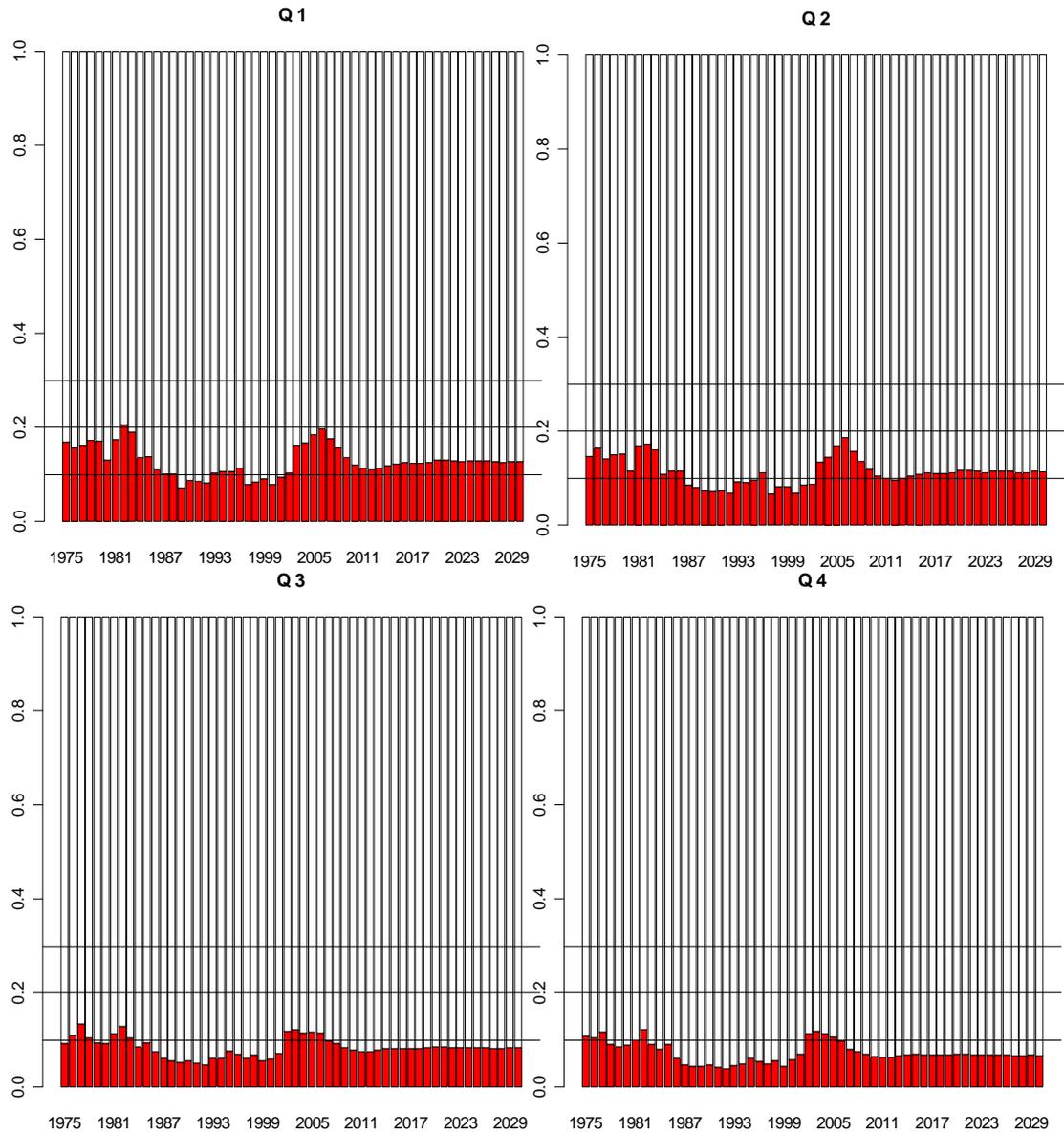
Figure 7.10. Proportion by weight of fish larger than 40 cm (red) in the North Sea by quarter of the year as estimated by SMS. Fishing mortality at 0.85 times F_{pa} is assumed for projection. The species includes *R. radiata,* grey gurnards, western mackerel, North Sea mackerel, western horse mackerel, North Sea horse mackerel, cod, whiting, haddock, saithe, herring, sandeel, Norway pout, plaice and sole.
