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ICES International Council for the Exploration of the Sea

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Executive summary

This is the fourth report of the pan-regional Working Group on Multispecies Assessment Methods (WGSAM). The group met at AZTI Tecnalia in San Sebastian, Spain and reviewed ongoing multispecies and ecosystem modelling activities in each ICES ecoregion (including the North Sea, Baltic Sea, Bay of Biscay, Mediterranean, Iceland, Barents/Norwegian Seas, and eastern USA).

The participants provided an updated inventory, to supplement the information collated in 2007–2009 (ToR 'a' and 'b'). New information was presented for Iceland, Barents Sea, North Sea, Celtic Sea, Irish Sea, Bay of Biscay, Adriatic Sea, Baltic Sea, Gulf of Maine, Georges Bank, Southern New England and Middle Atlantic Bight. The group reviewed a key run for the Barents Sea and in addition compiled a summary dataset of natural mortalities, stock numbers and biomasses of the modelled species which will be available for download with the report. The key run-concept was further developed and a summary sheet produced which will accompany future key runs.

As in prior years, WGSAM strongly recommends a new stomach sampling program for the North Sea, the Baltic and other areas where no regular stomach sampling takes place (ToR 'c'); further justification is provided. WGSAM concurrently continued work towards such a programme by constructing a detailed manual for sampling of stomachs which was send to IBTSWG and WGBFIS for commentary on feasibility.

WGSAM works continually towards significant improvements in model functionality. This year, the work was focused on the development of cross-model validation techniques and suggestions of how to test various multispecies models using a common, virtual dataset were discussed along with the necessary characteristics of such datasets (ToR 'd').

An overview of models, methods and data were reviewed for including lower trophic level information into multispecies models (ToR 'g'). It was noted that this was particularly germane for the "other food" category in multispecies models. An overview of methods for visualizing various multispecies foodweb indicators was made (ToR 'e') and the possibility of including invasive and introduced species (ToR 'f') and the work towards including fleet dynamics (ToR 'h') in existing multispecies models was also reviewed.

Following requests from other Expert Groups, WGSAM made estimates of natural mortality for the Baltic Sea and North Sea available and provided positive commentary on the ICES stomach database. A comparison of the estimated natural mortalities of Baltic Sea clupeids with estimates using a previous model assuming constant weight-at-age over the period shows that the trend in weight-at-age of particularly sprat has led to changes in natural mortality.

1 Opening of the meeting

The **Working Group on Multispecies Assessment Methods** [WGSAM] met at AZTI Tecnalia in San Sebastian, Spain from 4–8 October 2010. The list of participants and contact details are given in Annex 1. The two Co-Chairs, Jason Link (US) and Anna Rindorf (DTU-AQUA, Denmark) welcomed the participants and highlighted that like last year, the Working Group had a broad geographic scope, this year encompassing research in the Bay of Biscay, Barents Sea, Norwegian Sea, North Sea, Adriatic Sea, Baltic Sea as well as the east coast of North America. The Terms of Reference for the meeting (see Section 2) were discussed, and a plan of action was adopted with individuals providing presentations on particular issues and allocated separate tasks to begin work on all ToRs.

1.1 Acknowledgements

WGSAM would like to thank Eider Andonegi (AZTI) for logistics during the meeting and Claire Welling of the ICES Secretariat for her continued support with the WGSAM SharePoint site. WGSAM also thanks Marina Chiffet for her presentation on coupled hydrodynamic, lower trophic level and size-spectra models.

2 Terms of reference

The **Working Group on Multispecies Assessment Methods** (WGSAM) co-chaired by Anna Rindorf*, Denmark and Jason Link*, US will meet in San Sebastian, Spain from 4–8 October 2010 to:

a) Review further progress in multispecies and ecosystem modelling throughout the ICES region;

b) Report on the development of key-runs (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the North Sea, Baltic Sea, Barents Sea and others as appropriate)

c) Work towards implementing new stomach sampling programmes in the ICES area in 2011

d) Define properties of 'virtual multispecies datasets' (including survey, catch and stomach content data) for use in multiple multispecies models, for comparison and sensitivity testing

e) Investigate ways to communicate results from multispecies and ecosystem models to decision-makers, including development of foodweb indicators and visualization techniques

f) Explore the feasibility of including introduced and invasive species in multispecies and ecosystem models

g) Review estimates of abundance and productivity at lower trophic levels, and work towards the inclusion of such information in multispecies models

h) Work towards inclusion of fleet dynamics in multispecies models

Of these, a) and b) are standing terms of reference, while c), d), g) and h) are 'multi-year projects'.

3 ToR a) Review further progress in multispecies and ecosystem modelling throughout the ICES region

3.1 Ecoregion A: Greenland and Iceland Seas

In the last year MRI in Iceland continued sampling of stomachs from cod and haddock in the groundfish survey in March and shrimp surveys in July and October. Stomach contents from approximately 10 demersal fish species were then sampled in the groundfish survey in October. All stomachs sampled in the surveys are analysed at sea. The data are punched-in online and are available immediately. The quality of the analysis is less than if the samples were frozen for later analysis in a laboratory and depends a lot on the skill of the individuals doing the analysis.

Additionally, an ongoing program where fishers collect stomach samples was continued (ongoing since 2001) with approximately 10 vessels participating each year. The protocol calls for sampling stomachs of a few cod, haddock and saithe each day they are fishing and only include species that exceed 5–10% of the total catch. Numbers of stomach sampled each year in this program has been around 6000.

Apart from the routine stomach sampling, substantial stomach sampling from mackerel and demersal fish took place in 2010. The motivation was that the abundance of mackerel in Icelandic waters has increased dramatically in last 2–3 years, so information about their role in the Icelandic ecosystem is important. The sampling from demersal fishes was designed to test the hypothesis advanced by some fishers that large cod and saithe prey on mackerel.

Analytical work done in 2010 has concentrated on summarizing and plotting stomach content data rather than any new major modelling work using the data.

3.1 Ecoregion B: Barents Sea

3.1.1 Improved time-series of 0-group fish in the Barents Sea

Work has been conducted on improving and extending the time-series of the 0-group biomasses in the Barents Sea (Eriksen *et al.*, accepted). These young fish form an important food source within the Barents Sea ecosystem, and consequently affect the predation mortalities within multispecies modelling. There are significant seasonal variations in the spatial distribution of the different 0-group fish, as well as trends through time. The paper examines the temporal and spatial variations in biomass indices of 0-group capelin, herring, cod and haddock over the years 1993–2009, and discusses the observed variations in relation to ocean temperature fluctuations and previous findings. These have been investigated, giving a foundation for improving handling of food availability within multispecies modelling, as well as identifying relationships between temperature and recruitment. This will form a key part of improving the predation within the Gadget model.

A number of stocks spawn along the Norwegian (capelin, cod, haddock and herring) and Murman (capelin) coasts and off the coast along the continental shelf (haddock) in February-April. New time-series of 0-group fish biomass indices have been calculated based on pelagic trawl catches during the Barents Sea 0-group survey in the years 1993–2009. The total biomass of the four most abundant 0-group fish species can be up to 3.3 million tonnes, with an average of 1.3 million tonnes and significant seasonal variations in distribution. Consequently, these fish are an important, and variable, mechanism for energy transport within the Barents Sea. In recent years the capelin has shown a pronounced northward shift in biomass distribution. This work also examined the relative importance of temperature and spawning stock on recruitment. Cod 0-group biomasses since 1993 were positively correlated with spawning-stock biomass, while correlation with temperature was not significant. Haddock and herring showed increasing 0-group biomass with increased temperature (when the spawning stock was at a sufficiently high level), and capelin showed several successive strong year classes during warm temperature conditions. The method was based on the work by Dingsør (2005) and Anon. (2006), with the dataseries extended to 2009.

3.1.2 Gadget models

3.1.2.1 Gadget-FLR development

Work has been completed linking the multispecies Barents Sea Gadget model as an operating model, with an assessment model in FLR, thus producing a complete operating model – assessment model cycle. This combined model has been used to evaluate the performance of the existing and alternative harvest control rules under different environmental conditions (Howell and Bogstad, 2010).

3.1.2.2 SYMBIOSES decision support tool

A project to produce a linked series of models to examine the effects of potential oil spills on the Barents Sea fisheries is in the late stages of planning. The primary objective is to develop a modelling system for the petroleum industry to perform ecosystem based impact assessments for the marine environment, initially for the Lofoten/Barents Sea. This tool will integrate oceanography and ecotoxicology with linked models for adult fish, fish larvae and plankton models and simulate population dynamics in response to environmental and biological factors. The tool is designed to evaluate the possible impacts of an oil spill first on the larvae of cod and capelin, then on the subsequent development of the fish populations within the Barents Sea. The work will link together existing stand alone models for oceanography, plankton, larvae, and adult fish into a coherent whole, with the focus on larval mortality as the key linkage between the submodels. This tool will also focus on producing useable outputs for incorporation in risk assessments.

3.1.3 STOCOBAR

The STOCOBAR model simulates stock dynamics of cod in the Barents Sea, taking fishery, trophic interactions and environmental influence into accounts (Filin, 2007). The last update of the STOCOBAR model for the Barents Sea was done to include temperature in the stock–recruitment equation for cod; the inclusion of the external driver was suspected to influence cod survival during the first year of life and also addressed some sources of uncertainty associated with TAC control in the cod fishery. The historical STOCOBAR assessments of the young cod consumed by cod in 1973–2006 were performed (Filin, 2010). A reasonable consistency between these estimates and those ones obtained in PINRO and IMR was observed; these estimates used the conventional method based on the stomach content data and the gastric evacuation model. Both approaches show a strong link to cannibalism in the northeast Arctic cod stock since 1984. However, cannibalism in the cod stock in 1995–1997 was less than that estimated from the conventional estimates. According to the estimate for 1973–1983 the level of cannibalism in the northeast Arctic cod stock was relatively low. It was probably caused by good feeding conditions for cod in the 1970s due to a large capelin stock in the Barents Sea. Available qualitative data on cod stomach content for that period support the model findings.

Using the STOCOBAR model evaluation of possible modifications of the cod HCR were done by examining changes in F_{pa} due to the inclusion of a capelin dependent F_{pa} in addition to the fixed F_{pa}. This alternative HCR resulted in a relatively small positive effect for the mean long-term cod yield and stock size. In order to make this alternative HCR more effective, it probably needs to also take into account the ratio between young and adult fish in the cod stock.

The continued development of the STOCOBAR model has been done within the EU project UNCOVER and the joint PINRO-IMR project on Optimal long-term harvest in the Barents Sea. For further information see the references noted here (Anonymous 2006, Dingsør 2005, Erikson *et al*. in press, Howell and Bogstad 2010).

3.2 Ecoregion C: Faroes

No updates were available in 2010.

3.3 Ecoregion D: Norwegian Sea

No updates were available in 2010.

3.4 Ecoregion E: Celtic Seas

3.4.1 Ecopath in the Celtic Sea

Work has recently been completed (at Cefas, together with University of Plymouth) to parameterize a detailed (64 box) Ecopath model for the Celtic Sea (ICES area VIIf-h). This model makes use of locally relevant stomach datasets previously described by Pinnegar *et al*. (2003) and Trenkel *et al*. (2005); biomass data from groundfish surveys; and invertebrate data from recent epibenthos and infauna surveys (e.g. Ellis *et al*., 2002). Efforts are currently underway to 'tune' the model using time-series of fish, zooplankton and seabird biomass (from surveys and CPR) as well as fisheries catch data (see Figure 3.5.1). The model is being used to investigate the impact of fisheries management policies (e.g. elimination of discards) and long-term climate change on seabirds in the region. A detailed technical report describing the model is being drafted (Valentina Lauria; University of Plymouth, UK) and will be available in 2010/11.

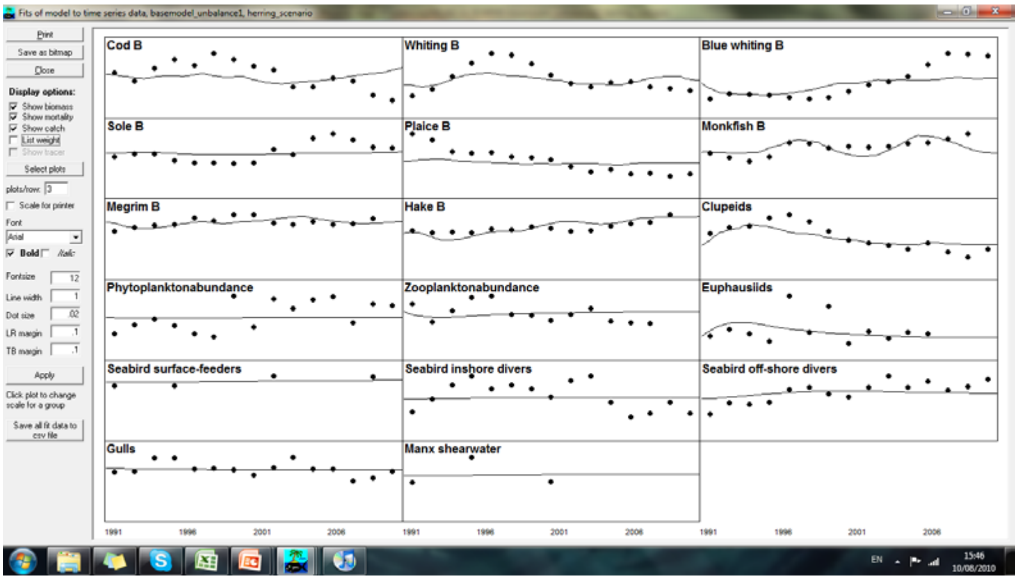

Figure 3.5.1. Preliminary Ecosim model fits for functional groups (commercial fish, plankton and seabirds) in the Celtic Sea (V. Lauria, unpublished data 2010).

In addition, the EU FP7 Project 'Basin' will resurrect an earlier 'Gadget' model (including cod, whiting and blue whiting) for the Celtic Sea (Trenkel *et al*., 2004)– the project is currently under negotiation and will begin in late 2010. The intention is for UK and French scientists to update the existing submodels and possibly add new parameterizations for hake and megrim.

3.4.2 A model of cod-Nephrops interactions in the Irish Sea

A recently completed data-rescue project (MF1109 – 'DAPSTOM-3') in the UK aimed at providing better understanding of trophic interactions among important commercial species in the Irish Sea, in particular those between cod and *Nephrops* (langoustine). This project aimed to digitize fish stomach content records for the region, including historic information spanning the 1970s, 1980s, 1990s and present day. A total of 9,194 additional records have been uploaded to the DAPSTOM database concerning fish in the Irish Sea, this has more than doubled (from 6181 records to 15,375 records) the quantity of data in the database from this region. There are now records for 60 species, including data on fish that are comparatively rare and of conservation importance such as angel-shark *Squatina squatina*, Aliss shad *Allosa allosa* and common skate *Raja batis*.

Initial efforts were made to use the length-based multispecies, multi-area modelling framework 'Gadget' (Begley and Howell 2004) to estimate cod and *Nephrops* population numbers, but this proved exceedingly complicated given that cod migrate into and out of the Nephrops area during different seasons (Bendall *et al*., 2009) and the fact that there is a general lack of information with which to parameterize the migration model. Consequently it was decided to abandon this idea, and to take a more empirical approach, making use of outputs (numbers-at-age) from the ICES stock assessment model for cod in the Irish Sea downscaled to the level of the *Nephrops* fishing grounds. This modelling work built upon earlier work by Brander and Bennett (1986, 1989), but used updated information on cod stomach contents, as well as improved survey data for both species. Knowledge of *Nephrops* abundance and biology was very limited in the 1980s (when the model of Brander and Bennett was constructed). However in recent years video survey techniques have evolved (at Cefas, AFBI and DARD) and hence it is now more feasible to examine the impact that exploitation on one species might have on the yield of another.

A first step involved calculation of cod numbers-at-age in each month of the year (for the whole Irish Sea), since the ICES stock assessment for cod only provides numbers for 1 January of each year (when juveniles 'recruit' to the population). A simple cohort decay model was used to calculate the numbers of animals remaining at the end of each month, subject to fishing and natural mortality (F and M). This model was extended to a two area model with three distinct time phases. Phase 1 comprised months 1–3, where cod numbers increased on the Nephrops ground due to spawning. Phase 2 comprised months 4–6 where cod started to migrate away from the spawning ground. Finally Phase 3 included months 7–12 where it was assumed no net migration would take place. The migration parameters were fitted using cod lpue bycatch data from the Northern Ireland commercial *Nephrops* fleet (single-rigged Nephrops trawlers), which inferred the temporal pattern of an increased and decreased abundance of cod on the *Nephrops* ground due to spawning (Figure 3.5.2). In addition to these data, evidence given in the report "MF160: Pilot study for fishery-independent monitoring of cod recovery in the Irish Sea by means of egg production surveys" suggesting that 50% of the SSB exists on the Nephrops ground in the spawning period was also used. The parameterized model was then used to give the numbers-at-age both on and off the *Nephrops* ground each month.

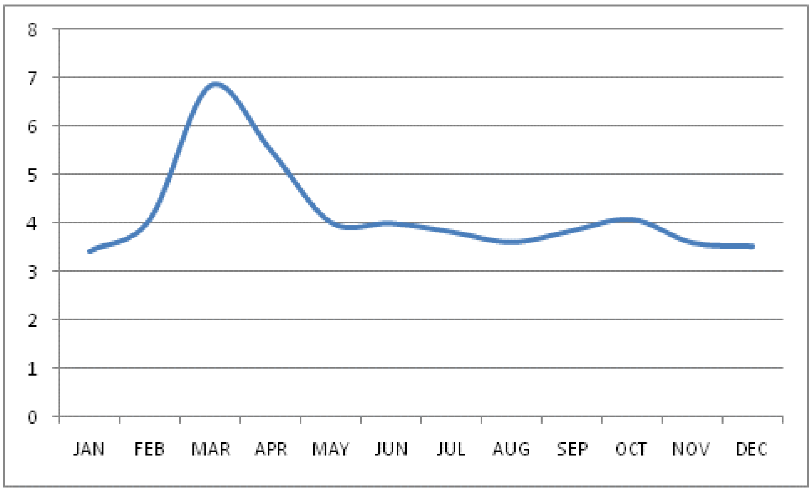

Figure 3.5.2. Relative landings-per-unit-effort (LPUE) of cod within ICES rectangles 36E4 and 37E4 throughout the year (averaged over 1995–2005) (M Platts, Unpublished Data 2010).

Because cod select their prey on the basis of size (both their own size and that of the prey) rather than age, it was necessary to convert numbers-at-age to numbers-at-length. This was achieved through the use of age-length datasets (spanning 1992–2003) provided by AFBI in Northern Ireland. Monthly data were aggregated (averaged) to quarters, since only quarterly age-length data were available, and a von-Bertalanffy growth function was fitted to these data. Data from all years were combined (because of the small sample sizes in particular years) and linear regression was used to establish the relationship between standard deviation (of the numbers-at-length per age group) and fish length, since it is known that the variability of fish lengths-at-age increase with size (i.e. young fish typically exhibit a narrow size range, but older cohorts typically exhibit a wider distribution of sizes). The resulting distributions (proportions of an age group falling in each 1cm length class) were then used to convert the numbers-at-age both 'within' and 'outside' the *Nephrops* area, into numbers-at-length.

Daily ration (food consumption) at length was estimated using a gastric evacuation model described in Armstrong *et al*. (1991). The mean daily intake per unit body mass was computed by means of the expression derived by Jones (1974) for the rate of elimination of food by haddock, cod and whiting:

$$r = 24 \cdot \left(\frac{L}{40}\right)^{1.4} \cdot w^{0.46} \cdot 10^{0.035\,(T_o - T_C)} \cdot Q$$

Where r is the rate of elimination (g per day) of food from the stomach of a fish L cm long with mean stomach content mass w resulting from continuous feeding at an ambient temperature To ºC, and Q is the hourly rate of elimination of 1g of food of appropriate type from the stomach of a 40cm fish at an arbitrary temperature TC ºC. Armstrong *et al*. (1991) suggested that *Nephrops* are evacuated from cod stomachs at approximately half the rate of fish prey, because of their thick exoskeletons. In view of this finding, it has been assumed that a value of Q = 0.075, i.e. half the value for fish prey given by Jones (1974), would be appropriate for Nephrops. The expression above was applied to each length-class of cod to estimate the mean daily intake of food r_j in each length class j as a percentage of the mean mass of fish ($100 \cdot r_j/W_j$), as follows:

First, the value of Q for Nephrops was applied in the equation above to estimate the daily intake for a situation in which 100% of the stomach contents comprised Nephrops. Multiplying the figure by the observed average proportion by mass of Nephrops in the stomach contents (at a particular length) gave an estimate of the mean daily intake of this species (see Armstrong 1982 for a worked example of this method). This procedure was repeated for the other food types, and the values of daily intake were summed over prey-types to give the overall daily intake of food per individual in each length class of cod. For the purposes of the present study, the prey items other than Nephrops and fish were treated as an aggregate with a value of Q = 0.12. The relative proportions of the different food items in the daily intake were re-estimated. As the mean mass of food in the stomachs during the first quarter of the year was found to be significantly lower (as was seawater temperature), separate estimates of food intake were made for each season.

Given the new stomach data collected in 2009/2010 and historic data contained in the DAPSTOM-3 database it was possible to estimate the proportion of the diet (at length) that comprised of *Nephrops* in recent years. Figure 3.5.3 shows that *Nephrops* (orange) and fish (various shades of blue) represent increasingly important prey items for cod as individuals grow larger (whereas shrimps and crabs become less important).

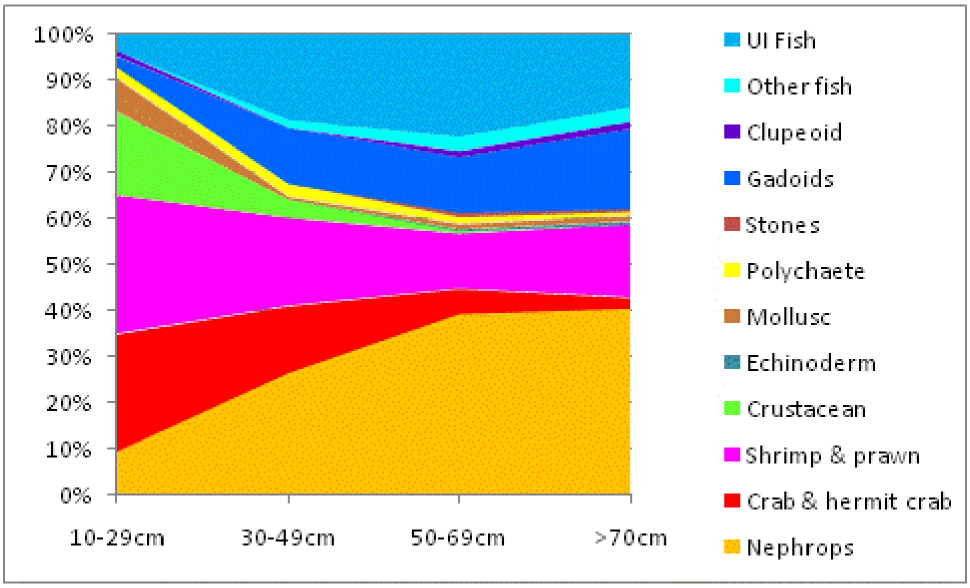

Figure 3.5.3. Proportion of diet represented by different prey types (number of prey items) in Irish Sea cod (ICES rectangles 36E4 and 37E4), based on data collected in 2009 and 2010 (J Pinnegar, Unpublished Data 2010).

Figure 3.5.4 illustrates the resulting estimates of *Nephrops* consumption by cod in the Irish Sea. The analysis suggests that the quantity of *Nephrops* consumed has declined steadily since 2003 to around 150 tonnes/quarter (yearly totals for 2003–2007: 1.56, 1.08, 0.94, 0.68, 0.61 thousand tonnes), and this has largely been associated with a decline in the size of the Irish Sea cod stock (particularly the number of large individuals). Given the large size of the *Nephrops* stock on this side of the Irish Sea, this represents a relatively low mortality rate (especially compared to the 8.4 thousand tonnes removed by fisheries in 2007) and is much lower than the estimate provided by Armstrong (1991) for the period 1982–1983 (~1.7–5.4 thousand tonnes/year).

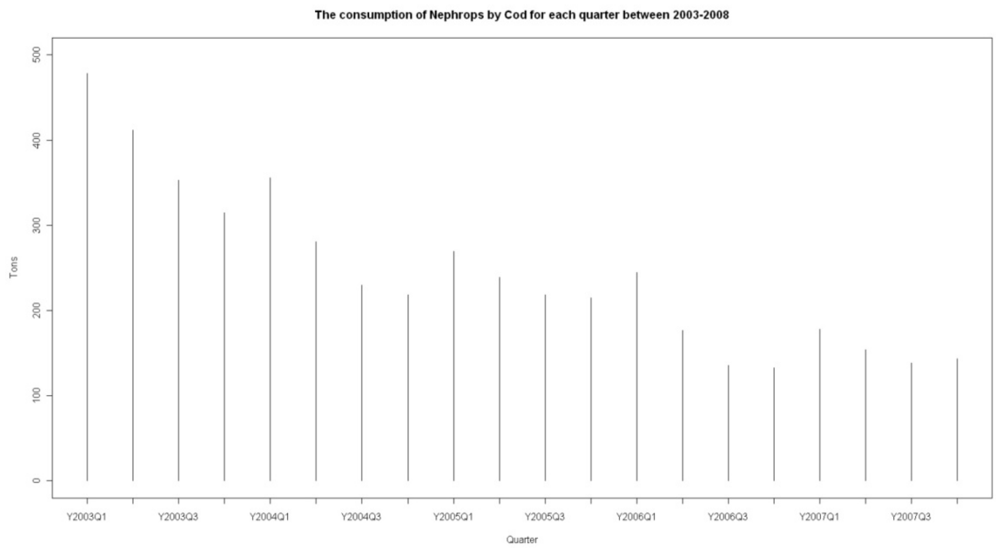

Figure 3.5.4. Consumption of *Nephrops* by cod in ICES rectangles 36E4 and 37E4, for the period 2003 to 2007 (M Platts, Unpublished Data 2010).

