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

5–9 October 2009

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l'Exploration de la Mer

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Contents

Executive summary

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

The participants provided an updated inventory, to supplement the information collated in 2007 and 2008 (ToR 'a' and 'b'). The group further provided a standardized format for reporting Ecopath key runs (ToR 'c'). The extent of knowledge about predation by pelagic fish on pre-settlement life stages of important demersal fish was reviewed for several areas including the North Sea, West of Scotland, Irish Sea, Barents Sea and Bay of Biscay (ToR 'd').

The possibility of including spatial overlap in existing multispecies models (ToR 'e') was reviewed for the North Sea, the Baltic and the Barents Sea, and an overview of methods for estimating consumption was made (ToR 'f'). WGSAM also provided strong recommendations for a new stomach sampling program in the North Sea, the Baltic and other areas where no regular stomach sampling has taken place (ToR g). Following a request from WKSHORT, WGSAM made estimates of predation on sprat in the North Sea in the 'years of the stomach' 1981 and 1991, which in the absence of other data are useful information for estimating the minimum stock level of sprat.

1 Opening of the meeting

The **Working Group on Multispecies Assessment Methods** [WGSAM] met at ICES Headquarters, Copenhagen, Denmark from 5–9 October 2009. The list of participants and contact details are given in Annex 1. The two Co-Chairs, John Pinnegar (CEFAS, UK) and Bjarte Bogstad (IMR, Norway) welcomed the participants and highlighted that like last year, the Working Group had a broad geographic scope, this year encompassing research in the Bay of Biscay, Barents Sea, Norwegian Sea, North Sea, Baltic Sea, Icelandic waters as well as the east coast of North America. The Terms of Reference for the meeting (see section 2) were discussed, and a plan of action was adopted with individuals providing presentations on particular issues and allocated separate tasks to begin work on all ToRs.

1.1 Acknowledgements

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

2 Terms of Reference

2008/2/RMC08 The **Working Group on Multispecies Assessment Methods [WGSAM]** (Co-Chairs: John Pinnegar, UK and Bjarte Bogstad, Norway) will meet at ICES Headquarters, Copenhagen from 5–9 October 2009 to:

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

b) report on the development of key-runs (standardized model runs updated with recent data, and agreed upon by WGSAM participants) of multispecies fishery models for different ICES regions;

c) Determine a standardized format for reporting Ecopath key-runs;

d) Review current process-knowledge, data requirements, and data available to model predation on pre-settlement life stages by pelagic predators;

e) Work towards the inclusion of spatial overlap in existing multispecies models;

f) Review methods for estimating consumption and diet composition in multispecies models;

g) Work towards implementing new stomach sampling programs in the ICES area in 2011 by reviewing protocols and estimating costs.

WGSAM will report by 20 November 2009 for the attention of SCICOM and ACOM.

In addition, the following request to WGSAM was made by WKSHORT:

WKSHORT asks WGSAM to attempt to generate an estimate of predation on sprat in the North Sea based on stomach content data and predator food requirements.

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

In 2007 and 2008 the working group provided a broad overview of the multispecies models currently used within each ICES Ecoregion. This chapter of the WGSAM 2009 report offers an update on further developments and progress made within the different geographic areas:

3.1 Ecoregion A: Greenland and Iceland Seas

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

3.2 Ecoregion B: Barents Sea

3.2.1 Species interactions as a background for multispecies modelling

As detailed in the WGSAM report in 2008 (ICES, 2008c) there are strong interactions between cod, capelin and herring in the Barents Sea. The interactions and correlations between these species have varied over time, with clearer links between capelin numbers and predator condition being observed in the capelin collapse of 1985–1989 than in two subsequent collapses (see ICES, 2008c and Gjøsæter *et al.*, 2009 for more details). Herring are significant predator on capelin larvae, but high herring stock does not appear to be sufficient, in itself, to cause a failure of capelin recruitment. Finally, clear links between the recruitment of cod and herring and temperature variations from the 1980s do not appear to be so clear in more recent years. All of these are described in more detail in ICES (2008c.) The strong, but complex and varying, nature of the dependencies in the Barents Sea ecosystem forms the background and rationale for the multispecies modelling work in the Barents Sea.

3.2.2 Modelling

3.2.2.1 Gadget models

The existing Barents Sea Gadget model includes minke whales, cod, capelin and herring and is described in the 2007 WGSAM report (ICES, 2007). The model is being used in an EU project (UNCOVER) to examine the likely effects of different fishing and/or recruitment scenarios on the multispecies system. As described in the 2008 WGSAM report (ICES, 2008c) the model includes the full herring life cycle and its predation on capelin larvae. This has been developed and refined since 2008. The inclusion of predation on the larvae simulates an important link in the ecosystem, and also allows for evaluation of scenarios impacting on the early life stages of the fish. This capability is being explored in a pilot project to examine the effects of oil spills on the marine ecosystem (Carroll, 2008). The aim of the project is to link a range of different models, covering possible oil spill timing, extent, and toxicity; oceanographic models; models of plankton and fish larvae; fish population model (Gadget). The multispecies fish population model will incorporate the modelled mortalities on fish larvae, and examine the likely effects on the modelled species over the medium term. The aim is for the final suite of linked models to be used as part of the risk assessment process for oil exploitation and exploration in Norway.

A two species model for redfish (*Sebastes mentella* and *Sebastes marinus*) is being developed for the Barents Sea. This model will use as an operating model to test simple assessment models being developed for deep-water fish as part of the DEEPFISHMAN EU project. The species modelled are typical of long-lived, late-maturing deep-water fish, but with more data available than is typical for deep-water fish. This makes it possible to produce a detailed operating model to use as a testbed for developing assessment models. The simpler models will be evaluated on their ability to replicate the population trends from the operating model under a range of different assumptions about data availability and quality. The two redfish species are difficult to distinguish, and some data errors are likely to be because of misattribution of individuals. The operating model will therefore be multispecies in order to simulate such errors in the data available to the simple assessment model. The multispecies model will not itself be used in management, however the simpler assessment models tested on it will be.

3.2.2.2 STOCOBAR

STOCOBAR (STOck of COd in the BARents Sea) is a cod-ecosystem coupled model that describes stock dynamics of cod in the Barents Sea, taking trophic interactions and environmental influences into account (Filin, 2007). The model is age-structured with abundance of various food sources affecting the development of the cod stock. It is designed as a tool for prediction and exploration of cod stock development as well as for evaluation of harvest strategies and recovery plans under different ecosystem scenarios. The model is described in the WGSAM 2008 report (ICES, 2008c). The model has been updated to allow testing of multispecies management rules that set cod fishing level according to the biomass of both cod and capelin.

A project is currently being conducted to examine the differences between the populations produced by the STOCOBAR and the Gadget models. This will examine the differences in the base case scenario produced by fitting both models to historical data and existing management rules, and looks at the differing responses of the models to different fishing or recruitment scenarios. This comparison is aimed at studying the degree of uncertainty because of model formulation.

3.2.2.3 MODELS USED IN MANAGEMENT

Predation by cod on capelin has for many years been taken into account in the management of capelin in the Barents Sea (Gjøsæter *et al.*, 2002, ICES 2008h).

The WKSHORT benchmark meeting 31 August – 4 September 2009 in Bergen (ICES, 2009d, 2008g) scrutinized the methodology used for assessing the Barents Sea capelin stock. Although the methodology was endorsed, the documentation provided was not endorsed, as it was found incomplete. Further advancements in the methodology will rest until the description of the present methodology has been approved by ICES.

The WKSHORT endorsed the way in which the Barents Sea capelin assessment has incorporated predator-prey interactions (specifically having identified the crucial role of cod predation on capelin mortality rate), and suggested that this is world-leading in development of an ecosystem approach. Similarly, the incorporation of uncertainty (through bootstrapping simulations) is to be applauded and has clearly been very effective.

3.3 Ecoregion C: Faroes

Steingrund (2009) studied the effect of food availability on spatial distribution, recruitment, natural production and fishery during the near-collapse of the Faroe Plateau cod (Gadus morhua L.) stock in the 1990s. He found that cannibalism on age 1 cod was an important factor in explaining variability of year-class strength (at-age 2) for this stock. Other multispecies modelling approaches applied in this region were described in the 2007 WGSAM report (ICES, 2007).

3.4 Ecoregion D: Norwegian Sea

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

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

3.5 Ecoregion E: Celtic Seas

3.5.1 Ecopath in the Celtic Sea

In 2009 Guenette and Gascuel published details of a EwE model for the Bay of Biscay and Celtic Sea (presented at the 25 anniversary Ecopath Conference). The model is primarily focused on 14 industrial species, their prey and predators, but contains in all 38 functional groups. Cod, hake and Norway lobster were separated into juvenile and adult stanzas to account for species size-structured interactions among themselves and the fisheries. Starting from 1980 the model was fitted to biomass and fishery landings datasets using time-series of fishing mortality. The authors also used various climate indices, including the North Atlantic Oscillation index (NAO) and sea surface temperature to modify phytoplankton production and obtain better fits. The model is still in a preliminary phase but it was still able to replicate biomass and catches of most exploited species, from 1980 to 2006. Forcing primary production with the NAO index did not improve the fit to time-series, although discrepancies in biomass and/or landing trends were corrected in some cases.

A completely separate, but more detailed model of the Celtic Sea is currently nearing completion at University of Plymouth (UK) in collaboration with scientists from Cefas. 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). The model will be used to investigate the dependence of seabirds and marine mammals on particular forage fish species within the region.

3.5.2 An Ecopath Model for Rockall Trough region

Work has recently begun at the Scottish Association for Marine Science (SAMS), together with Plymouth University and FRS to create an Ecopath with Ecosim (EwE) model of the Rockall Trough region (ICES area VIa,b and VIIb,c,k,j), in order to evaluate the potential impact of deep-water fisheries. The modelling framework will be used, in particular, to predict the effect of current fishing pressure on the target fish species but also to predict impacts on other ecosystem components over time (20 years, 50 years, 100 years etc), and to predict the effect of banning certain fishing gears within the region. This project is known as 'Deepfish' and was funded by the Esmee Fairbairn Foundation (see Howell *et al.*, 2009). The model is comprised of 34 functional groups (including 24 fish groups) and biomass estimates have been derived from German trawl survey data (1974–1986), trawl survey data held by SAMS (1975–1992) and recent fisheries survey data held by FRS (2000 – present). Diet data has been derived from published papers by Maucline and Gordon (1983a,b; 1984a,b,c) and Gordon and Duncan (1987, 1989).

3.5.4 A model of cod-*Nephrops* interactions in the Irish Sea.

A new research project (MF1109 – 'DAPSTOM3') has just begun in the UK (in 2009) 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 will digitize fish stomach content records for the region, including historical information spanning the 1970s, 1980s, 1990s and present day. It will then focus on the parameterization of a two species Gadget model, with particular relevance to cod (*Gadus morhua*) and Norway lobster (*Nephrops norvegicus*), building on the earlier work of Brander and Bennett (1986, 1989), but using updated information on cod stomach contents (work-package 1), 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). In recent years however, video survey techniques have evolved (at Cefas, AFBI and DARD) and hence it should be possible to examine the impact that exploitation on one species might have on the yield of the other.

3.5.5 The 'PREDATE' project in the Irish Sea

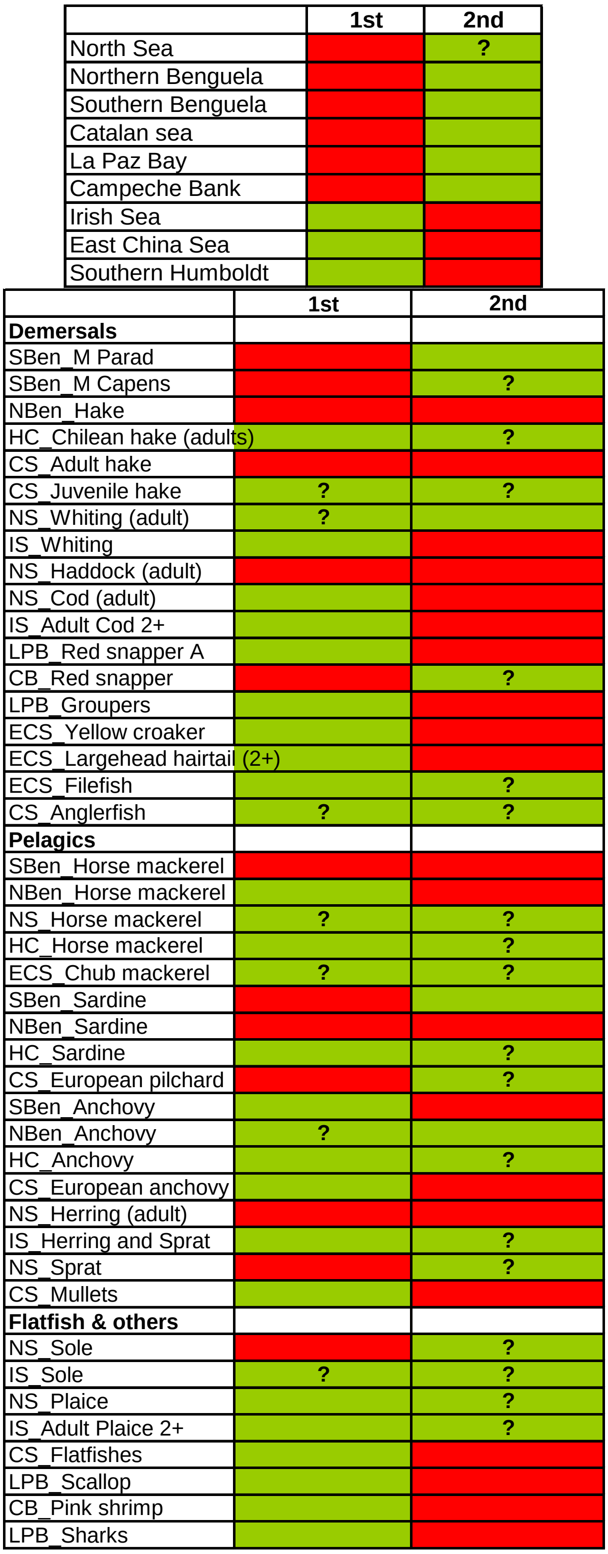
Most multispecies models do not take account of predation on the eggs and larvae. Juveniles simply recruit into the model at age-1, with little regard for what might have happened during the previous year. The PREDATE project at Cefas (UK), aims to develop molecular tools for detecting the presence of eggs and larvae which can be difficult to identify in the stomachs of predators. A full description is provided in section 6.3 of this report.

3.6 Ecoregion F: North Sea

3.6.1 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 has now been completed and fully documented (see Mackinson and Daskalov, 2007, www.cefas.co.uk/publications/techrep/tech142.pdf). 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). Current work is focused on establishing a 'key-run' (see Tor C), further investigation of the relative roles of fishing and climate on North Sea dynamics, and coupling the foodweb to biogeochemical models (through the MEECE project) so that future scenarios of climate change can be more adequately represented.

As part of initial efforts to examine the relative roles of fishing and changes in primary production on marine ecosystems (Mackinson *et al.*, 2008), historical trends in abundance were reconstructed by fitting model predictions to observations from stock assessments and fisheries independent survey data. The authors measured how much better or worse were model predictions were, when 'bottom–up' forcing by primary production was added to 'top–down' forcing through fishing. Using a simple qualitative method to display the results, fishing effects were found to more strongly influence 6 of 9 of the ecosystems examined, but primary production was more often found to be the main factor influencing selected pelagic and demersal fish stock trends (Figure 3.1). Examination of sensitivity to ecological and model parameters shows that the results are the product of complex foodweb interactions rather than simple deterministic responses of the models. Fishing was found to be the primary forcing factor in the North Sea (Figure 3.1), however primary production was found to be more important in the Irish Sea.



	1st	2nd
North Sea	🟥	🟩 ?
Northern Benguela	🟥	🟩
Southern Benguela	🟥	🟩
Catalan sea	🟥	🟩
La Paz Bay	🟥	🟩
Campeche Bank	🟥	🟩
Irish Sea	🟩	🟥
East China Sea	🟩	🟥
Southern Humboldt	🟩	🟥

	1st	2nd
Demersals		
SBen_M Parad	🟥	🟩
SBen_M Capens	🟥	🟩 ?
NBen_Hake	🟥	🟥
HC_Chilean hake (adults)	🟩	🟩 ?
CS_Adult hake	🟥	🟥
CS_Juvenile hake	🟩 ?	🟩 ?
NS_Whiting (adult)	🟩 ?	🟩
IS_Whiting	🟩	🟥
NS_Haddock (adult)	🟥	🟥
NS_Cod (adult)	🟩	🟥
IS_Adult Cod 2+	🟩	🟥
LPB_Red snapper A	🟩	🟥
CB_Red snapper	🟥	🟩 ?
LPB_Groupers	🟩	🟥
ECS_Yellow croaker	🟩	🟥
ECS_Largehead hairtail (2+)	🟩	🟥
ECS_Filefish	🟩	🟩 ?
CS_Anglerfish	🟩 ?	🟩 ?
Pelagics		
SBen_Horse mackerel	🟥	🟥
NBen_Horse mackerel	🟩	🟥
NS_Horse mackerel	🟩 ?	🟩 ?
HC_Horse mackerel	🟩	🟩 ?
ECS_Chub mackerel	🟩 ?	🟩 ?
SBen_Sardine	🟥	🟩
NBen_Sardine	🟥	🟥
HC_Sardine	🟩	🟩 ?
CS_European pilchard	🟥	🟩 ?
SBen_Anchovy	🟩	🟥
NBen_Anchovy	🟩 ?	🟩
HC_Anchovy	🟩	🟩 ?
CS_European anchovy	🟩	🟥
NS_Herring (adult)	🟥	🟥
IS_Herring and Sprat	🟩	🟩 ?
NS_Sprat	🟥	🟩 ?
CS_Mullets	🟩	🟥
Flatfish & others		
NS_Sole	🟥	🟩 ?
IS_Sole	🟩 ?	🟩 ?
NS_Plaice	🟩	🟩 ?
IS_Adult Plaice 2+	🟩	🟩 ?
CS_Flatfishes	🟩	🟥
LPB_Scallop	🟩	🟥
CB_Pink shrimp	🟩	🟥
LPB_Sharks	🟩	🟥

Figure 3.1. Main factors contributing to the model predicted past trends in biomass (a) system level (b) for selected species/ assemblages. Red – fishing, Green – primary production.

In response to the North Sea Regional Advisory Council (RACs) thinking on Maximum Sustainable Yield(MSY) and how it relates to the overall goal of developing long-term management plans, Mackinson *et al.* (2009), used the North Sea EwE model to investigate questions relating to MSY in the context of mixed demersal fisheries for cod, haddock, and whiting (also see the WGSAM report, ICES, 2008c). Results suggest that it is not possible to simultaneously achieve yields corresponding to MSYs predicted by single-species assessments (Figure 3.2) and that the contradictory response of whiting is central to the trade-offs in yield and value for mixed demersal fisheries (Figure 3.3). Incompatibility between mixed-fishery and ecosystem-scale considerations exemplify the difficult conceptual and practical challenges faced when moving toward an ecosystem approach (see ICES, 2008c).

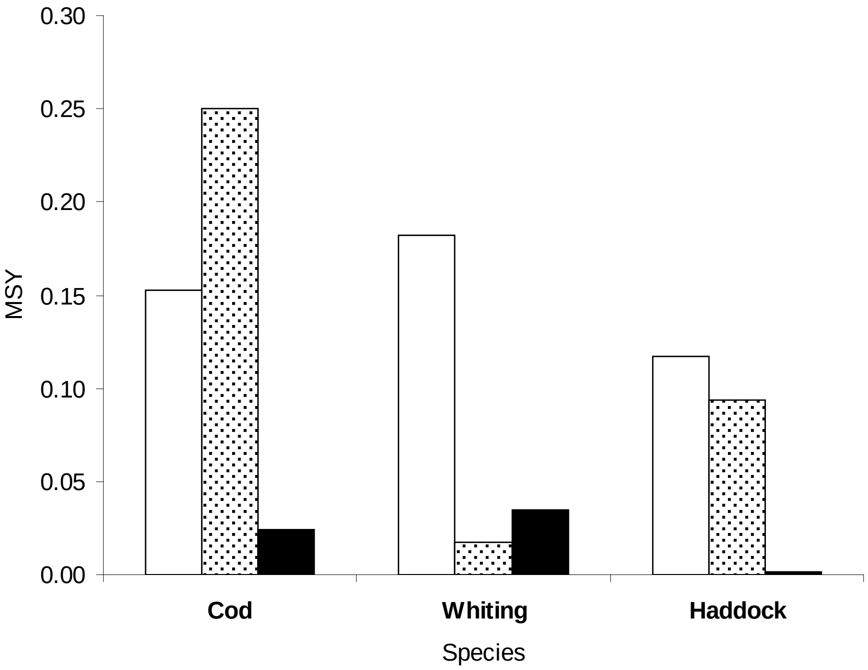


Figure 3.2. Predictions of MSY (million tonnes) when F_{msy} predicted by single species approach are applied in a single species (open bars), mixed-fishery (shaded bars) and ecosystem context (solid bars).