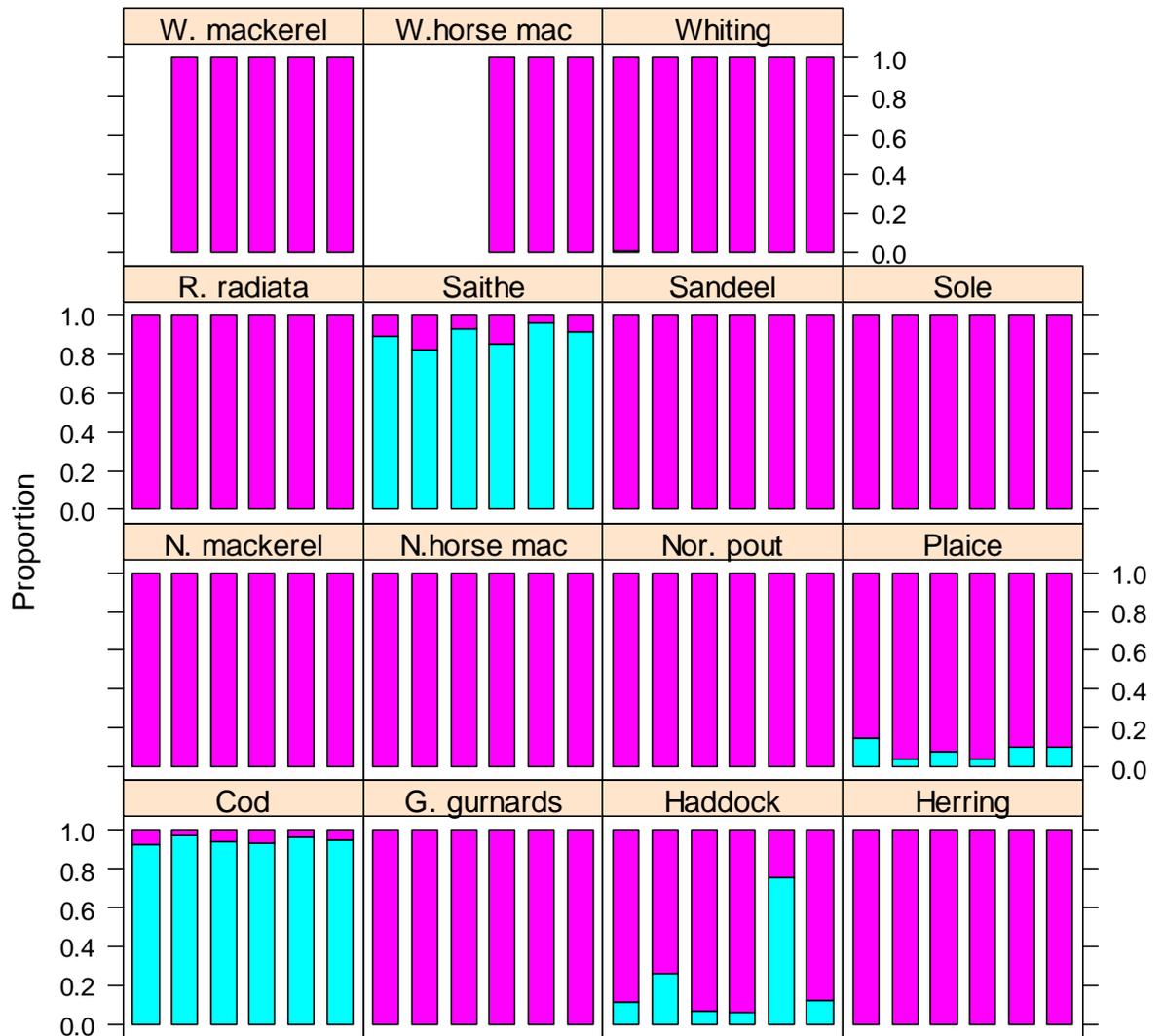
Figure 7.11. Proportion by weight of fish larger than 40 cm (cyan, lower) in the North Sea quarter one, for selected years (1975, 1985, 1990, 2000, 2005 and 2010) as estimated by SMS. Fishing mortality at 115% F$_{pa}$ is assumed for projection.
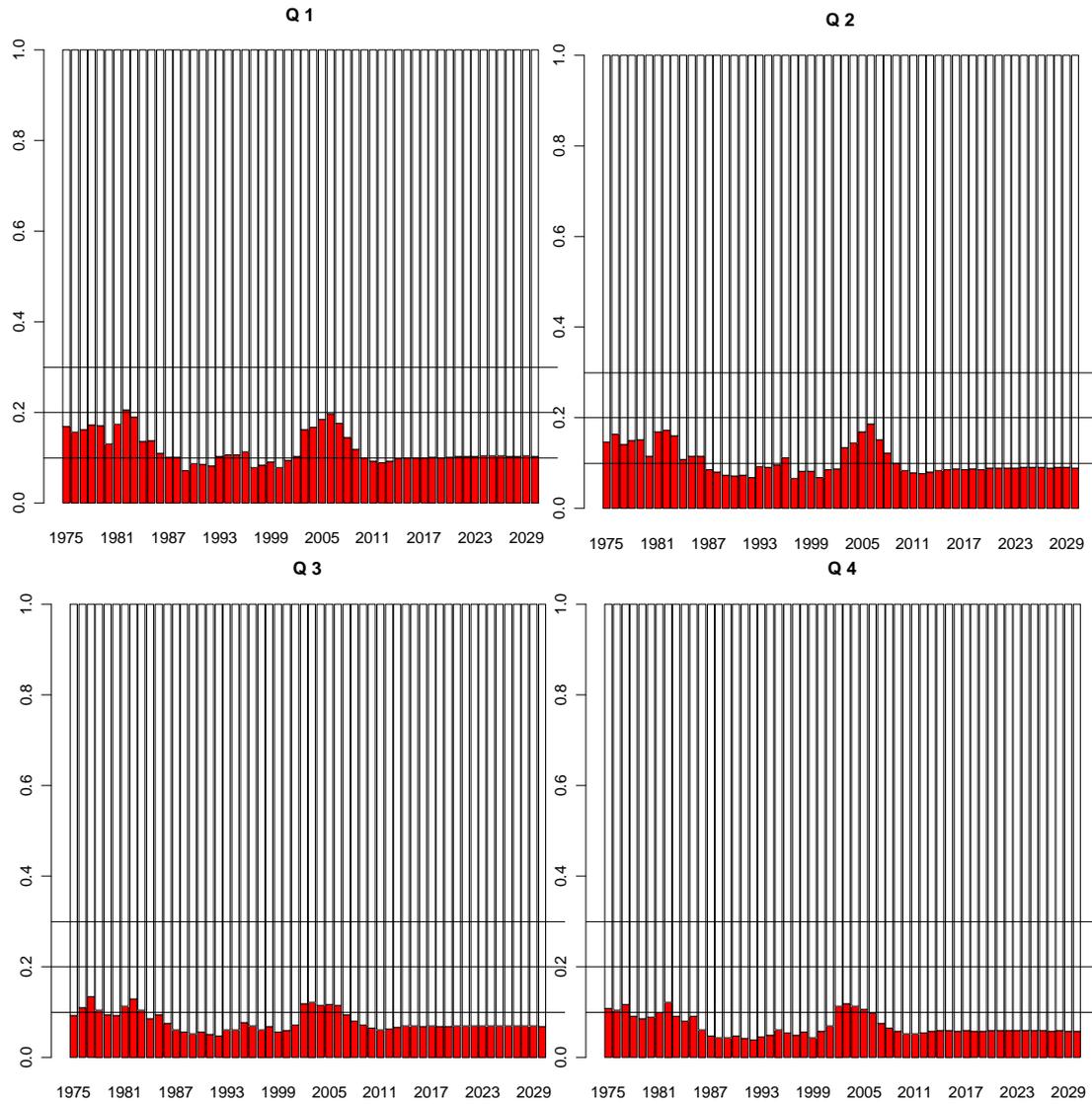
Figure 7.12. Proportion by weight of fish larger than 40 cm (red) in the North Sea by quarter of the year as estimated by SMS. Fishing mortality at 1.15 times F$_{pa}$ is assumed for projection. The species includes *R. radiata*, grey gurnards, western mackerel, North Sea mackerel, western horse mackerel, North Sea horse mackerel, cod, whiting, haddock, saithe, herring, sandeel, Norway pout, plaice and sole.