3.5 Ecoregion F: North Sea

3.5.1 Ecopath with Ecosim

A comprehensive Ecopath with Ecosim (EwE) model of the North Sea, comprising 68 functional groups 12 fishing fleets, and incorporating time and spatial dynamics was published by Mackinson and Daskalov (2007). The technical report includes data sources, assumptions and detailed outputs of sensitivity testing. The various chapters concerning particular functional groups are co-authored and have been peer-reviewed by international experts. The model has subsequently been used to investigate the relative roles of fishing and changes in primary production on changes in ecosystems around the world (Mackinson *et al.*, 2008), and to evaluate Maximum Sustainable Yield (MSY) within a multispecies context, on behalf of the North Sea Regional Advisory Council (Mackinson *et al.*, 2009). Spatial analyses to evaluate the efficacy of planned and existing marine protected areas in the North Sea is underway, preliminary work having been reported in LeQuesne *et al*. (2008). Recent work has been focused on four tasks (i) re-specification of the linkage between life stages using multi-stanza representation (ii) updating economic data based on Annual Economic Report 2008 and evaluating the effect of subsidies in the North Sea (Heymans *et al*. in prep), (iii) updating the proportion of the landings and discards of each species taken by each of 12 fleet defined by the DCF, as reported by STECF 2003–2007, (iv) including environmental drivers in dynamic simulation. In updating the model, a comprehensive time-series dataset consisting of 240 variables covering 1950–2008 has been compiled and is being used in an empirical analysis of changes in the North Sea. Work specific to ICES WGSAM ToRs is focused on establishing a 'key-run' (see ICES WGSAM 09, and ToR b below), with EU research projects supporting investigations of the relative roles of fishing and climate on North Sea dynamics, and coupling the foodweb to biogeochemical models (Beecham *et al*., 2010) so that future scenarios of climate change can be more adequately represented.

A key run of the North Sea EwE model is not available for this report, but with considerable progress having been made, completion and reporting is expected for 2011. WGSAM participants discussed how a key run for a EwE model should be constructed, particularly on the issue of whether parameters should be fitted using all ecosystem time-series to constrain the procedure or only time-series for fish. The group agreed that the great value of Ecopath as an ecosystem model is that it can use not just information on fish stocks but also on other parts of the ecosystem. It was therefore agreed that a key run should use all reliable and relevant time-series available in the model rather than just a subset.

An interesting outcome of the work on calibrating the North Sea EwE model was that when the fitting procedure is constrained by all available time-series ('Ecosystem constrained'), the model estimated primary production anomaly (NB: a function forcing changes in the PP, and cascading up the food chain) is more consistent with observed environmental time-series than the PP anomaly estimated by the model when only fish abundance time-series are used as a constraint ('Fish constrained'). It shows a strong positive correlation with Hadley SST, Atlantic multidecadal Oscillation and total nitrogen (Figure 3.6.1a) (and others including phosphorous, dissolved oxygen), and a moderate positive correlation with CPR estimates of phytoplankton cells (Figure 3.6.1.b).

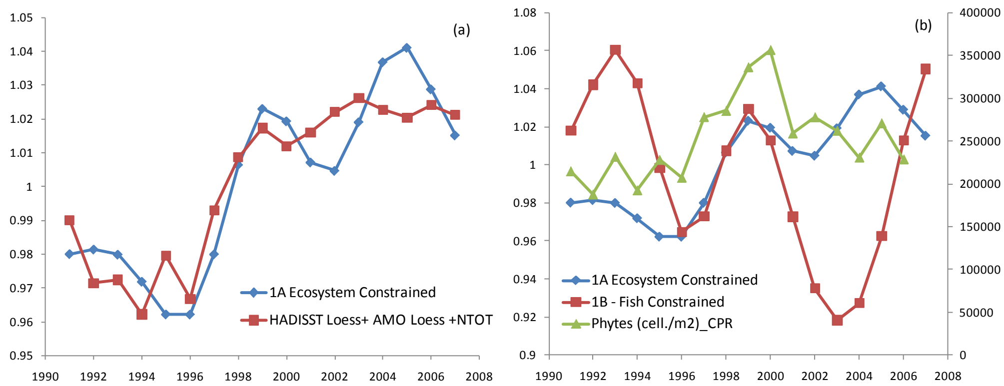

Figure 3.6.1. (a) 'Ecosystem constrained' model estimated PP anomaly compared to a combined environmental index (b) Model estimated PP anomalies compared to CPR phytoplankton data.

3.5.1.1 Ecopath interface for extraction of Key-run data

Through the course of 2009–2010, in collaboration with the University of British Columbia, Cefas (Mark Platts and Steven Mackinson) has developed a 'plugin' module for EwE version 6 that enables users to extract the results from Ecopath and Ecosim simulations tailor made to specific questions. The benefit of this is that the user only extracts the information needed, rather than dumping all data and filtering *post hoc*. For example, users may extract only information on the mortality of a prey caused by all its predators (or fleet), or the mortality that a given predator (or fleet) causes on its selected prey. Goodness of fit statistics, describing how well model predictions fit to observed time-series are now available for the first time. The statistics enable users to go in to the group level detail on how their model predictions perform over time. With the exception of network metrics, the facility also allows users to extract all the information required for describing a Key-Run (WGSAM 2009).

The latest version (includes fitting stats) and documentation on how to use it is packaged with the main EwE program; a BETA version can be found at the address below, with a main release to follow shortly:

ftp://ftp.fisheries.ubc.ca/ecopath/webfiles/EwE6/DailyBuilds/EwE6.1.0.1006_BETA_setup.exe

3.5.2 Implementation of varying spatial predator–prey overlap in the Stochastic Multi Species model SMS

The overlap between predators and prey is known to be a sensitive parameter in multispecies assessment models for fish; as such its parameterization is notoriously difficult. Schoener overlap indices were derived from trawl surveys and used to parameterize the North Sea Stochastic Multispecies model. For the first time suitability coefficients were no longer assumed to be constant over years. Instead the diet selection submodel was extended by allowing overlap coefficients and thus suitability coefficients to vary between years. The effect of time-invariant and year- and quarter-specific overlap estimates on the historical (1991–2007) predicted trophic interactions, as well as the development of predator and prey stocks, was investigated. The focus was on a general comparison between single-species and multispecies forecasts and the sensitivity of the predicted development of North Sea cod for the two types of overlap implementation (Table 3.6.1). Multispecies scenarios were highly influenced by assumptions on future spatial overlap (Figure 3.6.2), but they predicted a considerably lower recovery potential than single-species predictions did. In addition, a recovery of North Sea cod had strong negative effects on its prey stocks

(Figure 3.6.2). The spatial–temporal overlap between cod and its predators was found to increase with increasing temperature (Table 3.6.2), indicating that foodweb processes might reduce the recovery potential of cod during warm periods as could be shown in scenario forecasts (Figure 3.6.3). However, it has to be noted that absolute stock numbers should not be taken too *prima facie,* rather the focus of this work is on relative differences between the different forecasts. Especially in the absence of contemporary stomach data (the latest year of stomach data year collection was in 1991) predictions are highly uncertain. Although considerable effort was undertaken to include all processes needed to extrapolate from such dated information, validation with up to date data is warranted for future use multi species predictions for fisheries management.

For further information see Kempf *et al*. 2010.

Table 3.6.1. Single-species forecast (SS) and multispecies forecasts (MS) done with different assumptions on future spatial predator–prey overlap for the interactions between cod and its main predators (cod, whiting, grey gurnard). The overlap values calculated for 2007 were held constant for all other interactions in the multi species forecasts based on the hindcast with variable overlap.

SCENARIO	OVERLAP HINDCAST	OVERLAP FORECAST
SS	-	-
MS-ref	year-invariant	constant (hindcast)
MS-min	Variable	constant (minima 1991–2007)
MS-max	Variable	constant (maxima 1991–2007)
MS-0%	Variable	constant (average 2005–2007)
MS-2.5%	Variable	+2.5% year-1 (from average 2005–2007 for 2008)
MS-5%	Variable	+5% year–1 (from average 2005–2007 for 2008)

Table 3.6.2. Significant (*: <0.05; **: <0.005) Spearman-rho rank correlation coefficients between predator–prey overlap and mean North Sea SSTs by quarter (all other combinations failed the test).

OVERLAP (PREDATOR–PREY)	QUARTER 1	QUARTER 3
	(1983–2008)	(1991–2008)
Grey gurnard–cod	0.56**	0.74**
Cod–cod	0.41*	0.69*
Whiting–cod	0.65**	0.66**

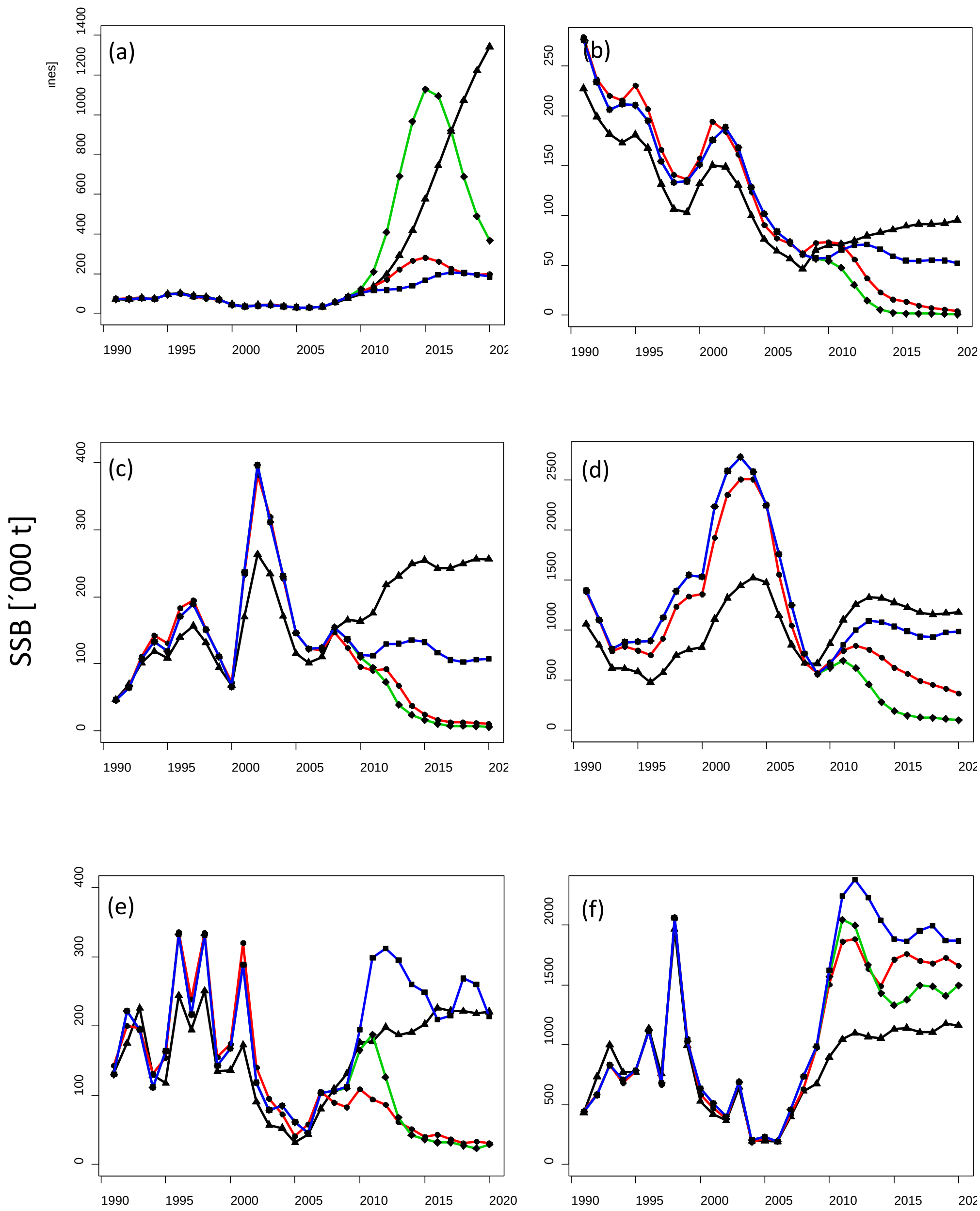

Figure 3.6.2. Hindcasted and forecasted first quarter spawning-stock biomass (SSB) trajectories for: (a) cod; (b) whiting; (c) haddock; (d) herring; (e) Norway pout; and (f) sandeel for different scenarios (cf. Table 3.6.1): SS: triangles; MS-ref: circles; MS-min: diamonds and MS-max: quadrats.

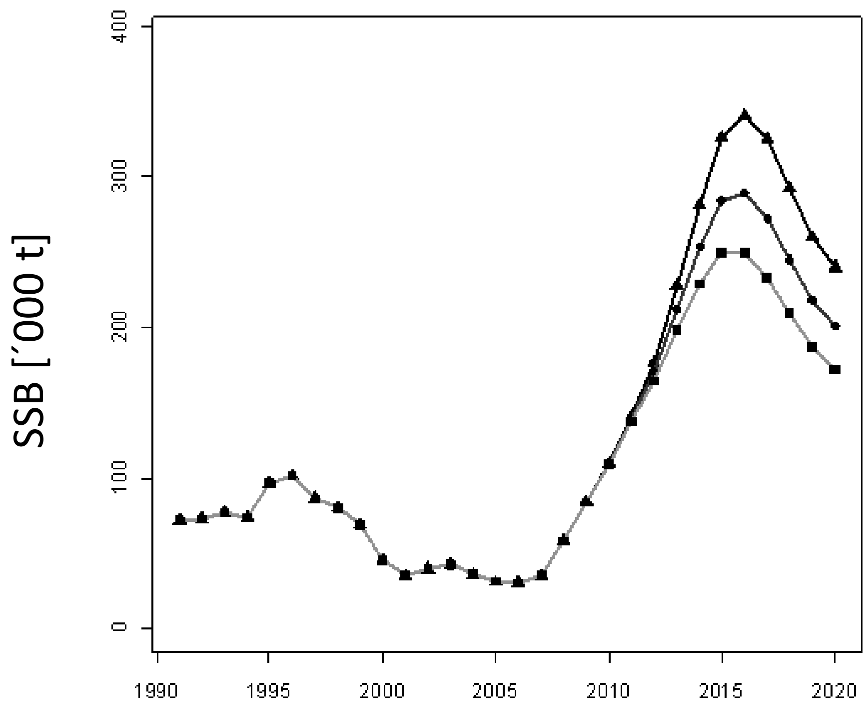

Figure 3.6.3. Hindcasted and forecasted first quarter cod spawning-stock biomass (SSB) trajectories under different assumptions on future spatial predator–prey overlap (cf. Table 3.6.1): MS-0%: triangles; MS-2.5%: circles and MS-5%: quadrats.

3.5.3 SMS

The work on the SMS model in the previous year has been centred on developing a likelihood compatible with a multispecies type II response (Murdoch, 1973) for the observed consumptions. The current food selection model is conceptually similar to the multispecies functional response with the exception that the total consumption is assumed constant over years and only the proportions of different prey types is modelled (Lewy and Vinther 2004). This requires the likelihoods to reflect that proportions must sum to one and this is currently attained by using the dirichlet statistical distribution. However, under a multispecies functional response with varying total consumption, there is no such restraint and a number of different distributions can potentially be used. The multispecies functional response has an additional parameter to the previous food selection parameters, the saturation level.

The work towards implementing varying total consumption has been divided into three: reestimating all consumptions with state-of-the-art methods (Rindorf *et al.*, 2010), estimating physiological saturation level from literature studies and developing a description of the likelihood of the observed stomach contents. The first of these has been completed and the methods are published in an ICES paper (Rindorf *et al.*, 2010). Work on the latter two is ongoing. Preliminary results show that larger predators are generally close to saturation whereas smaller predators are not. There are also differences between years, with saturation of cod and whiting being highest in the 3rd quarter in 1991.

3.6 Ecoregion G: South European Atlantic Shelf

3.6.1 Trophic data

Since 2009, AZTI-Tecnalia has been involved in an internal project funded by the Basque Government (called ECOSISTEMA) which includes as one of the main tasks sampling the stomachs from commercial landings of hake. Additionally, since July 2010 a new annual demersal sampling survey is conducted in the Basque coastal waters by AZTI-Tecnalia (funded by the Basque Government). This survey aims to provide additional information about the status of the ecosystem in those waters, which together with the stomach sampling programmes that already exist in the Bay of Biscay would help further the understanding of trophic processes in the southern Bay of Biscay ecosystem.

On the other hand, the annual demersal survey developed by the IEO since 1988 continued during 2009 and 2010 along the Cantabrian Sea and Galician Waters. In 2009, 12 800 stomachs of 45 different species, were analysed, focusing more on big predators and other commercial species (hake, monkfish, megrim, rays, blue withing, etc.). All these data have been used for multispecies modelling purposes in the Bay of Biscay and Iberian Peninsula.

3.6.2 Gadget models

Several Gadget models are being developed in this region. In particular there are two multispecies Gadget models that are being implemented in the Southern European Atlantic waters: the Gadget model in the Iberian Peninsula which aims to analyse the southern hake stock, including the cannibalism, and the Gadget model in the Bay of Biscay which aims to model the hake and anchovy trophic relationships in the study area. Both models are still in progress, with some updates to be noted in the sections below.

3.6.2.1 Gadget in the Iberian Peninsula for southern European hake

Since 2010 Gadget (Begley, 2004; Begley and Howell, 2004) is the model that has been chosen by ICES to be used in the Southern Hake assessment (ICES, 2010). Even if the official model is now a single-species model, the last goal of this study is to include cannibalism in it (Cerviño *et al*., 2008). As such, the cannibalistic version of the model represents an analytical advance for Southern hake. This model is now able to explain hake cannibalism and quantify mortality caused by cannibalism (M2).

3.6.2.2 Gadget in the Bay of Biscay for anchovy

A Gadget model has been developed to analyse the Bay of Biscay anchovy population. This application is intended to form a part of a fuller hake-anchovy multispecies model, with hake eating both small hake and anchovy. Anchovy is an important prey of hake, particularly in the northern and central part of the Bay of Biscay where it can comprise 18% of the weight of prey for some age groups of European hake (Mahe *et al*., 2007).

The model is capable of producing biomass and fishing mortality levels which are similar to those presented in the assessment working group (ICES, 2008). The recruitment historical series can also be simulated in this model in the same way as done in the assessment working group. This model has also been coupled to a new recruitment model developed in AZTI-Tecnalia (Fernandes *et al*., 2009); using supervised classification techniques to simulate both the recruitment levels given the environmental conditions of the area. This model has been used to simulate forecast scenarios under different fishing pressures (Andonegi *et al.*, submitted). Figure 3.7.1 shows a summary of the historical variation of the fishing pressure, the spawning-stock biomass (SSB), catches level and recruitment of the anchovy population in the Bay of Biscay. Therefore, some long-term forecast simulations have been included (the red line indicates the first year of the simulation) for a given fishing pressure scenario (high fishing pressure in this case).

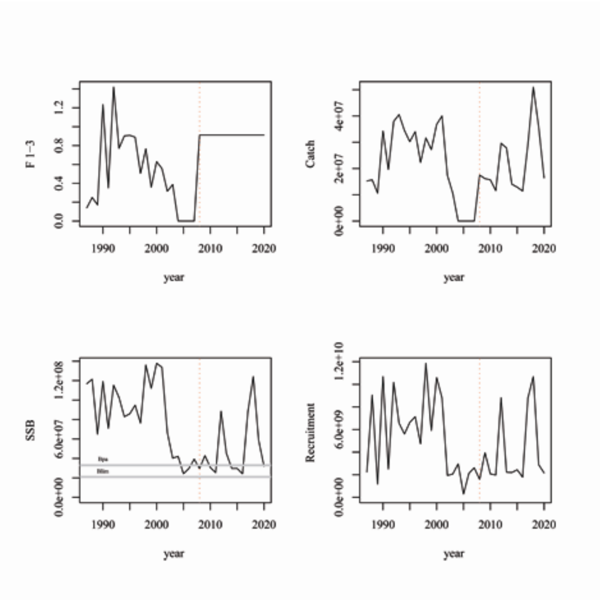

Figure 3.7.1. Summary of the evolution of the anchovy population dynamics in the Bay of Biscay.

3.6.2.3 Gadget in the Bay of Biscay for northern European hake

The multispecies model in the Bay of Biscay aims to simulate the effects hake predation have on the anchovy stock. Preliminary results show that the hake has a potential effect on anchovy dynamics, since the structure of the stock changes notably when comparing a single-species and multispecies model (see Figure 3.7.2). There is still some work to do since this model is only covering the hake and anchovy populations in the Bay of Biscay, and the goal is to extend it to the whole area of the northern stock of hake, as well as update it to 2009.

Since cannibalism is a very important process in the feeding patterns of hake, some work is being conducted in order to implement this process in the multispecies model. There are not yet reliable results since the model is still in a very preliminary stage.

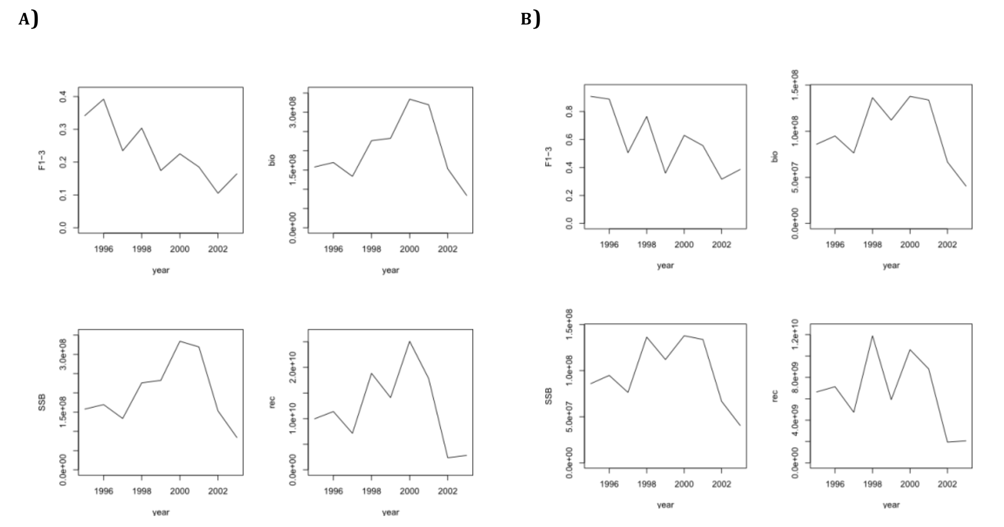

Figure 3.7.2. Comparison between the results obtained from the multispecies (a) and the single-species models for the anchovy population in the Bay of Biscay.

3.6.3 Ecopath and Ecosim

The Ecopath modelling (Polovina, 1984, Christensen and Pauly, 1992) tool was used to investigate the Bay of Biscay ecosystem as well as the multispecific fisheries operating in this region. The study defined this region as ICES areas VIIIa/b/c/d, constituting a total area of 223 000 km2. The model included 40 trophic groups corresponding to pelagic, demersal and benthic domains and also including detritus and fishery discards. Over 350 species were considered: Fish (200), invertebrates (89), seabirds (21), marine mammals (34) and primary producers. Basic Ecopath parameters and diet matrices were obtained from available literature, while catch information was obtained from available databases. Additional key parameters were also obtained from available literature or calculated externally to the Ecosim model. Groups for which data were unavailable were still accommodated but this necessitated that several potentially questionable assumptions had to be made.

The results indicated that the feeding pressure on primary producers, small and large zooplankton were all low in the system, which meant that a large percentage of the primary production in the Bay of Biscay passed to detritus. This observation emphasizes the importance of detritivorous species in the area. Estimation of the trophic level of the fishery, transfer efficiency between trophic levels, niche overlaps, mortalities, economic data and mixed trophic impact analysis (which considered the fishery both as an impacting and as an impacted component) were also included. Toothed cetaceans and large sharks were determined to be likely key groups in what is essentially an immature ecosystem (69% development capacity).

The mean trophic level of the Bay of Biscay fisheries has declined from 1983 (4.10) to 2008 (3.3). The negative trophic impact of fisheries on the different groups in the system was high. The various fishing gears also had a negative impact on each other due to the strong spatial competition between the different bottom and pelagic fisheries in the Bay of Biscay, and the inherent social conflicts present in the area.

3.6.4 OSMOSE

OSMOSE (Object-oriented Simulator of Marine ecOSystems Exploitation) is a multispecies model designed for upper trophic level marine organisms (fish species). This

2D model assumes opportunistic predation based on spatial co-occurrence and suitability of predator and prey sizes. It represents fish individuals grouped into schools, which are characterized by their size, weight, age, taxonomy and geographical location. The major life cycle processes such as growth, reproduction, predation, natural and starvation mortalities, migration and fishing mortality are modelled for each species. OSMOSE was first developed for the Benguela ecosystem (Shin and Cury 2001, Shin *et al.*, 2004), and is currently being adapted to the Bay of Biscay. The 8 most important commercial fish species have been included; these include small pelagic fish species to large predators. The basic parameters are taken from literature and survey reports. Phytoplankton and zooplankton concentrations simulated by the ROMS-NPZD model in the Bay of Biscay are used by OSMOSE as a prey field for the fish species. This model has a spatial resolution of 0.15º x 0.15º and a temporal resolution of two weeks.

In output, the biomass and abundance of the species are simulated. Additionally, a variety of size-based and species-based ecological indicators-- such as mean size, mean size-at-age, Shanon diversity index-- can be calculated. The model will be calibrated to observed biomass, using genetic algorithms. Twenty years simulation (2002–2022) will be performed, using the output of ROMS-ECOROMS model between 1998–2002 as input.

3.6.5 A Coupled ECOROMS+APECOSM model

A coupled regional hydrodynamic-ecosystem model (ROMS (Shchepetkin and Williams, 2003) + NPZD-type model) has been implemented for the Bay of Biscay system. The model domain covers the entire Bay of Biscay, extending from the French and Spanish coasts to south of the UK. Daily run-offs of most Spanish and French rivers, with temperature and nitrate and monthly climatologies when available, are used. The coupled hydrodynamic-lower trophic levels ECOROMS is then ready for coupling to the size-spectra ecosystem model APECOSM (Maury *et al.*, 2007).