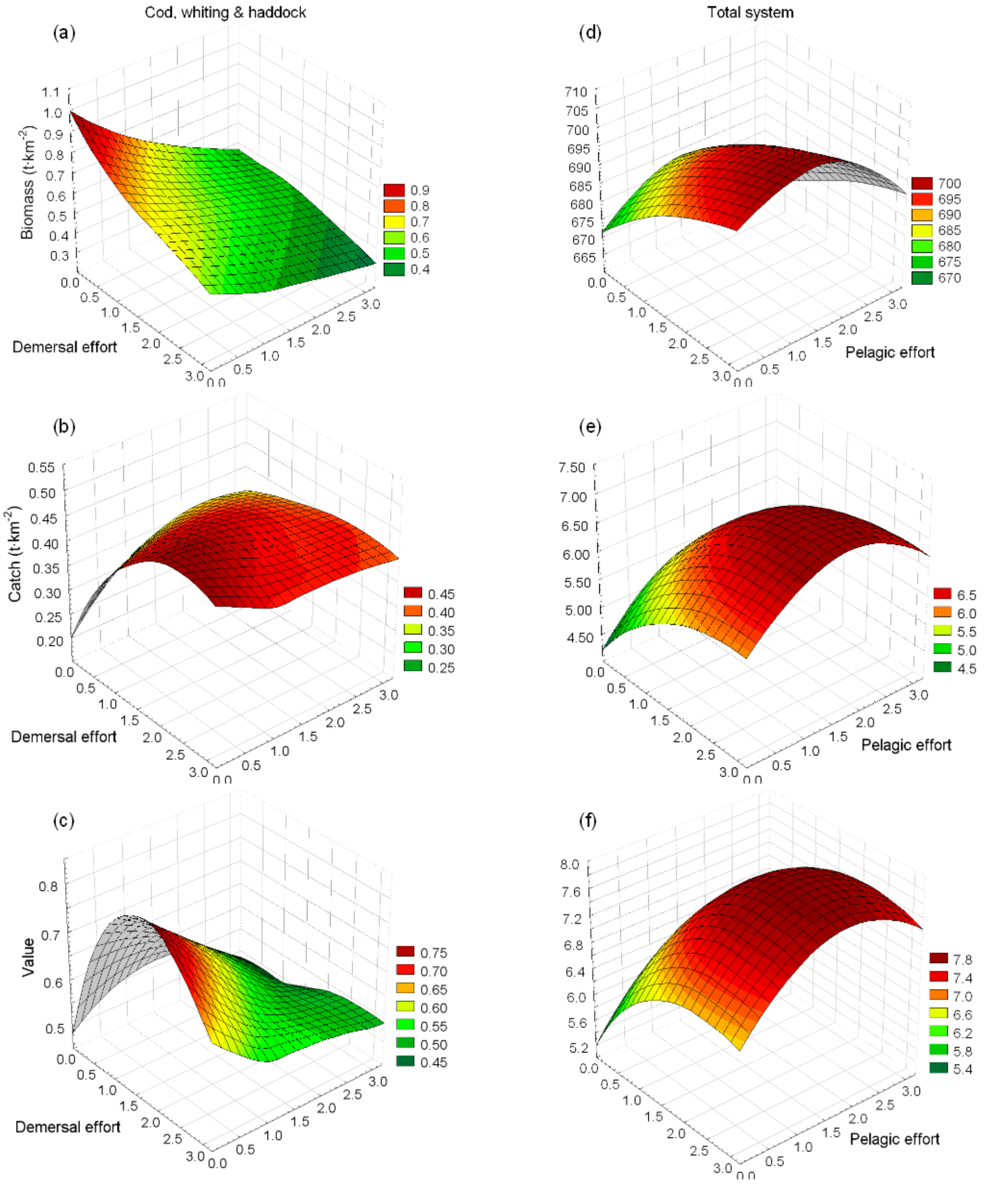


Figure 3.3. Response curves for mixed-demersal fisheries (cod, haddock and whiting) (a-c) and for all groups in the ecosystem (d-f).

3.6.2 Predator-prey spatial overlap

The stomach data available from the ICES 'years of the stomach' programmes in 1981–1991 were re-analysed in a new study by Kempf *et al.* (2008) in order to evaluate the influence of changes in predator-prey spatial overlap on the diet of North Sea cod and whiting. The large-scale response of North Sea cod and whiting populations to varying prey fields was analysed using Generalised Additive Models (GAMs). The composition of the prey field and changes in predator-prey overlap had a significant effect on the diet composition in the final GAMs, explaining 65.6% of the variance. The existence of a large-scale prey refuge at low prey abundances as proposed by the Holling type III functional response was demonstrated for the first time.

The detailed understanding gained by analysing the influence of changes in spatial predator-prey overlap has been used to evaluate the interplay between temperature related processes and predation in determining age 1 recruitment strength for North Sea cod and Norway pout (Kempf *et al.*, 2009). For this purpose an index of predation impact (PI) on 0-group juveniles was calculated out of survey data. PI was assumed to depend on the abundance of the predators as well as on the spatial overlap between predator and prey populations. Generalized Additive Models (GAMs) were created with the spawning-stock biomass (SSB), the sea surface temperature (SST) during the 1st, 2nd and 3rd quarter of the year in the respective spawning and nursery areas and PI as explanatory variables. SSB had no significant impact on recruitment strength for both species, i.e. there was no stock–recruitment relationship. By contrast, SSTs during the 2nd quarter and PI explained the interannual variability in age 1 recruitment to a large extent. The resulting GAMs explained 88% of the total variance for cod and 68% for Norway pout (Figures 3.4 and 3.5). The SST during the 2nd quarter determined thereby the overall level of recruitment strength. Above certain SSTs, however, the effect on recruitment strength was no longer significant. In these temperature ranges, predation was the dominant effect. The fate of North Sea cod and Norway pout stocks under global warming conditions will be therefore strongly influenced by the status of the North Sea foodweb and to a greater extent than in previous colder periods where temperature related processes ensured higher survival rates during egg and larval stages.

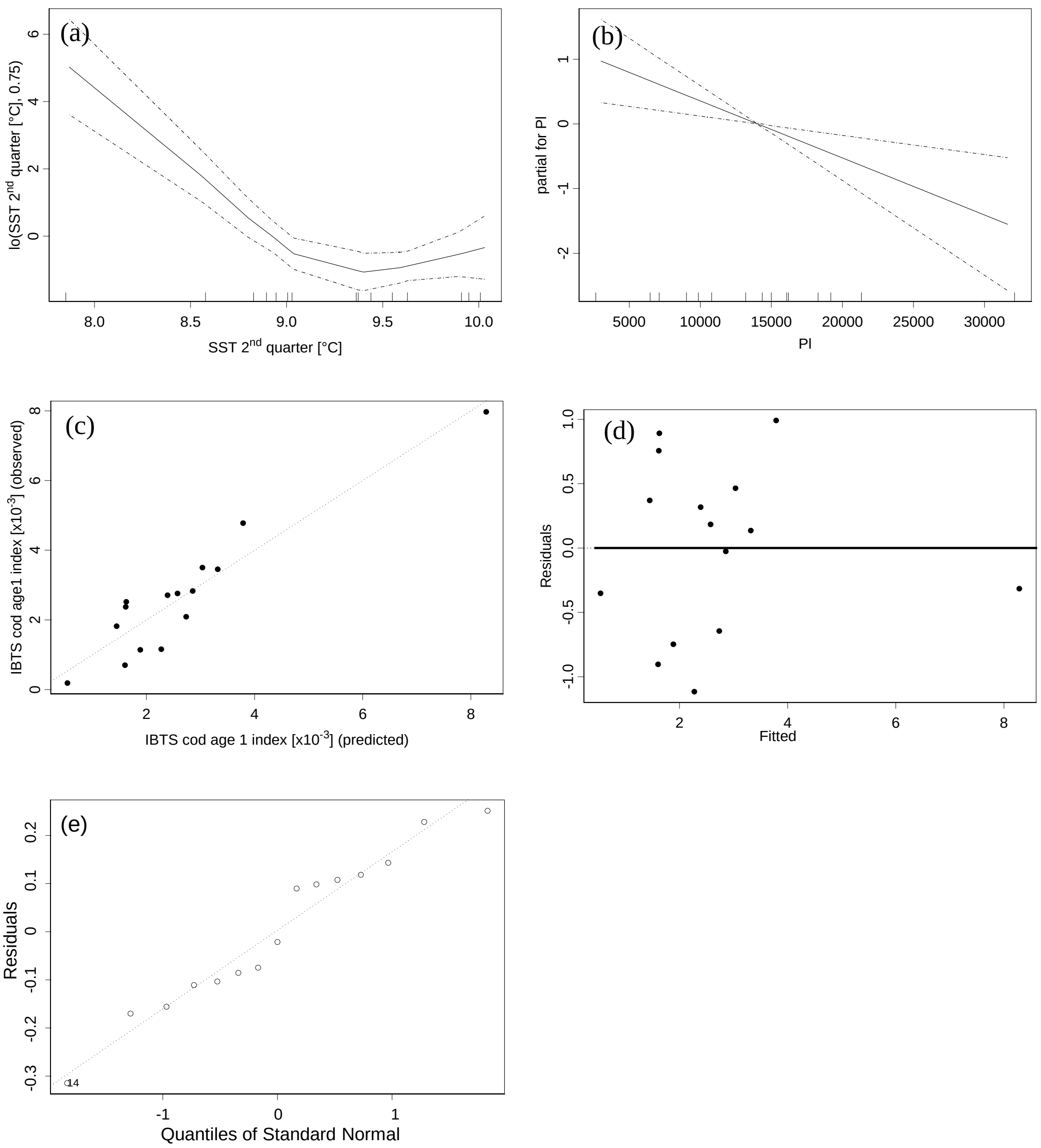


Figure 3.4. Fitted cod age 1 recruitment index as a function of the North Sea sea surface temperature (SST) during the 2nd quarter north of 55° latitude and the predation index (PI). (a) represents the contribution of SST and (b) the contribution of PI.(c) shows the relationship between predicted and observed IBTS cod age 1 index, (d) the residuals in dependence of the predicted model values and (e) a Q-Q plot for the residuals. Striped bars and dashed lines indicate the twice standard error. Bars on the x-axis indicate observations. The span argument for the loess smoother (lo) was 0.75.

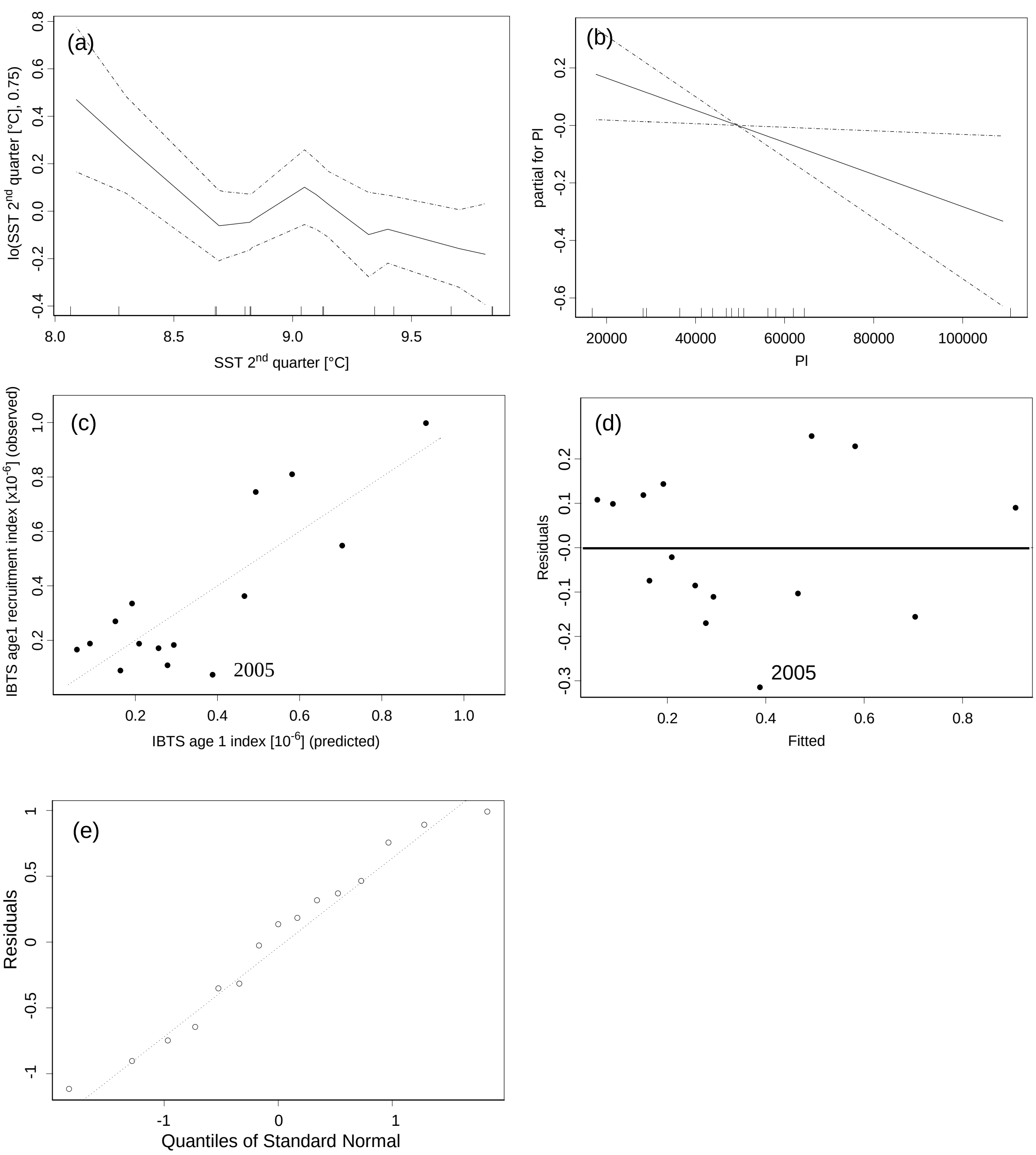


Figure 3.5. Fitted Norway pout age 1 recruitment index as a function of the North Sea surface temperature (SST) during the 2nd quarter north of 58° latitude and the predation index (PI). (a) presents the contribution of SST and (b) the contribution of PI. (c) shows the relationship between predicted and observed IBTS Norway pout age 1 index, (d) the residuals in dependence of the predicted model values and (e) the Q-Q plot for the residuals. Striped bars and dashed lines indicate the twice standard error. Bars on the x-axis indicate observations. The span argument for the loess smoother (lo) was 0.75.

3.6.3 North Sea size based community model and Observation error model

3.6.3.1 North Sea community model

Size-based models are ideal for exploring the trade-offs between fisheries and environmental management. This is because they capture the main interrelationships between population and community dynamics, as supported by theoretical and empirical analysis, and can be used to provide abundance and catch predictions for target populations as well as community properties such as size composition, mean maximum size and trophic level. The model developed by Julia Blanchard (CEFAS) and Ken Andersen (DTU-Aqua) adapts and applies a size-based model of the North Sea fish community to explore trade-offs between fisheries and conservation objectives for the North Sea. The performance of management in relation to fisheries and conservation objectives is described with indicators and agreed reference points for the abundance of target species, fish catches and community structure.

3.6.3.2 Observation error model

Observation-error models in fisheries-related studies are commonly applied to obtain a perceived view of the underlying simulated processes that are most often assumed to reflect reality. Here, an observation-error model is developed to mimic the behaviour of the IBTS survey, as the indices of this survey are widely used for management purposes. The observation-error model (OEM), samples from the community model and hence generates a simulated catch. Based on this catch, indicators can be computed to support management decisions.

3.6.3.3 Indicators

The indicators considered were:

- Slope of the weight spectrum
- Intercept of the weight spectrum
- Mean weight of the community
- Mean maximum weight of the community
- Mean maximum length of the community
- Proportion of fish greater that 40 cm

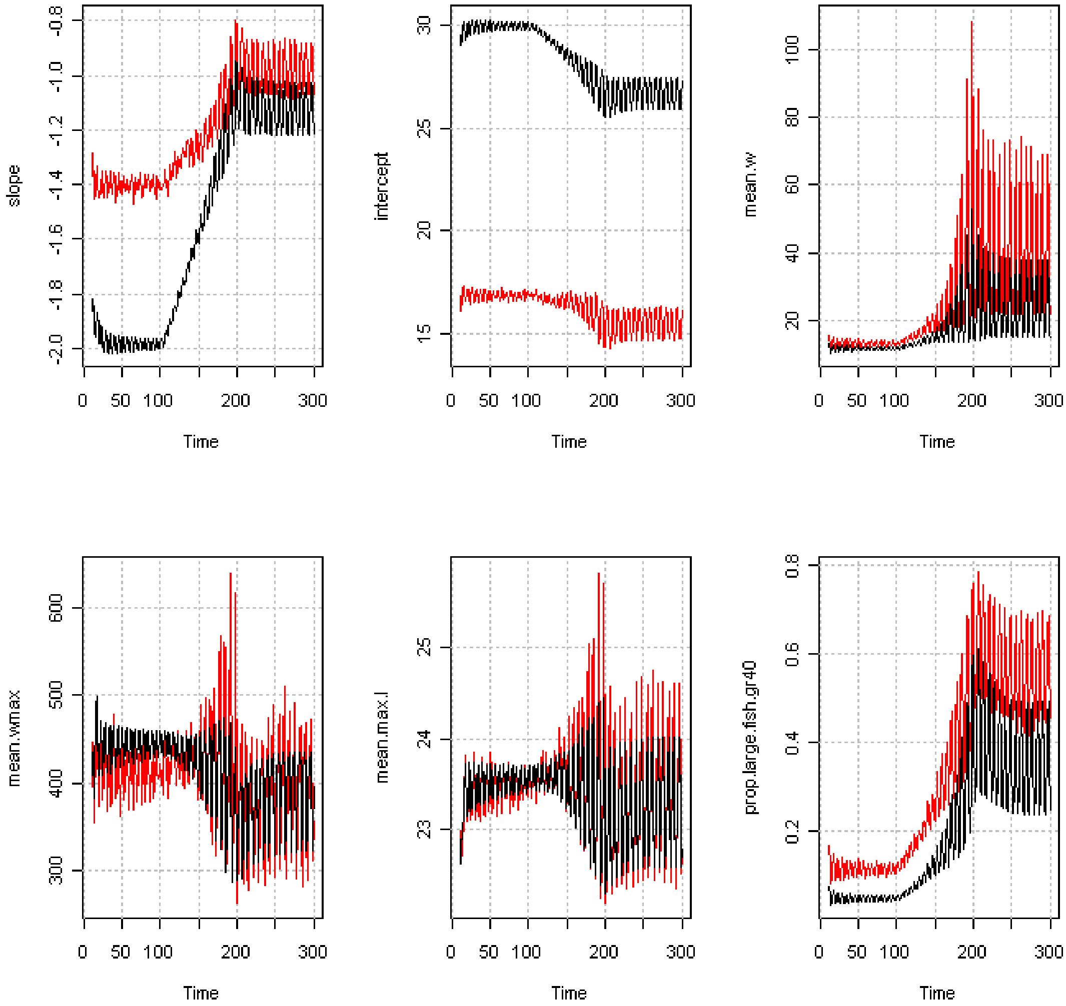


Figure 3.6. North Sea community model. Model results, where F = 1, from time-step 1 to 100. From time-step 100 onwards, F was reduced by 1% every step, resulting in an F of 0 at time-step 200. F was kept at 0 for the remaining time-steps.

3.6.3.4 Usefulness for management purposes

From Figure 3.6 it can be concluded that not all indicators are able to adequately indicate a change in F (i.e. they do not reflect changes in the 'pressure'. The slope of the size spectrum and proportion of large fish indicators do show a clear response to the change in F, however, all indicator trends show great variability over time, which makes it more difficult to distinguish changes in fish community because of management actions

3.6.4 SMS

Work on the SMS model (at DTU-Aqua) has concentrated on the improved estimation of size selection. This issue is complicated by the absence of information on the size distribution of the prey available in the North Sea. Though a length distribution can be obtained from the catches in the IBTS, the catches of very small fish are underrepresented because of the combined effects of mesh selection and changes in vertical distribution with size (transition from pelagic younger stages to demersal older stages of gadoids and flatfish). The model was adjusted to take account of gear selectivity using a function describing catchability as a sigmoid function of fish length. This improved model predictions of size selectivity of predators and the overall model fit. Work on this continues in the coming year.

As another aspect the diet selection model within SMS was expanded to allow for the parameterization with variable spatial overlap coefficients. The influence of changes in spatial predator-prey overlap on the diet composition of North Sea fish predators has been shown in a study carried out by Kempf *et al.* (2008). According to this study at low prey abundances the dynamics of predator-prey interactions highly depends on spatial predator-prey overlap.

Basically predation mortality is modelled in SMS according to the concept of food suitability and predation, developed by Andersen and Ursin (1977) in their ecosystem model for the North Sea.

Predation mortality, M2, is calculated as:

$$M2_{i,y,q} = \sum_{j} \frac{\overline{N}_{j,y,q}\, RA_{j,y,q}\, S_{i,j,q}}{AB_{j,y,q}}$$

where RA denotes the food ration per time unit, where S denotes the food suitability coefficient of prey entity i (prey species and size class) to predator entity j (predator species and size class) and where AB is the total available biomass. AB for predator entity j is defined as the sum of the biomass of preys weighted by its suitability. This prey biomass includes also the so-called "other food" (OF) component, which includes all prey items not explicitly modelled, e.g. species of invertebrates and non commercial fish species. Other food species are combined into one group, such that the total available prey biomass becomes:

$$AB_{j,y,q} = \sum_{i} \overline{N}_{i,y,q}\; w_{i,y,q}\; S_{i,j,q} + OF_{j}\; S_{other,j,q}$$

The suitability coefficient (S) is a measure for predator preferences in accordance with the availability of prey to the predator. The default SMS defines suitability of a prey i for a predator j in year y and season q as the product of a time invariant species vulnerability coefficient *vul(i,j)*, a time invariant size preference coefficient component *size(i,j)* and a season dependent overlap coefficient for the predator prey species:

$$S(i,j,y,q) = vul(i,j)\, size(i,j)\, so(i,j,q)$$

By default SMS estimates for the overlap coefficient are kept constant at one. However, in the new version of the model the overlap coefficients are allowed to change between years, such that suitability becomes:

$$S(i,j,y,q) = vul(i,j)\, size(i,j)\, so(i,j,y,q)$$

Such an extended matrix of overlap coefficients cannot be estimated within the model and must be given as fixed input values. Further details on parameterization, model results and a discussion on the influence of spatial predator-prey overlap on recovery rates of North Sea cod can be found in section 7.1.