7.5 Conclusions

In this section WGSAM summarise the findings with respect to the Fish Community EcoQO target of "The proportion (by weight) for fish greater than 40cm in length should be greater than 0.3" (with a ±10% range in target values). The likely time scales required to reach these targets in a multi species modelling environment, in order to fill the following tables:

Table 7.7. The proportion (by weight) for fish > than 40cm.

Fishing mortality averaged across the seven main demersal species (cod, haddock, whiting, saithe, sole, plaice, Norway pout)	EcoQO Indicator Proportion (by weight) of fish > 40cm in length	Time to reach Indicator target
$0.85F_{pa}$	0.27	never, always < 15%
	0.30	never, always < 15%
	0.33	never, always < 15%
$1.00F_{pa}$	0.27	never, always < 15%
	0.30	never, always < 15%
	0.33	never, always < 15%
$1.15F_{pa}$	0.27	never, always < 15%
	0.30	never, always < 15%
	0.33	never, always < 15%

Table 7.8. The proportion (by weight) for fish greater than 25cm.

Fishing mortality averaged across the seven main demersal species (cod, haddock, whiting, saithe, sole, plaice, Norway pout)	EcoQO Indicator Proportion (by weight) of fish > 40cm in length	Time to reach Indicator target
$1.00F_{pa}$	0.27	always > 30%, ~40%
	0.30	always > 30%, ~40%
	0.33	always > 30%, ~40%

Table 7.9. The proportion (by weight) for fish greater than 30cm.

Fishing mortality averaged across the seven main demersal species (cod, haddock, whiting, saithe, sole, plaice, Norway pout)	EcoQO Indicator Proportion (by weight) of fish > 40cm in length	Time to reach Indicator target
$1.00F_{pa}$	0.27	currently above, drops < 30% (but not in Q4)
	0.30	currently above, drops < 30% (but not in Q4)
	0.33	currently above, drops < 30% (but not in Q4)

In general, the indicator target set by WGECO can be reached in two ways. Either the stock size of large fish (mainly cod and saithe) can be increased or the stocks of small forage fish decreased. Especially in the current situation of low sandeel and Norway pout stocks the indicator may not work as intended. For example in the years around 2005 the index exhibits a clear maximum, which is due to the collapse of the forage fish stocks. In the predictions with F set at F_{pa} these forage fish stocks are predicted to recover, which leads to a decreasing index below the target percentage of 30%. Thus leading to the wrong perception that the situation becomes worse compared to the current situation.

The size threshold of 40cm leads to a situation where only cod and saithe (and a few haddock and plaice) contribute to the component of large fish in the community. When the threshold is lowered more species contribute to this component.

The change of F_{pa} by only 15% up and down does not lead to substantial differences in the development of the index.

The presented results are different from similar survey based analyses in the way that there are fewer species in the model, even though the model includes the main part of the fish biomass. The SMS model excludes e.g. large flatfish, sharks and rays but it also misses sprat, which makes the resulting index more conservative. On the other hand WGSAM have a better representation of sandeel in the model than in the survey data, because of the low catchability in the IBTS (Fraser *et al.,* 2007). Essentially, the analyses are not directly comparable and each has to be viewed with its own caveats.

In some cases the EcoQO index value depends highly on the quarter of the year. In quarters where recruitment takes place (3rd quarter in the model) the indicator value will be lower compared to quarters without larger recruitment events. In addition, the large predator stocks of western mackerel and horse mackerel invading the North Sea in the 3rd and 4th quarter have a high impact on the index value.