Neither of these models are used for management purposes at the moment. Further details of the results are described in Section 9.

3.7 Ecoregion H: Western Mediterranean Sea

No updates were available in 2010.

3.8 Ecoregion I: Adriatic-Ionian Seas

The upper part of the Adriatic Sea is characterized by low shoreline, bordered with lagoons on the Western side and prevalently high rocky coastline on the Eastern side. The counter clockwise current dominates the basin circulation and the discharge of many rivers highly influences the chemical and physical characteristics of the ecosystem, especially in terms of nutrients and pollutants. Being one of the more productive areas of the Mediterranean Sea, the basin has been heavily exploited.

The area has had notable effort in terms of ecosystem modelling applications. At present, three different EwE models, describing the northern – central area of the basin, have been published (Coll *et al.*, 2007; Barasse *et al.*, 2009; Pranovi and Link, 2009). The main goal for all of them was to analyse the structure/functioning of the system relation to fishing pressure. No management actions have yet been implemented from these model results.

Additionally, several models have been published about the lagoon of Venice, an important lagoon in the Mediterranean Sea that is located on the Western Adriatic coast (Carrer and Opitz, 1999; Libralato *et al*., 2002; Pranovi *et al*., 2003; Libralato *et al*., 2009; Brigolin *et al*., in press). In this case, besides structure/functioning analysis, there are some preliminary implementation of management strategies, and the application of the modelling approach is different from the Adriatic EwE examples, particularly as these instances are using the inverse model approach.

Finally, an EwE application to a very small MPA located near Trieste has been executed (Libralato *et al*., 2010).

3.9 Ecoregion J: Aegean-Levantine

No updates were available in 2010.

3.10 Ecoregion K: Oceanic Northeast Atlantic

No updates were available in 2010.

3.11 Ecoregion L: Baltic Sea

3.11.1 Biological ensemble modelling of climate impacts for the Eastern Baltic Sea

The ecosystem-based approach to fisheries management implies that management should explicitly account for interactions among species and other ecosystem processes. Thus, diversity and complexity of models used for predicting fish stock responses to management have increased. Yet, the structural uncertainty associated with alternative models is rarely accounted for. Here we present the biological ensemble modelling approach (BEMA, Gårdmark *et al*., in prep.; ICES, 2010) to deal with such structural uncertainty.

Four single-species models, four multispecies models and one foodweb model were used to predict the response of Eastern Baltic cod (*Gadus morhua morhua*) to five alternative fisheries management scenarios and two climate change scenarios, assuming no climate change or a warmer and less saline future Baltic Sea. Although predictions differed qualitatively between the models, the BEMA provided a means to (i) present the full set of projected stock responses, (ii) assess whether these imply different conclusions on management, and (iii) draw general conclusions valid across all models used.

Table 3.12.1. Models used in the intersessional work on BEMA (for more details, also on the climatic scenarios, see ICES, 2009, Gårdmark *et al*., in prep.).

1	Stochastic Cod model	Wikström et al. in prep.	Auto-regressive (AR(1)) model of total cod biomass.
2	MCMC cod long-term projection model	Aro, E. ICES, 2008b.	Modified ICES medium-term projection model, age-structured cod
3	Cod mini-model	Müller-Karulis, in prep.	Age-structured cod model, similar to medium-term prediction models for Baltic herring stocks
4	Dynamic cod-herring-sprat model	Heikinheimo, in prep.	Age-structured cod, sprat, herring model including cod predation, modified from MSVPA
5	SMS (stochastic multispecies model)	Neuenfeldt *et al*. in prep.; Lewy and Vinther (2004)	Age-structured cod, sprat, herring model including cod predation and cannibalism, with size-based diet parameterization

6	Stage-structured multispecies model	Van Leeuwen *et al*. (2008)	Size-structured cod and sprat, with 2 zooplankton and 1 zoobenthic resources, including cod predation and resource-dependent growth of cod and sprat
7	BALMAR	Lindegren *et al*. (2009)	Multivariate autoregressive (MAR(1)) model of total biomass of cod, sprat, herring, Pseudocalanus, including cod predation, negative effect of sprat on herring and cod
8	Baltic NEST EwE foodweb model	Tomczak *et al*., in prep.	Ecopath/Ecosim model of age-structured cod, sprat and herring, and total biomass of foodweb components on 7 trophic levels (incl. plankton groups, benthic groups and seals).

Although predictions differed qualitatively between the models, the BEMA provided a means to (i) present the full set of projected stock responses, (ii) assess whether these imply different conclusions for management, and (iii) draw general conclusions valid across all models used. For the Eastern Baltic cod example, it was found that no recovery of the stock will occur if fishing returns to mean levels of 1996–2005, but that the stock will recover if the harvest follows what is in the management plan (even under climate change). The Biological Ensemble Modelling Approach (BEMA) has proven to be useful for collating and comparing possible future population developments, and for providing and communicating the range of projected outcomes. BEMA therefore has the potential to assist in management advice by enabling readily accessible evaluation of conclusions across models and scenarios. By identifying critical uncertainties, knowledge gaps and thereby structural causes of model ensemble variability, it is possible to focus the collection of field or experimental data and need for further model development, e.g. interactions, feedbacks and improved S-R models.

3.11.2 EwE models for Baltic Sea

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

For five Baltic costal ecosystems (Puck Bay, Curonian lagoon, Lithuanian Open Baltic coast, Gulf of Riga coast and Pärnu Bay) Ecopath models have been built to investigate trophic networks and carbon flows (Tomczak *et al*., 2009). Authors compared the models using 12 common functional groups. The studied systems ranged from the hypertrophic Curonian Lagoon to the mesotrophic Gulf of Riga coast. Interestingly, authors found that macrophytes were not consumed by grazers, but rather channelled into the detritus food chain. In all ecosystems fisheries had far reaching impacts on their target species and on the foodweb in general.

The current NEST Ecopath with Ecosim model (Tomczak at al., in prep) covers the area of the Central Baltic Sea (ICES SD 25–29 excluding Gulf of Riga) and contains 22 functional groups. The model has been created based on different databases and literature. Cod, herring and sprat are split into multi-stanza groups to represent the main ontogenetic changes and shifts in diets. Mezo-zooplankton community are split in to functional groups represents the 3 main species related groups and one group combine other zooplankton components. Fisheries are represented by 3 fleets fishing on the main fish species, however current work is related to evaluate and add number of fleet. The mass-balanced model represents the state of the ecosystem in the middle of 1970's and 1974 has been chosen as a baseline for the temporal Ecosim simulation. To fit and drive the Ecosim model, time-series of biomasses (fish, benthos, mysids, zooplankton, chl-a), catches (all fish species), fishing mortalities (all fish species) and environmental drivers (Temperature, Cod Reproductive Volume, Salinity, Primary production) have been tested. Dynamics of the pelagic foodweb is described and the model is fitted relatively well; however benthic part of food needs to be improved.

The Ecopath and Ecosim model for Kattegat (Lindgren and Tomczak – work in progress) is in the construction phase. First preliminary testing version should be ready for the end of the 2010.

Using a 'plugin' module for EwE version 6 done by (Mark Platts and Steven Mackinson) key run for Baltic Sea and Kattegat are planned for 2011.

3.12 Ecoregion M: Black Sea

No updates were available in 2010.

3.13 Ecoregion: Canadian Northwest Atlantic

No updates were available in 2010.

3.14 Ecoregion: US Northwest Atlantic

3.14.1 Ecopath with Ecosim

As part of work developing The Energy Modeling and Analysis eXercise (EMAX), 4 Ecopath models were developed covering the Gulf of Maine, Georges Bank, Southern New England and Middle Atlantic Bight (Link *et al.*, 2006). No updates have been executed for this model in the past year. However, several derivative studies have resulted from this work, particularly in comparative analysis (Gaichas *et al.*, 2009; Megrey *et al.*, 2009) and diagnostic method development (Link, 2010).

3.14.2 ATLANTIS

ATLANTIS (Fulton *et al.*, 2005) is by far the largest, most complicated model that the NMFS NEFSC 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 hydro-dynamics, 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.

Calibration of a base model scenario has been completed. This involved calibration in four stages: biophysical alone, fixed catch with further tuning of the biophysical parameters, fixed effort with dynamic catch, and finally a full dynamic model in which effort was allowed to vary via a set of simple rules related to changing effort based on cpue. A technical memorandum of the ATLANTIS NEUS model is now in press, which describes the full initialization, parameterization, steps of calibration and outputs of the base scenario for ATLANTIS NEUS.

Although parameterized, initialized and 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. Scenarios of different management strategies have begun to be executed, including scenarios that explore various levels and extents of spatial management, seasonal closures, targeted removals of specific groups, changes in gear or vessel requirements via alterations to effort and catchability, changes in oceanic or climatic conditions (such as nutrient levels, temperature, ocean acidification). The NEUS application of ATLANTIS is scheduled for a formal model review in early 2011.

3.14.3 GOMAG

NMFS NEFSC has completed construction of a model of the Gulf of Maine (GOM) ecosystem based on results from Ecopath modelling exercises (Overholtz and Link 2009). 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 EMAX GOM model were used to construct a simulation model using recipient controlled equations to model the flow of biomass and the biomass update equation used in Ecosim to model the annual biomass transition. Various performance measures and metrics such as throughput, total flow, biomass ratios (i.e. pelagic fish to zooplankton), and trophic reference points were examined 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 showed distinct changes. GOMAG has not been through a formal model review. This remains a research tool and has not been used for management purposes.

3.14.4 Extended single-species models

A suite of 'minimum realistic' models have been developed and, these models seek to add predation removals of a stock into a single species assessment model. These have been both age/stage structured and bulk biomass/production models. Examples of species where this approach has been used are predominately forage stocks, including Atlantic herring, Atlantic mackerel, longfin squid, and Northern shrimp. This work was done for two species of hake (silver, red) and Loligio squid in 2010. Several of these models have now 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 either an additional fleet or an external scalar for estimates of the magnitude of biomass. These consumptive removals (C) are contrasted to fisheries removals (L) to obtain a relative C/L level, which indicates the degree to which predation can influence the stock dynamics relative to fisheries. 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). Currently issues surrounding uncertainty, namely in estimation of predator abundance and inclusion of other, non-fish predators, are being addressed.

3.14.5 Single Species Add-ons: Ecological Footprints

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

These 'footprints' have been calculated for a wide range of groundfish, elasmobranch, and pelagic fish species. Calculations have been executed for spiny dogfish, pollock and goosefish in 2010. Several of these estimates have now been through a formal stock assessment review; calculations for distinct species are in various stages of development. The data required are abundance of predators that eat the stock of interest, stomach contents, consumption matrices, and diet composition estimates.

3.14.6 MSVPA-X

This 'extended' multispecies virtual population analysis is an expanded version of the ICES MSVPA model applied in Europe, which is in effect a series of single species VPAs linked together via a feeding model. MSVPA-X has been applied to two-subsystems in this region. One application is in conjunction with colleagues in the NMFS 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. No significant updates have been executed for either MSVPA-X application, but documentation for the mid-Atlantic version was in print in 2010 (Garrison *et al.*, 2010).

3.14.7 Multispecies production models: MS-PROD

MS-PROD is a multispecies extension of the Schaeffer production model which includes predation and competition terms in a guild context. This model simulates the relative importance of predation, intra-guild competition, inter-guild competition, and fisheries removals. A software package with a GUI and simulation engine is available. The primary use of MS-PROD is as a simulator, parameterized with empirically based values that can then explore sensitivities and different scenarios. The minimum data required for each species in the model are estimates of initial biomass, carrying capacities, predation and competition interaction terms, growth rates, and fishery removals. Additionally, the model incorporates spatial overlap terms as a modifier to the competition and predation terms. This model has not yet been through a formal review for application, but did inform recent groundfish stock assessments.

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. It allows for examining the effects of various levels and types of aggregation and allows for comparisons among the source of removals of a stock (e.g. predation v. fishing removals). While it is parameter intensive compared to single species models, it is less so than many other multispecies models. Additionally, due to the simplicity of the model structure, model runs are measured in seconds rather than hours. In spite of its simplicity, the model can simulate emergent behaviour in ecosystems that have been observed in other studies (e.g. indirect effects of interactions between species, compensation within guilds and the system as a whole, etc.). The software package currently does not fit or tune to time-series of survey or catch data. Plans for 2011 include adding a fitting element to the model and adding stochasticity to the simulator.

MS-PROD was recently documented in print (Gamble and Link 2009). The NEUS application of MS-PROD is a parameterization of the model for the Northeast US Large Marine Ecosystem (NEUS LME) which includes 25 stocks partitioned into three guilds (Groundfish, Pelagics, and Elasmobranchs) as defined by management in the NEUS. One of the scenarios explored was the effect of increasing the harvest rate on the entire system. The primary results were: 1) There was greater stability in biomass at the system level than at the guild level which in turn showed greater stability in biomass than at the individual stock level, 2) In spite of the relatively stable biomass in the groundfish guild until a harvest rate of 0.5 was applied, diversity within the groundfish guild decreased dramatically as the harvest rate was increased, leaving species with the highest growth rates to dominate, 3) The losses to biomass caused by competition or predation were often of the same order of magnitude as losses due to harvest rates at a reasonable level, 4) It was not possible for each stock to be at its B_{MSY}, even with a harvest rate of 0, unless species interactions were assumed to be absent.

3.14.8 Aggregate production models: Agg-PROD + SPMW

This model uses the same equation as the MS-PROD model noted above, but is collapsed to aggregate groups of species or stocks. These groups can be parameterized as functional guilds and/or taxonomically related species, therefore simulating group BRPs and more systemic level production. This will be useful for considering a two-tier quota system, with estimates of B_{MSY} for species and aggregated taxa groups. An important positive is that it is even simpler to parameterize than the full multispecies version of the model

Additionally, NMFS NEFSC hosted a CAMEO-funded trilateral workshop on multispecies stock production (Link *et al*., 2010). This stock production modelling workshop (SPMW) sought to quantify the importance of biophysical processes, trophodynamics and fishing on productivity in 11 northern marine fishery ecosystems. The specific objectives of the workshop were to (1) create a novel database and (2) use production modelling as a platform to initiate comparisons across species and ecosystems; and (3) undertake simulation modelling to assess the impact of different levels of aggregation on the inferences drawn. Several important outcomes were noted from this workshop. These included the cross-training of several staff from all the institutes involved on aspects of the development of the multi-ecosystem database structures and computer code to extract and analyse data from the database. After appropriate quality controls and final updates, the database should represent a sizable collection of integrated physical, lower trophic level, biomass, and fisheries data. The development of several analytical tools, in open-source code, was also an important outcome. Many of these models are now being tested, updated, and shall be used as tools to explore biological reference points at various levels of aggregation. Preliminary results were developed for production models across total fish biomass for these ecosystems and for a few functionally analogous species (e.g. cods, herrings) across these ecosystems. These initial results suggest that there are some common patterns driving overall fisheries production in these northern hemisphere ecosystems, but that the prominence of any particular driver varies among these systems. Empirical, multivariate analyses were conducted and confirmed the modelling results. Further, a range of simulation model applications were developed, preliminarily showing important differences across ranges of aggregations. A follow up workshop is planned for 2011.

3.14.9 Production potential models

A range of production potential models are under development. These models initiate with estimates of primarily production then discount that production as it transfers from what is produced at trophic level (TL) 1 up to TLs that are fished. Various permutations and assumptions are being constructed, but no results are presentable at this time.

3.15 References

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4 ToR b) Report on the development of key-runs (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the North Sea, Baltic Sea, Barents Sea and others as appropriate)

4.1 Frequency of updates required for single species assessment

WGSAM discussed that with the increasing number of stocks using yearly natural mortalities or functions hereof, there is an increasing pressure towards providing yearly updates of the key runs. Hence, the group discussed whether yearly updates are useful for assessment purposes and concluded that an update every three years is more appropriate because:

- Multi species modelling is a dynamic field of research. Yearly updates would mean that M2 trajectories change whenever improvements in the multi species models are achieved. For the North Sea and Baltic SMS considerable improvements (inclusion of seals in the model, new likelihood for modelling consumption) are planned during the next year. Therefore, an update next year (last update 2008 in the North Sea) will avoid that potential retrospective bias is introduced to the assessments.
- Mortality rates fluctuate between years. The uncertainties around these fluctuations, however, are high. Input to single species assessments should focus on trends and not on interannual fluctuations. Therefore, M2 values have to be smoothed over at least 3 years. Three years are also needed at minimum to detect a trend over time with some degree of certainty.
- WGSAM works with many different models from many different areas and has ToRs aside model updates. It is more realistic to do key runs every three years in a rolling scheme between areas and models.

For the time in between the updates, WGSAM therefore suggests options listed in Table 4.1.1.

Table 4.1.1. Rules for the calculation of M2 values in between the model updates.

Recent changes	Estimation in recent years
No trend in M2 in the last three years of the available time-series	Average over the last three years from unsmoothed M2 values or smoothed M2 value from the latest year dependent on what is used in the stock annex.
Strong trend in M2 in the last three years of the available time-series	Calculate a moving average out of non smoothed M2 values. Take the average over the last three years in update year +1, an average over the last two years and the average calculated for update year +1 in update year +2 and an average over the last data year and the calculated average values for update year +1 and +2 in update year +3.
Large changes in the ecosystem (strong recovery of predatgor stocks, collapse of important prey species)	A special request can be sent to WGSAM to provide updated model runs outside the regular updates.

4.2 Further elaboration of the format for Key runs

4.2.1 Key run metadata summary sheet

Table 4.1.2. Key run metadata summary sheet. This example is given for the Barent's Sea Gadget model application, but also serves as a useful template for other key run metadata reports.

AREA	BARENTS SEA
Model name	Gadget
Type of model	Age-length structured statistical estimation model
Run year	2010
Predatory species	Cod, Minke whale, herring
Prey species	Cod, herring, capelin
Time range	1985–2008
Timestep	Monthly
Area structure	Barents Sea + 3 single species areas without species interactions
Stomach data	Yearly
Purpose of key run	Making historic data on natural mortality available to the broader scientific community
Model changes since last key run	Not applicable
Output available at	http://www.ices.dk/reports/SSGSUE/2010/WGSAM/Barents_Sea_Gadget_summary.csv
Further details in	Report of the Working Group on Multispecies Assessment Methods 2010

4.3 Key run for the Barents Sea

4.3.1 Development of key run for the Barents Sea

The multispecies key runs for the North Sea and the Baltic are used to provide predation mortalities to single species assessments. As a result it is important for this key run to be evaluated and approved by the WGSAM meeting. This is not the case for the Barents Sea, as the current assessment methodology for the relevant species already includes predation explicitly. However there is still value in producing a key run for the Barents Sea in the same format as for the other areas in order to facilitate cross-model and cross-area comparisons. To this end the metadata sheet (4.2) has been developed for the Barents Sea Gadget model, and a script is being developed to take the output from the age/length-structured Gadget model and generate the specific age-structured format used in the key run outputs. This script will be sufficiently general to take the output from any Gadget model and convert to the required format, making similar key runs from the Bay of Biscay and Icelandic Gadget models feasible. The Barents Sea key run will be based on the model presenting in (Howell and Bogstad, 2010).

5 ToR c) Work towards implementing new stomach sampling programmes in the ICES area in 2011

In support of policies for sustainable management strategies of living marine resources, ICES and national scientific institutes are faced with growing demands for integrated ecosystem advice on the long-term impacts of fisheries as well as for prediction of effects of climate change, acidification and species composition and dominance. Europe has a legal commitment to maintaining 'good ecological status' or 'healthy ecosystem functioning', and to 'restore stocks to levels that can produce the Maximum Sustainable Yield (MSY)'.

Providing the necessary advice relies heavily on ecosystem models capable of evaluating how the effects of fishing and environmental change are spread through the ecosystem by complex foodweb interactions. The heart of all of these models is information on who-eats-who and how much. The last comprehensive investigation of species interactions in the North Sea and Baltic was conducted 20 years ago and is unlikely be representative of what is now a very different ecosystem. In order to assure that the multispecies and ecosystem models provide reliable predictions, it is essential that they are calibrated with up to date information to ensure the reliability of natural mortality estimates for use by assessment groups. However, we note that fish food habits sampling has been initiated in the Bay of Biscay partially as a result of WGSAM calling attention to the issue. We also note that other ICES areas (Norwegian and Barents Sea, eastern coast of Canada, eastern coast of the US) have ongoing stomach sampling programs.

Therefore, WGSAM suggests that under the auspices of ICES, the process of collecting food composition data on existing surveys should be initiated in those ICES areas where it is lacking. To assure that the stomach data sampled are subsequently used in the multispecies and ecosystem models, it is essential that a standardized sampling protocol is followed as was the case in previous large-scale stomach sampling exercises (ICES, 1991). However, since these exercises were performed new knowledge of the statistical properties of stomach content analyses has been gained. Annex 5 contains a draft of an updated sampling manual and is intended to be the start of the communication with IBTSWG and WGBFIS on the details of the sampling procedure as requested by PGCCDBS. Salient features associated with that manual are noted below.

5.1 Changes to the sampling strategy described in 1991 and their rationale

The Study Group on Multispecies Assessment in the North Sea (SGMSNS; ICES, 2006, ICES, 2007) analysed the precision of average diet estimates for North Sea species and linked precision to sampling level. This section gives a summary of the main conclusions:

1) 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 little gain in sampling a larger number of stomachs at a station. If the number of stations is not a limiting factor, it is much more cost-effective to sample only a few fish at each station while increasing the number of sampling stations.

2) 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 by pooling stomachs is limited.

3) Due to its 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 in increasing 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 sufficient to give a reasonable precision of diet data.

4) The geographical coverage of a stomach sampling program should at least match the finest spatial units used in modelling.

5) The greatest information on natural mortality of commercially important stocks comes from predator species with a high consumption of these species, either because the prey constitute a large part of the biomass consumed or because the predator has a large biomass.

6) Different invertebrate types affect the evacuation rate in the stomachs of fish prey differently. However, to estimate mortality of fish prey, it is not necessary to identify invertebrates to species. Instead, lower taxonomic resolutions suffice, with such as bivalvia, gastropoda, various classes or orders of crustacea and annelida suffice.

Based on this summary, the group recommends that the predators sampled be focused to cod in the Baltic Sea and cod, haddock, whiting, saithe, gurnard, horse mackerel, mackerel, starry ray, turbot and brill in the North Sea with John Dory and hake as optional extensions. The Celtic Sea could focus on similar species as the North Sea. The group recommends sampling between 2–5 rather than 10 stomachs per 5 cm size group of each predator, with the exception of saithe, mackerel and horse mackerel, where a large proportion of the stomachs can be empty. For these species, 10–15 stomachs should be sampled from each size group. Stomachs should be taken from fish that are already being sampled for maturity and age whenever possible. Depending on the level of information required from the stomach analyses (see below), the samples can either be analysed on board (only level 1) or frozen individually in plastic bags (levels 1 and 2) including a label describing the sampled fish (Table 5.1). Prey is recorded using TSN codes with new codes added for species not currently listed.

Further, the group proposes two different levels of stomach sampling

1) Minimum level needed for assessment purposes only. Only predators larger than 15 cm are sampled as fish below this size are generally not piscivorous. Stomach samples are analysed individually and fish prey identified to species. Length of fish prey is measured or estimated to the nearest cm below (eggs are recorded as having length 0) and digestive stage is recorded. Invertebrates are identified to lower taxonomic resolution groups (Table 5.2). Total prey weight and weight of individual prey groups is recorded (species for fish).

2) Extended level providing information on invertebrates. Predators down to 5 cm are sampled. Stomach samples are frozen individually on board and analysed in the lab. Fish and invertebrate prey is identified to species when possible. Length of fish and invertebrate prey is measured or estimated to

the nearest cm below. Total prey weight and weight of individual prey groups are recorded (to species for both fish and invertebrates).

Prior to the survey, WGSAM recommends that WGDIM produces a list of TSN codes and translate the old data from NODC to TSN.

Data would then be reported to ICES using the existing data exchange format (Table 5.3). In addition to the report format, the old manual contains checklists to keep track of the number of stomachs sampled. If necessary, these can be used directly or updated by IBTSWG/WGBFIS. Again, a revised manual draft is given in Annex 5.

WGSAM recognizes that having another year of the stomach whereby approximately 100 000 stomachs are sampled in major effort may be unpalatable for several ICES members. One alternative to this low frequency, high intensity approach that might make re-initiation of sampling more likely is to spread out the sampling by only doing one or two species per year over the course of time. Another alternative is to have a high frequency, low intensity sampling regime, similar to what is done, for example, in the US or Canada, whereby each species is sampled each year but at lower sample sizes. These approaches have been described in detail in prior WGSAM reports. Also from those prior reports, we reiterate that such sampling as piggy-backed on existing surveys is actually rather efficient.

Tabel 5.1. Label to be included with each stomach sample.

ICES STOMACH SAMPLING PROGRAMME
Ship
Haul number
Date
Rectangle
Species
Size
Sample no

Tabel 5.2. Invertebrate groups and corresponding NODC codes.

Invertebrate group	NODC code in 1991 sampling manual
Amphipoda	6168000000 and 6169000000
Annellidae	5000000000
Astacidae (unidentified)	6181000000
Astacidae identifiable as not being N. norvegicus	
Anomura	6183000000
Bivalvia	5500000000
Brachyuran	6184000000
Caridea	6179000000
Cephalopoda	5700000000
Cnidaria and ctenophora	3700000000 and 3800000000
Crangonidae	6179220000
crustacea (unidentified)	6100000000
Echinodermata	8100000000
Euphasiacea and mysidae	6174000000 and 5153000000
Gastropoda	5100000000
Nephrops norvegicus	6181010301
Pandalidae	6179180000
other crustacean	
other invertebrates	
Plastic	
Isopoda (unidentified)	
Isopoda identifiable as not being S. entomon	
Saduria entomon	

Tabel 5.3. Exchange format for stomach data (revised from ICES, 1999).