In 2008 during the Benchmark workshop for roundfish (ICES, 2008g) it was decided to use variable natural mortality values from SMS hindcasts instead of constant natural mortalities in standard assessments for cod and whiting. The values for natural mortalities may be updated every two years to track changes in the North Sea food-web. However, it has to be stated that SMS calculations are based on stomach data from 1991 and older. The usage of such old data may no longer reflect the current status of the North Sea web (changes in distribution of fish stocks, massive changes in the predator assemblage from "traditional" predators as cod and whiting to emerging predators as grey gurnard, mackerel, horse mackerel, and invasive species). Therefore, calculations are uncertain and new stomach data would be needed to ensure that calculated natural mortalities used for the assessment of important commercial fish stocks reflect reality as much as possible.

In addition to providing estimates of predation mortality to single species assessments, the North Sea SMS provides estimates of the temporal development in consumption and stock numbers of fish which are used in a variety of other models including other ecosystem models such as the North Sea Ecopath.

3.7 Ecoregion G: South European Atlantic Shelf

3.7.1 Trophic data

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

A new project has started in 2009 at AZTI–Tecnalia which includes sampling of stomachs from commercial landings of hake. A project involving demersal sampling has also been proposed to the Basque Government, but the likelihood of this project being funded remain uncertain the moment.

3.7.2 Gadget models

Several single-species GADGET models exist for this area. Two separate hake models, one for southern hake and another for northern hake, and a separate anchovy model are under development. Trophic interactions between northern hake and anchovy have also been included in model.

3.7.2.1 Gadget in the Bay of Biscay for southern European hake

The southern hake model includes a cannibalistic trophic relationship. It was presented in the 2008 ICES WGHMM report (Cerviño *et al.*, 2008). The model covers the same area as the present ICES official assessment for Southern Hake. Since the 2008 WGSAM meeting the parameterization of cannibalism in the model for Southern hake has been improved, and thus the model is now able to explain hake cannibalism and quantify cannibal mortality (M2) as well as cannibal consumption together with fishing activity.

3.7.2.2 Gadget in the Bay of Biscay for anchovy

A Gadget model has been developed to analyse the Bay of Biscay anchovy population. This model is intended to form a part of a combined hake-anchovy multi species model, with the hake eating both, small hake and anchovy. Anchovy is a relevant prey of hake, particularly in the northern and central part of the Bay of Biscay, reaching the 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 last assessment working group (ICES, 2008e). Historical recruitment series can also be simulated in this model in the same way the working groups does.

3.7.2.3 Gadget in the Bay of Biscay for northern European hake

Hake stocks have been split into three substocks according to the literature (Mahe *et al.*, 2007; Velasco, 2007):

- Small hake: 4 -17 cm
- Medium hake: 18–31 cm
- Big hake: 32–100 cm

According to the hake-anchovy length relationship found in Velasco (2007), medium hake is the only stock component that is known to predate on anchovy.

New consumption data have been included in the current multispecies model:

- Maximum consumption parameters have been calculated outside the model, using the methodology showed in Jobling (1988). The data have been provided by the IEO and some of them are also available in the literature (Velasco, 2007).
- Stomach content data come from the Spanish demersal survey and from the literature (Velasco, 2007).
- Energy content of prey and predator-prey lengths relationship comes from the literature.

This model is capable of simulating the biomasses, recruitment levels and fishing mortalities of both stocks (hake and anchovy) given a selectivity pattern of their fleets. Some work is also being carried out in order to update the model to 2008. Data have been sent from the ICES WGHMM and will be introduced into the model during the next few months.

Recent work has also been directed to include the cannibalism of hake. Cannibalism is a very important process amounting to 50% of stomach contents (by weight) for the biggest individuals in the northern and central part of the Bay of Biscay. However the percentage of hake in terms of numbers seems to be less important than anchovy.

This model is still at a preliminary stage and more work is necessary to solve the problems of fitting it to ‘real’ data. Progress on this model was not presented at the WGSAM 2009 meeting.

3.7.3 ECOPATH and ECOSIM

An ECOPATH with ECOSIM model based on a database of bottom-trawl surveys, ICES stock assessment estimates, stomach analyses and information from literature was parameterized with 1994 data for the Cantabrian Sea region of the Bay of Biscay.

This model has 28 trophic groups corresponding to pelagic, demersal and benthic domains, as well as detritus and fishery discards (Sanchez and Olaso, 2004; Sanchez *et al.*, 2005). A new ECOPATH with ECOSIM model for the Cantabrian Sea was recently developed with 2004 information. It comprises 42 functional groups and 8 fisheries. The main improvement with respect to the past model is the inclusion of low level trophic groups, which in the past were estimated from predator requirement, from benthic and zooplankton surveys (infrabenthos, benthos, and suprabenthos).

3.7.4 APECOSIM+ROMS+PISCES

A coupled regional hydrodynamic-ecosystem model (ROMS (Shchepetkin and McWilliams, 2003) + N2P2Z2D2*) has been implemented for the Bay of Biscay system. The model domain covers the whole Bay of Biscay, extending from the French and Spanish coasts to the south of United Kingdom.

The objectives of this work are mainly:

- Develop a coupled model system to predict ecosystem response from plankton to fish:
- Explore the responses of the marine ecosystem at regional scale to the impacts of both climate drivers (light, circulation, temperature, rivers runoff and discharges…) and anthropogenic drivers (fishing, eutrophication…).

Special emphasis is given to the sardine and anchovy in the Bay of Biscay. Realistic hindcast simulations from 2000 to 2005 have been performed. Daily run-offs of most Spanish and French rivers, with temperature and nitrate monthly climatologies when available, and were used. This work will continue during 2008 and 2009, focused mainly on:

- Development of the planktonic model to use PISCES (Aumont *et al.*, 2003) and couple it to APECOSM (Maury *et al.*, 2007a,b)
- Implement/use the initial conditions, forcing fields and boundary conditions from PICSES-global.

The coupled hydrodynamic-lower trophic levels will thus be ready for coupling to APECOSM. None of these models are directly used for management purposes at the moment.

3.8 Ecoregion H: Western Mediterranean Sea

Considerable progress has been made over the past 5 years to build, develop and utilize EwE models for various regions of the Mediterranean, and these have recently been reviewed by Coll and Libralato (2009 at the "Ecopath 25 years Conference", held in Vancouver (Canada) in September 2009. The earliest EwE model of the Mediterranean is that of Pinnegar and Polunin (2004) for the Gulf of Calvi, Corsica. However at least 6 other models have since been developed, including examples from each of the 3 Mediterranean ecoregions (i.e. western; Adriatic-Ionian; Aegean-Levantine).

Foodweb models for the South Catalan Sea (Coll *et al.*, 2007, 2006a) have been used to examine ecosystem effects caused by fishing but have also been used for cross-system comparison to examine differences between global ecosystem types (Shannon *et al.*, 2009; Coll *et al.*, 2006b). A comparison of mass-balance models with binary network models highlighted that Mediterranean ecosystems are more degraded and less robust to species extinctions compared with non-Mediterranean areas (Coll *et al.*, 2008c). EwE models for this region have also been used to predict the potential ecosystem effects of protection, i.e. the effectiveness of marine protected areas (Libralato *et al.*, 2005).

Vargiu *et al.* (2009, Ecopath Conference) considered whether MPAs might provide an additional ecological benefit, in contrast to fishing effort reduction, to aid the recovery of hake in the NW Mediterranean Sea. Simulations were based on the South Catalan Sea ecosystem model (Coll *et al.*, 2006a) calibrated and fitted to catch time-series for 1994 to 2003 (Coll *et al.*, 2008b) using Ecosim v. 6. Reducing fishing effort increased adult hake biomass, while juvenile hake biomass was reduced because of cannibalism. The MPA was shown to have a positive effect on adult and juvenile hake biomasses, with broader benefits on juveniles. Full recovery of adult hake was obtained only within the protected area. The catch of both juvenile and adult hake generally increases with the MPA, while the catch of juvenile hake decreased when a reduction of fishing effort was simulated. Thus, both management options provide complementary results. When the MPA is implemented, the fishing effort surrounding the protected area substantially increased, with a notable concentration of fishing effort at 50–100 m depths.

An additional model has been developed by Albouy *et al.* (2009) for the Bonifacio Straits Natural Reserve (BSNR), Corsica. The BSNR was created in 1999 and is characterized by a predominantly rocky substratum. An Ecosim model was built to study the combined effects of artisanal and recreational fisheries on a Mediterranean ecosystem. The authors demonstrated that both artisanal and recreational fishing activities have top down effects on the foodweb and resulted in decreased biomass of targeted groups such as piscivorous fish. They also found unexpected 'trophic cascades' for some species and indicated that some prey species groups may exhibit negative responses when MPAs are established, and this agreed with outputs from a similar model for the Gulf of Calvi (Pinnegar and Polunin, 2004) where outputs for a simulated marine reserve were compared with observed responses among fish and invertebrate groups throughout the western Mediterranean.

Following the analysis of Albouy *et al.* (2009), an Ecospace model was developed taking into account reserve effects, together with the degrees of protection, the different types of fleets (recreational and professional), fishing zones, and affinities of species to particular substrates.

3.9 Ecoregion I: Adriatic-Ionian Seas

Piroddi *et al.* (2009, Ecopath Conference) described a marine ecosystem in the northeastern Ionian Sea, western Greece. The study area covers 1021 km^2 of sea surface. According to Tsikliras *et al.* (2007), about 70 species of fish, cephalopods and crustaceans are fished commercially in the area, although relatively few constitute the main targets. A EwE model was constructed for the baseline year of 1964. This year was chosen because catch time-series were available from 1964 to 2003. In all 22 functional groups were considered in the model, including 3 marine mammal species, 1 sea turtle species, 1 seabird, 8 fish, 5 invertebrates, and 2 primary producer groups. European hake, European pilchard, round sardinella (*Sardinella aurita*) and European anchovy as well as the three species of marine mammals were considered separately because of their importance in commercial catches.

Ecosim scenarios were fitted by adjusting prey vulnerability and/or by searching for nutrient inload anomalies. Ecopath with Ecosim was able to reproduce the main biomass trend of important species such as common dolphins, sardines, anchovies, other pelagics and other demersals (Figure 3.7). The model suggested that the decline observed in various functional groups throughout the period was a consequence of the intense fishing pressure that occurred in the area until the end of the 1990s.

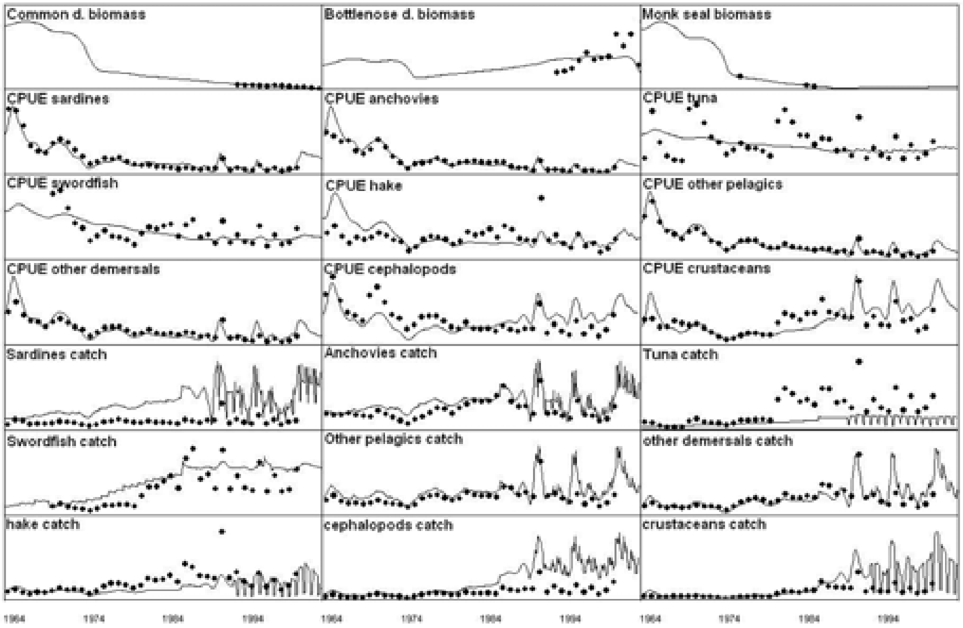


Figure 3.7. Time series fitting between predicted and estimated functional groups biomass, CPUE and yield from 1964 to 2003 in the northeastern Ionian Sea, western Greece.

A mass balance model has also been used to explore energy pathways of the Miramare Marine Protected Area foodweb, Gulf of Trieste, Italy (Libralato *et al.*, 2006) and a spatial one has been used to assess the effectiveness of MPAs of different sizes in the North Adriatic Sea (Zucchetta *et al.*, 2003).

3.10 Ecoregion J: Aegean-Levantine

For the first time, an Ecopath model has been built to describe the North Aegean Sea (24–26°E, 40–41°N; Greece) and this was described by Tsgarakis *et al.* (2009) at the "Ecopath 25 Years Conference" in October 2009. The study area, despite the fact that it is an oligotrophic region, is one of the most productive areas in the Eastern Mediterranean which is reflected in the high relative fishing catch (30% of Greek fisheries landings). The ecosystem model was built for the period 2003–2006 and was restricted to the continental shelf (depths of 20–300 m) where most fishing vessels operate. 40 functional groups (FGs) were defined including pelagic and demersal fish, several benthic invertebrates, dolphins, turtles, seabirds, detritus and discards. Five fleets were included: trawls, purse-seines, static nets, longlines and pots. Anchovy and sardine were described as multi-stanza groups, i.e. split into juveniles and adults. The rest of the fish species where integrated into 18 FGs depending on phylogenetic, behavioural and feeding criteria.

3.11 Ecoregion K: Oceanic Northeast Atlantic

Nothing submitted for this Ecoregion

3.12 Ecoregion L: Baltic Sea

In the Baltic Sea, the interacting fish community in the open sea is dominated by three species namely cod, herring, and sprat. Cod is known to feed on herring and sprat and in addition juvenile cod. The biomass of cod has varied by a factor of around 5 with the highest biomass recorded at the beginning of the 1980s and the lowest in the most recent period. There seems to be a clear link between the biomass of the predator and the biomass of the prey species, especially sprat. The Baltic Sea is heavily influenced by environmental driving forces, which impact reproduction, survival and species interactions, especially eutrophication, hypoxia and water inflow from the North Sea. However also the importance of top down and bottom up control of the Baltic ecosystem leading to trophic cascades linked to threshold-like shifts in the pelagic system have been documented (Casini *et al.*, 2009) and need full consideration for moving toward an integrated ecosystem based approach management that includes fisheries. Turning to models, the recent development of size-based ecological approaches showed the importance of size-dependent life-history traits related to the collapse of top predators (De Roos and Persson, 2002), and further development of this approach in the Baltic Sea showed the importance of the Allele effect and this should be considered in any management action (Van Leeuwen *et al.*, 2008) for promoting the restoration of top predators in the Baltic Sea.

3.12.1 Ecopath with Ecosim

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

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

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

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

For five Baltic coastal 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.*, 2009a,b). Authors compared the models using 12 common functional groups. The studied systems ranged from the hypertrophic Curonian Lagoon to the mesotrophic Gulf of Riga coast. Interestingly, authors found that macrophytes were not consumed by grazers, but rather channelled into the detritus food chain. In all ecosystems fisheries had far reaching impacts on their target species and on the foodweb in general.

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

The current NEST Ecopath with Ecosim model (Tomczak *et al.*, 2009a) covers the area of the Central Baltic Sea (ICES SD 25–29 excluding Gulf of Riga) and contains 28 functional groups (Figure 3.8). 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. Meso-zooplankton are split in to functional groups that represent the 3 main species-related components. Fisheries are represented by 3 fleets fishing on the main fish species. The mass-balanced model represents the state of the ecosystem in the middle of the 1970s, and 1974 has been chosen as a baseline for the temporal Ecosim simulation. To fit and drive the Ecosim model, time-series of biomasses, fishing mortalities and environmental drivers have been used (Table 3.1). Biomasses and fishing mortalities are derived from the ICES Working Group Baltic Fisheries Assessment (ICES, WGBFAS, 2008f report, based on eXtended Survival Analysis (XSA) single species assessment. Calibration time-series represent 33 years (1974–2007). Environmental forcing factors (Table 3.1) come from the ICES/HELCOM Working Group on Integrated Assessment of the Baltic Sea (ICES, 2008i). Based on results so-far, two papers and a poster have been presented at ICES ASC 2009 in Berlin (Niiranen *et al.*, 2008, Tomczak *et al.*, 2009a, Tomczak *et al.*, 2009b). These studies demonstrate that i) the regime shift phenomenon observed in the Baltic Sea in the late 1980s is reflected by the ENA indices, ii) two different ecosystem states can be described: the first between 1974 and 1989 reflecting higher stability, resilience, high mTLc and fishing pressure, and the second one between 1993 and 2007 characterized as a more stressed, less stable state of the system with high fishing pressure on lower TL implying the linearization of -the-foodweb", iii) Large scale environmental drivers and high fishing pressure explain most of the variation in fish stocks and intermediate trophic level dynamics including cascading effects on key meso-zooplankton groups. The study is based on a preliminary model (Tomczak *et al.*, in prep), that is still in the testing phase where the fitting and model behaviour will be improved. Thus, these results have to be interpreted with caution. During the model construction phase at WGIAB 2009 in Rostock, the model showed similar trends as other models applied to the Baltic Sea (ICES, 2009c)

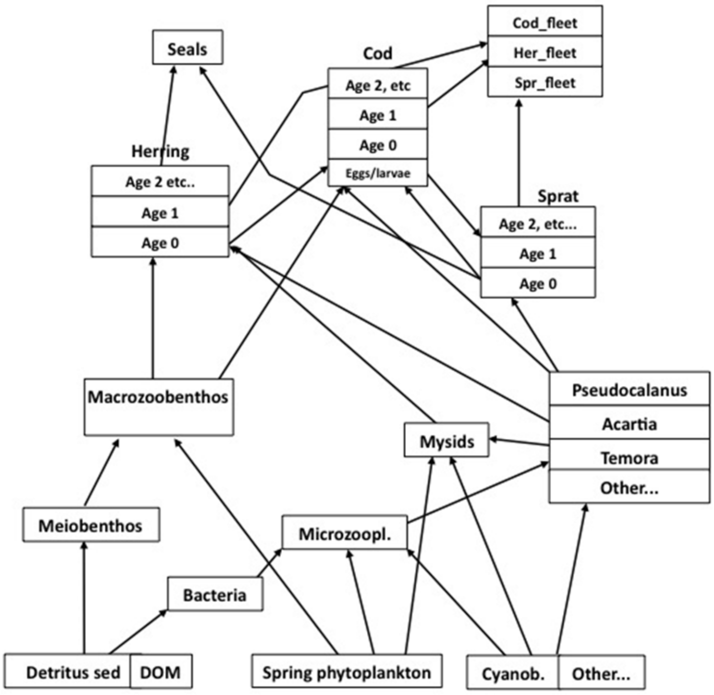


Figure 3.8. NEST Ecopath with Ecosim model structure.

Table 3.1. Time series used in Ecosim NEST model simulations.

FORCING FACTOR OR TIME-SERIES USED FOR FITTING	SEASON	IMPACTED GROUP	TYPE OF IMPACT/FUNCTION
Mean temperature from 0–10m at August (MacKenzie and Köster, 2004)	Summer	Sprat	Proxy of eggs production
Mean temperature from 0–50m at March-May	Spring	Acartia sp; Themora sp	Search rate
Cod RV (Cod reproductive volume Plikshs *et al.*, 1993)	Annual	Cod	Proxy of eggs production
Biomass_Acartia_Spr	Annual	Acartia sp	Calibration data
Biomass_Temora_Spr	Annual	Temora sp	
Biomass_Pseudo_Ann	Annual	Pseudocalanus sp	
Biomass_Sprat 1	Annual	Sprat Age 1	
Biomass_Ad. Sprat	Annual	Sprat Age 2+	
Biomass_Herring 1	Annual	Herring Age 1	
Biomass_Herring 2	Annual	Herring Age 2	
Biomass_Ad. Herring	Annual	Herring Age 3+	
Biomass_Cod 2	Annual	Cod Age 2	
Biomass_Cod3	Annual	Cod Age 3	
Biomass_Ad. Cod	Annual	Cod Age 4+	
F_Sprat 1	Annual	Sprat Age 1	Fishing mortality (F) – impact on biomass
F_Ad. Sprat	Annual	Sprat Age 2+	
F_Herring 1	Annual	Herring Age 1	
F_herring 2	Annual	Herring Age 2	
F_Ad. Herring	Annual	Herring Age 3+	
F_Cod 2	Annual	Cod Age 2	
F_Cod3	Annual	Cod Age 3	
F_Ad. Cod	Annual	Cod Age 4+	

3.12.2 SMS

SMS (Stochastic Multi Species model) (Lewy and Vinther, 2004) is a stock assessment model including biological interactions estimated from a parameterized size-dependent food selection function. The model is formulated and fitted to observations of total catches, survey CPUE and stomach contents. Parameters are estimated by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix. Once the parameters have been estimated, the model can be run in projection mode, using recruitments from stock recruitment relations and fishery mortality is derived from an array of Harvest Control Rules.