WGSAM would like to repeat the modelling exercise but it would be good to have more detailed guidelines, especially which quarters to use and which species to include in the index. WGSAM hopes that the presented results help to revive the discussion on the behaviour of the EcoQQ and the most useful size threshold.

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Annex 2: Agenda

Monday 15 October

10:00	Welcome and Introductions
10:30	Plan of activities for the week, Terms-of-Reference, list of presentations
11:00	Refreshment break
11:30	*Term of Reference 'a'*. A series of short presentations (10 minute) describing multispecies/ecosystem modelling efforts across the ICES area – including an account of activities under the EU 'BECAUSE' Project.
12:30	Lunch break
13:30	(continued) presentations from partner institutions.
15:30	Refreshment break
15:45	*Discussion session*: a matrix of multispecies modelling efforts (past and present) across the ICES area, by Ecoregion.
	Drafting session: a table of known multispecies models, the number of species/groups included, date of the last update etc. Identification of regions where there has been limited research.
17:00	Close

Tuesday 16 October

09:00	Short plenary session, followed by break-out groups writing text on each ICES Ecoregion (as well as examples from western Atlantic) for inclusion in WGSAM final report. What models have been applied, what data exist, future plans etc.
11:00	Refreshment break
11:30	*Term of Reference 'c' and 'd'*. Series of short (10 minute) presentations focussing data and modelling – with respect to the 'bottom up' impacts of limited prey availability on predator body 'condition', weight at age etc. Examples might include:

- projects focussing on sandeels and their predators in the North Sea (IMPRESS, MF0323, McCann *et al.*, early MSVPA work on industrial fisheries)

- projects focussing on capelin and cod in Iceland and the Barents Sea.

- MSGVPA and BECAUSE work in the Baltic (cod cannibalism and sprat etc.)

12:30	Lunch break
13:30	(continued) presentations from partner institutions.
15:30	Refreshment break

15:45	*Discussion session*: what can we say about the likely 'bottom up' impacts of limited prey availability? Are there likely to be strong influences on other commercial fish stocks?
	Drafting session: preparation of text, outlining what is known regarding influence of forage fishes on production and condition of predators (by ICES Ecoregion?).
17:00	Close
20:00	Group Dinner

Wednesday 17 October

09:00	Short plenary session, followed by break-out groups writing text on each ICES Ecoregion (continued from previous day)
11:00	Refreshment break
11:30	*Term of Reference 'b'* Series of short (10 minute) presentations focussing on stomach sampling protocols across different ICES regions. Presentations will include: (1) Cefas – DAPSTOM database, (2) protocols/principles agreed at 2006 meeting of SGMSNS, (3) year-of-the-stomach database, (4) Norwegian stomach database, (5) other databases and sampling programmes.
12:30	Lunch break
13:30	*Discussion session:* experiences of 'good practice', common reporting/database standards/conventions, possible areas of expansion/collaboration. Use of stomach data to calculate mean-trophic-index (convention on biodiversity).
15:30	Refreshment break
15:45	Drafting session: preparation of guidelines and operation manual(s).
18:00	Close

Thursday 18 October

09:00	Short plenary session.
09:15	*Term of Reference 'e'*. Progress with Ecopath with Ecosim (EwE) models across the ICES area (models included in matrix – above). Any comparisons with multispecies assessment models?
11:00	Refreshment break
11:30	*Discussion/modelling session:* further comparisons between EwE and other model types. Is it possible to run comparative model trials during this workshop?
12:30	Lunch break
13:30	*Discussion/drafting session:* planned future model comparisons (at next meeting of WGSAM and elsewhere). Do we want to commit ourselves to running specific scenarios next year, if so – which models, what scenarios. New areas of model development.
15:30	Refreshment break

15:45   *Discussion/drafting session:* examine request for information/model outputs from WGECO. Do we need to instigate a series of model updates/key-runs next year? Draft a section of text in response.

18:00   Close

Friday 19 October

09:00   Short plenary session.