Position	Name	Type1	Range	Comments
1–2	Record type	2A		Fixed value 'SS'
3	Quarter	1N	1–4	
4–6	Country	3A		ICES alpha code
7–10	Ship	4A		ICES alpha code
11–13	Method	3A		See Table 5.4
14–17	Square	4AN		ICES statistical rectangle
18–23	Haul number	6AN		Compatible with the haul number available in DATRAS assuring that stomach samples can be matched with trawl data
24–27	Sample no	4N	1–9999	
28–29	Temperature	2N	-2–26	oC, not known 99.
30–31	Year	2N	10–99	
32–33	Month	2N	1–12	
34–35	Day	2N	1–31	
36–45	Predator code	10N		TSN Codes
46	Size group code	1A	E, F	E= 1cm groups, F=1mm groups below 2 cm, 1 cm groups above 2 cm
47–50	Predator size class code	4N	0–9999	Predator length measured to nearest cm below
59–61	Number with food	3N		1 if sample of food is taken, 0 if sample contains regurgitated, stomachs with skeletal remains or empty stomachs
62–64	Number regurgitated	3N		
65–67	Number with skeletal remains	3N		
68–70	Number empty	3N		
71–80	Prey species code	10N		TSN Codes for fish. For invertebrates and unidentified items, use TSN codes if available from WGDIM, otherwise use NODC codes
81–84	Prey size	4N		Prey length measured to nearest cm below (size group code E), or to nearest mm below up to 2 cm, then nearest cm below (size group code F). Eggs have size 0.
85–92	Prey weight	8N		Prey can be weighed together if they are of the same species/species group and same length
93–98	Prey number	6N		
99	Stage of digestion	1N	0–2	0= Intact prey, 1= partially digested prey, 2= skeletal material
100	Padding field			

[1]**All numeric field (N), all Alpha (A) and mixed alpha numeric (AN).**

Table 5.4. Fishing method codes.

DEM	Demersally caught by trawling or seining gears
PEL	Pelagically caught by trawling or seining gears
DHL	Demersal hook and line
PHL	Pelagic hook and line
DGN	Demersal gillnets
PGN	Pelagic gillnets

6 ToR d) Define properties of 'virtual multispecies datasets' (including survey, catch and stomach content data) for use in multiple multispecies models, for comparison and sensitivity testing

Multispecies models differ in their underlying assumptions. To compare their performance and sensitivity to violations of these assumptions, a common dataset is needed. Such a dataset would also create a test bed for newly designed models to accredit them. This document lists the first initiatives towards developing such a dataset.

The virtual dataset should initially focus on being relevant to a simple, minimum realistic model. By this, we mean the minimum dataset required to adequately describe the dynamics of a system and the minimum data needed by the multispecies models which will be compared, such as (e.g. MSVPA, MSVPA-X, SMS, GADGET, etc). WGSAM recognizes that in future the virtual dataset could be expanded, for example, to lower or higher trophic levels, additional species, etc.

Before the data can be simulated, it must first be clear what questions one would want to answer as this will determine the outputs needed. A suggestion is that output would be tied to management objectives and reference points (mortality rates, biomass, etc.) but also to determining which models are more useful for making management decisions under different circumstances.

It was suggested that to obtain an interesting multispecies system, at least 2 forage fish, 1 or probably 2 predators, and at least one non-targeted species which has weak links to other species would be required. As noted, the possibilities to look at bottom–up effects, higher or lower trophic levels, mixed-fisheries, and so forth were also mentioned but deemed to be too complicating of factors at this point.

6.1 Input data needed

The full set of input data we propose for the virtual dataset will not be needed by all multispecies models. Our philosophy is to provide the data at the finest reasonable scale possible. The data can then be aggregated to the level at which an individual model operates. The types of data, and the considerations for such data, we propose for the virtual dataset are:

- All data, if applicable, generally needs to be age and length structured
- Survey indices of abundance/biomass
- Catches: total catches, preferable by landings and discards

- Diet composition (prey species and size/age of prey) and amount of food consumed
- Calorific value of each species
- "Other food" biomass estimates (split into groups: benthic, pelagic, nekton, phytoplankton (likely to be added later), etc) – size structured (e.g. small, medium, large)
- Length/age key and maturity ogive
- Length/weight key
- Ambient temperature

6.2 Properties of Input Data

In addition to the data themselves, there are certain properties that need to be considered, for example, from trade-offs between independence of assumptions and consistency of the data, to resolution of the data, etc., including:

- The data should be independent of the models used, internally consistent and biologically realistic
- No significant outliers
- Spatial resolution: The plan is to initially use 1 spatial unit, but the data should be able to be expanded to include more areas. One could readily envision adding a georeferenced field to the dataset denoting spatial units, or one could simply replicate the dataset for each spatial unit
- Temporal resolution of the virtual data should not necessarily be constrained by 'real world' sampling restrictions. It could be delivered with finer temporal resolution then aggregated to appropriate level by each model. Something seasonal would be useful, but likely at least annual.
- Provision of the statistical distribution of each variable
- Data contrast desired – different levels of variation in biomass/diets/etc both between species and across the time-series

6.3 How to create the Virtual Data Set

Creating the virtual dataset is not a trivial matter. Some of the data properties desired may contradict each other (specifically consistency and realism vs. independence from model assumptions). We recommend that this become a Term of Reference for the next WGSAM meeting

7 ToR e) Investigate ways to communicate results from multispecies and ecosystem models to decision makers, including development of foodweb indicators and visualization techniques

The demand of fisheries managers, industry and related NGOs to receive clear and comprehensive advice from scientists is increasing, especially given their statutory responsibilities to move towards an 'ecosystem approach to fisheries management'. However, the models used by scientists (including WGSAM) are becoming increasingly complex, making it more difficult to communicate the results and outputs in a form that is easily understandable and usable by non-specialists. Consequently there is a need to develop methodologies and techniques that can help to communicate key characteristics of foodwebs and outputs from modelling exercises.

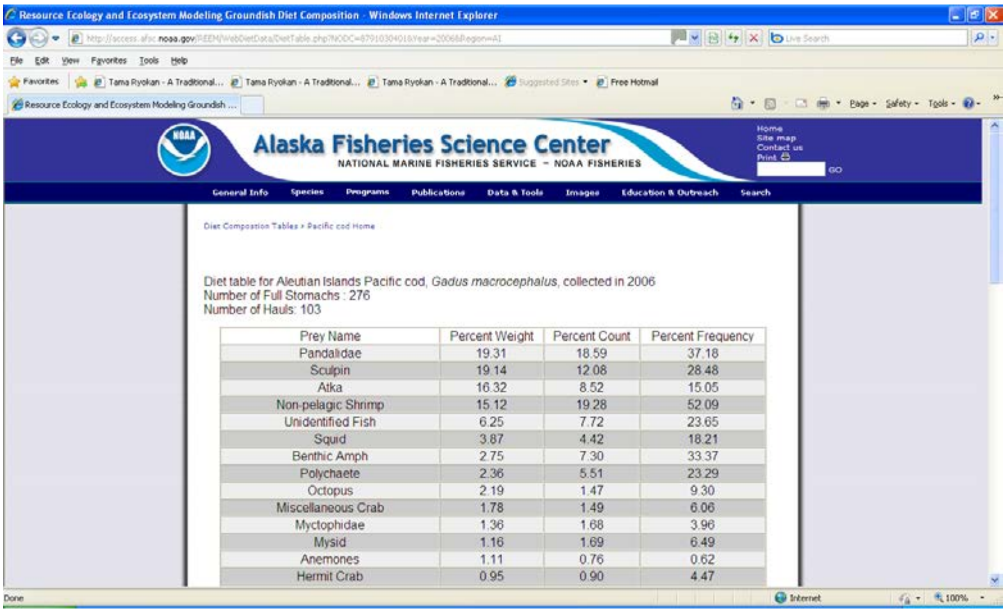
WGSAM discussed various attempts that have been made across Europe and North America to provide summary information in an attractive and easily understandable form, including visualization techniques, web portals and foodweb indicators/metrics. What follows is a brief, but by no means exhaustive, review thereof.

7.1 Visualisation techniques via web portals

A very basic approach to visualizing the inter-dependencies within a foodweb is simply to consider 'what species x eats' and 'what predators eat species x'. A number of web-portals have been created based on stomach content datasets, to generate pie charts or plots of diet composition and/or charts of predators – in order to inform stock assessment scientists or managers about the role that a particular species plays in an ecosystem.

Researchers at the Alaska Fishery Science Centre (AFSC), developed a useful web-portal to help draft the now obligatory 'ecosystem' section of stock-assessment reports (www.afsc.noaa.gov/refm/reem/models/). This includes a series of pages focussing on 'Data Products' whereby diet composition tables can be generated 'in real time' by selecting from a dropdown-list of 119 species (see Figure 7.1.1), within 3 different ecosystems (Aleutian Islands, Bering Sea, Gulf of Alaska). Data are given on the number of stomachs sampled, the number of hauls, the proportion by weight represented by each prey type, the per cent in terms of number and the frequency of occurrence. Diet composition maps are also available as an output from an interactive GIS-based mapping tool (see Figure 7.1.2), and a tool is available to access life history information for species inhabiting the region based on an extensive review of the literature. Inspired by the AFSC web-portal, the DAPSTOM initiative (www.cefas.co.uk/dapstom) was established in the UK. In 2006 the EU Network of Excellence programme 'Eur-Oceans' issued a call for 'data rescue' projects and DAPSTOM (Phase 1) was one of the first to be funded.

As of May 2010, the total number of stomach content records in the DAPSTOM database amounted to 175,247. The DAPSTOM database contains information on the feeding preferences of 139 fish species in the North Sea, Celtic Sea, Irish Sea and Arctic. 'Pie Charts' are generated 'in real time' by selecting from a drop-down list of predators (Figure 7.1.3), or alternatively individual prey types can be selected from a drop-down list, and a database query is automatically created and a 'Pie Chart' generated, indicating predator types. The user can select "all years" or a particular selection by 'checking' the appropriate boxes. The portal will then list the ICES subareas for which data are available and ask the user to make a selection (or "select all"). CSV data files can be outputted containing all records from a particular query.



Prey Name	Percent Weight	Percent Count	Percent Frequency
Pandalidae	19.31	18.59	37.18
Sculpin	19.14	12.08	28.48
Atka	16.32	8.52	15.05
Non-pelagic Shrimp	15.12	19.28	52.09
Unidentified Fish	6.25	7.72	23.65
Squid	3.87	4.42	18.21
Benthic Amph	2.75	7.30	33.37
Polychaete	2.36	5.51	23.29
Octopus	2.19	1.47	9.30
Miscellaneous Crab	1.78	1.49	6.06
Myctophidae	1.36	1.68	3.96
Mysid	1.16	1.69	6.49
Anemones	1.11	0.76	0.62
Hermit Crab	0.95	0.90	4.47

Figure 7.1.1. Diet composition table downloaded for Gadus macrocephalus in the Aleutian Islands. (an output from the Alaska Fishery Science Centre (AFSC) data portal).

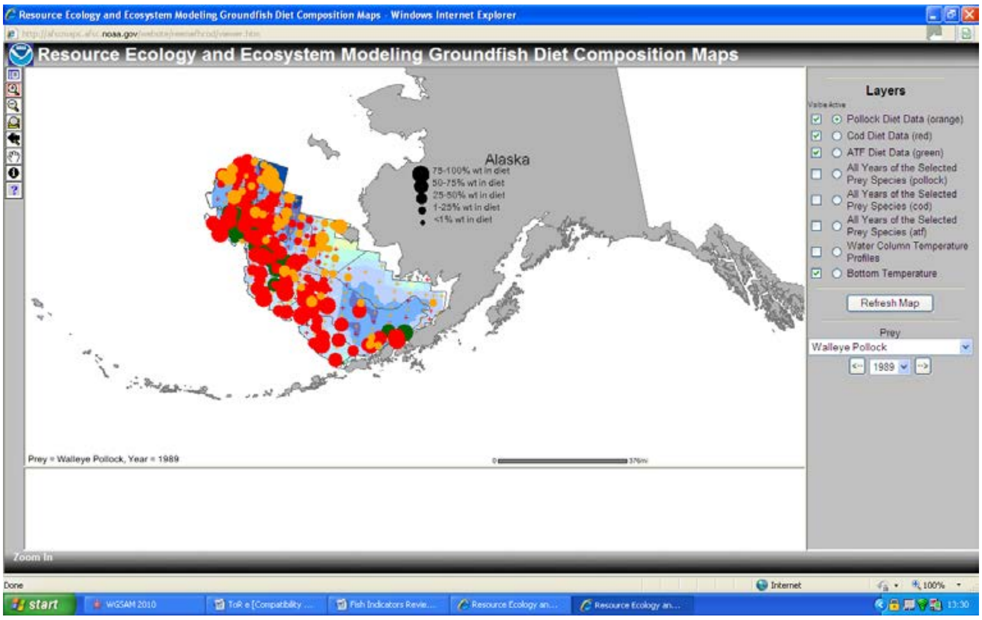


Figure 7.1.2. Groundfish Diet Composition Map (an output from the Alaska Fishery Science Centre (AFSC) data portal).

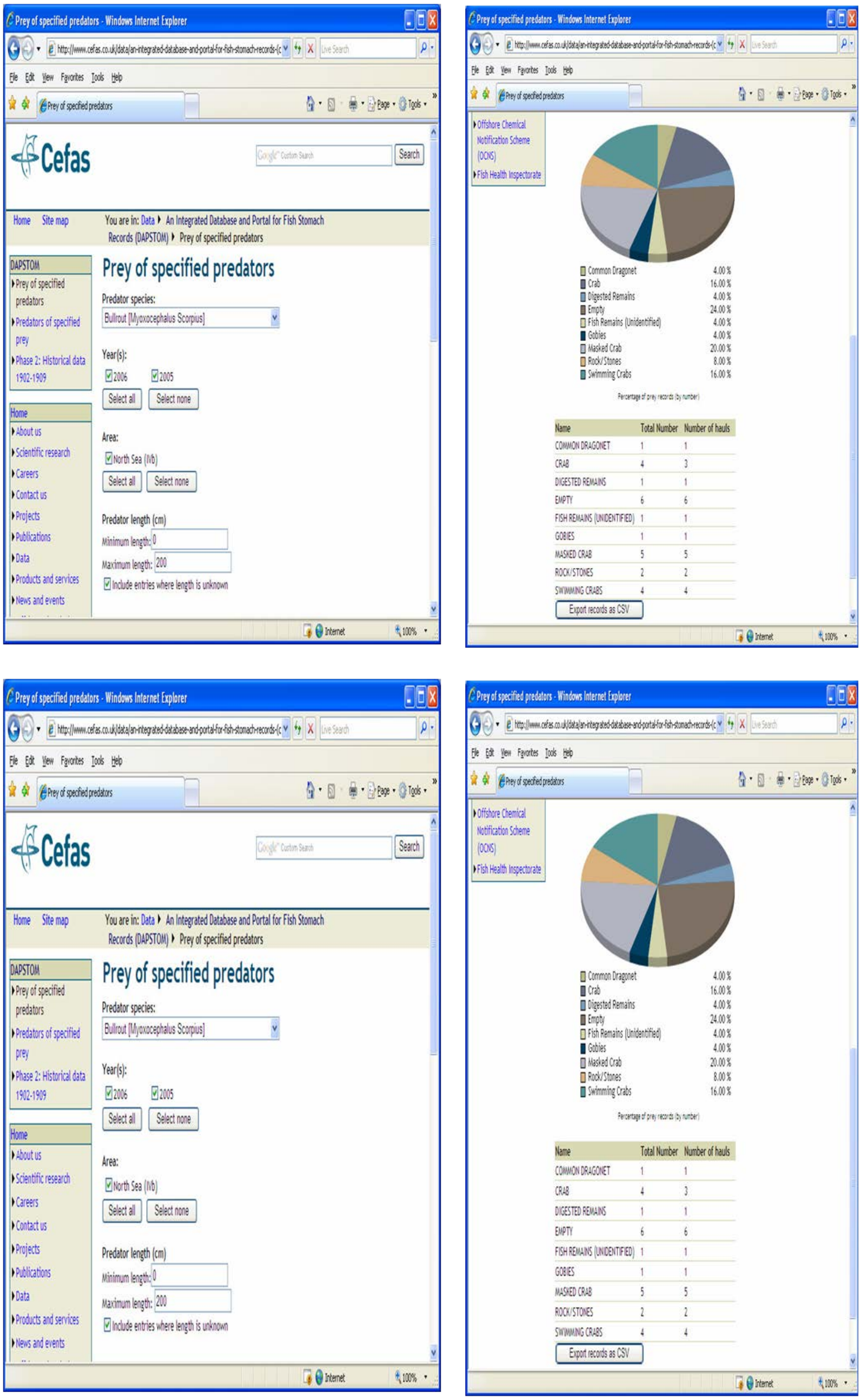


Figure 7.1.3. Screen-grab of the DAPSTOM data portal user-interface 'predator data' page, allowing users to select the year, area and size of individuals to be included in the output data file.

Similar visualization tools could make use of outputs from other databases (for example the newly available ICES 'Year of the Stomach' dataset; http://ecosystemdata.ices.dk/stomachdata/download.aspx) or from multispecies or foodweb model outputs (e.g. SMS, Gadget, Ecopath etc.), where estimates of 'partial mortality' are usually available and thus it is possible to obtain a true picture of the suite of predators impacting a particular species and the absolute magnitude of such fluxes (rather than simply the number of times that the interaction has been observed). SGMSNS has previously provided such data from it's North Sea 'key run' of MSVPA/4M, these online tables proved very useful and popular – since it was relatively straightforward to observe 'who eats who' in the ecosystem, without having to wade too deeply into technical outputs of the model or reports.

A number of vizualisation approaches have been developed to illustrate the connectedness of marine foodweb models, including the well known 'horrendo-grams' generated by Ecopath (Figure 7.1.4 a). Whether or not these visualization techniques are useful, beyond giving the overall impression of how complex things are, is debatable. Because of this overall complexity, scientists and managers have tended towards more simple approaches, for example making use of foodweb indicators.

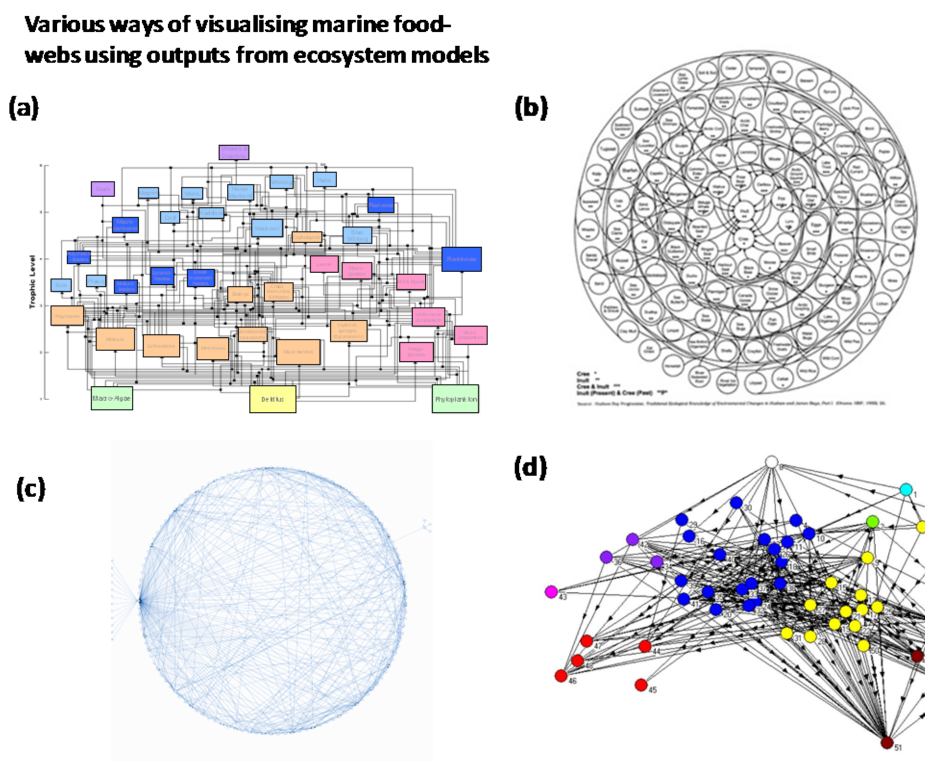


Figure 7.1.4. Diagramatic representations of marine foodwebs using various vizualisation techniques. (a) Celtic Sea Ecopath model, (b) Hudson Bay food-web, (c) Cayman Islands coral reef food-web, (d) St. Marks National Wildlife Refuge, food web - Florida. Sources (a) J. Pinnegar unpublished data; (b); www.visualcomplexity.com/; (c) http://proopnarine.wordpress.com/2010/04/14/regional-biases-in-caribbean-coral-reef-food-webs/; (d) http://core.ecu.edu/BIOL/luczkovichj/aers/aers_2005.html.

7.2 Foodweb Indicators and Metrics

Publications on ecosystem indicators have proliferated dramatically over the last ten years. Long lists of indicators have been proposed by scientists (e.g. Daan *et al.*, 2005; ICES, 2005a) and agreed by agencies (FAO, 1999; EEA, 2003). The confusion about indicator roles and the ambiguity of the concept generally has resulted in a perceived need to reduce these long lists using certain objective criteria and evaluation frameworks (e.g. FAO, 1999; UNCSD, 2001; ICES, 2002; Rice and Rochet, 2005). ICES (2001) has attempted to identify the ideal properties of indicators that can be used to monitor and manage the effects of fishing. The indicators should be:

- relatively easy to understand by non-scientists and those who will decide on their use,
- based on an existing body of work or time-series of data to allow a realistic setting of objectives,
- measurable over a large proportion of the area in which the indicator is likely to be used,
- easily and accurately measured, with a low error rate,
- sensitive to a manageable human activity (e.g. fishing) and responsive primarily to that activity, with low responsiveness to other causes of change,
- relatively tightly linked in space and time to that activity.

The 2008 European Marine Strategy Framework Directive (2008/56/EC) includes a requirement for EU Member States to report on the environmental status of the seas under their jurisdiction and to work to achieve 'Good Environmental Status' (GES). This is defined by eleven qualitative descriptors, and one of these deals with "Food-webs".

ICES and JRC were contracted to provide scientific support for the Commission in meeting this obligation. " Task Group 4" focused on the "Foodwebs" descriptor and specifically they were asked to develop indicators to measure and apply at a regional scale focusing on: a) ratios of production at different trophic levels, b) the productivity (production per unit biomass) of key species or groups, and c) trophic relationships. Many indicators within each criterion require further elaboration to become operational, and it is not yet possible to robustly define thresholds or limit reference points, or the full extent to which climate change may affect the metrics. However, WGSAM can play an important role in helping to develop new foodweb indicators and metrics, as well as methodologies for visualizing and presenting such data.

In their latest COMMISSION DECISION of … 2010 on criteria and methodological standards on good environmental status of marine waters" the focus was on:

(1) *Performance of key predator species using their production per unit biomass (productivity) (4.1.1);*

(2) *Large fish (by weight) (4.2.1)*

(3) *Abundance trends of functionally important selected groups/species (4.3.1).*

This document suggests that detailed indicators need to be further specified, taking account of their importance to the foodwebs, on the basis of suitable groups/species in a region, subregion or subdivision, including where appropriate:

- groups with fast turnover rates (e.g. phytoplankton, zooplankton, jellyfish, bivalve molluscs, short-living pelagic fish) that will respond quickly to ecosystem change and are useful as early warning indicators;
- groups/species that are targeted by human activities or that are indirectly affected by them (in particular, bycatch and discards);
- habitat-defining groups/species;
- groups/species at the top of the foodweb;

- long-distance anadromous and catadromous migrating species;
- groups/species that are tightly linked to specific groups/species at another trophic level.

This latter point can only be established through the use of multispecies or ecosystem models, and/or examination of stomach contents, i.e. the main focus of work within WGSAM. WGSAM also recognizes that much further work has been executed in other ICES and non-ICES regions on this topic, but the focus here is on what is specifically required by the Commission.

7.3 Visualisation of foodweb Indicators and Metrics

Various visualization techniques have been developed to help communicate multiple ecosystem and foodweb metrics. A good example of this is provided by the INDISEAS web portal (www.indiseas.org). Launched in 2005 under the auspices of the EurOceans scientific programme, the indiSeas project aims to evaluate the effects of fisheries on marine ecosystems by using a panel of ecological indicators, and to facilitate effective communication of these effects. With the web portal it is possible to view an ecosystem and an evaluation of its state, by clicking on the corresponding location in the world map or consulting a drop-down list. The results are displayed in the 'amoeba plots' illustrated in Figure 7.1.5. It is also possible to select and compare the states and trends of several ecosystems simultaneously (using pie diagrams and time-series).