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

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

Baltic Main Basin combined subdivisions (ICES, WGSAM Report 2008c):

Years 1974–2008
Cod in Subdivisions 25–29+32
Sprat in Subdivisions 25–32,
Herring in Subdivisions 25–29+32 (i.e. including the Gulf of Riga),
a total of 55000 cod stomachs sampled in the period 1977–1994

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

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

During WGIAB (ICES, 2009c) SMS has been modified in order to include a deterministic recruitment function for cod and sprat. The August surface temperature was used as the forcing factor for sprat (following Baumann *et al.*, 2006), and spring salinity in the Gotland basin (80–100m) for cod (cf. Heikinheimo 2008; S. Neuenfeldt, DTU-Aqua, unpublished data), whereas no climate effects on herring were incorporated. Climate effects were included as an environmentally sensitive stock–recruitment (SSB-R) relationship for cod (see below) and a pure temperature-recruitment relationship for sprat (Baumann *et al.*, 2006). The basic model for the cod SSB-R relationship is given in Heikinheimo (2008), but has been modified according to the salinity data used for the climate change scenarios. The stock–recruitment relationship fits an exponential relationship to SSB and salinity data, accounting for approximately 80% in the observed variance in cod recruitment. However, the fitted relationship cannot account for a negative effect of cod SSB on recruitment at high levels of spawning-stock biomass (S. Neuenfeldt, DTU-Aqua, unpublished data). In order to avoid potential unrealistically large numbers of cod at high salinities and SSB, a ceiling of 5*109 recruits has been implemented.

SMS has been used regularly to update natural mortality rates for herring and sprat in WGBFAS (ICES, 2009e) and to test harvest control rules in WKMAMPEL (ICES, 2009b). Furthermore, SMS is used to generate the input necessary for Baltic Ecopath modelling and several other multispecies models applied for the Baltic.

3.13 Ecoregion M: Black Sea

Nothing submitted for this Ecoregion

3.14 Ecoregion: Canadian Northwest Atlantic

Ecosystem modelling plays an important role in the implementation of ecosystem-based management approaches. However, the development and implementation of these models is often a time consuming and data demanding proposition. In this context, choosing the proper modelling approach for the specific goals in mind, as well as ensuring that the necessary data are available (or will be collected) requires advance planning and organization. Since the last WGSAM meeting, several activities at Fisheries and Oceans Canada (DFO 2008) have been investigated towards addressing these types of issues. Instead of a detailed report of all activities, progress can be better illustrated by providing some details on key activities and programs.

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

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

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

3.15 Ecoregion: US Northwest Atlantic

3.15.1 Ecopath with Ecosim

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

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

3.15.2 ATLANTIS

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

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

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

3.15.3 ECOGOMAG

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

3.15.4 Extended single-species models

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

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

3.15.5 Single Species Add-ons: Ecological Footprints

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

These 'footprints' have been calculated for a wide range of groundfish, elasmobranch, and pelagic fish species. One set of stocks (the skate complex) has had these estimates go through a formal stock assessment review; the others are in various stages of development. The data required are abundance of predators that eat the stock of interest, stomach contents, consumption matrices, and diet composition estimates (broadly similar to the approach taken to estimate sprat removals in section 10 of this report).

3.15.6 MSVPA-X

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

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

3.15.7 Multispecies production models: MSPROD

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

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

3.15.8 Multispecies production models: Agg-PROD

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

4 Development of key runs

4.1 Bay of Biscay

4.1.1 Key runs for Southern Hake cannibal model.

Since the 2008 WGSAM meeting the cannibalism model for Southern hake has been improved, now being able to quantify cannibal mortality (M2).

The current cannibal subprocess considers a group of predators ranging from 15 to 25 cm that prey on a group of fish below 15 cm. The cannibal component for the likelihood function considers 2 predator groups spanning 5 cm each. Differences between proportions observed in stomach and estimated by the model are minimized. The model produces estimations of consumption, M2 and new abundances able to satisfy the hake energetic requirements.

The quality of the fit is similar to that in the previous model without cannibalism. Regarding the cannibal likelihood component, the model is able to explain most of the observed proportion in stomach, with a slight bias to underestimate cannibalism (Figure 4.1).

Cannibal mortality (M2) increases considerably for ages 0 and 1, with values between 1 and 1.5 for age 0 and about 0.5 for age 1. M2 decreases when hake exceed the 15 cm size and are no longer predated (Figure 4.2). In terms of consumption, these M2 rates result in figures between 700 and 3000 tonnes consumed since 1990, which represents between 10 and 20% on total landings.

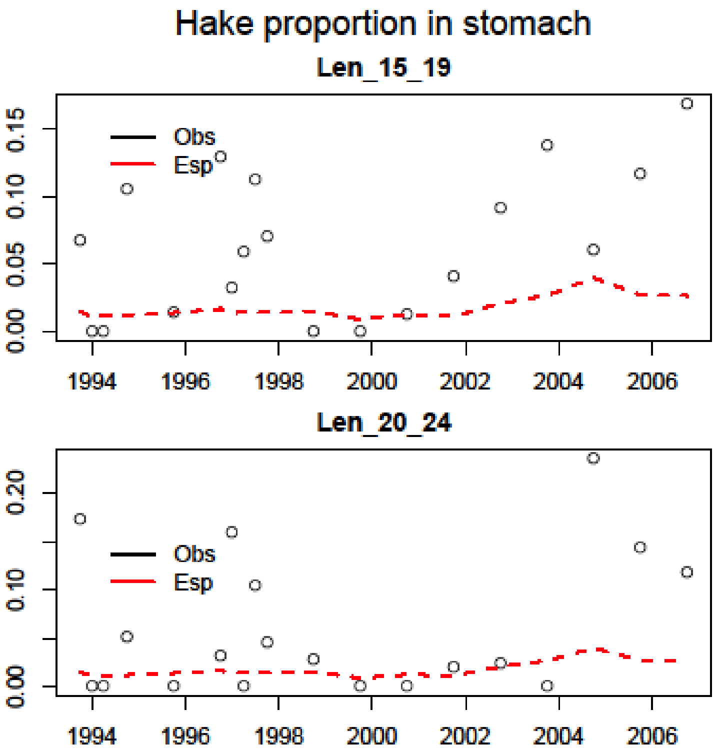


Figure 4.1. Observed (dots) and expected (red line) proportion of hake in hake stomachs. Upper panel shows the fit for smaller predators (15–20 cm) and below for bigger predators (20–25 cm).

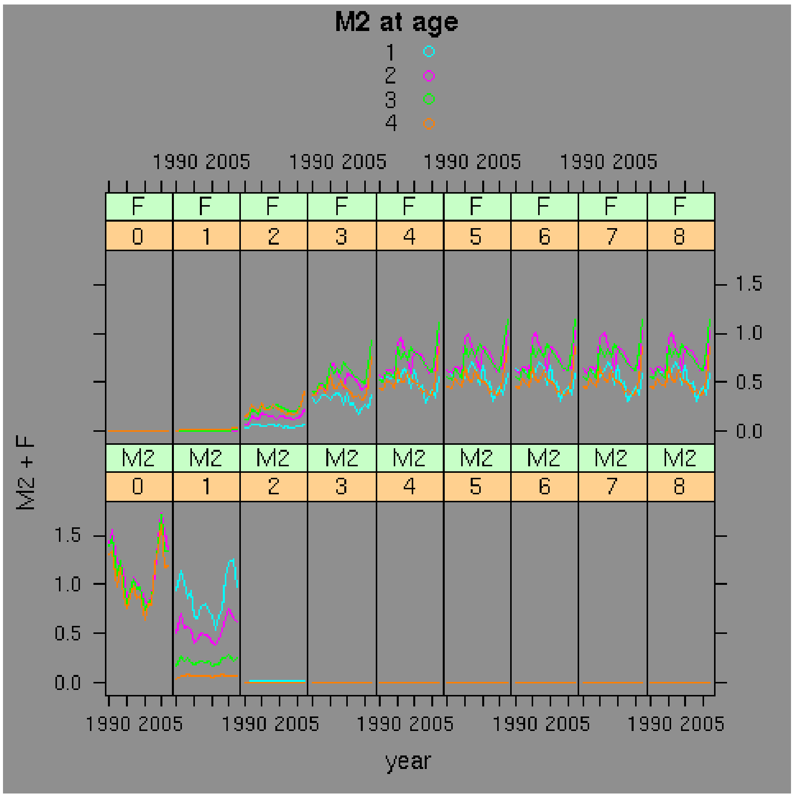


Figure 4.2. F and M2 by age and quarter (1^{st} to 4^{th} quarter).

Historical results show quite similar trends in mean F and SSB (age 4 plus) but higher recruitment within the cannibal model. When we project the population forward under a fishing strategy following the hake 'recovery plan' (10% F reduction annually) with a recruitment equivalent to historical mean recruitment, we observe different recovery trends (Figure 4.3). The cannibal model shows a slow SSB recovery until 2015 (Recovery Plan deadline) and also a lower level of fishery landings. This could be explained as an indirect effect of F reduction, because lower Fs lead to higher abundances then an increasing cannibalism that slows down the stock recovery.

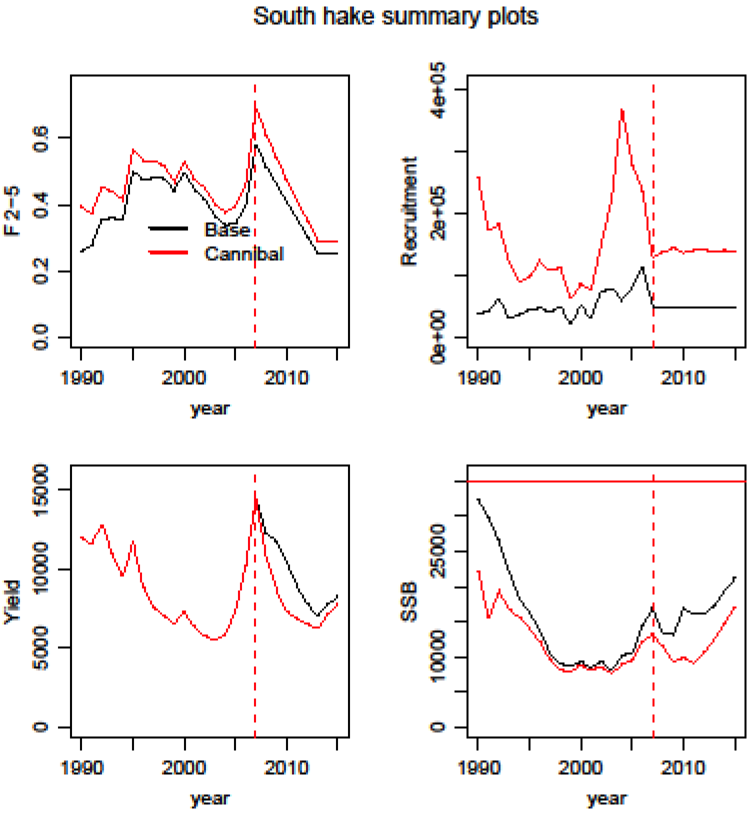


Figure 4.3. Historical trends (1990–2007) and projections (2008–2015) for F, recruitment yield and SSB- Red line for cannibal model and black line for model without cannibalism.

4.1.2 Gadget models

4.1.2.1 Gadget in the Bay of Biscay for anchovy

The anchovy model has shown a great improvement during the last year, being now able to reproduce the biomass and recruitment level in the same way that the current assessment working group does. Thus, this model is now ready to be included in a multispecies model for hake predating on anchovy. The data has also been updated and so the model is now set up from 1987 to 2008.

Overall structure

The model runs from 1987 to 2008, with quarterly time-steps. Anchovy will be modelled initially with a single-species, single-area model, with a single mature population group. The 0-group is not included into this model. The fish will be modelled in 0.5cm length categories. The length range spans from 11 to 21cm and the age range from 1 to 4 (in years). Fish may enter the model at age 1, and the upper age limit (the plus group) has been set at 4.

Biological processes

Anchovy will be considered to have von Bertalanffy growth, with "sensible" initial parameters being provided. A length-weight relationship based on available data are included in the model. Both of these are fixed for all years, with no annual variations. There will be no cannibalism or modelled predation(by anchovy) – mortality will be limited exclusively because of fishing and residual natural mortality, to be set initially at 1.2, following the ICES WGMHSA and ICES WGANC considerations. Recruitment will be handled as a number of recruits (of age 1, in this case) to be estimated per year. Initial recruitment comes from the working group report. The time-step of recruitment is being set at 1 (first time-step of the first year) in order to consider all the individuals of age 1 to be part of this fishery.

Fleets

Fishing will be handled as one fleet: "INTERNATIONAL PURSE SEINER", with a L50 selectivity pattern by quarter. The amount fished each time-step will be input from catch data as a fixed amount. No account of possible errors in the catch-in-tons data will be made.

Surveys

The main surveys considered in this model are the DEPM and the PELGAS survey. The first one, DEPM, gives abundance indices by age (1, 2 and 3+) from an egg survey carried out by AZTI-Tecnalia in the Bay of Biscay during the second quarter of the year (called BIOMAN) from 1987 to 2008, with a gap in 1993. The second survey, PELGAS, is the spring French acoustic survey, available from 1983 (not yearly). The abundance indices by age (1 and 2+) from PELGAS are not available in the following years: 1993, 1994, 1995, 1996, 1998, 1999 and 2000.

There is another survey called EVHOE that is carried our yearly in the area by IFREMER. This survey does not target anchovy, but it provides some abundance data by length. These data are not included in this model at the moment, but they are available.

Parameters

Each parameter is estimated during the modelling process, but "sensible" starting values are required. Because of a lack of sensible initial values, they have been estimated as a known percentage of a total biomass that is taken from the literature (mainly assessment reports). For each parameter, a range of possible values is also required. This should be the absolute maximum range the parameters can reach, as the model will not search values outside this range. Lack of knowledge will dictate a wide range of possible values.

Estimated parameters for anchovy:

- Two growth parameters L_∞ and k (21 and 0.8 respectively)
- Annual recruitment – one per year in the first step of the year
- Eight parameters governing commercial selectivity (two per fleet): L50 suitability function

- Two parameters per survey governing selectivity (one per fleet): constant selectivity pattern being α=1 for both.
- Natural mortality (M = 1.2)
- Likelihood components: all of them have a similar weight along the optimization process.

4.1.2.2 Gadget in the Bay of Biscay for hake

1. Hake predating on anchovy:

The following is a brief summary of the outline structure of the proposed Gadget multispecies model for European Hake (Merluccius merluccius) eating European Anchovy (*Engraulius encrasicolus*). All the data are coming from the single-species models described above.

Overall structure

The model runs will span the period 1987 to 2003, with quarterly time-steps. The main model period will be considered to be from 1994, with earlier years acting as a lead-in period to the model. New consumption parameters have been included in the model: These parameters come mainly from literature, and some of them have been estimated outside the model.

- Maximum consumption parameters have been calculated outside the model, using the methodology described in Jobling (1988). The data have been provided by the IEO and some of them are also available in the literature (Velasco, 2007).
- Stomach content data come from the Spanish demersal survey and from the literature (Velasco, 2007).
- Energy content of prey and predator-prey lengths relationship comes from the literature.

This "ecosystem" is modelled with a multispecies, single-area model. There is a single predator (hake), and there are two preys (anchovy and the "otherfood").

Parameters

The following parameters will be estimated by the model.

- Two growth parameters for each of the species in the model
- Annual recruitment – one per year. In the first step of the year for anchovy (anchovy recruits at age 1); and in the third one for hake (hake recruits at age 0).
- Eight parameters governing commercial selectivity for anchovy (two per fleet) with a L50 selectivity pattern
- Two parameters per survey governing selectivity (one per fleet) by the moment (Constant selectivity pattern being α=1 in both cases) for anchovy
- Four parameters governing commercial selectivity for hake (L50 suitability functions ; two per fleet)
- Three parameters per survey governing selectivity for hake (Andersen suitability function).
- Natural mortalities coming from the WG reports

- Two parameters regarding the preference of hake for each of its preys are included in this model. The second prey of the model is the "otherfood".

Considerable progress is been made in developing this model during this meeting and some reasonable results are expected to be ready in a month.

4.2 Barents Sea

A new multispecies Gadget key run is being developed as part of the UNCOVER EU project. This model covers cod, capelin, herring and minke whales in the Barents Sea. The results from this will be available by the end of 2009, and will be published on the ICES website in a similar format to that for the key run from the North Sea.

4.3 Baltic Sea

4.3.1 Overview

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

The model developed is a mixture of age and size structured components. The catch model is age-structured while the food preference model is size-based because preference depends on size rather than age. This could also be said fishery mortality as well, but catch data by size classes are not available for the Baltic Sea. The mixed age-size structure implies that data by age groups are transformed to sizes using age–length keys.

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

4.3.2 Input data

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

Cod and sprat

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

To estimate the predation mortality on these stocks, the cod assessment unit was adjusted accordingly, thus not considering part of the stock in Subdivision 30 and 31. Landings reported in these Subdivisions are in general less than 1% and a maximum 3.5% of the total catch from the Central Baltic. Consequently the effect of ignoring the two Subdivisions should not hamper a direct comparison between single species and multispecies assessment output. For sprat, the multi- and single species assessment units are not directly comparable, as the sprat stock in entire Baltic including Subdivision 22–24, is treated as a single-stock unit in the single species assessment.

Herring in Subdivisions 25–29 and 32

ICES stock assessments of Baltic herring have been made on 3 different units:

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

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

4.3.3 Input data

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

1) catch number
2) catch mean weight
3) proportion mature,
4) mean weight in the sea,
5) food consumption (ration)
6) M1 (residual natural mortality)

4.3.4 Survey CPUE data

Survey indices at age data were copied from ICES single species assessment reports (ICES, 2009e, WGBFAS report). These time-series includes CUE indices from the commercial fishery, but as the commercial tuning data also are included in the catch data, the two sets are strongly correlated, which might bias the parameter estimate. The commercial CPUE series were not used by SMS.

4.3.5 Stomach contents data

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

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

4.3.5.1 Errors in "number of stomachs" previously used

A few errors in the previous version of stomach data were spotted during the re-compilation of data. When data were exchanged on "table format" used in the first sampling years, values in the table gave number of stomachs investigated (I see them as number of stomachs with food=n_full) and proportion empty (I see them a proportion of the total number of stomachs, n_stom=n_full+n_empty that is empty).

Example USSR, 1978, Q4, Subdivision 26

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

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

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

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

It cannot be interpreted as total number of stomachs and proportion empty. E.g. a) 29% of 5 stomachs or b) 50% of 7 stomachs do not give integer values.

Data in "table format" are given per stomach (e.g. total stomach content (g) /no of stomachs). It was interpreted as mean stomach content for all stomachs, including the empty stomachs. In the previous compilation of data (ICES 1993/J:11) and later used in MSVPA, it has been assumed that the "number of stomach investigated" included empty stomachs. More than half of all available stomachs (Poland, USSR, Latvia and GDR) were reported on the "table format" and bias in population mean stomach content might be heavily biased.

When stomach data are given by individual stomachs (Denmark, Sweden and Germany) the previous compilation of data counted the number of empty and stomachs with food in the correct way.

4.3.5.2 Re-compilation of stomach content data

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

Data compilation was done in two major steps:

1) Transform observations into a new exchange format similar to the one used in the North Sea (Hislop *et al.*, 1997);

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

4.3.5.3 Standardisation of cod size classes

The cod length classes had not been standardized between countries in the sampling. Example: 1977, quarter 1 has data by cod length:

…

26–31 cm,

26–35 cm,

31–35 cm,

36–40 cm,

36–45 cm

41–50 cm,

46–55 cm

….

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

4.3.5.4 Weighting of stomach data by subarea

SMS uses stomach content data by size classes for the whole Baltic Sea area. Stomachs have been sampled and compiled for each subarea individually. To calculate a mean stomach contents by size class it is necessary to weight the mean stomach content by sub-area by the proportion of the stock for the particularly sub-area.

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

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

4.3.5.5 Treatment of "unidentified clupeids"

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

Alternatively by allocation keys based on the stratifications:

1) cod length, subd, year

2) cod length, subd,

3) cod length

4) all data

When allocation keys included more than one subdivision, the keys were made as a weighted average of the content within the basic strata using the proportion of the stock within the area as weighting factor.

Length information of unidentified clupeids were available in a very few cases, but ignored in the data compilation.

4.3.5.6 Definition of prey size classes for herring and sprat

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

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

4.3.5.7 Estimation of missing prey size for herring and sprat

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

1) cod length, prey, subd and quarter
2) cod length, prey and subd,
3) cod length and prey

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

4.3.5.8 Estimation of size distribution of cod as prey

Cod as prey was originally not considered important in the initial period of the stomach samples and were consequently not reported routinely.

4.3.5.9 Prey mean size in the stomach

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

Mean weight per prey mean size was calculated from a length weight relation: $W=a*L^b$

SPECIES	A	B
Cod	8.7E-6	3
Herring	4.9E-6	3.089
Sprat	6.4E-6	3.0

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

ALKs for use in years with stomach content observations were calculated based on mean length-at-age (ml) and the standard deviation (SD) of the length distribution at age.

Cod mean length-at-age were copied from Table 5 in ICES 1993/J:11 (Based on RV "DANA" surveys in Subdivisions 25, 26 and 28 in 1981–1988).

Sprat data were copied from Table 9 in ICES 1993/J:11 (based on Polish data on commercial catches in Subdivisions 25 and 26 in 1977–1989).

Herring mean length-at-age data are from the same source where it is presented in 3 tables:

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

Stock numbers from an area-disaggregated 4M run (ICES, 2005) were used to weight the area specific length data calculated from Tables 6–8 input. Mean length estimated for herring in 1989 were copied to the period up to 1994.