09:15   *Discussion/drafting session:* what should our ToRs be for next year? Should we aim for an ambitious program of model evaluation/comparison? Are there any pressing needs for data and analysis (e.g. increasing seal populations, climate change). Any requests for information from ACFM, LRC RMC?

11:00   Refreshment break

11:30   *Discussion:* future funding opportunities and plans for collaborative research. 'The big idea?'

12:30   Lunch break

13:30   *Drafting session:* completion of text for WGSAM report.

15:30   Any other business? Date/location of next year's WGSAM meeting.

15:45   Close

Annex 3: WGSAM Terms of Reference for the next meeting

2006/2/RMC08 The **Working Group on Multispecies Assessment Methods** [WGSAM] (Co-Chairs: John Pinnegar, UK and Bjarte Bogstad, Norway) will meet at the Department for Environment, Food and Rural Affairs (Defra), London, UK from 6–10 October 2008 to:

- a) Explore the concept of Maximum Sustainable Yield (MSY) within a multispecies context;
- b) Report on 'key-runs' (standardised 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 standardised 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.

Longer term aspirations (possible ToRs for future years)

Consider possible methodologies and techniques to better characterise predation processes affecting early-life history stages of fish.

Evaluate complementarities between different ecosystem and multispecies modelling approaches, for example the use of whole food-web models to provide better estimates of 'other food' in multispecies assessment models. Also links between biogeochemical ecosystem models, and models which focus on higher trophic levels.

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 for 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 which they are part of.
	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. Hence this pan-regional ICES working-group, accommodating these activities and including sea areas where multispecies development has been less linked to ICES should continue. 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 forum for reviewing progress within this field (ToR e).
	As ICES moves towards studies of target reference points, MSY is a key concept. Most countries are committed to achieving MSY under the terms of the World Summit of Sustainable Development by 2015. In a multispecies context, trade-offs will have to be considered, as the yield of all species cannot be maximized simultaneously (ToR a). Standardised outputs and reporting protocols are also needed (ToR b). There is also need for comparison of modelling exercises, both within and across regions (ToR c).
	Stomach content data serve as the basis for a plethora of multi-species, extended single-species, and ecosystem models. Having a solid foundation of adequate stomach content data is a pre-requisite 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. Feeding patterns should be evaluated to study inter-annual variations (ToR d). Such variations will have implications for multispecies models and future sampling requirements.
RESOURCE REQUIREMENTS:	–
PARTICIPANTS:	Approx 25. 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 WGs
LINKAGES TO OTHER ORGANISATIONS:	–

Annex 4: Stomach databases available to ICES partners

Area	Name	Accessibility	Software/Platform	Time Period	Structure	Size (records)	Pooled/Individual Stomachs	No. Predator Species	Contact Person/Reference/Institution
Barents Sea	Nor-Rus stomach DB	Limited, contact host	ASCII files	1984–present	Flat	366000+	Individual	20 (but 2/3 of total is cod)	Bjarte Bogstad, IMR/Andrey Dolgov, PINRO
Barents Sea	Marine mammals diet	Limited, contact host		1990–present			Individual	Harp seal, minke whale	Ulf Lindstrøm, IMR
Baltic	ICES Baltic cod	To be clarified	ASCII files	1977–1994	Flat	62000+	Pooled	1 (Cod)	Stefan Neuenfeldt, DIFRES
NW Atlantic (US)	FHDBS	Limited, contact host	Oracle data base	1973–present	Relational	500000	Individual	120	Jason Link, NMFS + web page
North Sea	ICES year of stomach	To be clarified		1981, 1985–1987, 1991	Flat		Mixed	8	Henrik Sparholt, ICES
Bay of Biscay	IEO	Limited, contact host	DBASEIII	1988–present	Flat	188000+	Individual	25	Ignacio Olaso, Francisco velasco IEO Santander
NW Atlantic (Newfoundland)	No name	Limited, contact host	ASCII files	1978–present	Flat	100000+	Individual	2 main spp (cod and Greenland halibut),	Mariano Koen-Alonso, NAFC
NW Atlantic (Scotian Shelf and Bay of Fundy)	Groundfish	Limited, contact host	Oracle data base	1958–present	Relational	100000+	Individual	32	Laurinolli *et al.* 2004
Iceland	No name	Limited, contact host	Oracle data base	1975–Present	Relational	280000	Individual since 1993	50, 10 regularly (60% from cod)	Ólafur Karvel Pálsson (okp@hafro.is)
UK waters (North Sea, Irish sea, Celtic Sea)	DAPSTOM	Partially open access (www.cefas.co.uk/dapstom)	MS ACCESS	1902–2006	Relational	103827	Mixed (mostly individual)	82	John Pinnegar, CEFAS (john.pinnegar@cefas.co.uk)