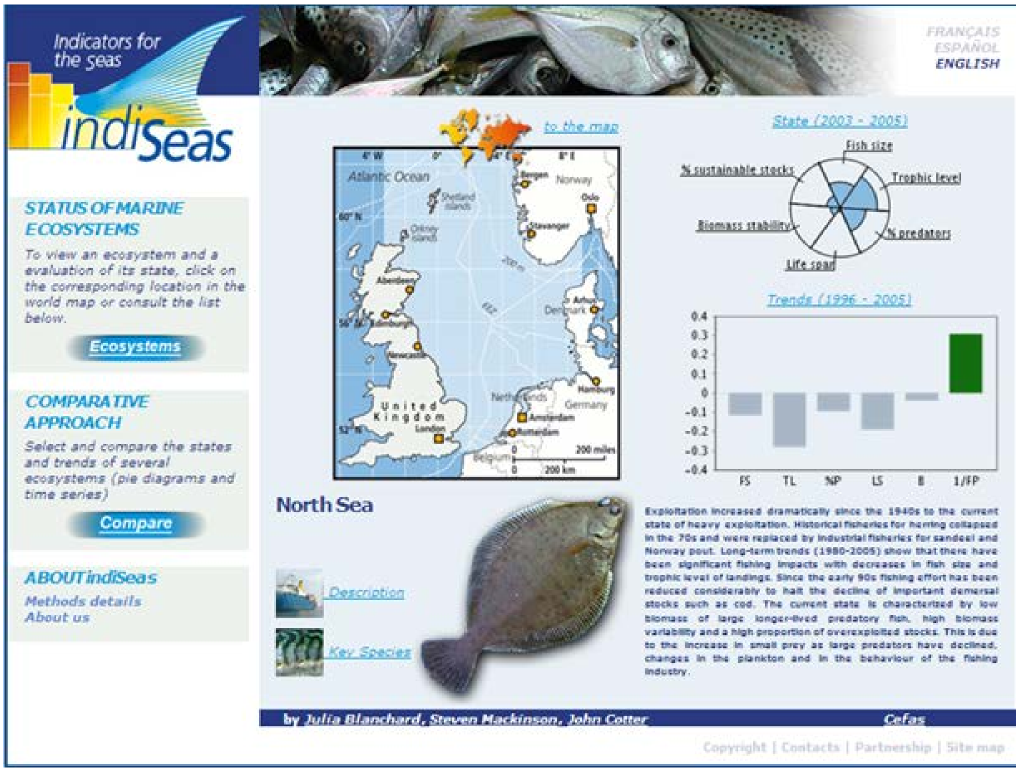


Figure 7.1.5. Screen-grab of the indiSeas data portal for the North Sea showing amoeba plot of multiple 'state' indicators (fish size, mean trophic level, % predators, average lifespan, biomass stability, % sustainable stocks), as well as histogram of trends (1995–2005). www.indiseas.org/

7.4 Other Approaches for Visualisation

Examples of the web-based portals and foodweb metric visualization approaches noted in the sections above are useful. WGSAM also acknowledges that there are other approaches to visualize data, particularly foodweb associated data. Without providing an exhausting list or review of examples, we generally note that other approaches include:

- Polar plots, dash boards, amoeba plots, etc. as shown in Figure 7.1.5.
- Multivariate or canonical plots that reduce the dimensionality of data
- Animations of model results and simulations
- "Cartoonizations" of model outputs and data
- Web-based interactive platforms such as http://slgo.ca/app-cdeena/en/nord_golfe/ecosystemes.jsp
- gaming style ecosystem applications such as http://chesapeakebay.noaa.gov/ecosystem-modeling/public-visualization-tool or http://www.youtube.com/watch?v=_H0nrhM21cw

The point being that there are copious methods to visualize indicators derived from foodweb and multispecies models. WGSAM notes that some thought should be given to these when presenting complex model outputs to non-specialists.

7.5 References

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8 ToR f) Explore the feasibility of including introduced and invasive species in multispecies and ecosystem models

WGSAM included this Term of Reference in order to contribute directly towards the stated "High priority research topic" raised in the 2009–13 ICES Science Plan *"Introduced and invasive species, their impacts on ecosystems and interactions with climate change processes"*, but also to scope out possible issues, methodologies and techniques that might prove useful for the working group in the long-term, given that reports of invasive and non-native marine species seem to be increasing across Europe and North America. Therefore, WGSAM considered the following questions:

1) What defines a non-native species?
2) Are all non-native species introductions negative or damaging – can some be beneficial?
3) How can we model the introduction of non-native species?
4) What are the issues for foodwebs about which WGSAM can provide information?

Below are example 'case studies' whereby non-native fish, mollusc or crustacean species have been introduced to European waters (or the Great Lakes, in North America) with significant consequences for foodwebs and/or fisheries. The introduction of non-native species and their subsequent establishment may cause effects ranging from the almost undetectable with no distinct impact, to the complete domination and displacement of native communities. Several European projects have attempted to summarize what is known about non-native marine species across Europe, these include the DASIE initiative (www.europe-aliens.org/) and MarBEF (www.marbef.org/).

Large areas of Europe may have been inhospitable to certain incoming species in the past, but changed environmental conditions in recent years have allowed species to become established and spread once they have arrived. For example, Chinese mitten crabs first arrived (via ship ballast waters) in the UK in 1935, but the species has only spread more widely (from the Thames Estuary) in recent years due to warmer temperatures. Various 'bioclimate envelope' modelling techniques are available to predict the extent of 'suitable' habitat for incoming species (and thus their future potential to spread) (e.g. Herborg *et al.*, 2007) – however, much less work has been done to evaluate the possible foodweb consequences of incoming, invasive species.

8.1 Are all non-native species introductions negative or damaging – can some be beneficial?

Although the overwhelming perception is that incoming, invasive species have negative consequences for marine foodwebs and ecosystems, WGSAM considered examples where non-native species appeared to be beneficial for commercial fisheries. The Kamchatka king crab (*Paralithodes camtschaticus*) is native to the Bering Sea, north Pacific and Alaskan waters. It was introduced artificially and deliberately by the Soviet Union into the Murmansk Fjord, Barents Sea, during the 1960s to provide new valuable catch for Soviet fishers. Within four decades, the released stock of 15,000 adults grew to >12 million individuals and it now supports major commercial fisheries (with Norwegian landings of ~5 000 tonnes/year, Russian landings are larger than Norwegian landings). Little is known about the ecological role that *P. camtschaticus* now plays in the Barents Sea ecosystem, although it has been suggested that it might impact other fisheries and commercial stocks, for example by consuming the eggs of capelin and by clogging trawlnets used to catch cod. Ecopath with Ecosim software was used by Falk-Petersen (2004) in a preliminary study aimed at investigating the ecological factors that lead to growth of king crab populations as well as factors that could potentially control their biomass. Possible foodweb implications of the king crab invasion on the Sørfjord ecosystem were also investigated (see www.ub.uit.no/munin/bitstream/10037/316/1/thesis.pdf). The modelling exercise indicated that mammals could have a negative impact on large king crab abundance through predation, while fish predation is expected to have minor effects on king crab biomass. King crabs are expected to have a negative effect on the benthic community through predation, but limited impact on the pelagic community.

Another commercially exploitable, non-native species that has become established in Europe is *Ensis directus* (American Jacknife clam), first recorded in 1978/79 in the Elbe estuary and now the target of a directed fishery in several countries (e.g. England and Spain). Locally this species may exclude native species and dominate benthic communities (Tulp *et al.*, 2010). Currently it is the most common shellfish species in the Dutch coastal zone, and diet studies show that *E. directus* makes up a significant proportion in the stomach contents of plaice, sole, dab, flounder and dragonet, but also eider duck and common scoter. In recent years *E. directus* contributed 20–100% of the total wet weight in fish stomachs from the region (Tulp *et al.*, 2010).

WGSAM considered species that are naturally spreading and expanding their distribution throughout northern Europe. European fishers have witnessed and responded to a number of new opportunities in recent years, as warm-water species have moved further North and/or their exploitation has become commercially viable for the first time. Notable examples include new and/or expanding fisheries for sea bass, red mullet, John Dory, anchovy and squid in the English Channel and southern North Sea.

Red mullet is a non-quota species of moderate, but increasing, importance to northern European fisheries. From 1990 onwards, international landings from the ICES area VIId and VIIe increased strongly, and so have the landings from the North Sea. France is the main country targeting this species (with landings of 5392t in 2007) however UK commercial catches have also increased dramatically, from only 26t in 1980 to 355 t in 2007. Beare *et al.* (2004) demonstrated that red mullet are one of many species that have become significantly more prevalent in North Sea bottom-trawl surveys in recent years, rising from near-absence during surveys between 1925 and 1990, to about 0.1 – 4 fish per hour of trawling between 1994 and 2004 (Figure 8.1.1). The consequences of this increased prevalence for prey resources and potential predators is unknown, however WGSAM may have to consider including such species in multispecies models of the North Sea in future.

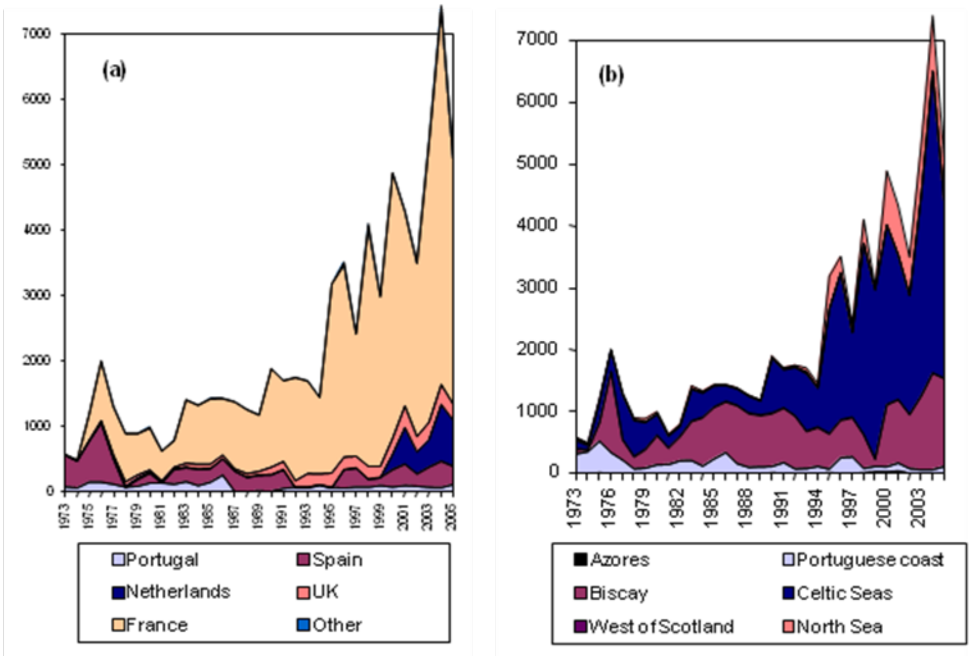

Figure 8.1.1. International fishery landings of red mullet *Mullus surmuletus* between 1973 and 2005 (a) by country, (b) by sea area. Redrawn from Rijnsdorp *et al.* (2010).

Similarly, commercial catches of anchovy increased considerably around UK coasts in 2007, rising to around 939t, with the result that several pelagic fishing boats switched to actively targeting this species for the first time. The apparent increase coincided with a gradual spread of anchovy (as indicated by research surveys) northward into the western Channel, southern North Sea and Irish Sea over the past decade and observations of large populations of juveniles in the Thames estuary and along the Dutch coast. A recent ICES report (Tasker, M. L. (Ed.) 2008) confirmed that the species is now widely distributed over almost 80% of the North Sea, even though only occasional records of anchovy had been made off Britain and in the Skagerrak in the period between 1977 and 1989 (see Figure 8.1.1). Elsewhere in the Northeast Atlantic anchovy represent an important prey resource for many fish, marine mammal and seabird predators – their potential role in North Sea foodwebs is poorly understood.

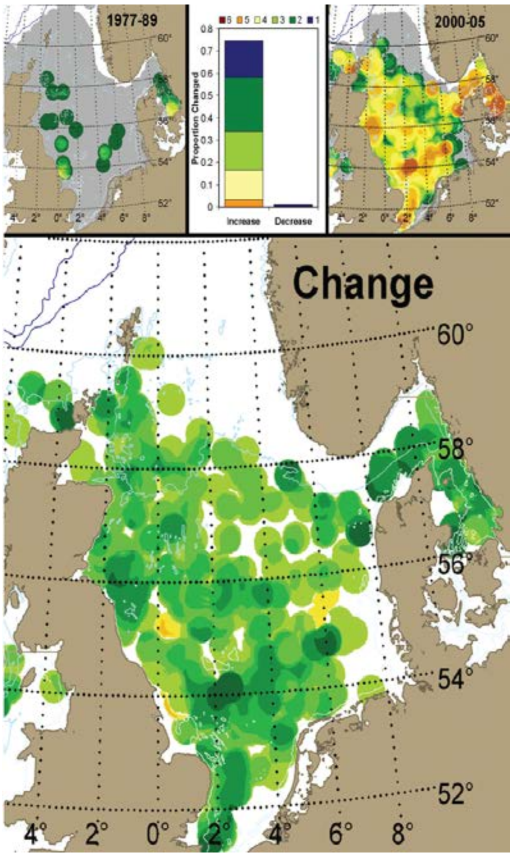

Figure 8.1.2. Changes in distribution of anchovy (*Engraulis encrasicolus*) between 1977–1989 and 2000–2005 (From Tasker, M. L. (Ed.) 2008).

The Mediterranean Sea is a region that has been particularly characterized by changes in fish communities as a consequence of non-native species introductions, both from the North Atlantic but also invasions through the Suez Canal. The Ligurian Sea (in the west), one of the coldest areas in the Mediterranean, has a smaller number of subtropical species and a higher abundance of species characteristic of cold-temperate waters. The warming of Ligurian waters (Béthoux *et al*., 1990; Astraldi *et al*., 1995) in recent years has favoured penetration of warm-water Atlantic species, including the ornate wrasse *Thalassoma pavo*, which established large and stable populations from 1985 onward (Bianchi and Morri, 1994).

The opening of the Suez Canal in 1869 allowed entry into the eastern Mediterranean of Indo-Pacific and Red Sea biota, where these so-called Lessepsian migrants now dominate the community structure (50–90% of fish biomass). For many decades, this migration was limited, partly due to extremely high salinity within the Suez Canal where dry salt valleys had existed previously, but the process has accelerated in recent years associated with a warming trend of the seawater and a significant drop in the canal's salinity to 'normal' marine levels. Recent records of lessepsian fish species in the Sicily Channel and in the southern Tyrrhenian Sea (Castriota and Andaloro, 2005) show that these alien species are spreading throughout the Mediterranean. In some cases (e.g. the rabbit fish *Siganus luridus*), species took advantage of vacant ecological niches (i.e. very few 'native' herbivorous fish species), however in other cases, introductions have resulted in the complete exclusion of native Mediterranean species. The alien Erythrean goldband goatfish *Upeneus moluccensis* was first recorded in the Levant in the 1930s, and has since established populations from Rhodes to Libya.

By the late 1940s it made up 10–15% of the total mullid catches off the Israeli coast (Wirszubski 1953). Following the exceptionally warm winter of 1954–1955 its percentage increased to 83% of the catch, replacing the native red mullet *Mullus barbatus* in commercial fisheries throughout the region (Perlmutter 1956).

The round goby, *Neogobius melanostomus*, is a bottom-dwelling goby native to central Eurasia including the Black Sea and the Caspian. The species was accidentally introduced into the North American Great Lakes by way of ballast water transfer in cargo ships. First discovered in North America in the St. Clair River in 1990, the round goby is considered an invasive species with significant ecological and economic impact. The round goby is also considered invasive in parts of Europe including the Gulf of Gdańsk (Baltic Sea). In June 1990, the first round gobies were caught in the vicinity of the port in Hel. In the same year, more round gobies were caught near Gdynia harbour (Poland). Over the next few years, the colonization of new regions and a general increase in round goby numbers occurred, and from 1999, the round goby became one of the more abundant species in the shallow water ecosystem in the western part of the Gulf of Gdańsk as well as the Vistula Lagoon (Figure 8.1.3).

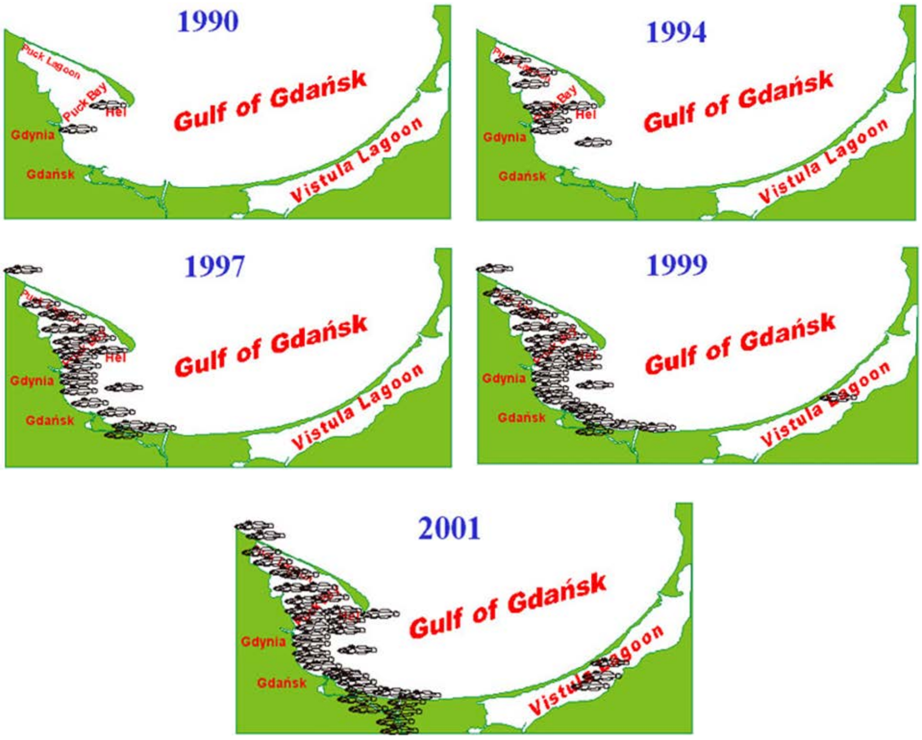

Figure 8.1.3. The spread of round goby in the Gulf of Gdańsk over the last decade (from M. Sapota, www.biomareweb.org/2.4.html).

Almqvist *et al*. 2010 assessed the role of round gobies as prey for two important fish species in the Gulf of Gdańsk, cod (*Gadus morhua*) and perch (*Perca fluviatilis*). They compared the present diet with stomach analyses from the area prior to the round goby establishment, as well as with diet analysis from Baltic regions where round gobies are absent. There were large differences in the diet between cod from the Gulf of Gdańsk 2003–2006 compared to cod in earlier studies (1977–1981) from the southern Baltic Sea. Presently, round goby constitutes the most important prey item for medium sized cod in the Gulf of Gdańsk, and perch from the same area feed almost exclusively on gobiids. *N. melanostomus* represents an important component in the diet of fish eating birds, and some Ecopath with Ecosim modelling work has been carried out comparing the structure of the ecosystem before and after the appearance of this species. The preliminary Ecopath model for Puck bay (only shallow Puck lagoon) have been constructed to investigate the place of round goby in the Puck bay foodweb (Tomczak, 2005). The models covered only mid-1990s and so represent the situation when the round goby stock was still under development. Outputs show that round-goby occupy a relatively high trophic level in comparison with the traditional prey of top predators such as *Salmo salar; Gadus morhua* or the Cormorant *Phalacrocorax carbo.* The level of fishing mortality inflicted on *N.melanostomus* was extremely low (F = 0.001), which is in contrast to high predation (Pr = 0.313). Because of round goby population development we may anticipate competition with eel (*Anguilla anguilla*), flounder (*Platythies flesus*) and "benthic-feeding fish", because round-goby share the same niche with those groups. As mentioned before *N. melanostomus* abundance may be one of the trophic factors having an impact on great cormorant population size. The Omnivory Index value close to zero confirms that *N. melanostomus* feeds on a single trophic level. That the current study suggests that round goby invasion could change the balance and structure of the ecosystem, especially impacting pelagic-benthic energy pathways of the coastal ecosystem.

Round gobies entered Lake Erie in 1994, and it is clear that they have subsequently altered energy, contaminant, and nutrient pathways. Johnson *et al*. (2005) used bioenergetic models parameterized with data collected between 1995 and 2002 to estimate the type and amount of prey eaten, the biomass accumulation rate for the round goby population, and partitioning of the food energy. Standing stock biomass of round gobies ranged between 203 and 4,803 tonnes year. Piscivorous fish showed an increasing reliance on round gobies as prey, with round gobies being the dominant prey fish in the diets of benthic-oriented predators. In addition an unintended benefit of the round goby's introduction is that the Lake Erie watersnake (*Nerodia sipedon insularum*), an endangered species, has found it to be a preferred addition to its diet. King *et al*. (2006) suggested that the introduced fish now accounts for 90% of the snake's diet. The new food supply means that the water snake is staging a partial recovery.

8.2 How can we model the introduction of non-native species?

WGSAM reviewed the literature to identify possible techniques to model foodweb implications of incoming and invasive species. The following approaches were highlighted, with some discussion of strengths, weaknesses and gaps:

1) 'Before' vs. 'after' models, e.g. using Ecopath (e.g. Lake Victoria and Black Sea).

2) Bioenergetic models, e.g. Johnson *et al*. 2005 (round goby in Lake Erie).

3) Ecological Attribute models, e.g. Olden *et al*. 2006 (Colorado River Basin).

4) Risk assessment approaches and protocols (e.g. Copp *et al*., 2008).

5) Rank proportion algorithm (RPA) models to predict diet composition (Link 2004).

As the primary working group within the ICES system responsible for multispecies modelling and prediction WGSAM need to consider the following key questions with regard to non-native species:

1) Can we predict what an incoming species will eat – on the basis of its diet elsewhere (or other methods)?

2) If a new species becomes established can we predict what predators will predate upon it?

3) If nothing eats a new species will it expand and out-compete native species (for food and habitat)?

4) Is it easier to predict the impact of naturally occurring but expanding species, rather than completely new species?

5) Where people have constructed 'before' and 'after' models (e.g. using Ecopath) – is it possible to simulate the transition from one period to the other? Could we have predicted what subsequently happened?

6) What other tools are available to model the impact of non-native species on foodwebs?

These questions could serve as a starting plan for future research in investigating the potential effects of invasive species on ecosystems and foodweb functioning. A ToR for a future WGSAM meeting might also consider this topic.

It is important to note that many of the approaches listed above are largely retrospective and benefit from observations of what actually happened. Such approaches offer limited predictive capability but can be useful when trying to understand or validate mechanisms and processes (e.g. Daskalov, 2002). Other approaches provide some predictive capacity or are based around the principles of risk assessment, but offer limited utility in terms of understanding specific consequences for particular predators, prey or competitors in the ecosystem.

8.2.1 Before' vs. 'after' models, e.g. using Ecopath (Lake Victoria and Black Sea examples)

Various authors (e.g. Daskalov, 2002; Moreau *et al.*, 1993; Darwall *et al.*, 2010) have used Ecopath with Ecosim (EwE) models constructed for periods in the past (<u>before</u> a non-native species became established) and the present (<u>after</u> a non-native species became established), to consider whether or not foodweb changes could have been accurately predicted in advance. Based on an analysis of long-term time-series in the Black Sea, Daskalov (2002) reported inverse trends of decreasing predators (marine mammals and tunas), increasing planktivorous fish, decreasing zooplankton and increasing phytoplankton in the early 1980s, when an already unfavourable ecological situation was exacerbated by the invasion of an exotic ctenophore, *Mnemiopsis leidyi*, and there was a severe collapse in fisheries. This species has proven particularly disruptive to marine foodwebs, and has been associated with ecosystem collapse both in the Black Sea and also the Caspian. A balanced EwE model was built using 15 ecological groups including bacteria, phytoplankton, zooplankton, protozoa, ctenophores, medusae, chaetognaths, fish and dolphins. Ecosystem dynamics were simulated over a 30 year period. The main conclusion of this paper was that the observed tropic-cascade pattern is best explained by the removal of predators (by intensive fishing), but also poor recruitment of fish indirectly caused by *Mnemiopsis* and its effect on trophic interactions, while the simulated inclusion of eutrophication effects lead to a very different pattern, with biomass increase in all groups. *Mnemiopsis leidyi* is currently spreading through European Seas and has recently reached the Baltic and North Sea (see *ICES Insight*, September 2008). An EU InteReg project proposal has recently been submitted focussing on the southern North Sea, with the intention to carry out complex individual-based modelling in order to characterize and predict the likely spread and foodweb consequences of further invasion within this region.

During the early 1960s, Nile Perch (*Lates niloticus)* were introduced into Lake Victoria (central Africa) and had a huge impact on the dominant taxa of commercial fish species in the lake. At the time of this introduction, the fishery was primarily focused on tilapia and haplochromine cichlids, but by 1980 *L. niloticus* had become the primary fishery target, and dominated yields, including significant exports to Europe (Matsuishi *et al*., 2006). The introduction of Nile Perch also had profound effects on Lake Victoria's ecosystem and biodiversity, predation causing a large drop in haplochromine cichlids, which previously constituted about 90% of the fish biomass (Matsuishi *et al*., 2006). This caused researchers to proclaim that around 200 endemic prey species had become extinct, although some recovery in endemic haplochromine cichlids has been recorded in recent years. A number of different EwE models have been developed for Lake Victoria over the past 20 years. Moreau *et al*. (1993) used Ecopath II to model Lake Victoria before and after the introduction of Nile Perch to document how this introduction impacted the dynamics of the ecosystem. Darwall *et al*. (2010) used a EwE model of Lake Malawi to investigate the effect of fishing on fish community composition, and the potential interaction with the lakefly *Chaoborus edulis*. The authors considered a theoretical scenario whereby a non-native plantivorous fish species might be introduced to the lake, and concluded that this would likely have a negative impact on the stability and productivity of the lake ecosystem.

8.2.2 Bioenergetic models

Several authors have taken a bioenergetics approach to investigating the possible consequences of an incoming invasive predator species (e.g. Kitchell *et al*., 1997; Johnson *et al*., 2005) for other parts of the ecosystem. Typically this has involved a look back at what actually happened in an impacted system, i.e. a retrospective rather that predictive outlook. Kitchell *et al*. (1997) used a bioenergetics model of Nile perch predation rates in Lake Victoria to evaluate the consequences of previous, current, and future fishery exploitation patterns and their ecological implications. The bioenergetics model is simply a means for estimating daily energy budgets based on five basic kinds of information (1) physiological parameters defining the temperature and size dependence of growth and metabolic rates, (2) estimates of temperatures experienced during the annual cycle, (3) growth curves (size and age) for the species at the particular sites, (4) proportions by mass of prey in the diet and estimates of energy densities for both the predator and prey, (5) estimates of population parameters (natural and fishing mortality rates). The analysis produced three main conclusions: (1) Development of fisheries based on large-mesh gillnets reduced total predation by Nile perch to ≈40% of that estimated during the late 1970s, when Nile perch densities were greatest. (2) Expansion of recent intensive beach-seine and small-mesh gillnet fisheries for juvenile Nile perch could reduce total predation to ≈25%. (3) The combination of fishing methods could reduce total predation on the diverse, endemic ichthyofauna to ≈10% of previous levels. A broadly similar bioenergetics model was used by Johnson *et al*. (2005) to estimate the type and amount of prey eaten by round gobies in Lake Erie (see above). Weight- and temperature-dependent coefficients for metabolism and consumption were derived (Lee and Johnson 2005). The bioenergetics model accurately characterized growth of round gobies not only in Lake Erie, but also in their native range.