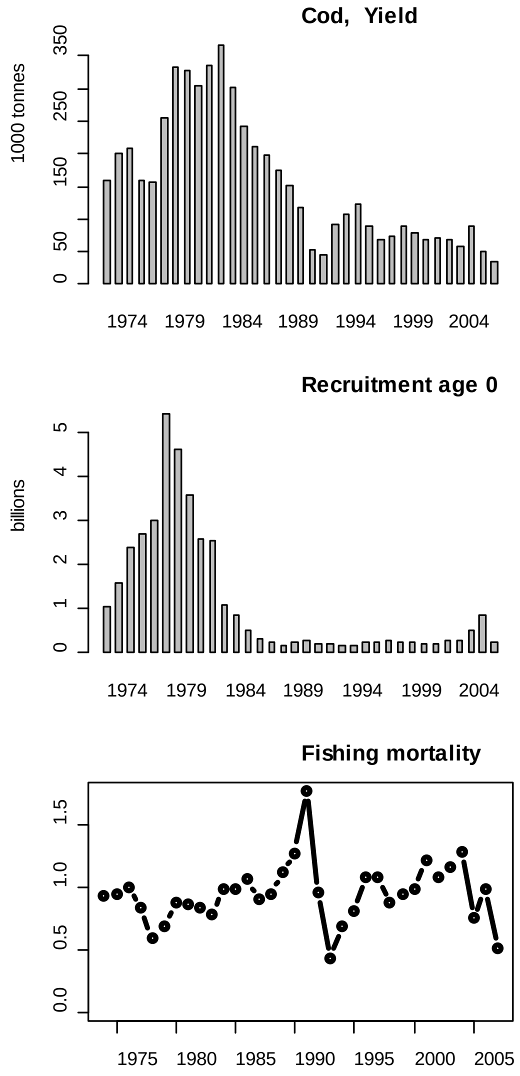
To avoid insignificant and unrealistic length observation, only data from a truncated normal distribution (ml ± 3*SD) were used.

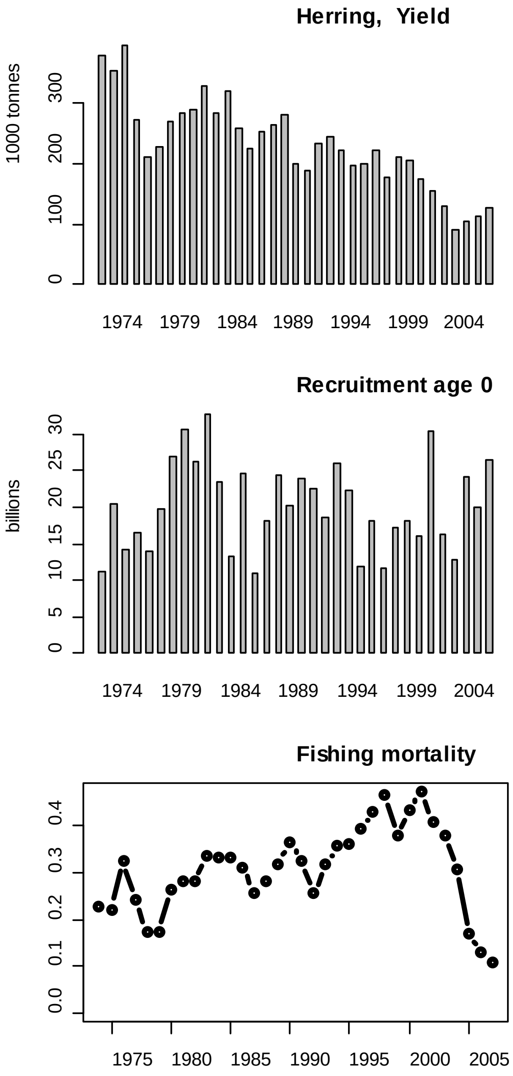
4.3.7 Results

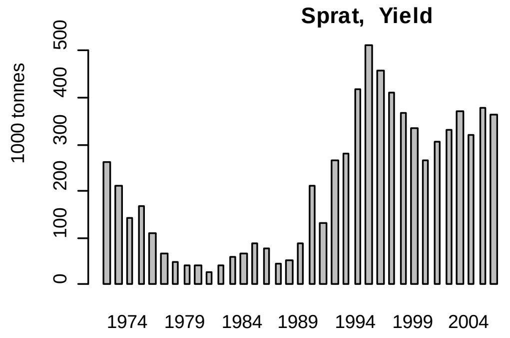
The summary output is presented in Figures 4.4 to 4.6.

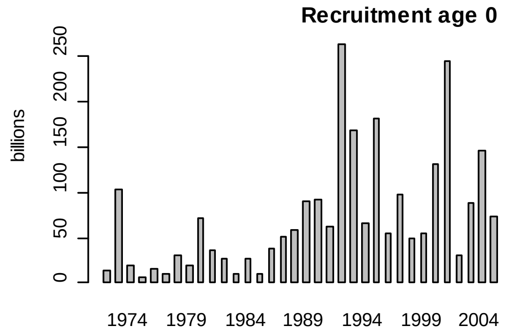
Predation mortalities generally increased in 2005 to 2008, parallel to the increase in cod spawning stock. However, despite the increased predation rates, SMS predicts both herring and sprat stock to be within safe biological limits.

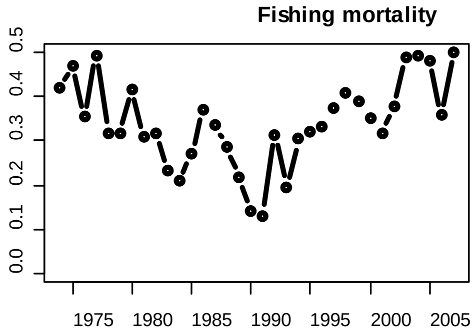
Cod cannibalism has increased, but in contrast to comparable spawning stock sizes in the early 1990s, cannibalism in 2005–2008 is basically limited to the 0-group, whereas cannibalism on age-1 cod is at a lower level. This is due to the different age- and size-structures in the two periods, with older and larger cod in the early 1990s.


Cod, Yield
1000 tonnes
0
50
150
250
350
1974
1979
1984
1989
1994
1999
2004
Recruitment age 0
billions
0
1
2
3
4
5
1974
1979
1984
1989
1994
1999
2004
Fishing mortality
0.0
0.5
1.0
1.5
1975
1980
1985
1990
1995
2000
2005


Herring, Yield
1000 tonnes
0
100
200
300
1974
1979
1984
1989
1994
1999
2004
Recruitment age 0
billions
0
5
10
15
20
25
30
1974
1979
1984
1989
1994
1999
2004
Fishing mortality
0.0
0.1
0.2
0.3
0.4
1975
1980
1985
1990
1995
2000
2005


Sprat, Yield
1000 tonnes
0
100
200
300
400
500
1974
1979
1984
1989
1994
1999
2004


Recruitment age 0
billions
0
50
100
150
200
250
1974
1979
1984
1989
1994
1999
2004


Fishing mortality
0.0
0.1
0.2
0.3
0.4
0.5
1975
1980
1985
1990
1995
2000
2005

5 Standardised format for reporting Ecopath key-runs

What is a key-run?

The term Ecopath 'Key-run' originated from earlier multispecies working groups as a way to facilitate a common understanding among modellers using MSVPA and EwE approaches. We define what is meant by a 'key-run' and provide a suggested format for the reporting of results and model diagnostics that facilitate comparisons among models and provide flexibility to tailor model outputs to specific questions.

A 'key-run' refers to a model parameterization and output that is accepted as a standard, judged and endorsed principally by the ICES WGSAM members. The input parameters and output results of the key run are reported, and the year of this report is used to label the year of the key-run. Key-runs are performed either when a substantive change is made to the model parameters, when sufficient new data becomes available, or when the previous key-run is deemed out of date.

An EwE 'key-run' refers to a model whose time-series dynamics (Ecosim predictions) are fitted to time-series observation data. It is sometimes referred to as a calibrated model. The procedure involves forcing changes biomass dynamics of functional groups in Ecosim from the top–down and bottom–up, by inputting data on fishing and environmentally driven changes in primary production. A non-linear fitting routine minimizes the difference between observations and model predictions by estimating the interaction strength between predator-prey nodes in the foodweb (vulnerability parameters), and sometimes a time-series of primary production anomalies as well.

Essential components of the key-run are a balanced Ecopath model (a snapshot account of the foodweb), that conforms to a quality standard judged through publication/ and or established using quality criteria (see PREBAL, below), and the calibrated Ecosim predictions (Figure 5.1).

When an Ecospace representation is also available, this too can be included in the key-run. In this case, vulnerability parameters estimated by time-series fitting in Ecosim are used in combination with changes to dispersal rates and habitat assignments, to establish a stable spatial distribution of functional groups that matches, as closely as possible, long-term (10 year) distributions of fauna, known from surveys or other sources.

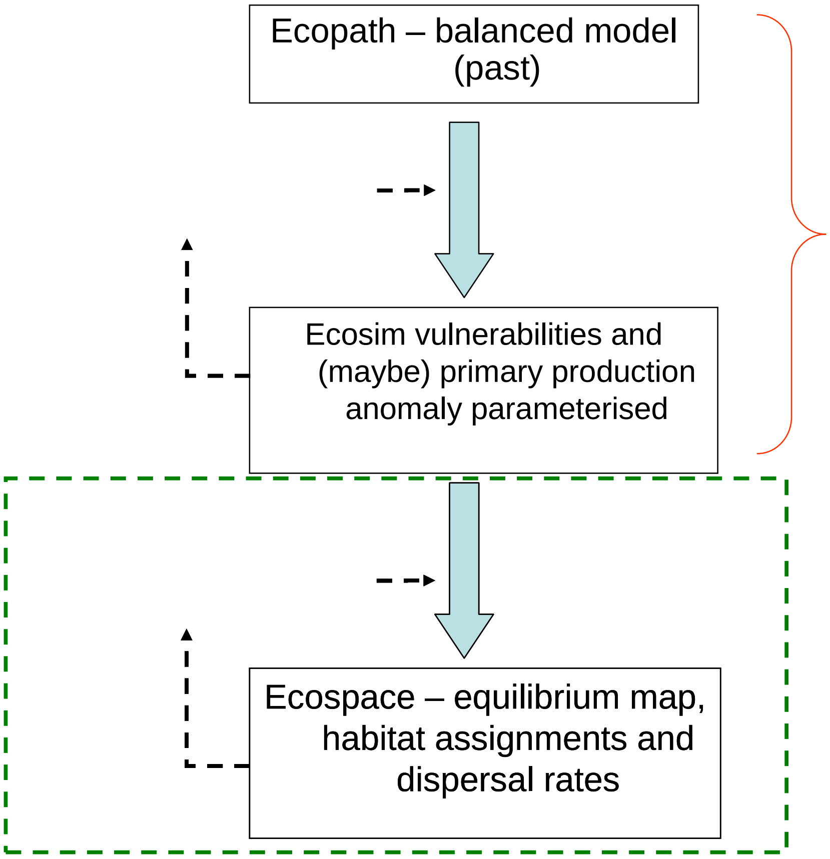


Figure 5.1. Schematic of an Ecopath with Ecosim key run.

Information components

There are 3 principal information components for determining a standardized output for EwE runs:

1) Baseline Ecopath Model – should be published and /or quality established using clear criteria (see PREBAL below)

2) Observation Data used in forcing and fitting – the time-series data file should be made available, or at the very least the metadata so that users are able to understand clearly which data are driving the model and which are being used to constrain the model fit.

3) Fit of Ecosim prediction to observations – including the time-series trends and fitting diagnostics (see below for detail)

Standard format for EwE results based on the fit of Ecosim predictions to observations

Standardised outputs of key-runs should provide information on the functional groups, the fisheries, ecosystem indicators and diagnostics of the parameterization. Selection buttons are used to allow users to select the groups and fleets for which results are required. This approach helps tailor results to address specific questions of interest and facilitate model comparisons. The format of output files is CSV. The following results (Table 5.1) are suggested as being required as standard.

Ecosystem function indicators have been ranked as a highly important to the EU Common Fisheries Policy. Chosen indicators (Table 5.1) should denote whether or not harvesting at one level of the ecosystem does not unduly affect harvesting or functioning at other levels.

Table 5.1. Results to be recorded as standard for a EwE key-run.

Functional groups (by year, stanza)

- Biomass trend (and integrated)
- Consumption (who eats who)
- Mortality rates (predation and fishing)
- Catch
- Diet proportions

Fisheries (by year)

- Fishing mortality (partial Fs)
- Landings
- Discards
- Value

Ecological and Network Indicators (can also serve as diagnostic measures, see below)

- Production metrics (ratios, PPR, TL catch, etc.)
- Total system biomass (and apportionments thereof into major aggregate groupings, e.g. pelagic, demersal, benthos, plankton, or trophic guilds)
- Trophic transfer efficiencies across TL and decomposition metrics (e.g. Mean Transfer Efficiency, Finn Cycling Index or Proportional flow to detritus, etc)
- Cybernetic metrics (system level structural indicators, e.g. connectivity, complexity, redundancy, resilience, throughput, etc)

Diagnostics – statistics and parameters

- Goodness of fit (least squares, residual analysis by group/ fleet)
- Parameter Selection Criteria (taking in to account the number of parameters, e.g. AIC, BIC)
- Ecosim - Vulnerability matrix, primary production anomalies
- Ecospace - Dispersal rates, habitat assignments

5.1 Guidelines for Ecopath Key-runs- PREBAL of (Ecopath's) Ecological Networks

Why- Background and Rationale

The use of Ecopath with Ecosim (EwE) has been expanding in recent years. EwE is a widespread and easy-to-use software package with several laudable characteristics (Christensen and Pauly, 1992, Kavanagh *et al.*, 2004, Walters *et al.*, 1997). In a contemporary review of foodweb and network models, the vast majority were of the form of energy flows, and the vast majority of those were using EwE (Link *et al.*, 2005). Having seen a veritable explosion of these models, it has been recognized that the content and use of them has spanned a range of quality. The ubiquitousness of EwE means that it is a modelling tool that has begun to be increasingly used directly in the provision of Living Marine Resource (LMR) management information and advice.

Thus, as the use of these ecological network models in general and EwE in particular continue to increasingly be used in a LMR context, review panels and other evaluators of these models would benefit from a set of rigorous and standard criteria from which the basis for all EwE and related applications for any given system— i.e. the initial, static energy budget—can be evaluated. As has been noted for some time, using any model outputs in an LMR context poses some extra challenges. For model outputs to be used in an LMR management context, there is an extra level of QA/QC rigor that is required. Further, this extra level is needed for enhanced "comfort" level for participants in LMR management contexts. Experts that have served an wide array of International Review Panels, have reviewed a vast range of numerous journal manuscripts, and as model developers for particular applications, there is an obvious need for a set of standardized and rigorous criteria for use of EwE in a LMR context. What is proposed below is to establish a set of common diagnostics that modellers and reviewers alike can use.

By establishing feasible diagnostics (which can be calculated in spreadsheets / or as a module in the Ew/E package, all done before balancing- PREBAL), one can both draw on general ecological and fishery principles to ensure theoretical practical rigor. Furthermore, using these diagnostics can help to head off problems in initial network balancing and subsequent dynamic applications. As much of the dynamic applications are constrained by departures from equilibria in the static network (Link *et al.*, 2009), a clear assurance of reasonable balance as checked by a pre-balancing protocol is clearly merited.

Methods and Proposed Diagnostics

The intention is to provide a set of guidelines for both modellers and reviewers. Not every item on the list needs to be met, but a clear understanding of why a particular application departs from these proposed guidelines is warranted in any particular case. These guidelines are presented as almost a checklist for a model developer or reviewer to step through to ensure that any potential and major problems are captured before model outputs are used in an LMR context.

The set of criteria fall into one of five general classes. We note them then provide some simple rules of thumb and examples for each. Examples presented are either hypothetical or based upon a system that has undergone extensive PREBAL diagnostics (Link *et al.*, 2006).

Throughout, TL = trophic level, B = biomass, C = consumption, P = production, R = respiration, PP = primary producers/production, ZP = zooplankton.

1) Biomasses across taxa/TLs
2) Biomass ratios
3) Vital Rates across taxa/TLs
4) Vital Rate ratios
5) Total Production and Removals

Biomasses across taxa/TLs

Rules of thumb (Figure 5.2):

- Biomass should span 5–7 orders of magnitude
- Slope (on log scale) should be ~5–10% decline
- Taxa notably above or below slope-line may need more attention
- Detritus doesn’t count, but worth including for context

Biomass ratios

Rules of thumb (Figure 5.3):

- Compared across taxa, predators biomass should be less than that of their prey
- Number of zeroes indicates potential trophic difference between predators and prey
- Compared across taxa, ratios indicate major pathways of trophic flows (benthic vs. pelagic)

Proportional representation also helps to characterize any potential imbalances within a network (e.g. % of invertebrates as allocated to major groups, such as too high of gelatinous zooplankton as a fraction of all invertebrate biomass).

Vital Rates across taxa/TLs

Rules of thumb (Figure 5.4):

- Need to have a general decline with increasing TL, with a similar trophic decomposition as in the biomasses
- Exception for homeotherms at upper TLs
- Taxa notably above or below trend merit further attention

Vital Rate ratios

Rules of thumb (Figure 5.5):

- Compared across taxa, predators should be less than that of their prey
- Number of zeroes indicates potential trophic difference between predators and prey
- Relative to PP approximate TL
- No taxa should have a P relative to PP >, or even close, to 1
- Compared across vital rates (across all taxa), P should not exceed C
- P/Cs or P/Rs near 1 merit re-evaluating

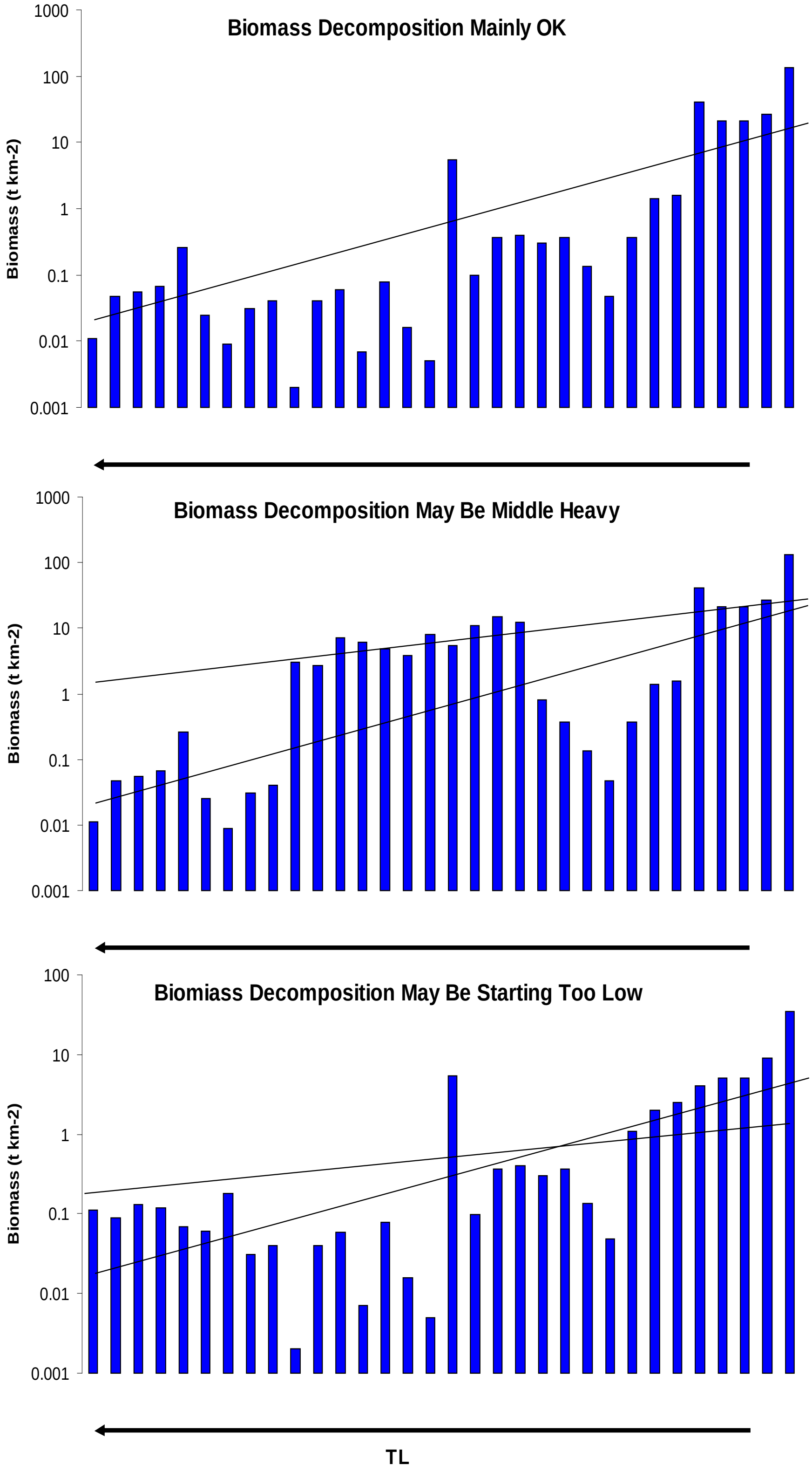
Total Production and Removals

Rules of thumb (Figure 5.6):

- Total, scaled production should again follow a decomposition with increasing TL
- Consumption of a taxa should be less than production by that taxa
- Consumption by a taxa should be more than production by that taxa
- Total human removals should be less than total production of a taxa
- Total human removals should be compared to consumption of a taxa

Summary

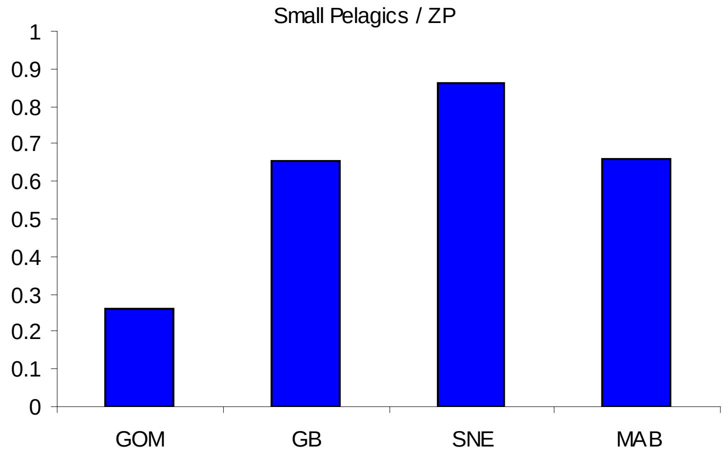
We assert that there are some general ecological and fishery principles that can be used in conjunction with PREBAL diagnostics to flag issues of model structure and data quality before balancing and dynamic applications are executed. This PREBAL information is presented as a simple, yet general approach that could be easily implemented and should ultimately result in a straightforward way to evaluate (and perhaps identify areas for improving) initial conditions in foodweb modelling efforts. Again, these are presented as suggestions to ensure that any modellers or reviewers associated with any particular application have improved assurance as to the quality of Ecopath output. They are also presented as a means to further elucidate the understanding of key ecosystem processes that might otherwise be overlooked by proceeding to the dynamic phase of foodweb modelling without pausing to rigorously evaluate these diagnostics.