Annex 5: Multispecies Models Overview

Annex 5 - Table of Existing models by area.

REGION	ICES Ecoregion	Ecopath with Ecosim	MSVPA/4M	SMS	Gadget	ESAM	APECOSM	IBM	Dynamic	Osmose	ATLANTIS	MS-PROD, AGG-PROD
North Sea	F	Cefas (Mackinson and Daskalov 2007)	DIFRES, ICE	DIFRES & UniHH (BECAUSE & UNCOVER projects)					Cefas	IRD (Travers, Shin)/Cefas (Blanchard)		
Irish Sea	E	Cefas (Lees and Mackinson 2007)										Brander & Bennet (cod, Nephrops)
English Channel	F & E	Cefas, IFREMER (Mackinson, Stanford, Araujo, Villaneuva)										
Celtic Sea	E	Cefas (Lauria, Pinnegar, Mackinson)				CEFAS & IFREMER (Trenkel & Pinnegar)						
West Scotland	E	UBC, SAMS (Haggan, Pitcher, McGill, Heymans)										
Adriatic sea (Northern, Central, whole)	I	Coll et al. 2006, Uni Palermo, (Luca Palmeri, Alberto Barausse, Simone Libralato)								IRD (Shin)		
Barents Sea	B	Cefas (Blanchard, Mackinson, Pinnegar)				IMR - (Bjarte Bogstad, Daniel Howell)						
Norwegian shelf / Barents Sea	D & B	IMR - (Bjarte Bogstad, Are Domasness)/ UniTromso (Jannike Falk-				IMR - (Bjarte Bogstad, Daniel Howell)						
Black sea		Cefas (Daskalov 2002)										
Aegean sea	J	HCMR										
Bay of Biscay	G	Ainsworth et al. 2001				BECAUSE project	IRD/AZTI					
Baltic		Harvey et al. 2003	DIFRES	Difres, UniH, Lithunania? AWI?								
Meditteranean	H	Pinnegar and Polunin 2004		Vinther, Nu	BECAUSE project: Francesco Colloca (University of Rome "La Sapienza", Italy) & Mary LabropoulouAthens, Greece							
South Catalan Sea	H	Coll et al. 2006										
Cantabrian Sea	G	Sanchez and Olaso 2004										
Cantabrian Sea	G	Sanchez et al., 2005										
Iceland	A	Mendy and Buchary 2001			Yes							
Canada (4 regions)												
Eastern Scotian shelf		Bundy et al. 2004, 2005										
Northern Gulf of St Lawrence		Morisette et al. 2006										
Newfpundland-labrador shelf		Bundy et al. 2000										
NEUS (4 regions)												
Gulf of Maine		Link et al. 2006	MSVPA-X			Yes					Yes	Yes
Georges Bank		Link et al. 2006	MSVPA-X			Yes					Yes	Yes
Southern New England		Link et al. 2006	MSVPA-X			Yes					Yes	Yes
Middle Atlantic Bight		Link et al. 2006	MSVPA-X			Yes					Yes	Yes
Faroes	C	Zeller and Freire 2001, Zeller and Reinhart 2004, Booth and Seller 2005										
Azores	K	Guenette and Morato 2001										
Oceanic NE Atlantic	K	Vasconcellos 2002										
Atlantic Iberian Peninsula	G	IEO				YES						
Meditteranean-Adriatic	I	Coll et al, 2002										

Annex 5 - Table of Brief description of existing model types.