8.2.3 Ecological Attribute models

An altogether simpler approach that has been adopted by several authors (e.g. Olden *et al*., 2006) is to consider common life-history strategies or traits that characterize whether a species is likely to 'invade' or be easily 'extirpated' (i.e. 'Ecological Attribute models'). Understanding the mechanisms by which non-native species successfully invade new regions and the consequences for native fauna are a pressing ecological issue, and one for which niche theory can play an important role. Olden *et al*. (2006) define a comprehensive suite of morphological, behavioural, physiological, trophic, and life-history traits for the entire fish species pool in the Colorado River Basin to explore a number of hypotheses regarding linkages between human-induced environmental change, the creation and modification of ecological niche opportunities, and subsequent invasion and extirpation of species over the past 150 years. Specifically, the authors use the fish life-history model of Winemiller and Rose (1992) to quantitatively evaluate how the rates of non-native species spread and native species range contraction reflect the interplay between overlapping life-history strategies and an anthropogenically altered adaptive landscape. The results reveal a number of intriguing findings. First, non-native species are located throughout the 'adaptive surface' defined by the life-history attributes, and they surround the ecological niche volume represented by the native fish species pool. Second, native species that show the greatest distributional declines are separated into those exhibiting strong life-history overlap with non-native species (evidence of biotic interactions) and those having a periodic strategy that is not well adapted to present-day modified environmental conditions. Third, rapidly spreading non-native fish generally occupy "vacant" niche positions in 'life-history space', which is associated either with "niche opportunities" provided by human-created environmental conditions or with minimal overlap with native life-history strategies (consistent with the biotic-resistance hypothesis). This study was the first to identify specific life-history strategies that are associated with extensive range reduction of native species and expansion of non-native species. However, Alcaraz *et al*. (2005) carried out a similar life-history 'profiling' study of 69 inland fish species of the Iberian Peninsula, including native, invasive and migratory species.

8.2.4 Risk assessment approaches and protocols

Several research groups have developed 'Risk Assessment' approaches and protocols that aim to predict the possible ecosystem and foodweb consequences of particular non-native fish species becoming established. Kolor and Lodge (2002) used a generalized risk assessment approach and statistical models of fish introductions in the Great Lakes, to target prevention efforts on species most likely to cause damage. Models correctly categorized quickly spreading and nuisance fish with 87 to 94% accuracy. The authors then identified fish that pose a significant risk to the Great Lakes ecosystem if introduced from unintentional (ballast water) or intentional pathways (sport, pet, bait, and aquaculture industries). Copp *et al*. (2008) published a similar report on "Risk identification and assessment of non-native freshwater fish: concepts and perspectives on protocols for the UK" in 2005. During a review of existing hazard identification schemes, two approaches were deemed particularly suitable for the hazard identification stage: the Australian weed risk assessment (WRA) approach of Pheloung *et al*. (1999) and the Kolar and Lodge (2002) decision tree approach, known as 'fish profiling'. Following initial screening, a hazard assessment phase, referred to as the Invasive Fish Risk Assessment (IFRA), was developed. The IFRA assumes that past invasiveness history and environmental similarity are important for determining the level of risk posed by a species (Ricciardi, 2003). The WRA methodology has been used by Copp *et al*. (2008) to develop 'FISK', the Fish Invasiveness Screening Kit. This includes some consideration of 'Undesirable Traits' but also recognizes that those fish that are predatory or omnivorous at some stage of their life cycle are more likely to be successful invaders (Ricciardi and Rasmussen, 1998).

8.2.5 Rank proportion algorithm (RPA) models to predict diet composition

The final class of models that WGSAM considered in terms of their potential application to understanding and predicting the foodweb impacts of invasive and incoming species was those that attempt to predict diet composition on the basis of food availability, spatio-temporal overlap and physical traits of the predator. Link (2004) developed a 'rank proportion algorithm' (RPA) model that predicts prey preference, the hypothesis being that there is a set of general criteria— based on the past 40 or so years of empirical evidence— whereby one can determine *a priori* the prey preference of fish species given their characteristics and environmental conditions. The model was applied to benthivore, planktivore, and piscivore examples from lentic, lotic, estuarine, and marine environments. Compared with observed stomach contents, the RPA model's predictions of diet composition exhibited more than 83% accuracy, and in the vast majority of the cases the model accurately predicted the predominant prey item. The entire prey rank order was predicted correctly on the order of 70–80% of the time.

The author (Link 2004) acknowledged that the methodology would benefit from a broader range of testing and validation from other ecosystems and types of fish (e.g. reef fish, detritivores, etc.), yet it was designed to be and should be robust for the vast majority of situations. The RPA is not the first attempt to codify predation in aquatic ecosystems. However, the RPA is the first attempt to generalize the size and type selectivity of fish feeding relative to a broad suite of empirically based theories of the predation process while minimizing assumptions as to underlying processes. The value of the RPA approach is fivefold: it provides a representation of all components of the predation process without imposing additional constraints; it allows one to make predictions in situations in which there are limited field data (e.g. for non-native species); it is adaptable to a wide range of fish and ecosystems; it has been validated with both field-caught and experimentally manipulated fish; and it simplifies the evaluation of predation into an intuitive, empirically backed algorithm that is easily used. The RPA approach has several applications and uses. Bioenergetic modelling, Ecopath/Ecosim, multispecies virtual population analysis and similar multispecies models, all have an implicit underpinning of prey selectivity. Often diet composition and prey preference are taken from the literature or costly stomach sampling campaigns, but this is not always available or possible – especially when a predator is new to a particular environment or ecosystem. WGSAM felt that this is one of the few tools available that might feasibly provide quantitative insight into the future role that an incoming, non-native species might play in a foodweb.

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9 ToR g) Review estimates of abundance and productivity at lower trophic levels, and work towards the inclusion of such information in multispecies models

Although ecosystem models try to integrate information from the whole foodweb, information on lower trophic levels is often scarce. Additionally, most multi species assessment models like MSVPA, SMS or Gadget focus on higher trophic levels and to a large extent ignore the dynamics of lower trophic levels. In multi species assessment models only a constant biomass pool (often called "Other Food") of non-modelled prey species is implemented for predators to feed on. Due to the assumption of a constant biomass pool and, in most cases, constant suitability coefficients (or similar measures for preference and availability) in the diet selection submodels, the relative stomach content of Other Food only changes if the available prey biomass from commercially important prey species changes. However, the relative stomach content of Other Food can also change because of changes in the abundance of "Other Food" species which cannot be taken into account in these models. This can lead to serious biases in these models. To overcome this shortcoming, hydrodynamic and lower trophic level models could be coupled to higher trophic level and fisheries assessment models (end to end modelling) or multi species assessment models should be extended to incorporate abundance changes inside "Other Food".

9.1 End to end modelling

A Coupled ECOROMS+APECOSM model

This coupled model has been briefly described in Section 3.

A realistic 13-year hindcast simulation from 1997 to 2009 has been performed and. simulated temperature and salinity fields validated with in situ data and satellite images. Currently, the validation of the dynamical processes from this simulation is in progress, focusing on the shelf and slope circulation.

Chlorophyll a blooms in river plumes and over the slope in the northern part of Bay of Biscay are reproduced by the coupled model. However, the "general" spring bloom over the plain appears too early in the season in comparison to satellite images (chla at the surface). Hence, the validation and calibration of nutrient concentration and chlorophyll a biomass are in progress.

Special emphasis is given to the sardine and anchovy in the Bay of Biscay. The 1997–2009 periods include the collapse of anchovy in the Bay of Biscay; hence, the ECOROMS (ROMS+NPZD) results are analysed to determine if and which physical/biological parameters present a major change during this period.

Following the work of O. Maury and O. Aumont (IRD, France) at a global scale, the APECOSM model is currently implemented at a regional scale for the Bay of Biscay in AZTI. First the APECOSM model will be used offline, with ROMS-ECOROMS ouput, for a climatologic year, as a "test simulation". Eventually these two models could be dynamically coupled; directly showing how lower trophic level dynamics can influence apex predators.

9.2 Inter annual changes in relative stomach contents of Other Food

As a first step to work towards the implementation of information on lower trophic levels in multi species assessment models like SMS, their importance in the diet of predators has to be analysed. It is especially important to know whether changes over years are caused by shifts inside Other Food or are simply caused by changes in accordance with a Holling Type II functional feeding response. Therefore, changes in relative stomach contents over the five "Years of the Stomach" in the North Sea (1981, 1985, 1986, 1987, and 1991) were analysed with GAMs (Hasti and Tibshirani 1990) for the three predators (cod, whiting and saithe) in a working document provided by A. Kempf to the group.

The relative stomach content of Other Food was explained by a year and quarter effect as well as the predator length class. The 4M model suite (Vinther *et al.*, 2002) was used to predict relative stomach contents of Other Food in 1991 in accordance to a Holling Type II functional feeding response. Afterwards, the predictions were compared to the relative stomach contents sampled in order to identify changes that were not explained by the feeding response. Another analysis tried to identify the most important prey types inside "Other Food" responsible for the observed changes. However, only groups with more than 3% were taken into account. The analysis also focused on the 3rd quarter of the year only since this is the quarter where the predation on the 0 group of VPA prey species takes place, having high impact on predicted stock trajectories.

For all three predator species it became obvious in the GAMs that the relative stomach content for Other Food in 1991 was significantly lower than in 1981 (see Figures 9.2.1–9.2.3). For whiting, 1981 appeared more as an outlier, but for cod a more general decreasing trend over years became obvious. For saithe only two years of stomach data are available. For all predators, as expected, Other Food was more important for smaller size classes than for larger ones.

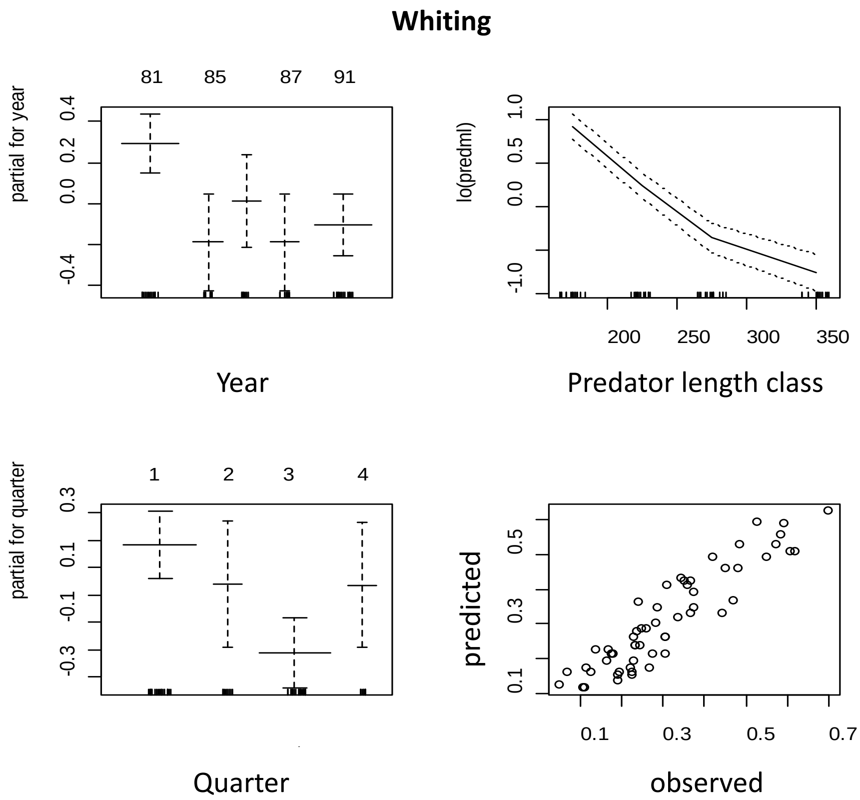

Figure 9.2.1. Fitted relative stomach contents for Other Food as a function of year, quarter and predator length class. In addition, the relationship between observed and predicted relative stomach contents for whiting is shown.

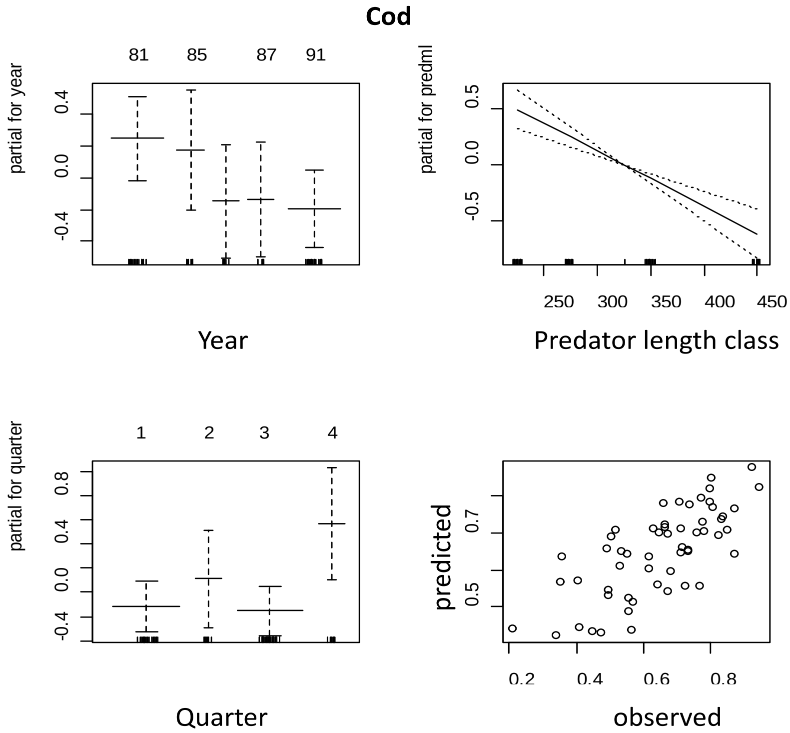

Figure 9.2.2. Fitted relative stomach contents for Other Food as a function of year, quarter and predator length class. In addition, the relationship between observed and predicted relative stomach contents for cod is shown.

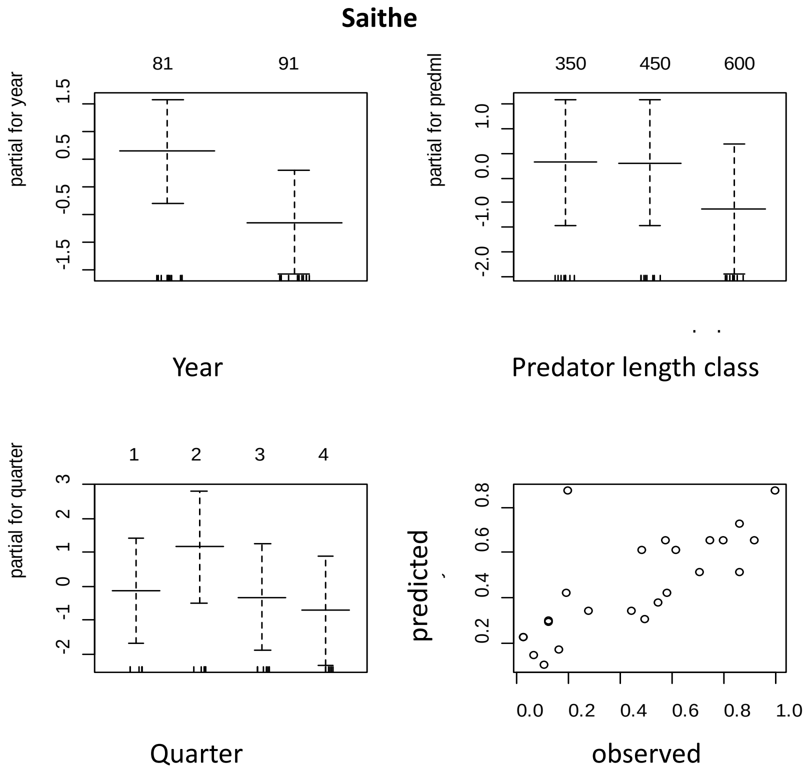

Figure 9.2.3. Fitted relative stomach contents for Other Food as a function of year, quarter and predator length class. In addition, the relationship between observed and predicted relative stomach contents for saithe is shown.

Changes in the amount of "Other Food" consumed occurred as a shift in the North Sea foodweb even if a Holling Type II functional feeding response is taken into account (Figure 9.2.4). Cod, whiting and saithe consumed substantially less "Other Food" in 1991 than predicted by the currently implemented MSVPA diet selection model. This means, that in reality more of the so-called MSVPA prey species (e.g. cod, whiting, Norway pout, sandeel) were consumed by these predators in 1991 than predicted by a Holling type II functional feeding response implemented in the model.

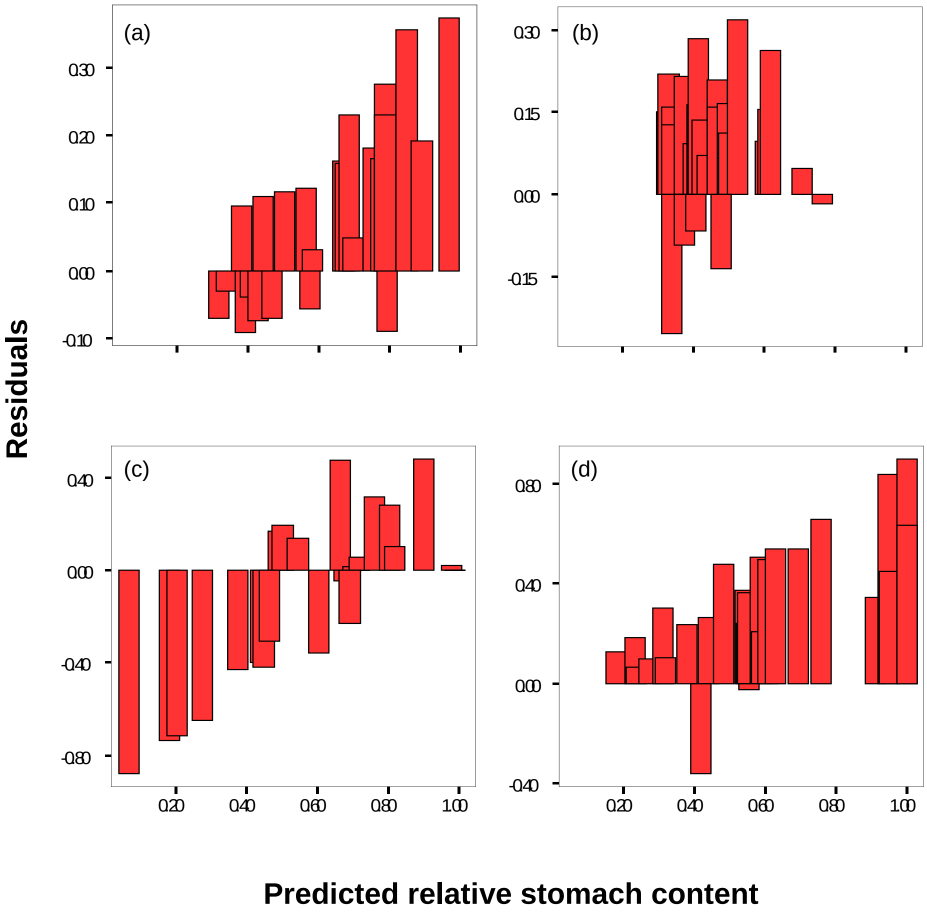

Figure 9.2.4. Residuals observed when contrasting predicted relative stomach contents for "Other Food" in 1991 with relative stomach contents of "Other Food" observed in 1991. Each bar represents the residuals from the line of equality for a single predator age group in a single quarter. Positive values depict overestimations and vice versa. Maximum residuals= ± 1. Bar charts are shown for (a) cod (*Gadus morhua*), (b) whiting (*Merlangius merlangus*), (c) haddock (*Melanogrammus aeglefinus*) and (d) saithe (*Pollachius virens*).

In general, many different prey types comprised more than 3% in the diet of cod and whiting in the 3rd quarter (Figures 9.2.5 and 9.2.6). Only saithe had a very limited number of different prey types (Figure 9.2.7). The analyses carried out gave a strong indication that abundance changes inside "Other Food" occurred between 1981 and 1991 (i.e. euphausiids lost their importance). The observed shift between VPA fish and Other Food led to an increased predation pressure on VPA fish. This can, in some circumstances, be an alternative explanation why the productivity of stocks changed during the supposed regime shift in the late 80's. Not only the available food for fish larvae has changed but also the available prey types for predators preying on fish larvae and 0 groups.

As next steps it would help to have abundance trajectories for Euphausiacea, Anomura, Brachyryncha and flatfish to model the dynamics of Other Food in the 3rd quarter. If relationships between relative stomach contents and abundance could be established, a dynamic modelling of relative stomach contents for these prey types should be possible. This would enable a more realistic modelling of foodweb dynamics in multi species models which focus on higher trophic levels instead of simply assuming a constant Other Food pool. It also reinforces the need for updated stomach sampling in the ICES area (Section 5).

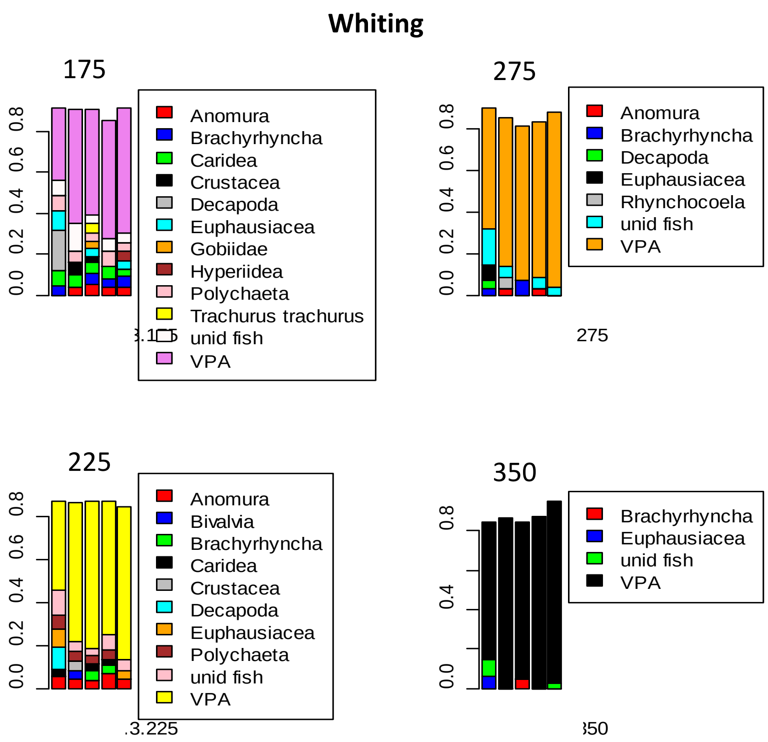

Figure. 9.2.5. Diet composition of different predator length classes of whiting in the 3rd quarter.

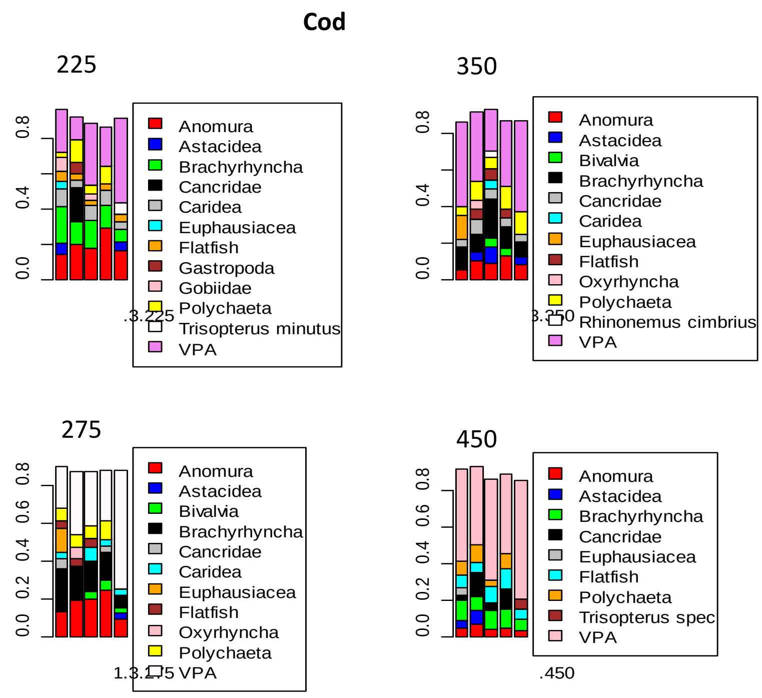

Figure 9.2.6. Diet composition of different predator length classes of cod in the third quarter. Only prey types with more than 3% relative stomach content are taken into account.

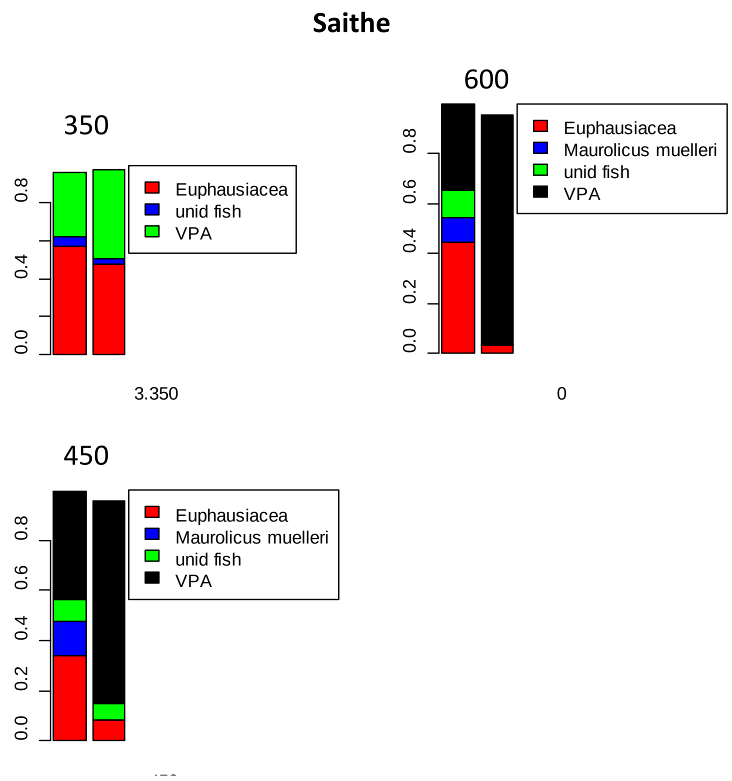

Figure. 9.2.7. Diet composition of different predator length classes of saithe in the third quarter. Only prey types with more than 3% relative stomach content are taken into account.