Biomass Decomposition Mainly OK

Biomass Decomposition May Be Middle Heavy

Biomiass Decomposition May Be Starting Too Low

Figure 5.2. Examples of trophic decomposition.



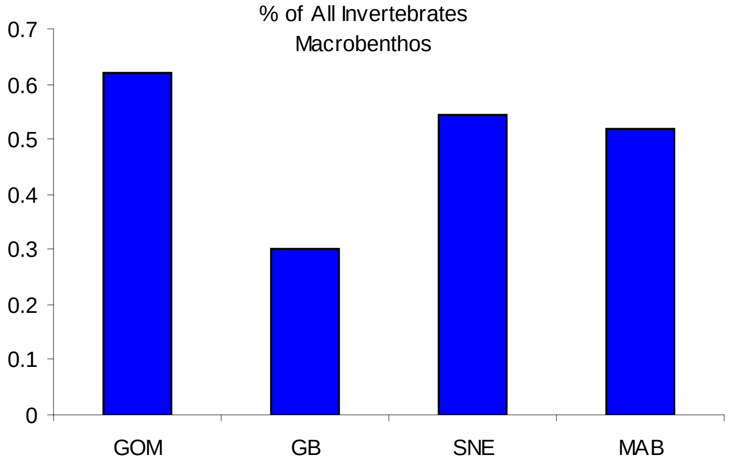


Figure 5.3. Examples of biomass ratios, either of groups to groups or as percentages of total for a group. X-Axis codes refer to different models of Northwest Atlantic ecosystem. ZP = zooplankton production.

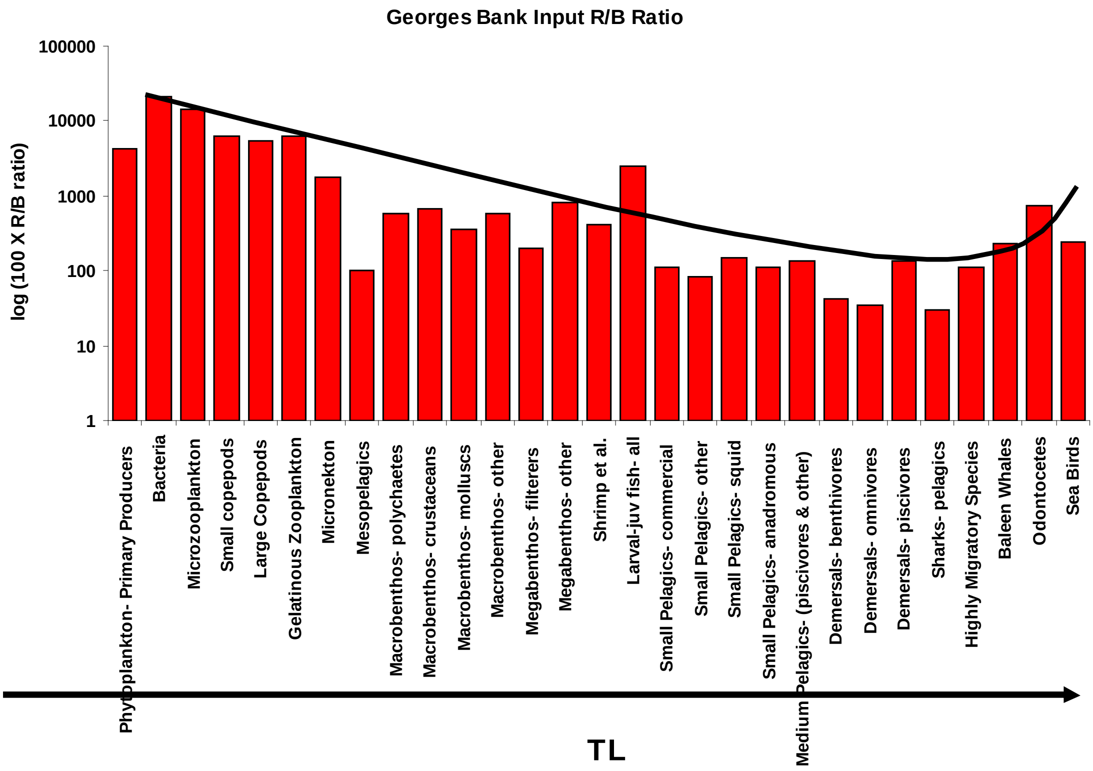


Figure 5.4. Examples of a vital rate that also expresses trophic decomposition with the exception of homeotherms.

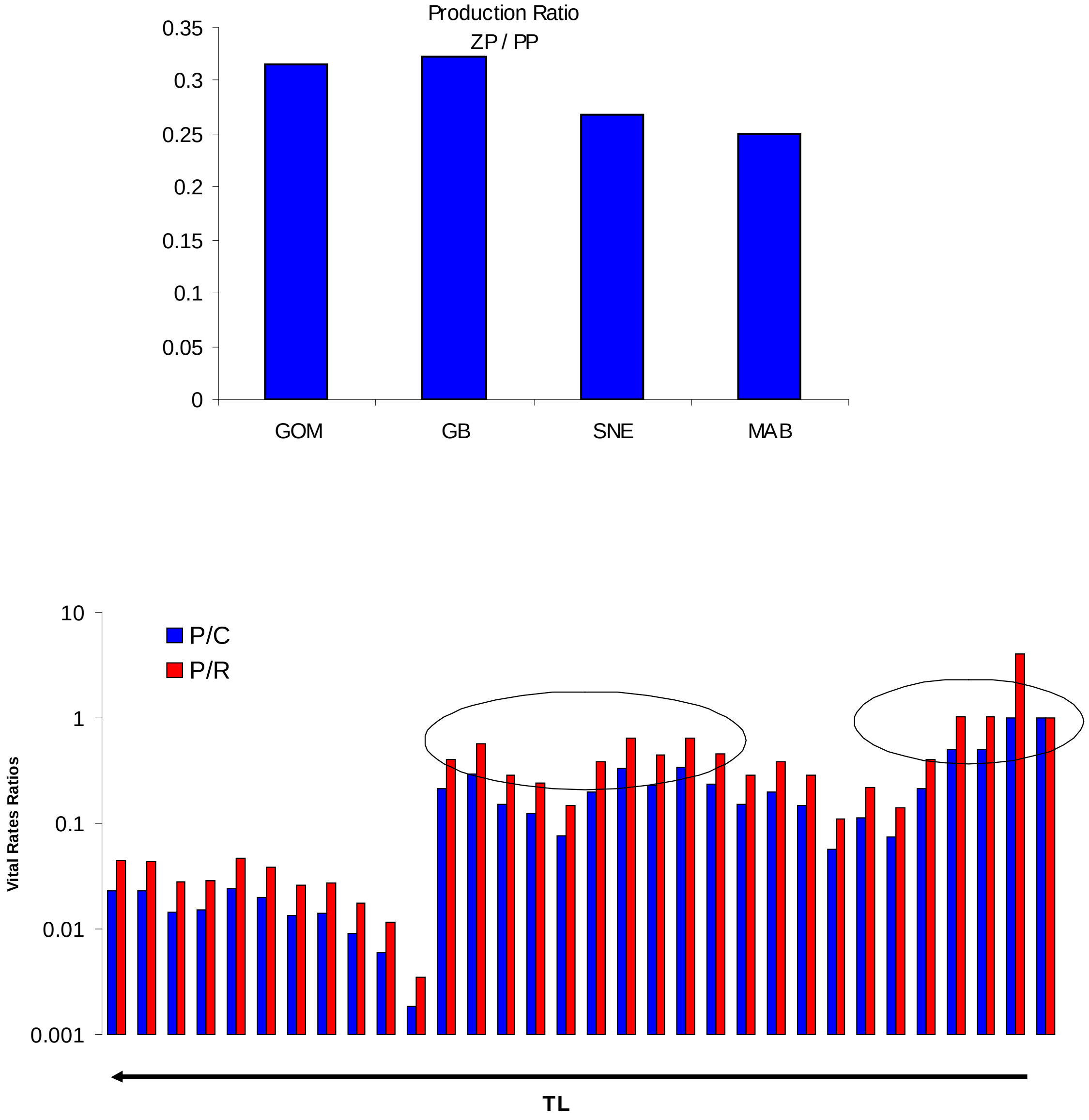
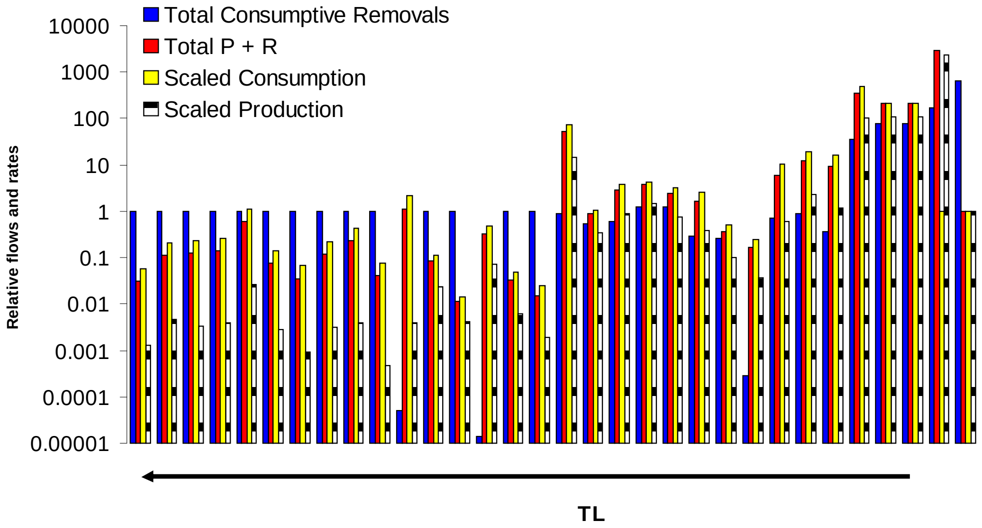


Figure 5.5. Examples of vital rate ratios, either comparing the rates of specific groups or the ratio of rates.



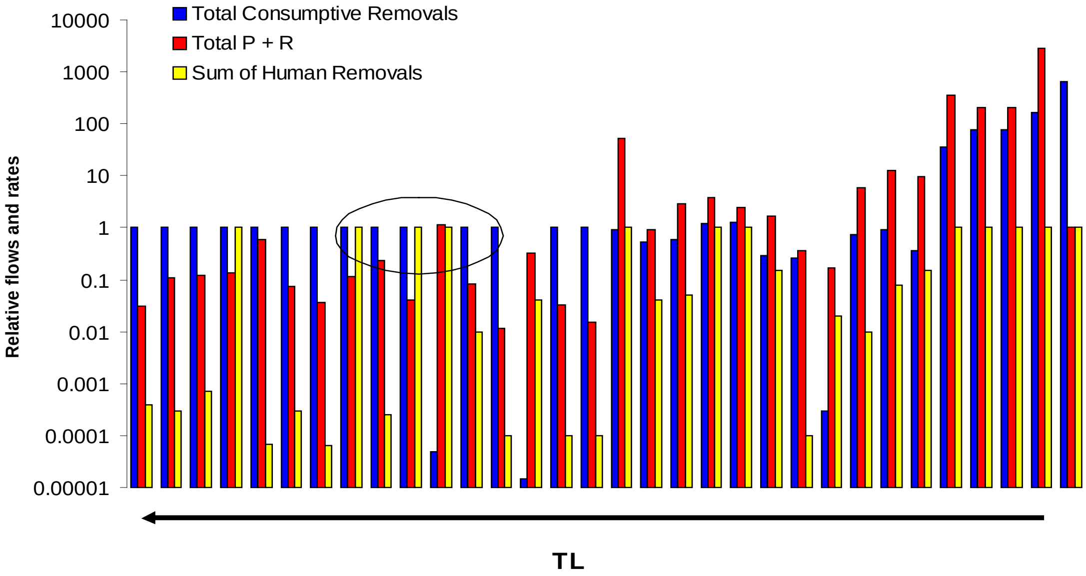


Figure 5.6. Examples of total production and removals, scaled to the full ecosystem.

6 ToR d) Review current process-knowledge, data requirements, and data available to model predation on pre-settlement life stages by pelagic predators

The diet of fish species such as herring, sprat, anchovy and sardine are widely accepted as being dominated by planktonic crustaceans and in particular copepods, amphipods, and euphausids, however there is a long history of research which confirms that such species also consume quantities of fish eggs and larvae, at certain times of year and at particular localities. As a consequence, there has been much debate about the potential impact that such predation pressure might have on the year-to-year recruitment patterns of important commercial fish stocks such as cod, haddock and plaice (e.g. Cushing 1980). Analysis of survivorship of early life stages of fish have confirmed that relationships between the parental stock size and the recruitment of juvenile fish, largely break down during the pelagic larval and juvenile stages (e.g. Nash and Dickey-Collas 2005; Nash 1998), and the assumption is that this is largely due to varying predation pressure by pelagic predators (Bailey and Houde 1989) and/or starvation due a lack of suitable planktonic food in some years for larvae (Leggett and DeBlois, 1994).

In this section WGSAM has reviewed the evidence on predation by pelagic predators in the ICES area, and has attempted to establish the current process knowledge and availability of useful datasets.

6.1 Sprat and Herring in the North Sea

For almost 100 years scientists have been studying herring diets in the North Sea, although the first comprehensive study is that carried out by Alistair Hardy in 1929. This study reported on the contents of 11656 stomachs, taken from 299 commercial hauls during the years 1922 and 1923. Herring were sampled in the southern North Sea off Lowestoft (ICES Subarea IVc), but also off the northeast coast of England (ICES Subarea IVb), and data were available for each month between March and December. The author reports a rapid increase in the number of fish taking food (a decline in the number of empty stomachs), reaching a maximum at the end of May (at~60%), followed by a gradual decrease through June, August and September, to a period in autumn when feeding was almost entirely suspended.

On reviewing the results of the stomach examinations carried out throughout the two years, and having corrected for the weight of individual prey items, one sees a sequence of different forms taken, and a change from non-crustacean food (mostly young sandeels) in March and April, to an almost completely crustacean diet towards the end of summer (first hyperiid amphipods, then to copepods and euphausiids) [Figure 6.1]. Besides young sandeels, other young fish are occasionally taken, including gadoids, clupeoids and the larvae of various flatfish.

Although the importance of fish eggs compared with other forms of food is on the whole small (1.28%, Figure 6.2), the eggs of plaice and herring itself are sometimes taken in large numbers. In spring both 1922 and 1923 stomachs were opened containing nothing but plaice eggs, in one case as many as 247. In autumn (November and December) fish eggs became a major component of the diet (although most were not feeding), primarily those of herring themselves. The data collected by Hardy in 1922–1924 has recently been digitized and made available in a 'pooled' form through the DAPSTOM data portal (see Pinnegar 2009).

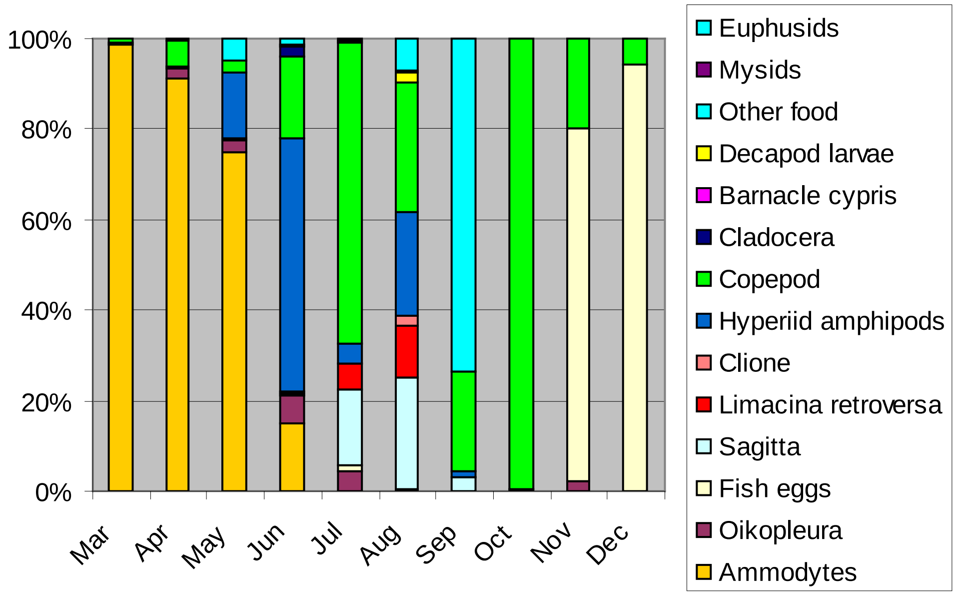


Figure 6.1. Changing diet composition of herring in the North Sea from March to December in 1922 and 1923 (based on Hardy, 1929).

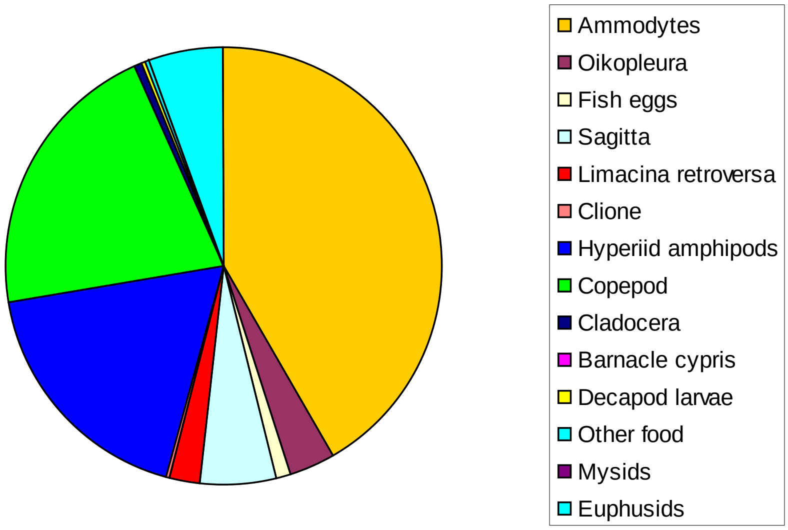


Figure 6.2. Diagram showing the relative importance of the principle food organisms of herring as percentages of the total year's food (based on Hardy, 1929).

Building on the work of Hardy (1929), Savage (1931) carried out further sampling in 1926 and 1929 and compared the abundance of different prey types in stomachs with abundance in the environment, as determined by zooplankton and trawlnets. Altogether 13,923 stomachs were examined from 414 hauls off Lowestoft but also off Shields and Scarborough in northeast England.

During April 1926 the principle constituent in the food off Lowestoft was post-larval sandeel (as was the found by Hardy 1929 in this season, and at the same locality), and an average of 536 were detected per 100 feeding herring, as well as some fish remains that could not be identified. *Temora longicornis* with an average of 622 and *Oikopleura* spp. with 607 were the next most important prey items in terms of numbers, though not in terms mass. By contrast in April/May 1929, sandeel was practically absent from the food at this locality and copepods (especially *Temora longicornis*) formed the bulk of the contents, but in addition the large diatom *Coscinodiscus concinnus* was also abundant.

Samples collected between May and October off northeast England in 1926 were dominated by *Calanus, Oikopleura* and Evadne in May to June, Temora in June to July, decapod larvae and chaetognaths in July to August and Centropages/Limacina in autumn (September to October), although the proportion of herring observed to be feeding was very low in autumn. Fish eggs were present in June up to a maximum of 918 (18 June), but after the first of July were only rarely encountered. Larval and post-larval fish were very rarely taken. 209 stomachs were sampled off Scarborough (UK Yorkshire coast) in September/October 1929, and were found to contain large quantities of the pteropod mollusc *Limacina retroversa,* as well as the copepod Centropages and a considerable quantity of Paracalanus/Pseudocalanus. Again there was very little evidence of predation on fish eggs or larvae during this autumn season.