Shortname	Name	Purpose	Used in management	Brief description	Key references	
SYSTMOD	System model for the Norwegian and Barents Sea	Multispecies fish and fisheries		Piscivores and small pelagics with climate driver	Hamre and Hatlebakk 1998	
GADGET	Globally applicable area dissagregated general ecosystem toolbox,	Multi-species, -fleet, - area model.	Extended single species (AFWG), two-species mixed fishery (Mozambique)	Age-length structured multi-species, -fleet, - area model. Can include fish and marine mammals. Statistical fitting to data.	Frøysa et al. 2002; Begley and Howell, 2004; http://www.hafro.is/gadget	
EwE	Ecopath with Ecosim	Mutli compartment ecosystem model for ecological and fisheries investigations	Being applied to evaluate MSY for mixed demersal fisheries in the North Sea.	Food web model with temporal and spatial dynamics.	Mackinson and Daskalov *2007*	
OSMOSE	Marine ecOSystems Exploitation	multispecies and Individual-based		School based predator-prey model, focus on fish species, fish life cycles	Travers et al 2006, Shin and Cury 2004, Shin et al 2004,	
MSVPA/MSFOR	Multispecies Virtual Population Analysis	Stock assessment model including estimation of predation mortality.	Estimates of M2 is used in single species assessment for the North and Baltic Sea. A year independent M2 is assumed for the North Sea, while M2 changes by year for the Baltic Sea stocks.	MSVPA is an extension of the traditional VPA using catch at age and stomach contents data to estimate fishing and predation mortality at age. The model assumes constant food suitability defined for combinations of predators and prey species at age and by quarter of the year. Predator food ration is assumed constant. The model is deterministic and estimates the large number of suitabilities by an iterative process. MSFOR is the forecast mode of the model.	Sparre, P. 1991. Introduction to multispecies virtual population analysis. ICES J. Mar. Sci. Symp. 193: 12-21.	
4M	Multi-species, Multi-fleet, Multi-area Model	Multispecies,-fleet, -area model	Average M2s by species, age and season are transferred to single species assessment in Baltic and North Sea	MSVPA derivate, including fleets/areas covering top-predators, piscivores fish and small pelagics	Vinther et al., 2002 Köster et al. 2003	
SMS	Stochastic Multispecies Model	Stochastic assessment model including estimation of predation mortatlity from both fish species and dependent wildlife.	Single species version is used for stock assessment and for in evaluation of HCRs.	Stock assessment model including biological interaction estimated from a parameterised size dependent food selection model. Maximum likelihood is use to fit observations of catch-at-age data, survey CPUE and stomach contents data. When run in projection mode, the model can be used for management strategy evaluations.	Lewy and Vinther, 2004	
APESCOM	Apex Predators ECOSystem Model	Whole ecosystem		Spatially explicit size-based model of open-ocean ecosystems. Dynamic energy budget based.	Maury et al 2007 a and b *In Press*	
BIMS_HTL	Black Sea Integrated Modeling System	Small, medium and large pelagics		Dynamic mass flux model for the prey-predator interactions in the Black Sea. 3D pelagic lower trophic food web model (BIMS_ECO) coupled to POM-based circulation model (BIMS_CIR). Multiple functional groups of plankton coupled with nutrient cycling and redox processes	Oguz, 2007 (to appear in MEPS)	
Size spectra	Dynamic size sepctra				Blanchard	
ESAM	Extended Single Species models	Adding in other key factors that determine stock dynamics	Y	Extended Single Species models	multiple, e.g. NEFSC 2007a, b; Overholtz et al. 2007	
MS-PROD	Multi-species production model	Accounting for ecological interactions and fishery harvest in a production modeling framework	Y	Multi-species production models	Link 2003, Prager 1994	
ATLANTIS	ATLANTIS	Mutli-compartment, mutli-scale, multi-species, interdisciplinary mutli-ocean use sector simulation model and management evaluator	strategic only	Dynamic ecosystem model	Fulton et al. 2003, 2004	