9.3 ToR h) Work towards inclusion of fleet dynamics in multispecies models

9.3.1 North Sea

WGSAM requested (in 2010) WGMIXFISH to 'Provide quarterly data on catch-at age by fleet in the North Sea for the longest period possible'. The group has received the following reply

The previous groups to WGMIXFISH have decided temporarily not to work with age-based data by fleet but only catch composition by species. The reason for this is data availability. Fleet-based sampling has been the subject of enormous scientific activity since 2006 and the early stages of the new Data Collection Framework, but unfortunately it seems that we have not reached a mature stage yet. This means that

- Métiers definitions are not yet standardized and agreed upon.
- Sampling is insufficient to cover all categories. MIXFISH has tried to run fleet-based models but realized that data were too noisy: if you combine the catch-at-age data for the various fleets and métiers, catch compositions are very different from the aggregated catch-at-age matrices from single-stock assessment. The approach in MIXFISH has thus been to first focus on model outputs without age-based info, i.e. work at the Fbar level and to define fleets and métiers that match the various biological and economic data available while keeping the number of fleet categories low. Resulting in categorizing 29 fleets (from 9 countries and 4 types of vessel type), 14 métiers (e.g. combination of gear type, target species, mesh size, etc), 15 stocks and 7 years (2003–2009). Since each fleet is engaged in one to five métiers and vessels can change activity over the years, this results in a combination of 630 cells of fleet*métier*stock.'

WGSAM discussed the number of categories available and agreed that what is needed for including fleets in the North Sea SMS is:

1) Total landings by year, quarter, species and age (not segregated by fleet)
2) Total landings by year, quarter, species and fleet from a total of 10 to 20 aggregated fleets, preferably defined by the gear they deploy. Examples could be gillnet, beam trawl, otter trawl, etc. If possible, the age distribution for each aggregated fleet and species would be useful even if yearly and quarterly values are not reliable.

The group will pass requests to WGNSSK on point 1 and WGMIXFISH on point 2. The data from 1 will be used in the North Sea SMS key run planned for next year and 2 will be used for further work on including fleet dynamics in the North Sea models.

9.3.2 Baltic Sea

The group discussed the possibility of modelling fleet interactions in the Baltic but decided not to pursue this until a working group specializing in fleet interactions addresses this issue.

9.3.3 Bay of Biscay

A simulation model is under development to investigate fleet dynamics in the Bay of Biscay. The model is a multispecies and multifleet model with seasonal resolution and it is oriented to perform bioeconomic evaluation of management strategies. The model is coded in R (R Development Core Team 2009) using FLR (Kell *et al.*, 2007) libraries and has 4 main modules, the biological, the fleet and the covariates operating models and the management procedure model.

The biological operating model can include as many species as required and they can be simulated as age structured populations or as biomass dynamic populations. Within the biological operating model there is no interaction between species, so predation or competition between species cannot be modelled directly.

The fleets operating model can also include as many fleets as required. The activity of each fleet is divided into métiers and each métier has each own catch profile in terms of species and catchabilities. As the fleet dynamics are very case specific we are working in 3 different case studies, the demersal Basque fisheries, the pelagic Basque fisheries and the tropical tuna fisheries operating in the Indian Ocean. For each of these case studies we will develop a specific function to describe their dynamics, depending on data availability and fleet behaviour.

The covariate operating model can be used for two purposes. The first one is to model the interaction between exogenous variables, such as temperature or fuel price, with the biological populations and the fleets. And the second one is to use the covariates as a bridge to model the interaction between the biological populations, such as predation between species, the interaction between fleets or the interaction between biological and fleet variables. By using this covariate operating model, the main algorithm will be opened to introduce new functions whenever a new variable needs to be introduced, just by implementing the correspondent function.

Finally the management procedure model simulates the whole management process of the biological populations under management, from the data collection to the management advice. It is not mandatory to simulate the whole management process and for example if the assessment model is not available in R/FLR the management advice can be based on assuming a perfect observation of the population.

9.4 References

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10 Other requests

WGSAM has received the following requests from other EGs:

FROM	VIA	REQUEST
WGDIM	SSGSUE	Provide feedback to WGDIM and the Data Centre on the North Sea element of the Year of the Stomach Database
WGDIM	SSGSUE	Consider the Baltic dataset (in its current state); whether there is enough value in undertaking further work and if so what resources are needed (i.e. volunteer experts from the Baltic States along with IT experts from the Data Centre).
WGBFAS	SSGSUE	WGSAM is asked to supply WGBFAS 2011 with new M values for the Central Baltic herring (SD 25–29 and 32 (excl. Gulf of Riga herring) and Baltic Sprat stock based on an update of the last MSVPA-run conducted in 2006
WGNSSK	Email	WGSAM is requested to provide yearly mortality parameters for the stocks of cod, haddock, whiting, sandeel and Norway Pout in the North Sea for inclusion in single-stock assessments to be performed by WGNSSK in 2011.
PGCCDBS	SCICOM	PGCCDBS recommends that WGSAM, in conjunction with IBTSWG and WGBIFS formulate a common proposal to address multispecies interactions in the North Sea and Baltic Sea. A new international coordinated stomach sampling program is recommended both in the North Sea and the Baltic Sea to track changes in the foodweb, to be used for estimation of predation mortalities and to facilitate an ecosystem approach to management.

10.1 Feedback to WGDIM and the Data Centre on the North Sea element of the Year of the Stomach Database

The group considered the extensive progress and efforts made by WGDIM and the ICES Data Centre to recover correct and standardize datasets from the various 'Year of the Stomach' campaigns in the North Sea. WGSAM would like to express their sincere thanks to the Data Centre for this very useful service. The following points were raised, highlighting the utility of the new data resources but also a few areas where additional effort or clarification would be beneficial:

Highlights related to the documentation:

1) It is appreciated that the two data reports were also scanned, since this helps to provide context to the dataset. It might also be beneficial to upload a digital copy of the 1991 stomach sampling manual (ICES CM 1991/G:3) – [WGSAM Co-Chair Anna Rindorf has a pdf version if this would be helpful.]
2) It is currently difficult to navigate through the ICES website to find the download site within the 'ecosystem portal' (http://ecosystemdata.ices.dk/). It would be beneficial if navigation routes could be simplified, and indexed from the drop-down lists on the ICES website front-page.
3) The download page (http://ecosystemdata.ices.dk/stomachdata/download.aspx) is easy to use and includes a useful list of numbers of records by predator species, year

and country. This includes stomach records (e.g. for turbot and monkfish) that even WGSAM didn't previously know about.

4) WGSAM appreciate the efforts that have been made to highlight and publicize the availability of these datasets most notably on the ICES website but also in the ICES newsletter (www.ices.dk/InSideOut/August10/Insideout2010-No.3article%206.pdf).

Areas where additional effort would be beneficial:

5) Much of the taxonomy has changed (not least the switch from NODC to TSN codes) and thus the update is very helpful. However it would be beneficial to include TSN codes in the downloadable dataset.

6) The database structure seems eminently sensible and is flexible enough to accommodate various forms of data, in particular pooled data (as was characteristic of the YOS campaigns) and data from individual stomachs. For future applications, it might be desirable to include additional fields to allow for estimates of 'fullness', and 'Predator Maturity'. Also a field for 'Gear Type' might be useful.

Highlights related to usage of the database:

7) Anna Rindorf and Morten Vinther have used this standardized version of the dataset for input into the multispecies model SMS. This work provides direct input to assessment working groups (estimates of natural mortality) and hence the process of setting TACs and quotas. Model outputs making use of the datasets that have been made available by WGDIM and the ICES Data Centre were presented this at this years' ICES ASC (ICES CM 2010/C18).

8) WGSAM intends to work towards a new stomach sampling campaign (in the near future, 2011/12) and thus it is very helpful to have a 'model' database structure on which to design future data management protocols. WGSAM urge that WGDIM and the ICES Data Centre be fully engaged as the new sampling campaign is planned and implemented.

9) The website includes a very useful account of data coverage (maps), and what has been done to the datasets (how they have been manipulated) http://ecosystemdata.ices.dk/stomachdata/index.aspx.

10) It is extremely useful to have a single point of contact (the ICES Data Centre) to report mistakes or errors to. Previously, individual scientists would have their own versions of the dataset, subject to various levels of data screening and cleaning.

General points of interest:

11) Prior to the efforts by WGDIM and the ICES Data Centre there was a very real risk that these datasets (which are fundamental to the work of WGSAM) would have been lost, given the recent retirement of key staff who had been involved in the collection of these datasets.

12) These are some of the most comprehensive datasets on marine foodwebs anywhere in the world – they are likely to be of use to marine ecologists and modellers generally – but also for management, as we try to develop indicators of foodweb status under the EU Marine Strategy Framework Directive.

13) Prior to the efforts by WGDIM and the ICES Data Centre there had been many variant subsets of the data in circulation (where not all species or years were included) and so it is incredibly useful that there is now a central repository for a cleaned and standardized form of these dataset.

14) WGDIM/Data Centre have done an excellent job of 'cleaning' the data, and in particular spotting odd (and incorrect) cases where fish were consuming prey items bigger than themselves. This seems to have been particularly a problem with data on mackerel.

For the future:

- WGDIM and the ICES Data Centre should work with WGSAM to design a structure for incoming datasets from future sampling campaigns.
- Consider the feasibility of expanding this part of the ICES database to accommodate other datasets from the region, e.g. explore complementarities with the Cefas 'DAPSTOM' dataset, which includes information on 130+ fish species from the North, Irish, Celtic, Norwegian and Barents Seas, or the US NMFS NEFSC 'FHDBS' which includes information on 100+ species in the northeast US waters.
- A combined stomach dataset currently exists for the Barents Sea, accommodating data from Norway (IMR) and Russia (PINRO). WGSAM, WGDIM and the ICES Data Centre could explore the feasibility of a centralized database for this region (managed by ICES).

10.2 Consider the Baltic dataset (in its current state) and whether there is enough value in undertaking further work

The combined Baltic Sea stomach dataset was submitted to the ICES Data Centre by Stefan Neuenfeldt (DTU-Aqua, Denmark) in 2010. Only one variant of this dataset exists, and this has been used extensively to parameterize the multispecies model SMS (and its predecessor MSVPA) but also for multiple Ecopath models in the Baltic Sea (see outputs of the WGIAB – ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea). Only one predator is included in the dataset (cod), and the database contains 60,000 stomachs. In terms of prey types, only herring and sprat are identified specifically (along with 'other' prey). The database also includes total stomach content weights.

Key Responses:

1) The dataset has a lower degree of standardization (in comparison with the North Sea dataset) and it would be worth looking into the additional features WGDIM/ICES Data Centre can offer.

2) Much work was done before the data were submitted to ICES to 'clean' the dataset and correct apparent errors.

3) Without considerable further effort (going back to the original paper records in individual laboratories) limited further progress can be made in terms of providing better resolution of prey types.

4) The data were originally collated by an ICES study group based on what was available in national databases and datasets (for varying years) at that time. It was not the result of a coordinated sampling campaign. The one-off nature of this data collation exercise (and the difficulty of reconvening this group) makes it seem unfeasible that the raw datasets could be revisited.

5) WGSAM intends to work towards a new stomach sampling campaign in the Baltic, and thus it is very helpful to have a 'model' database structure on which to design future data management protocols. WGSAM urge that WGDIM and the ICES Data Centre be fully engaged as the new sampling campaign is planned and implemented.

10.3 Supply WGBFAS 2011 with new M values for the Central Baltic herring and Baltic Sprat

WGSAM was asked by WGBFAS to

> "supply WGBFAS 2011 with new M values for the Central Baltic herring (SD 25–29 and 32 (excl. Gulf of Riga herring) and Baltic Sprat stock based on an update of the last MSVPA-run conducted in 2006."

WGSAM conducted a key run of a multispecies model in the Baltic in 2009 using the SMS model (stochastic multispecies model)(WGSAM 2009). However, the previous natural mortalities estimated for this area were derived from the so called 4M-package, conducting the MSVPA (multispecies virtual population analysis). Among other things, the advantage of SMS over the MSVPA is that the food selection sub-model is able to take into account observed changes in herring and sprat weight-at-age (Figure 10.3.1).

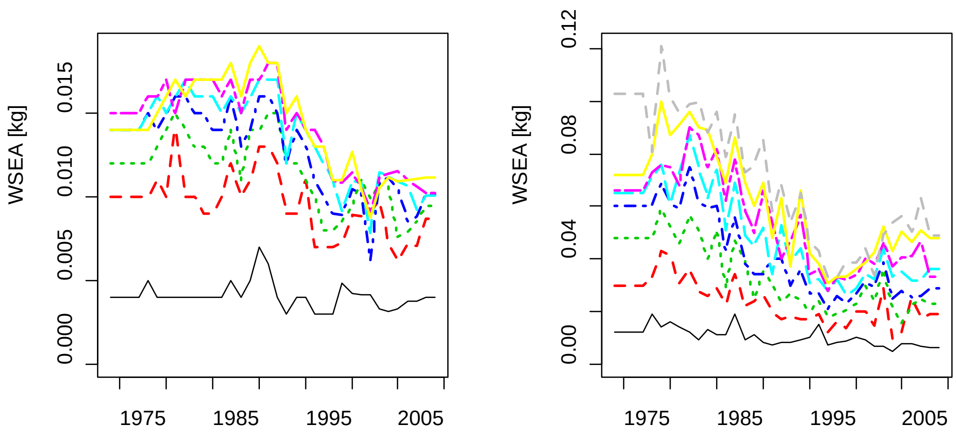

Figure 10.3.1. Weight in the sea by age group for Eastern Baltic sprat (left panel) and Eastern Baltic herring (excl. Gulf of Riga, right panel).

The decrease in growth of herring and sprat during the 1990s (Grygiel and Wyszynski 2003, Götze and Gröhsler 2004) is related to the decrease in abundance of the copepod Pseudocalanus sp., one of the most important food item of sprat during spawning in spring (Szypuła *et al.*, 1997). Total abundance of clupeids (a top–down process) is by far the most significant predictor of both herring and sprat condition; the strong correlation between clupeid abundance and total zooplankton biomass points to food competition and to top–down control by herring and sprat on common food resources (Casini *et al.*, 2006).

Accounting for decreased herring and sprat weight in the cod food selection sub-model did not result in major changes in estimates for spawning-stock biomasses (SSB) of the cod, herring and sprat stocks. Both 4M and SMS cod SSB estimates are very close to the WGBFAS estimates based on the XSA (Figure 10.3.2). This implies that using SMS does not induce major changes. However, the cod stock has increased significantly in recent years, and it **should be considered for updating the predation mortalities for cod**, since cannibalism rates cannot necessarily be taken from the period before 2005 when the abundance of large, cannibalistic cod was low. This discrepancy becomes visible in the deviation between XSA and SMS estimates of cod spawning-stock biomass between 2007 and 2009. However, these values are subject to uncertainty under any circumstances.

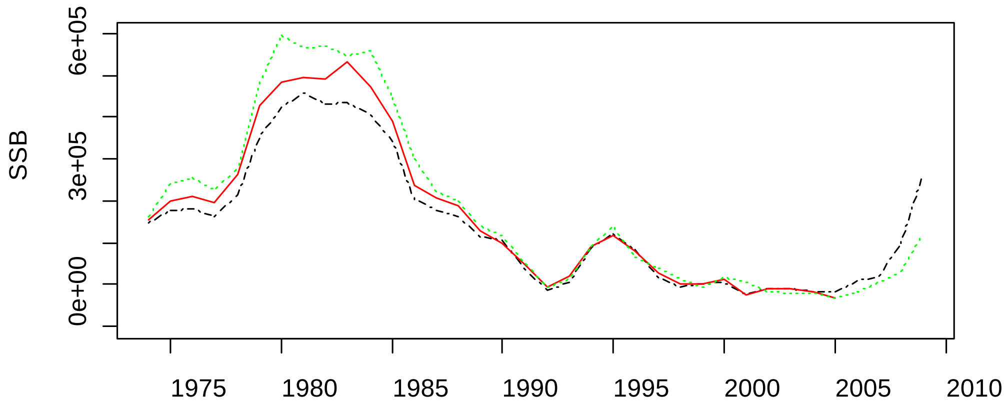

Figure 10.3.2. Time series of Eastern Baltic cod SSB, based on 4M (red solid), SMS (black dot-dashed), and XSA (green dotted).

The spawning-stock biomass estimates for herring and sprat were also very similar between 4M and SMS. The SMS based spawning-stock biomasses are generally lower, bit are still very close to the 4M estimates (Figure 10.3.3). In the period after 2005, when 4M had been replaced by SMS, spawning-stock biomass of herring increased slightly, whereas spawning-stock biomass of sprat decreased, probably due to the increased predation pressure by cod which are not yet big enough to forage on herring.

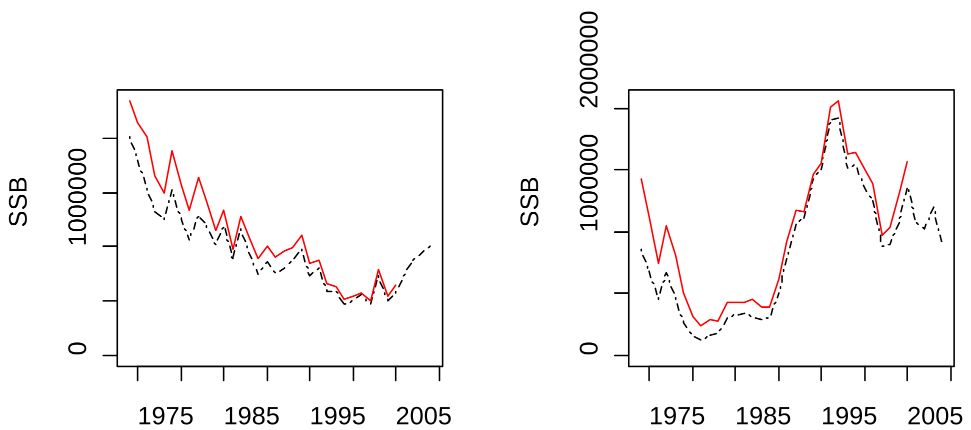

Figure 10.3.3. Time series of Eastern Baltic herring (left) and sprat (right) SSB, based on 4M (red solid), and SMS (black dot-dashed).

Predation mortality (M2) estimates for sprat and herring were about 50% lower for the 0-group, but only slight lower than the 4M estimates for the 2+ group (Figures 11.3.4 and 11.3.5). The slightly lower predation mortalities are consistent with the lower SSB estimates. It is worth noting that the differences in both SSB and M2 were marginal in time of low cod predation pressure, but possibly increase now that the predator (cod) abundance is increasing again. The reason for the differences in M2 estimates is the usage of a different food selection submodel in SMS, which accounts for the changes in herring and sprat growth.

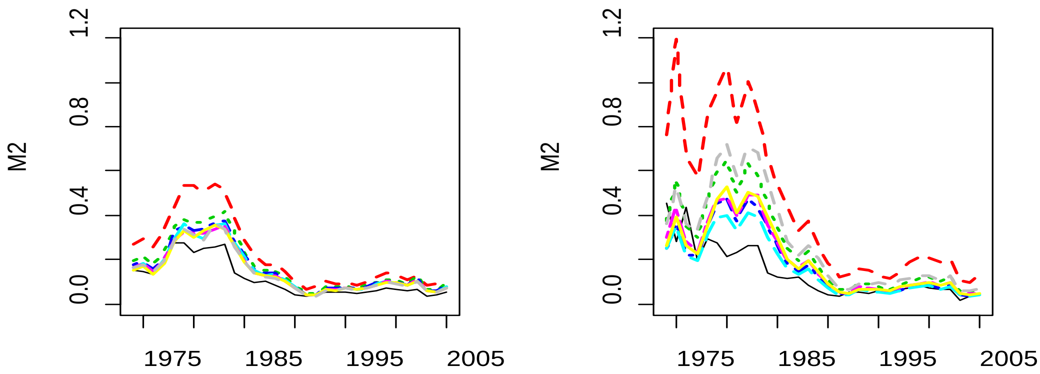

Figure 10.3.4. Predation mortality (M2) of sprat, left SMS, right 4M, increasing age from top to bottom.

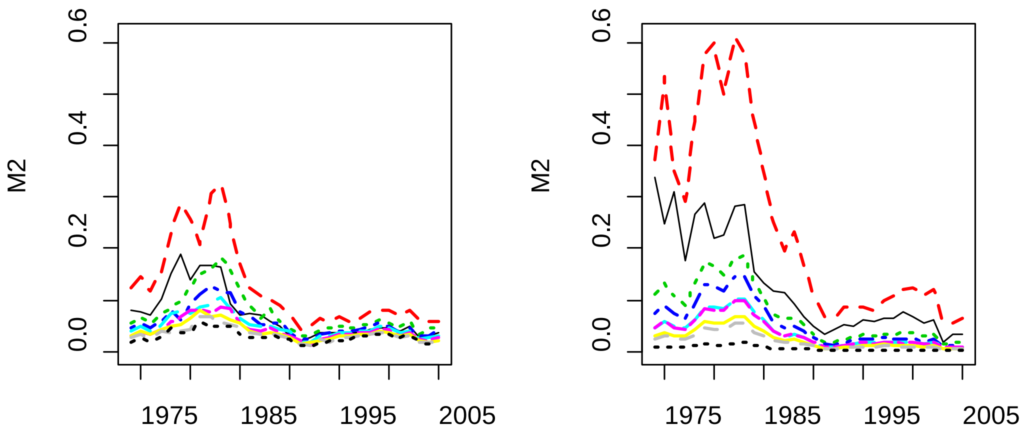

Figure 10.3.5. Predation mortality (M2) of herring left SMS, right 4M, and increasing age from top to bottom.

Similar to the predation mortality estimates, SMS-based estimates of fishing mortality (F) are slightly lower for sprat than the 4M estimates. Furthermore, year-to-variability is lower within the SMS estimates (Figure 10.3.6).

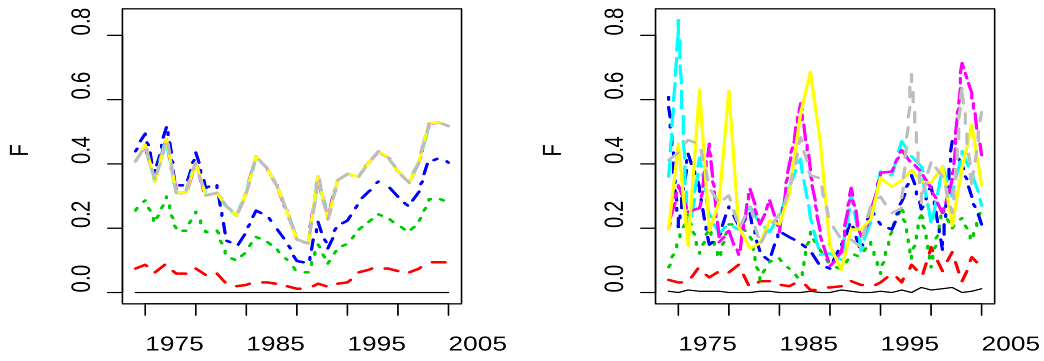

Figure 10.3.6. Fishing mortality (F) of sprat, left SMS, right 4M, increasing age from bottom to top.

Fishing mortalities for herring are very similar between SMS and 4M, but again with lower year-to-year variability of SMS (Figure 10.3.7). In conclusion, the **application of SMS base predation mortalities will not drastically change the historic development of herring and sprat SSB, but will improve the realism of the food selection model** by accounting for observed changes in herring and sprat weight-at-age. Predation mortalities up to 2009 are available at http://www.ices.dk/workinggroups/ViewWorkingGroup.aspx?ID=193 under 'Report 2009'. The next key-run will be performed in 2012. In between, it is recommended that predation mortalities are calculated as outlined in Section 4.1. That is, a smoothed average from the last key run should be used.

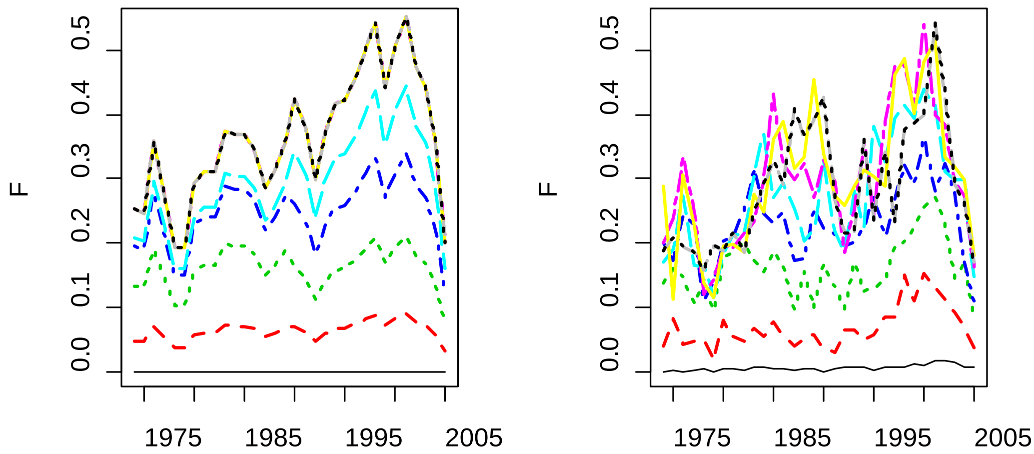

Figure 10.3.7. Fishing mortality (F) of herring left SMS, right 4M, increasing age from bottom to top.