An examination of the stomach records that have been digitized and included in the DAPSTOM data portal (see Pinnegar 2009) revealed 955 records (398 stomachs) for herring in the North Sea and 2319 records (694 stomachs) for sprat. Most of these data were derived from research cruises in 1972, 1973 and 1974 (Corella 07–72, 04–73, 07–73 and 05–74) and in excess of 51% of the prey recorded for herring comprised plaice eggs, plus 9% sandeel larvae (Figure 6.3). It is likely that the number of individual copepods has been grossly underestimated in the database, and when one considers the frequency of occurrence (Table 6.1) it is clear that fish eggs and larvae occur in relatively few stomachs. Sandeel larvae occurred in 8.3% of stomachs examined, whereas plaice eggs occurred in 3.8%. Unidentified fish eggs (some of which are probably plaice) occurred in a further 2.8% of stomachs and dab eggs in 2.5%. Stomachs were collected between February and May and the results largely agree with the analyses of Hardy (1929) fifty years earlier.

Examination of sprat stomach data revealed that plaice eggs and 'unidentified fish eggs' comprised a large proportion of all records available (20% and 15% respectively; Figure 6.3). However, 'unidentified fish eggs' occurred in only 16.9% of stomachs examined between February and May and plaice eggs occurred in only 12.7%. This compares to the copepods Temora and Psuedocalanus which occurred in 59.4 and 56.9% of sprat stomachs respectively.

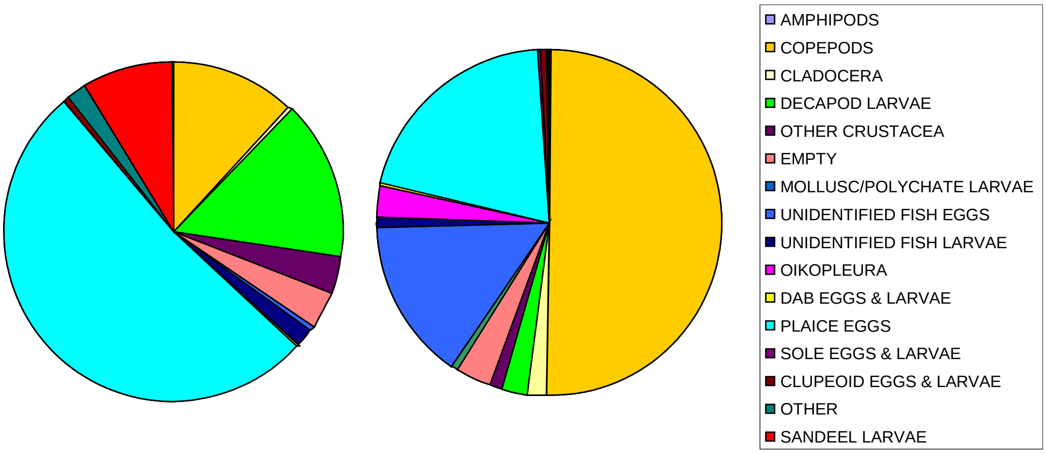


Figure 6.3. Proportion of prey items identified within stomachs of herring and sprat between 1972 and 1974, and recorded in the DAPSTOM database (Pinnegar, 2009).

Table 6.1. Frequency of occurrence of particular prey items within the stomachs of 398 North Sea herring, between 1972 and 1974. Data extracted from the DAPSTOM database (Pinnegar, 2009).

SPECIES	FREQUENCY OF OCCURENCE (%)
EMPTY	39.4
TEMORA SPP	33.9
PSEUDOCALANUS SPP	31.2
DECAPOD (LARVAE)	21.6
CALANUS SPP	19.3
EUPHAUSIIDAE	13.6
PARACALANUS SPP	11.8
COPEPODA-CALANOIDA (EGGS)	10.6
SANDEELS (LARVAE)	8.3
FISH REMAINS (UNIDENTIFIED)	5.0
PLAICE (EGGS)	3.8
COPEPODA-CALANOIDA	3.5
DIGESTED REMAINS	3.3
CRAB (LARVAE)	3.0
MARINE CRUSTACEANS	3.0
FISH EGGS	2.8
DAB (EGGS)	2.5
CLADOCERA	1.8
FISH LARVAE	1.8
SAGITTA SPP	1.0
BARNACLES (LARVAE)	1.0
CENTROPAGES TYPICUS	1.0
CYCLOPOID COPEPOD	1.0
FLATFISH (LARVAE)	1.0

Table 6.2. Frequency of occurrence of particular prey items within the stomachs of 694 North Sea sprat, between 1972 and 1974. Data extracted from the DAPSTOM database (Pinnegar, 2009).

SPECIES	FREQUENCY OF OCCURENCE (%)
TEMORA SPP	59.4
PSEUDOCALANUS SPP	56.9
COPEPODA-CALANOIDA (EGGS)	30.1
PARACALANUS SPP	26.2
OIKOPLEURA SPP	18.6
EMPTY	17.9
FISH EGGS	16.9
CALANUS SPP	15.7
ACARTIA CLAUSI	13.1
COPEPODA-CALANOIDA	13.1
PLAICE (EGGS)	12.7
CENTROPAGES TYPICUS	12.4
CLADOCERA	11.2

SPECIES	FREQUENCY OF OCCURENCE (%)
DECAPOD (LARVAE)	6.1
BARNACLES (LARVAE)	3.7
DIGESTED REMAINS	2.6
FISH LARVAE	2.2
DIATOMS	2.0
MARINE CRUSTACEANS	1.6
POLYCHAETE (LARVAE)	1.3
MYSID SHRIMPS	1.0
SOLE (EGGS)	0.9
BIVALVE (LARVAE)	0.7
DAB (EGGS)	0.4
AMPHIPODA	0.3
SAGITTA SPP	0.3
DAB (LARVAE)	0.3

The DAPSTOM database includes a small number of records for anchovy stomachs in the central North Sea (from cruise Corella 07–72 and Cirolana 03–91), and of the prey items recorded, 73.3% were listed as sandeel larvae, 13.1% were 'unidentified fish larvae' and only 5.1% were copepods. Sandeel larvae occurred in 68% of the stomachs examined (73 out of 107); fish eggs occurred in 9.3% and were 'unidentified fish larvae' in 22.4%. However, anchovy have occurred only sporadically in the North Sea since the 1970s, although they have increased in recent years.

Last (1989) examined the stomach contents of 5762 herring caught during North Sea trawl surveys in February 1983, February 1984 and February, May and August 1986. The principal prey organisms were the copepods *Calanus finmarchicus* and *Temora longicaudata*, but Euphausiacea and the post-larval stages of Ammodytes spp. and clupeoids contributed a large percentage of the weight. Fish eggs were eaten, chiefly those of plaice, but not in large numbers.

Daan *et al.* (1985) examined the stomach contents of 5,408 herring caught throughout the North Sea in February 1980, 1982 and 1983. Predation on plaice and cod eggs was generally confined to the southern North Sea and only younger age groups of herring (ages 2 and 3) consumed substantial numbers of fish eggs. The estimated fraction consumed of the initial numbers of eggs produced varied from 0.7 to 1.9% for plaice and from 0.04 to 0.19% for cod. Thus, the authors argue that although some effect of herring stock size on the level of recruitment in plaice might be expected, it is unlikely that the generally observed increase in recruitment to various demersal stocks in the 1970s could be entirely accounted for by a reduced predation on eggs by herring.

In 2007 Segers *et al.* revisited the issue of predation by herring in the North Sea, largely because the herring stock had recovered to almost 2 million tonnes by the early 2000s from a low of 50 000 t in the 1970s. Changes in biomass of such magnitude will impact an ecosystem (Greenstreet *et al.*, 1997; Jennings *et al.*, 2002) and have led to interest in quantifying the impact of herring on the rest of the North Sea ecosystem and other fish stocks (ICES, 2004b). The authors argued that quantifying the impact of herring is difficult, because most of the recent studies took place against the backdrop of a much smaller population size (Daan *et al.*, 1985; Last, 1989). Raising these estimates from the 1980s is naïve, because an assumed linearity is probably inappropriate given the complexities of ecosystem dynamics, and ecosystem states may have changed (MacKenzie and Köster, 2004).

Samples of herring were collected during the Dutch contribution to the International Bottom Trawl Survey (IBTS) of the southern and western part of the North Sea in February 2004. Of the 855 analysed herring stomachs, 578 had food and 111 contained fish eggs, varying from 1 to 63 items per stomach. A variety of taxonomic groups was found, with large variance in significance. As expected, copepods dominated the diet numerically (59%) and were also found in the most stomachs (40%). Fish eggs seem to be the preferred food type after crustaceans (Figure 6.4). Although numerically less important than crustaceans, fish eggs were present in a considerable proportion of the stomachs (19%). Interestingly, in contrast to the large quantities of juvenile sandeel in herring stomachs collected in spring 1922, 1923, 1984, and 1986 (Hardy, 1924; Last, 1989), no sandeels were found during the study of Segers *et al.* (2007), similar to the situation in spring 1983 (Last, 1989).

Most fish eggs from the stomachs could not be measured because of their advanced state of digestion. However, the distribution of egg diameters from the field was broader than the distribution of egg diameters found in herring stomachs in the same areas. The average diameter of the eggs in the stomachs was significantly larger than that of the eggs collected in the field suggesting selective foraging by herring. The authors suggest that herring forage on fish eggs, only when other prey is not available. The fact that daylight-feeding herring select for eggs that are larger and in later developmental stages is probably related to the greater visibility of those eggs. The works of Wieland and Köster (1996) and Ellis and Nash (1997) support this hypothesis. When foraging on fish eggs, North Sea herring consume mainly eggs of cod and plaice. Comparing the relative frequency distributions of the stomach and field eggs reveals that herring select eggs 1.3 mm diameter. The eggs of cod and plaice are typically in the size category that herring prefer to eat (1.3–2.2 mm, respectively).

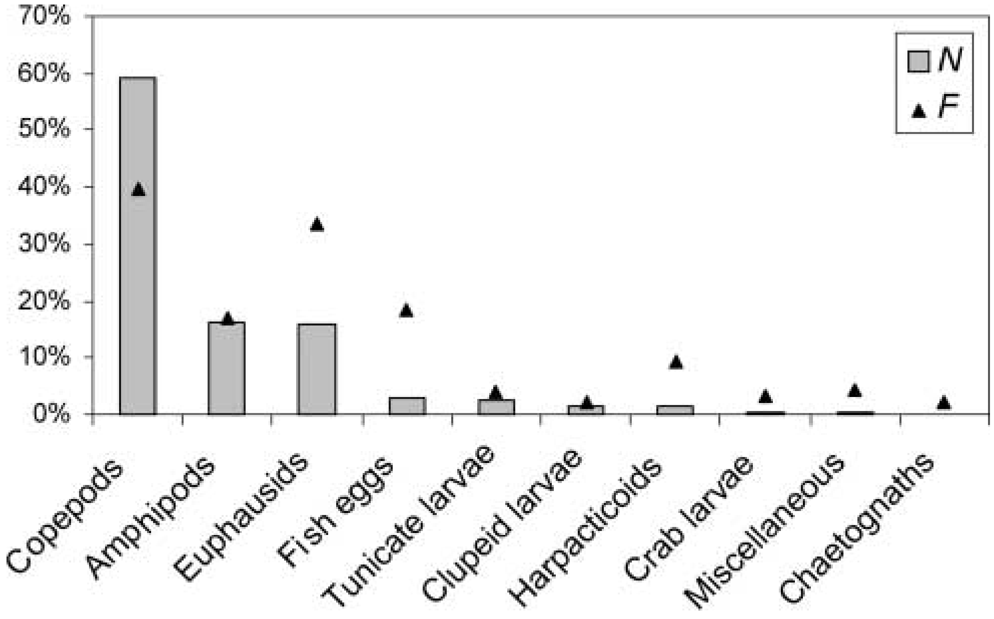


Figure 6.4. Numerical percentage (N) and food importance index (F) grouped by taxonomic group encountered in herring stomachs. Of the 855 herring stomachs analysed, 578 had food and 111 contained fish eggs, varying from 1 to 63 prey items per stomach (Reproduced from Segers , 2007).

Cushing (1980) attempted to unravel the circumstances which surrounded the crash of North Sea herring stocks in the early 1970s and the concurrent increase in most gadoid and sandeel stocks around this time. The author examined the possibility that a reduction in herring predation pressure might have caused an increase in the availability (a 'release') of planktonic prey items, such as the copepods Pseudocalanus and Calanus, which in-turn provided better foraging conditions for larval gadoids and sandeels and hence higher recruitment during this period. However, an alternative hypothesis was that the collapse of the herring stock resulted in a reduction in predation pressure on larval gadoids and sandeels, which were known to be consumed by herring, sometimes in large numbers. Cushing (1980) was unable to resolve which of these mechanisms might be the most important, although the author stated that relaxed predation is particularly hard to identify. Cod larvae might be eaten by adult herring (or adolescents on their way from the nursery ground) but they were much scarcer in the guts during the period of abundance than might have been expected. They could have been taken on the eastern nursery ground, but the cod were probably already too big when they arrived there. The third possibility is that the gadoid and sandeel upsurge in the 1970s was of climatic origin quite independent of the interactions between herring and/or other species in the North Sea.

6.2 Sprat and Herring in the West of Scotland and Irish Sea

Relatively few studies have considered the diet of pelagic fish west of the British Isles, however De Silva (1973) examined the food and feeding habits of herring and sprat in inshore waters off the west coast of Scotland from April, 1970 to March, 1972, and Ellis and Nash (1997) looked at predation on planktonic fish eggs (of plaice) in the plaice spawning area to the east of the Isle of Man (Irish Sea) in March 1993.

The study of De Silva (1973) collected herring and sprat from sea lochs and surrounding inshore areas around Oban (Scotland). Among the older age groups, 79.1% herring and 78.2% sprats contained food. A seasonal pattern of feeding activity was apparent; the percentage of individuals feeding tended to decrease from August-September, reached a minimum during the winter months and, thereafter, progressively increased during spring. During the summer months, nearly all the fish were feeding. Mysids and euphausiids (grouped together as schizopods in Figure 6.5) constituted 28.6% of the diet in herring compared with 1.1% in sprats. The reverse was found in the ease of Oikopleura, which constituted 21.4% of the diet in adult sprat and only 4.1% in herring. Decapod larvae and Balanus cyprids were taken in greater quantity by herring than sprats.

The relative importance of each food item for each month was calculated, the data for the 2 years were pooled, and the mean relative importance of each item was expressed as a percentage of feeding fish in each month. Some important yearly differences in the diet were evident. For example, in herring, fish larvae were eaten in appreciable numbers in April and May, 1970, whereas in 1971 they were not eaten at all. Copepods were eaten throughout the year by both clupeids. During the main feeding season, from March to September, copepods constituted the bulk of the diet in sprats, except in March, when cladocerans were the dominant item. In herring, copepods constituted the major portion of the diet from April to June, but were replaced by cladocerans in March and by mysids and euphausiids from July to September. During winter, the diet of herring was almost entirely composed of copepods, whereas in sprats, copepods were supplemented by other organisms. Among non-crustacean food, Oikopleura was the most important, and was taken by 65% sprats and 36.2% herring. During the winter, Oikopleura was an important food item in sprats; in herring it was only important in October.

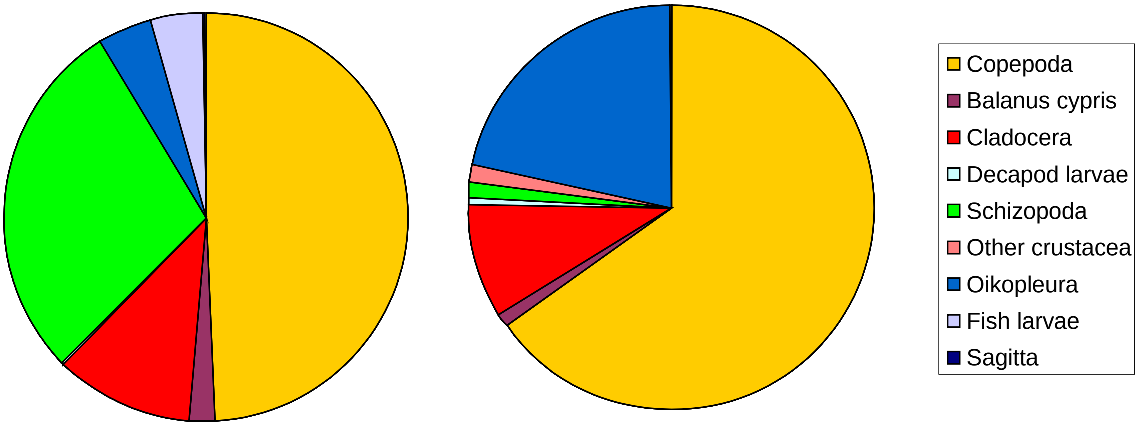


Figure 6.5. Relative importance (see text) of principle food organisms for herring and sprat off the west of Scotland as a percentage of total year's food (redrafted after De Silva, 1973). Mysids and euphausiids are grouped together as schizopods.

Ellis and Nash (1997) used herring and sprat stomach data from a field study in the Irish Sea to examine two hypotheses relating to predation on early life stages of fish. First, that pigmentation and transparency affect vulnerability to visual predators

(Leggett and DeBlois, 1994). Second, that the large size of plaice *Pleuronectes platessa* L. eggs confers a survival advantage over smaller eggs (i.e. the ' bigger is better ' hypothesis (see Leggett and DeBlois, 1994). Sprat and herring were sampled off the east coast of the Isle of Man in the Irish Sea during March 1993. March is the main spawning period of plaice in the Irish Sea and there is a relatively high density of plaice eggs off the east coast during this month.

Plaice eggs were distinguished within the stomachs from other planktonic fish eggs by their large size, c. 2 mm in diameter. Where digestion had not proceeded too far, plaice eggs were staged according to development. The small quantities of planktonic prey items in stomachs made wet weight determination impractical, so a simple points method was used, considered appropriate to coarse assessment of diet. The population of planktonic fish eggs was sampled with a modified Gulf V high speed plankton sampler.

The sprat was feeding more intensively than the herring, as shown by the greater proportion of fish containing food and the numbers of fish eggs in the stomachs. The occurrence of fish eggs in stomachs was high (36–97%) and plaice eggs were an important volumetric component of the stomach contents of both sprat and herring. The occurrence of plaice eggs was higher in sprat (57 and 97%) than herring (25–48%), as was the mean number of plaice eggs per fish (2·7 and 8·7 plaice eggs sprat-1; 0·8–1·7 plaice eggs herring"). The maximum number of plaice eggs recorded in a single stomach was 38 for sprat and 26 for herring, on 24 March. The majority of plaice eggs recovered from stomachs could not be staged due to digestion of the embryo. However, the frequencies of egg stages recognizable in stomach contents differed from frequencies recorded in plankton samples. The clupeids ate more plaice eggs in the later stages of development (III–V) than expected.

Bailey and Houde (1989) suggested that the transparency of planktonic fish eggs reduces visibility to predators encountering prey by sight. More advanced plaice embryos develop pigment spots and eyes, so the contrast between the largely transparent egg and the water will increase during development. Therefore, later developmental stages of eggs may be more easily seen by clupeids which are assumed to encounter prey visually. In this respect, it is interesting to compare the mortality rates of plaice eggs at different stages of development estimated from field surveys (data from Harding *et al.*, 1978). The authors found that mortality rates do differ between stages, and are higher between stages IV and V than between stages II and III.

Large egg size has been suggested as a strategy that reduces predation mortality (Bailey and Houde, 1989). However, the concept that larger individuals have a survival advantage over smaller individuals, i.e. the 'bigger is better hypothesis', has been questioned for fish larvae. Leggett and DeBlois (1994) recognized that predators select prey which are more obvious and of a higher energy content. Sprat and herring >80 mm presumably selected plaice eggs for just such reasons. With regard to these larger predators, plaice eggs that will suffer higher mortality rates than smaller eggs and 'smaller would be better '. Different size classes of prey will be vulnerable to different size classes of predator. Whether 'bigger is better' will depend upon the numbers (Cushing, 1974) and size-structure of the predator and prey populations (Rice *et al.*, 1993), and also the feeding activity of different size classes of predator. Plaice eggs had a refuge in size from sprat <80 mm. These smaller predators select smaller eggs of other fish species that are more numerous in the environment.

6.3 Genetic determination of plaice eggs and larvae in fish stomachs

Although predation on plaice eggs by fish can be detected visually (see above), scientists at Cefas and the Scottish Association for Marine Science (UK) have recently been engaged in a project (funded by the UK government) to compare the overall rates of detection by visual and molecular methods as regurgitation of gut contents in trawl hauls is a common problem in predation studies, and eggs of different fish species can be indistinguishable when partially digested. In previous papers (e.g. Fox *et al.*, 2005) the authors described the development of a genetic TaqMan probe specific for plaice DNA. In the 'PREDATE' (MF0432) study, which began in 2007, Cefas scientists attempted to address the following questions:

1) To identify the range of predators consuming plaice eggs/larvae in the Irish Sea,
2) To compare the percentages of predators estimated to be consuming plaice eggs by the molecular and visual approaches,
3) To examine the temporal feeding patterns (interannual variability) of the main predators,
4) To examine how the distributions of the predators and prey overlapped.