10.4 Provide yearly mortality parameters for inclusion in single-stock assessments for WGNSSK

WGSAM acknowledges and appreciates the request of WGNSSK and WGBFAS to provide yearly mortality parameters for North Sea stocks for inclusion in single-stock assessments. However, the group discussed whether yearly updates are useful for assessment purposes and concluded that an update every three years is more appropriate (Section 4.1). Yet to fully address this request and as a supplement, WGSAM has recommended a method to extrapolate in the years between the key runs

10.5 In conjunction with IBTSWG and WGBIFS, formulate a common proposal to address multispecies interactions in the North Sea and Baltic Sea

The work done by WGSAM on this point has been centered on drafting a manual for use in new stomachs sampling programmes. This was deemed to be the most efficient method of communicating with the other two working groups as back to back meetings of the three groups seemed unlikely to be achievable. The work on the manual is described in Section 5. WGSAM shall also continue petitioning ICES, its relevant expert groups, and its member states to implement a novel stomach sampling plan for the ICES areas currently lacking one. Communication between IBTSWG and WGBIFS with WGSAM to develop such a common proposal remains a high WGSAM priority.

10.6 References

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Annex 2: Agenda

	MONDAY 04-OCT
1000	Opening of the meeting
	Adoption of ToR and Agenda
	Volunteers to work on different ToRs and overview of presentations prepared for the meeting
1100	Coffee
	ToR a, Presentations describing further progress in multispecies and ecosystem modelling
1300	Lunch
1400	Reconvene
	ToR a, Presentations describing further progress in multispecies and ecosystem modelling
1600	Tea
	Wrap up on ToR a
	Develop Following Day Workplan, Updates from earlier in day, Wrap up
1730	Adjourn
	TUESDAY 05-OCT
900	Initial presentations of ToR b: Key runs.
	Key runs scheduled for 2010:
	Ecopath North Sea and Baltic Sea, Gadget Barents Sea, Others?
1030	Coffee
	Disussion on ToR d, volunteers IDed to write up
1300	Lunch
1400	Reconvene
	Disussion on ToR e, volunteers IDed to write up
1600	Tea
	Continue discussion on ToR d, e, Subgroup reporting
	Develop Following Day Workplan, Updates from earlier in day, Wrap up
1730	Adjourn
	WEDNESDAY 06-OCT
900	Revisit ToR b, Key run reports
	Revisit, as need be, ToR d-e
1030	Coffee
	ToR g and h, discussion and workplan
1300	Lunch
1400	Reconvene
	ToR i, discussion and workplan
1600	Tea
	Discuss ToR c
	Subgroup reporting
	Develop Following Day Workplan, Updates from earlier in day, Wrap up
1730	Adjourn

	THURSDAY 07-OCT
900	Preliminary check on WG report elements
	Revisit, as need be, ToR b-e
1030	Coffee
	ToR g, h
1300	Lunch
1400	Reconvene
	ToR f, i discussion and workplan
1600	Tea
	ToR f, g, h,i
	Subgroup reporting
	Drafting session
	Develop Following Day Workplan, Updates from earlier in day, Wrap up
1730	Adjourn
	FRIDAY 08-OCT
900	Revisit, as need be, ToR b-e
	Revisit, as need be, ToR f-i
1030	Coffee
	Subgroup reporting
	Drafting session
	Scope out next year meeting plan, schedule, ToR
1300	Adjourn

Annex 3: WGSAM terms of reference for the next meeting

The **Working Group on Multispecies Assessment Methods** (WGSAM) chaired by Anna Rindorf, Denmark and Jason Link, US, will meet in Woods Hole, USA, 10–14 October 2011 to:

a) Review **further progress** and report on key updates in multispecies and ecosystem modelling throughout the ICES region;

b) Report on the development of **key-runs** (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the North Sea, Baltic Sea, Barents Sea, Bay of Biscay and others as appropriate);

c) Work towards implementing new **stomach sampling** programmes in the ICES area in the near future;

d) Explore how '**virtual multispecies datasets**' (including survey, catch and stomach content data) for use in multiple multispecies models, especially for comparison and sensitivity testing, could be constructed;

e) Work towards inclusion of **fleet dynamics** in multispecies models;

f) Explore **simple statistical relationships between M and B** among predator and prey from output of multispecies models;

g) Improve quantification of the role of top predators (marine mammals, seabirds, large pelagics) on **forage fish** in the ICES area ecosystems;

h) Explore the expected **trophic role of invasive species** using a simulation model package under anticipated conditions;

i) Address **requests** from other ICES Expert Groups as appropriate.

Of these, a, b and i are standing terms of reference, while c, d, and e are 'multiyear projects'

Longer-term aspirations (possible ToRs for future years)

Review estimates of abundance and productivity at **lower trophic levels**, and work towards the inclusion of such information in multispecies models

Evaluate the major **sources of uncertainty** when making projections using multispecies and eco-system models and explore possible best practices for addressing said uncertainties

Evaluate and explore **end-to-end models** and compare to multispecies models in use in the ICES region and compare to multispecies models

Evaluate and explore **size spectra models** and compare to multispecies models in use in the ICES region and compare to multispecies models

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

Evaluate feasibility of including more **spatial structure** in models, and apply this e.g. to investigating the effects of marine protected areas

Provide advice on the '**infrastructure**' needed to support ecosystem/multispecies advice and modelling (data collection including process studies, modelling needs, database management, communication of results)

Work towards linking ecology and **economy** – valuation of goods and services from the ecosystem, exploring trade-off between MSY, MEY and conservation objectives

Connection with the ICES science plan

The work outlined above fits well with the high priority research topics given in the ICES Science Plan for 2009–2013, and applies to all three thematic areas (Understanding ecosystem functioning, Understanding interactions of human activities with ecosystems, and Development of options for sustainable use of ecosystems).

Supporting information

Priority	Multispecies assessment modelling is essential to the development of viable long-term management strategies.
Scientific Justification and relation to action plan	The increased emphasis on ecosystem management (e.g. under the revised Common Fisheries Policy), and a move away from advising on single-stocks in isolation, necessitate consideration of interactions between key fish stocks and the ecosystems of which they are part. Historically the various ICES multispecies working and study groups have acted as a useful conduit, drawing together advice and quantitative outputs from many different assessment groups and combining these into an integrated product of direct use to managers and researchers. The past several meetings of WGSAM showed that there is much ongoing work within this field, and that there is a need for a pan-European forum for reviewing progress, and for learning about the 'best practice' of other research groups (ongoing ToR a). Multispecies models have often been used to provide updates of natural mortality M for inclusion in conventional single-species stock assessments (ToR b). Consequently it is considered useful to have occasional 'key-runs' for each region, whereby time-series are updated and model configurations are agreed and 'peer reviewed' by a number of regional experts. WGSAM will continue to work towards improved key-runs in the Barents Sea, Bay of Biscay, Baltic and North Sea, as well as working towards significant improvements in model functionality, for example the better characterization of benthic food sources, and the development of cross-model validation techniques (ToRs a and d). In intervening years between key-runs, WGSAM will work to provide statistical extensions for estimates of M until such time as new key runs can be executed (ToR f). Stomach content data serve as the basis for a plethora of multispecies, extended single-species, and ecosystem models. Having a solid foundation of adequate stomach content data are a prerequisite for implementing the ecosystem-based approaches to fisheries. Stomach sampling has been annual in some areas, while in other areas (e.g. the North Sea) a large effort ('Year of the Stomach') has been made sporadically. At the 2011 WGSAM meeting the group will continue work towards implementing new stomach sampling programmes throughout the ICES area in the near future by reviewing protocols, pursuing new funding opportunities and gathering institutional support (ToR c). The ICES Science Plan for 2009–2013 highlights a top research priority for better understanding top predators (marine mammals, seabirds, and large pelagics) in marine ecosystems. Further, explicitly accounting for the trophic role of forage species is increasingly recognized as an important consideration in moving towards an ecosystem approach to management. In 2011 WGSAM will explore approaches for estimating the quantitative relationships among top predators and forage fish (ToR g).

	The ICES Science Plan for 2009–2013 specifically calls for research and advice with regard to the risks and threats posed by invasive and non-native species. There is currently relatively little information available concerning the role that such species might play in marine foodwebs in future, and little thought has been dedicated to understanding how other marine organisms might be displaced or affected once a new species has established itself. In 2011 WGSAM will use an extent simulator to evaluate the potential trophic role of introduced and invasive species (ToR h). Other priority research areas that have been highlighted in the ICES Science Plan and which will be addressed by WGSAM at its 2011 meeting include: biodiversity and the health of marine ecosystems (ToRs c, g and h); top predators (marine mammals, seabirds, and large pelagics) in marine ecosystems (ToR g), impacts of fishing on marine ecosystems (ToR b, e, h), and marine living resource management tools (ToRs a, b, d, e and f).
Resource Requirements	–
Participants	Approx 20. Expertise in ecosystem, modelling and fish stock assessment from across the whole ICES region.
Secretariat Facilities	None
Financial	No financial implications
Linkage to Advisory Committees	ACOM
Linkage to other Comities or groups	WGDIM, WGBIFS, IBTSWG, WGECO,WGMIXFISH, WGFE, most assessment Expert Groups
Linkages to other organizations	–

Annex 4: Recommendations

RECOMMENDATION	FOR FOLLOW UP BY:
1. BEWG: Produce a digitalized map of average benthos production and biomass by quarter and area for the North Sea (see explanation above)	BEWG
2. BEWG: Consider whether stomach data could provide information on the spatial and temporal changes in abundance of species or species groups difficult to sample with traditional gear types, and if the answer to this is affirmative, consider whether there would be interest in cooperating with WGSAM, IBTSWG and WGBIFS on planning and conducting future stomach sampling programmes	BEWG
3. WGNSSK: Total landings by year, quarter, species and age (not segregated by fleet)	WGNSSK
4. WGMIXFISH: Total landings by year, quarter, species and fleet from a total of 10 to 20 aggregated fleets, preferably defined by the gear they deploy. Examples could be gillnet, beam trawl, otter trawl etc. If possible, the age distribution for each aggregated fleet and species would be useful even if yearly and quarterly values are not reliable.	WGMIXFISH
5. IBTSWG: WGSAM requests IBTSWG to investigate the manual for stomach samplings given in annex 5 and comment on whether the sampling can be carried out in practice, whether the manual is sufficiently clear, what the expected number of stomachs collected during the exercise would be (given expected length distributions and catch rates), what the demands would be regarding additional personnel and vessel time and whether the exchange format and labels suggested in Annex 5 are appropriate and sufficient.	IBTSWG
6. WGBIFS: WGSAM requests WGBFIS to investigate the manual for stomach samplings given in annex 5 and comment on whether the sampling can be carried out in practice, whether the manual is sufficiently clear, what the expected number of stomachs collected during the exercise would be (given expected length distributions and catch rates), what the demands would be regarding additional personnel and vessel time and whether the exchange format and labels suggested in Annex 5 are appropriate and sufficient.	WGBIFS
7. WGDIM: WGSAM suggests that the ICES Data Centre should work with WGSAM to design a structure for incoming datasets from future sampling campaigns and to assure that the exchange format suggested in Annex 5 is appropriate	WGDIM

Requests to other groups:

BEWG: Produce a digitalized map of average benthos production and biomass by quarter and area for the North Sea (Same as last year and the year before) or send a reply stating why this is not accomplished

Explanation

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

BEWG: Consider whether stomach data could provide information on the spatial and temporal changes in abundance of species or species groups difficult to sample with traditional gear types, and if the answer to this is affirmative, consider whether there would be interest in cooperating with WGSAM, IBTSWG and WGBIFS on planning and conducting future stomach sampling programmes

Explanation

Benthic food plays a large role in the diet of several North Sea predators and in future sampling programmes, information on the diet of these predators may be of value to BEWG though it does not improve estimates of the amount of fish consumed. WGSAM therefore asks BEWG to consider whether determining benthos in stomach contents to species or species groups would provide a significant value to BEWG.

WGNSSK: Total landings by year, quarter, species and age (not segregated by fleet)

Explanation

Total landings per quarter are needed to make the key run of the North Sea SMS planned for 2011 and hence ultimately to estimate the natural mortalities requested by WGNSSK.

WGMIXFISH: Total landings by year, quarter, species and fleet from a total of 10 to 20 aggregated fleets, preferably defined by the gear they deploy. Examples could be gillnet, beam trawl, otter trawl etc. If possible, the age distribution for each aggregated fleet and species would be useful even if yearly and quarterly values are not reliable.

Explanation

WGSAM would like to investigate how simple parameterizations of fleet dynamics would affect the predictions of the North Sea SMS of issues such as multispecies MSY. Currently, the fishing mortalities of different stocks are assumed to be independent.

IBTSWG, WGBIFS and WGDIM: WGSAM requests IBTSWG, WGBIFS and WGDIM to assist in developing a manual for stomach samplings, comment on whether the sampling can be carried out in practice, whether the manual is sufficiently clear, what the expected number of stomachs collected during the exercise would be (given expected length distributions and catch rates), what the demands would be regarding additional personnel and vessel time, whether the exchange format and labels suggested in Annex 5 are appropriate and sufficient and to design a structure for incoming datasets from future sampling campaigns.

Explanation

Providing advice on natural mortalities relies heavily on ecosystem models capable of evaluating how the effects of fishing and environmental change are spread through the ecosystem by complex foodweb interactions. The heart of all of these models is information on who-eats-who and how much. The last comprehensive investigation of species interactions in the North Sea and Baltic was conducted 20 years ago and is unlikely be representative of what is now a very different ecosystem. In order to assure that the multispecies and ecosystem models provide reliable predictions, WGSAM considers that they should be calibrated with up to date information.

WGSAM therefore suggests that under the auspices of ICES, the process of collecting food composition data on existing surveys should be initiated. To assure that the stomach data sampled are subsequently used in the multispecies and ecosystem models, it is essential that a standardized sampling protocol is followed as was the case in previous large-scale stomach sampling exercises (ICES, 1991). However, since these exercises were performed new knowledge of the statistical properties of stomach content analyses has been gained. The annex attached to WGSAM 2010 (Annex 5) is a first draft of an updated sampling manual and is intended to be the start of the communication with IBTSWG and WGBFIS on the details of the sampling procedure as requested by PGCCDBS.

Annex 5: Manual for ICES Stomach sampling projects in the North Sea and Baltic Sea

The Study Group on Multispecies Assessment in the North Sea (SGMSNS; ICES, 2006, ICES, 2007) analysed the precision of average diet estimates for North Sea species and linked precision to sampling level. Based on this summary, the group recommends that the predators sampled are restricted to cod in the Baltic Sea and cod, haddock, whiting, saithe, gurnard, horse mackerel, mackerel, starry ray, turbot and brill in the North Sea with John Dory and hake as optional extensions. The group recommends sampling 5 rather than 10 stomachs per 5 cm size group of each predator, with the exception of saithe, mackerel and horse mackerel, where a large proportion of the stomachs are empty. For these species, 15 stomachs should be sampled from each size group. Stomachs could be taken from fish sampled for maturity and age when possible. Depending on the level of information required from the stomach analyses (see below), the samples can either be analysed on board (only level 1) or frozen individually in plastic bags (levels 1 and 2) including a label describing the sampled fish (Table 5.1). Prey is recorded using TSN codes with new codes added for species not currently listed.

Further, the group proposes two different levels of stomach sampling

1) Minimum level. Only predators larger than 15 cm are sampled as fish below this size are generally not piscivorous. Stomach samples are analysed individually and fish prey identified to species. Length of fish prey is measured or estimated to nearest cm below (eggs are recorded as having length 0) and digestive stage is recorded. Invertebrates are identified to larger groups (Table 5.1). Total prey weight and weight of individual prey groups is recorded (species and length groups separately for fish).

2) Extended level providing information on invertebrates. Predators down to 5 cm sampled. Stomach samples are frozen individually on board and analysed in the lab. Fish and invertebrate prey is identified to species when possible. Length of fish and invertebrate prey is measured or estimated to nearest cm below. Total prey weight and weight of individual prey groups is recorded (species for both fish and invertebrates).

It is vital for later use of the data that the information recorded in the exchange format and on the labels used for year, quarter, ship and haul are consistent with those used when haul information is uploaded to DATRAS. This assures that further details of the haul can be obtained when necessary.

Selection of stomachs at sea

The fish sampled for stomachs must be selected with care. To assure the random selection within size classes, the group recommends using the fish selected for maturity sampling whenever possible. Among these fish, care must be taken to obtain reliable data:

1) Everted stomachs. Some fish have everted stomachs. Since it not known whether these stomachs contained food or not, such fish must not be used for stomach sampling.

2) Regurgitated stomachs. Some fish have regurgitated all or part of their stomach contents and these fish must not be collected for analyses. However, the number of regurgitated stomachs encountered during the exami-

nation must be recorded to ensure that the proportion of feeding fish in the sample is accurately defined. In practice, it is often difficult to tell whether regurgitation has taken place, but in situations where the stomach is flaccid or distended, but contains little food, experimental work by Robb (Robb 1992) indicates that the size of the gall bladder is a useful practical indicator of the recent feeding history of the fish. A large densely coloured gall bladder indicates that a stomach has been empty for some time and has not recently lost its content by regurgitation. The criterions are summarized in Table A5.1 and should be applied when assessing whether a stomach should be classified as regurgitated or empty.

3) Stomachs of feeding fish showing no signs of regurgitation. These should be collected for analyses. It should be noted that not all feeding fish have grossly distended stomachs, i.e. feeding does not necessarily mean full.

4) Empty stomachs.

5) Stomachs with only indigestible skeletal remains (polychaete bristles, mollusc shells and opercula, fish bones and otoliths etc).

When stomachs are opened at sea, it is possible to distinguish between those which are truly empty and those containing small prey or indigestible remains. Accurate records can be kept and any indigestible materials should be included in the material collected. However, when entire stomachs are collected at sea, their true state cannot be determined until they are opened in the laboratory and in this case the stomachs of apparently non-feeding fish should be collected.

The material collected at sea to meet the sampling targets should originate in feeding fish showing no evidence of regurgitation and from non-feeding fish. There is, the sampling should continue until a total of 5 stomachs (empty+skeletal remains+feeding-regurgitation). The state of the gall bladder should be recorded using the scale in Table A5.1 and to adjust for regurgitated stomachs discovered in the laboratory, 6 rather than 5 (20 rather than 15 for mackerel, horse mackerel and saithe) samples should be taken per 5 cm length group when stomachs are not opened at sea.

Sampling strategy at sea

1) For each predator species and 5 cm size group, aim to collect 5 stomachs per 5 cm size group of each predator, with the exception of saithe, mackerel and horse mackerel, where 15 stomachs should be sampled from each 5 cm size group. Take care not to include fish showing evidence of regurgitation. If stomachs are not opened at sea, collect 6 stomachs per 5 cm size group of each predator, with the exception of saithe, mackerel and horse mackerel, where 20 stomachs should be sampled from each size group.

2) If stomachs are opened at sea: Record the number of stomachs regurgitated, containing food and containing skeletal remains and containing food.

3) Preserve stomachs by freezing. Contents can be emptied into plastic bags before freezing.

4) Each sample should contain a label giving all the information listed in able A5.2.

5) Data are recorded using the data exchange format in Table A5.3 (fields 1–70).

6) If stomachs are analysed at sea, Table A5.3 fields 71–99 should be used.

7) Stomach samples are analysed individually and fish prey identified to species. When possible, length of fish prey is measured (whole prey) or estimated to fresh length (partially digested but original length still recognizable) in nearest cm below (eggs are recorded as having length 0) and digestive stage is recorded. Invertebrates are identified to larger groups (Table A5.2). Total prey weight and weight of individual prey groups is recorded (species for fish). Questions can be posed to the species coordinator.

8) After stomach contents have been analysed and recorded, results are submitted to the ICES data centre using the exchange format. ICES will then include the data in the current stomach database

References

ICES. 1991. Manual for the ICES North Sea stomach sampling project in 1991. ICES C.M. 1991/G:3.

Robb, A. P. 1992. Changes in the gall bladder of whiting (*Merlangius merlangus*) in relation to recent feeding history. ICES J. Mar. Sci. 49:431–436.

Table A5.1. Condition of gall bladder and hind guts used to differentiate between empty and regurgitated stomachs.

Stage	Gall bladder	Bile colour	Hind gut	State
1	Shrunken, empty or with small amount of bile	Pale	Contains large amounts of bile and digested food material	Feeding*
2	Elongate	Pale green to light emerald green	Contains some bile and digested food particles	Feeding*
3	Elongate	Dark green	Empty or contains some food particles	Empty
4	Round	Dark blue	Empty	Empty

***If fish satisfying these criteria are found without food in their stomach they should be classified as regurgitated**

TableA5.2. Label to be included with each stomach sample.

ICES Stomach sampling programme
Ship
Haul number
Date
Rectangle
Species
Size
Gall bladder Class (whole stomachs only)
Sample no

TabelA5.3. Invertebrate groups and corresponding NODC codes.

Invertebrate group	NODC code in 1991 sampling manual
Amphipoda	6168000000 and 6169000000
Annellidae	5000000000
Astacidae	6181000000
Anomura	6183000000
bivalvia	5500000000
brachyura	6184000000
caridea	6179000000
cephalopoda	5700000000
Cnidaria and ctenophora	3700000000 and 3800000000
crangonidae	6179220000
crustacea (unidentified)	6100000000
echinodermata	8100000000
Euphasiacea and mysidae	6174000000 and 5153000000
gastropoda	5100000000
Nephrops norvegicus	6181010301
pandalidae	6179180000
other crustacea	
other invertebrates	
plastic	
Saduria enthomon	

Tabel A5.3. Exchange format for stomach data (revised from ICES, 1999).

Position	Name	Type1	Range	Comments
1–2	Record type	2A		Fixed value 'SS'
3	Quarter	1N	1–4	
4–6	Country	3A		ICES alpha code
7–10	Ship	4A		ICES alpha code
11–13	Method	3A		See Table A5.4
14–17	Square	4AN		ICES statistical rectangle
18–23	Haul number	6AN		Compatible with the haul number available in DATRAS assuring that stomach samples can be matched with trawl data
24–27	Sample no	4N	1–9999	ID number of the stomach collected. If all stomachs in the 5 cm size group are empty, the number is 9999.
28–29	Temperature	2N	-2–26	oC, not known 99.
30–31	Year	2N	10–99	
32–33	Month	2N	1–12	
34–35	Day	2N	1–31	
36–45	Predator code	10N		TSN Codes
46	Size group code	1A	E, F	E= 1cm groups, F=1mm groups below 2 cm, 1 cm groups above 2 cm

Position	Name	Type1	Range	Comments
47–50	Predator size class code	4N	0–9999	Predator length measured to nearest cm below
59–61	Number with food	3N		Total in 5 cm size group of the predator species
62–64	Number regurgitated	3N		Total in 5 cm size group of the predator species
65–67	Number with skeletal remains	3N		Total in 5 cm size group of the predator species
68–70	Number empty	3N		Total in 5 cm size group of the predator species
71–80	Prey species code	10N		TSN Codes for fish. For invertebrates and unidentified items, use TSN codes if available from WGDIM, otherwise use NODC codes
81–84	Prey size	4N		Prey length measured to nearest cm below (size group code E), or to nearest mm below up to 2 cm, then nearest cm below (size group code F). Eggs have size 0.
85–92	Prey weight	8N		Prey can be weighed together if they are of the same species/species group and same length
93–98	Prey number	6N		
99	Stage of digestion	1N	0–2	0= Intact prey, 1= partially digested prey, 2= skeletal material
100	Padding field			

[1]All numeric field (N), all Alpha (A) and mixed alpha numeric (AN).

Table A.5.4. Fishing method codes.

DEM	Demersally caught by trawling or seining gears
PEL	Pelagically caught by trawling or seining gears
DHL	Demersal hook and line
PHL	Pelagic hook and line
DGN	Demersal gillnets
PGN	Pelagic gillnets

Annex 6: List of Acronyms

AFBI	AGRI-FOOD AND BIOSCIENCES INSTITUTE
Agg-PROD	Aggregate Production Models
SPMW	Stock Production Modelling Workshop
APECOSM	Apex Predators ECOSystem Model
ASMFC	Atlantic States Marine Fisheries Commission
ATLANTIS NEUS	NorthEast US Application of ATLANTIS
BALMAR	Baltic Sea MAR(1) food-web model
BEMA	Biological Ensemble Modelling Approach
BMSY	Biomass at Maximum Sustainable Yield
BRP	Biological Reference Points
CAMEO	Comparative Analysis of Marine Ecosystem Organization
Cefas	Centre for Environment, Fisheries & Aquaculture Science
CPR	Continuous Plancton Recorder
CPUE	Change per Unit Effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAPSTOM	Integrated Database and Portal for Fish Stomach Records
DARD	Department of Agriculture and Rural Development
ECOROMS	NPZD-ROMS coupled model
EMAX	Energy Modeling and Analysis eXercise
F	Fishing mortality
FLR	R library that facilitates the construction of bioeconomic simulation models of fisheries and ecological systems
Fpa	Fishing mortality for the Precautionary Approach
GAGDET	Generally Applicable Area Disaggregated Ecosystem Toolbox
GOM	Gulf of Maine
GOMAG	Gulf of Maine Aggregate model
HCR	Harvest Control Rules
IMR	Norwegian Institute of Marine Research
LPUE	Length per Unit Effort
M	Natural Mortality
MAR	Multivariate auto-regressive
MCMC	Markov Chain Monte Carlo
MS	Multispecies
MS-PROD	Multispecies Production Model
MSVPA	Multispecies Virtual Population Analysis
MSVPA-X	Extended Multispecies Virtual Population Analysis
NEST	A decision support system for management of eutrophication in the Baltic Sea
NEUS LME	NorthEast US Large Marine Ecosystem
NMFS	National Marine Fisheries Service
NEFSC	NorthEast Fisheries Science Centre
SEFSC	SouthEast Fisheries Science Centre
NPZD	Nutrient-Phytoplankton-Zooplankton-Detritus
OSMOSE	Object-oriented Simulator of Marine ecOSystems Exploitation

AFBI	Agri-Food and Biosciences Institute
PINRO	Polar Research Institute Of Marine Fisheries And Oceanography
ROMS	Regional Ocean Modeling System
SARC	Stock Assessment Review Committee
SMS	Stochastic Multi-Species model
SPMW	Stock Production Modelling Workshop
S-R	Stock -Recruitment
SS	Single-species
SSB	Spawning Stock Biomass
SST	Sea Surface Temperature
STOCOBAR	STOck of COd in the BARents Sea
TL	Trophic Level
UNCOVER	UNderstanding the Mechanisms of Stock ReCOVERy