Work in the laboratory as part of this project suggested that the TaqMan method can detect prey DNA in predators up to 24 h after ingestion, even when there are no visible remains in the stomach. The T90s (time since ingestion when > 90% of predators test positive) were around 4–5 hrs at typical water temperature for fish and crustaceans. However, it is probably necessary to combine molecular approaches with visual analysis, as molecular approaches do not give any quantities - just an indication of presence or absence. This being said, analysis of predators in the Irish Sea during 2008 produced positive results for eight out of a potential 31 species sampled. The plaice probe revealed that for those fish sampled, sprat (40.3%), mackerel (33.3%) and herring (29.6%) were the most significant predators, with positive detections of plaice DNA also from dogfish [LSD], poor cod [POD] and whiting [WHG]. More surprising were positive detections from lesser weaver fish [WEL] and squid [SQC] (Figure 6.6). The following species were tested in small numbers (n<10) with no positive TaqMan results: *Crangon crangon*, *Trigla lucerna*, *Aspitrigla cuculus*, *Gadus morhua*, *Sepia officianalis*, *Ciliata mustela*, *Agonus cataphractus*, *Trachurus trachurus*, *Pomatoschistus minutus*, *Pandalus* spp. *Liocarcinus puber*, *Sepiola atlantica*, *Trisopterus luscus*.

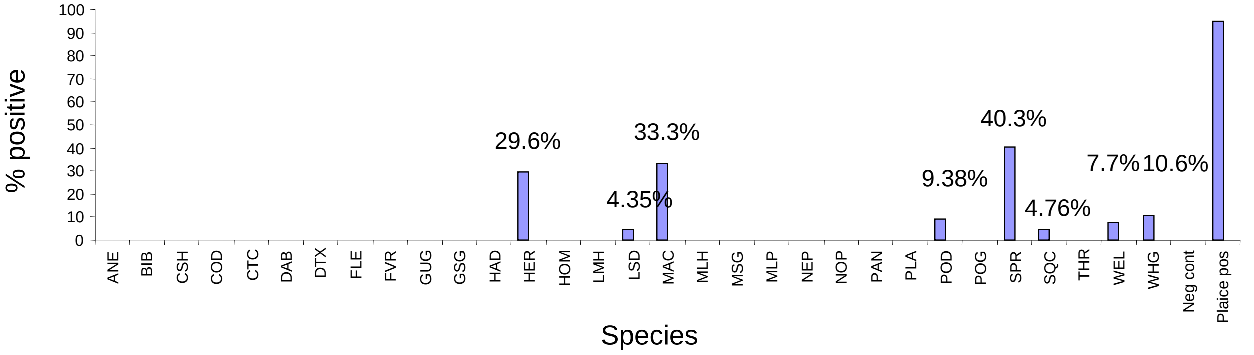


Figure 6.6. Results from the plaice probe during the February 2008 field survey of predators of plaice eggs and larvae in Liverpool Bay.

Nearly twice as many predators were sampled during the 2009 survey, therefore the authors anticipate having a much more complete understanding of the predator community when the remaining results have been analysed and interpreted. Initial results indicate higher levels of detection of plaice DNA in sprat during 2009 than was observed during 2008.

Overall therefore, the genetic approach looks useful for rapid screening of large numbers of predators or where you cannot identify the prey e.g. many species eggs are not visually identifiable.

6.4 Predation on pre-settlement stages by pelagic predators- Barents Sea

Predation by juvenile herring on capelin larvae was documented during the 1990s (Huse and Toresen, 2000). Such predation has been claimed to be the main cause for the three capelin collapses observed during the last 25 years (Hamre, 1994; Gjøsæter and Bogstad, 1998; Mikkelsen and Pedersen, 2004). Recent analyses indicate that high juvenile herring abundance in the Barents Sea is a necessary, but not sufficient, precondition for a capelin collapse (Hjermann *et al.* in press). 0-group cod (Hallfredsson and Pedersen, 2007) and sandeel (Godiksen *et al.*, 2006) have also been observed to prey on capelin larvae, and the analysis by Hjermann *et al.* (in press) indicates that predation by 0-group and older cod may affect capelin recruitment significantly.

The research programme BASECOEX (Capelin and herring in the Barents Sea – Coexistence or Exclusion) was established to model and investigate the effect of predators and prey (juvenile herring, juvenile cod, and capelin larvae) resulting in a large quantity of laboratory and field data.

Based on stomach contents and abundance estimates of predators from surveys during summer 2001 and 2003 in the Barents Sea, the rates of predation mortality for capelin larvae in areas and years with prey and predator overlap have been estimated to be ~10% d-1 for herring as predator (Hallfredsson and Pedersen, 2009). Based on similar field data from 2002 and 2003, Hallfredsson and Pedersen (2007) estimated the predation mortality rate for cod as predator to be about 1.5% d-1.

Pedersen *et al.* (2009) modelled spatial and temporal mortality rates of capelin in 2001 as a function of herring predation, using Lagrangian modelling, field surveys and experimental data. The impact of juvenile herring predation on capelin recruitment was corroborated, in particular the importance of the integrated spatio-temporal overlap between the two stocks. Capelin larvae were reduced to 20–50% in two weeks in accordance with different simulation scenarios.

6.5 Trophic ecology of small pelagic fish in the Bay of Biscay

Some new work is being carried out in the Bay of Biscay regarding the trophic ecology of small pelagic fish. This work is part of an open project called ECOANCHOA. It is a 4 year project (2008–2012) that was promoted by the Department of Agriculture and Fisheries of the Basque country government through the Interregional Committee for Cantabrian Sea and Northwest Fisheries Coordination. It has initial funding from the Basque Country, Cantabria, Asturias and Galicia autonomous regional governments.

Part of the work shown below has being explained in more detail in a master thesis project carried out during last year. The objective of this study was to investigate the diet of juveniles on and off-the-shelf to understand the trophodynamics of the species during the recruitment period. In addition, the effects of fishing hour and of location according to main hydrographic features (i.e. Gironde Estuary and Arcachon Areas) have been studied (Bachiller, 2008).

The sampling area is the Bay of Biscay and four sub-areas have been identified (according to the areas defined by Cotano *et al.*, 2008) to carry out sampling work: Cantabrian Area (C), Continental Slope Area (CS), Adour-Arcachon Area (A) and Gironde Area (G) (Figure 6.7).

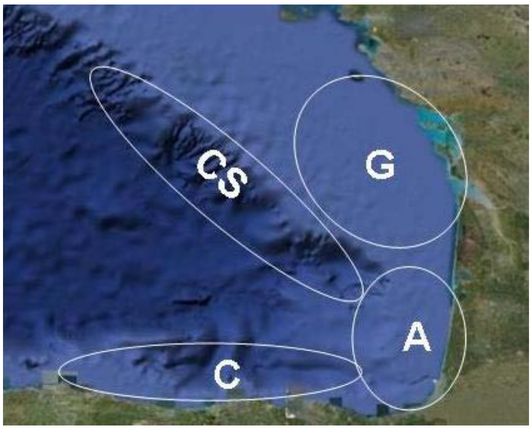


Figure 6.7. Sampling area and subareas: Cantabrian Area (C), Continental Slope Area (CS), Adour-Arcachon Area (A) and Gironde Area (G).

A complete diet characterization of juvenile anchovy was carried out, making some observations in terms of feeding behaviour: active pursuit when feeding on large mobile prey and passive filtration when feeding on small items (Loukashkin, 1970; James, 1987; James and Findlay, 1989; Bulgakova, 1993; Tudela and Palomera, 1995; Bulgakova, 1996; Plounevez and Champalbert, 1999, 2000; Bacha and Amara, 2009).

The continental shelf plays an essential role in determining distribution of zooplankton (Tudela and Palomera, 1997; Conway *et al.*, 1998; Albaina and Irigoien, 2004; Albaina, 2007). However, and in contrast to zooplankton abundance (higher on the shelf), in this research no significant difference was found from the shelf to off-the-shelf in terms of biomass in stomach contents. This is due to the large number of small preys ingested off-the-shelf, compared to a small number of larger preys ingested on the shelf. This is similar to the result found by Plounevez and Champalbert (1999). So although small juveniles off-the-shelf could encounter lower food concentrations, juveniles do not seem to be food limited compared with those on the shelf.

Regarding the complementary work in this field done up to now with other small pelagic species, it has been observed that the gear type could result in significant differences in terms of observed stomach contents. In fact, all sampled species (except sardines) showed higher stomach contents caught by purse-seiners, compared with those caught by pelagic trawl (Figure 6.8).

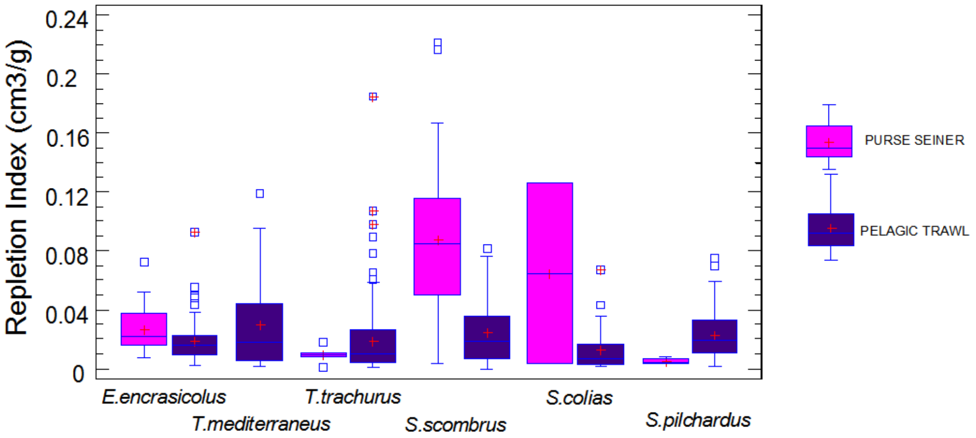


Figure 6.8. Stomach content differences depending on the gear type.

In terms of feeding time, the maximum feeding activity for anchovy juveniles was during daytime, especially with high light intensity (Bachiller, 2008). In contrast, for adult anchovies the maximum activity was observed before the peak of spawning, at dusk, and in case of sardines, they seem to have their maximum activity at night. It is important to note that difference was found between anchovy and sardine in one hand (feeding at dusk-night), and horse mackerel on the other hand which showed maximum feeding activity clearly during daytime. No significant differences were found for *Scomber scombrus* and *Scomber colias*.

The common tendency for all species is that as they grow in size, they eat more (Figure 6.9). This is not an enormous discovery but, it is clear that anchovy and sardine are relatively more voracious as they grow, than other species studied.

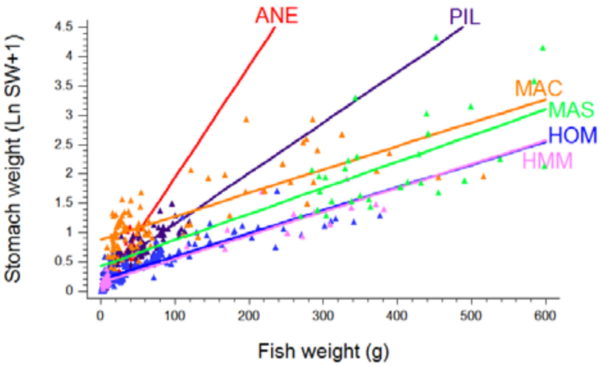


Figure 6.9. Fish weight – stomach content weigh relationship by species.

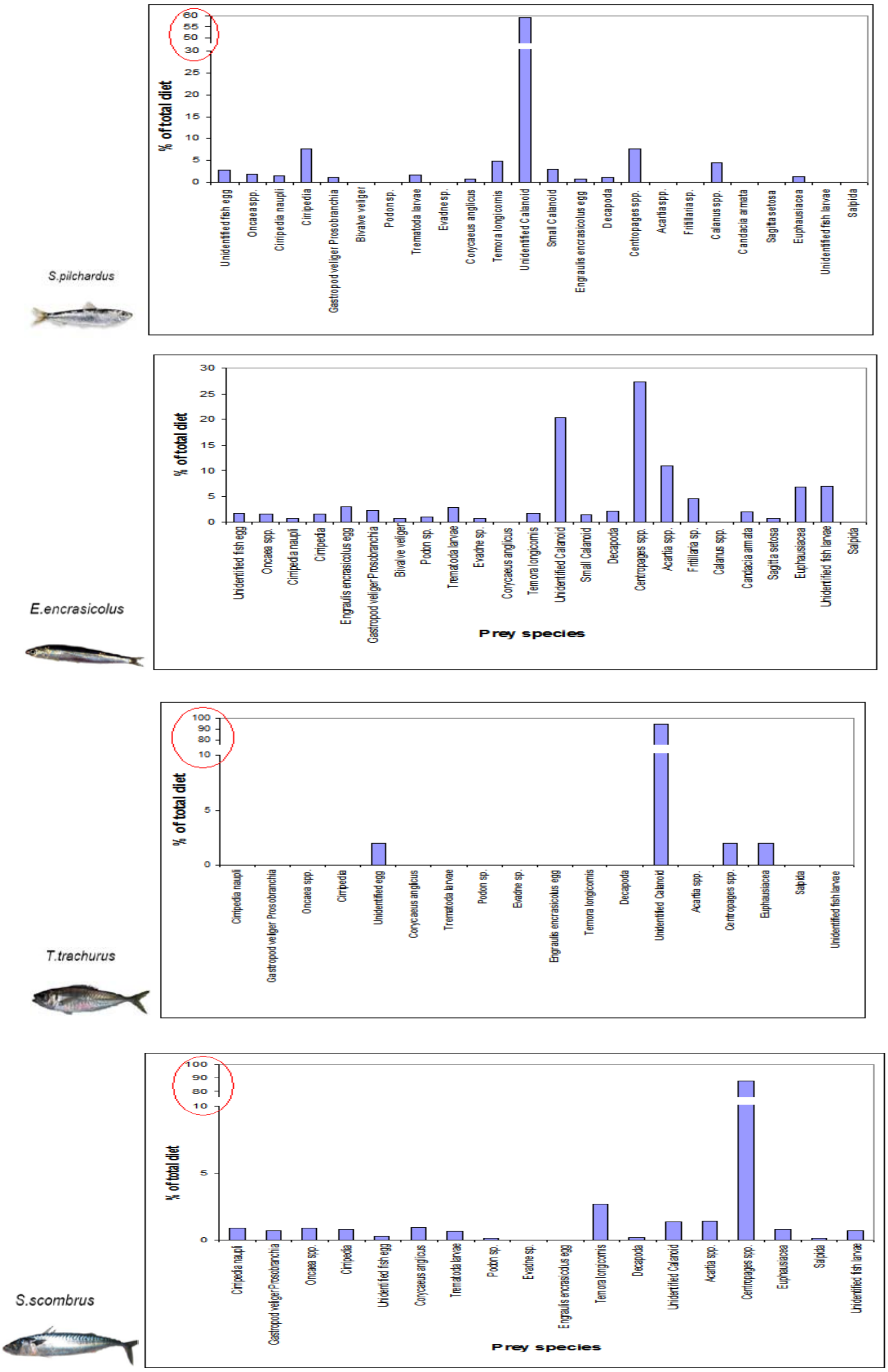


Figure 6.10. Preliminary diet characterization for small pelagic fish in the Bay of Biscay. Preys are ordered by size from left to right.

From Figure 6.10 it can be noticed that the main food resource, not only for sardines but also for anchovies, is clearly copepods. Euphausiids and decapods are less abundant but more important in terms of biomass. For horse mackerel and mackerel, no big differences were found in prey diversity. In case of *Trachurus spp.*: almost all stomachs were empty, probably due to the stress produced by trawling.

Regarding the Intra Guild Predation task and looking at stomachs of potential predators with presence of eggs, it is clear that the most important predator is the sardine, which showed an important amount of eggs in some catches, and also mackerel (*S.scombrus* and *S.colias*), but in this case only at one station. More samples have to be analysed before making conclusions about this topic.

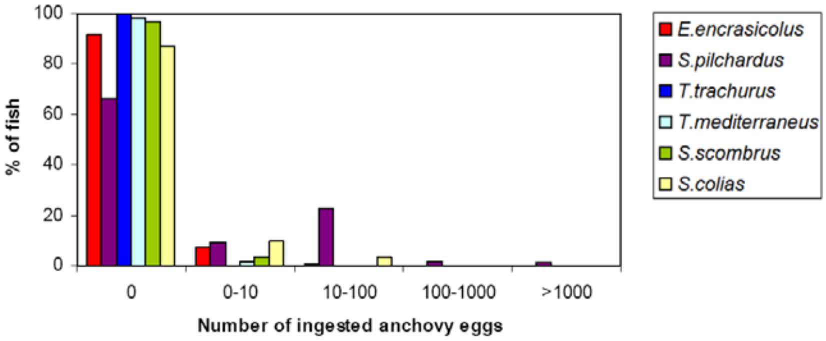


Figure 6.11. Number of anchovy eggs in the stomachs of various species of pelagic fish in the Bay of Biscay.

6.6 D4- Forthcoming Workshop on understanding and quantifying mortality

A "Workshop on understanding and quantifying mortality in pelagic, early life stages of marine organisms: experiments, observations and models (WKMOR)" is planned for 22–24 March 2010 in Aberdeen, Scotland (Co-chairs: Alejandro Gallego, UK, Edward Houde, USA, Elizabeth North, USA). This workshop will:

a) Review current and emerging laboratory, mesocosm, field and modelling methodologies aimed at understanding the underlying mechanisms that control mortality during fish and shellfish early life stages;

b) Summarize the state of our understanding of the mechanisms that control mortality of eggs, larvae and juveniles, identify information gaps, and list future research directions as proceedings from the workshop;

c) Develop recommended techniques to quantify mortality in the field and model its impact on subsequent recruitment.

7 Work towards the inclusion of spatial overlap in existing multispecies models

Recent studies highlight the fact that spatial heterogeneity is an important factor determining the dynamics of predator-prey interactions (e.g. Temming *et al.*, 2007, Kempf *et al.*, 2008, 2009; Neuenfeldt and Beyer 2006). Thereby spatial predator-prey overlap was investigated at different scales spanning from small scale feeding hot spots (e.g. Temming *et al.*, 2007) via mesoscale vertical overlap to large-scale changes in the distribution of whole predator and prey populations (e.g. Kempf *et al.*, 2008). These different scales have to be combined to give a complete picture on the dynamics of predator-prey interactions. However, information on spatial predator-prey is hardly used in any multi species model. This section gives an overview on ongoing work to analyse the influence of changes in spatial predator-prey overlap on predator-prey dynamics as well as on approaches to include information on spatial predator-prey overlap in existing multi species models in the different eco regions.

7.1 North Sea

7.1.1 Analyses on the influence of spatial predator-prey overlap on the dynamic of predator-prey interactions in the North Sea

The German Small Scale Bottom Trawl Survey (Ehrich *et al.*, 2007) was developed to better resolve the spatio-temporal characteristics of fish distributions and allow detailed process studies. Temming *et al.* (2007) used this survey as a platform for collecting fish stomach contents data at a very localized scale, and compared the predation patterns observed in one ICES rectangle (25 randomly located trawl hauls in three successive days), with the picture provided at the much broader scale via the International Bottom Trawl Survey (IBTS). The authors found that an aggregation of more than 50 million juvenile cod was entirely wiped out in only 5 days by predatory whiting, specifically aggregating on these juveniles in an area of <18 km2. The authors point out that consumption of only 32 'hot spots' of similar magnitude would add up to the average size of an incoming year class of North Sea cod. These findings support the hypothesis of predation as the major source of mortality in young-of-the-year demersal fish species and questions the generality of fish aggregation as an effective anti-predator strategy. This study highlights the system-wide consequences of small-scale predation hot spots and further points to the importance of a more realistic implementation of local high-intensity predation events in foodweb models.

Stomach data from the ICES 'years of the stomach' programmes in 1981 to 1991 were reanalysed in a study by Kempf *et al.* (2008) in order to evaluate the influence of changes in predator-prey spatial overlap on the apparent diet of North Sea cod and whiting. The large-scale response of North Sea cod and whiting populations to varying prey fields was analysed using Generalised Additive Models (GAMs). The composition of the prey field and changes in predator-prey overlap had a significant effect on the diet composition in the final GAMs explaining 65.6% of the variance. The existence of a large-scale prey refuge at low prey abundances as proposed by the Holling type III functional response was demonstrated for the first time.

The detailed understanding gained by analysing the influence of changes in spatial predator-prey overlap has been used to evaluate the interplay between temperature related processes and predation in determining age 1 recruitment strength for North Sea cod and Norway pout (Kempf *et al.*, 2009). For this purpose an index of predation impact (PI) on 0-group juveniles was calculated out of survey data. PI was assumed to depend on the abundance of the predators as well as on the spatial overlap between predator and prey populations. Generalized Additive Models (GAMs) were created with the spawning-stock biomass (SSB), the sea surface temperature (SST) during the 1st, 2nd and 3rd quarter of the year in the respective spawning and nursery areas and PI as explanatory variables. SSB had no significant impact on recruitment strength for both species, i.e. there was no stock-recruitment relationship. By contrast, SSTs during the 2nd quarter and PI explained the interannual variability in age 1 recruitment to a large extent. The resulting GAMs explained 88% of the total variance for cod and 68% for Norway pout. The SST during the 2nd quarter determined thereby the overall level of recruitment strength. Above certain SSTs, however, the effect on recruitment strength was no longer significant. In these temperature ranges, predation was the dominant effect.

7.1.2 Inclusion of information on large-scale spatial predator-prey overlap in the North Sea SMS model

The North Sea SMS model (Lewy and Vinther 2004) was used to evaluate the influence of large-scale spatial predator-prey overlap on prediction results.

Inside SMS the suitability coefficient (S) is as measure for predator preferences multiplied by the availability of prey to the predator. The default version of SMS defines suitability of a prey i for a predator j in year y and season q as the product of a time invariant species vulnerability coefficient *vul(i,j),* a time invariant size preference coefficient component *size(i,j)* and a season dependent overlap coefficient for the predator prey species:

$$S(i,j,y,q)=vul(i,j)\,size(i,j)\,so(i,j,q)$$

In this paper the overlap coefficients are allowed to change between years, such that suitability becomes:

$$S(i,j,y,q)=vul(i,j)\,size(i,j)\,so(i,j,y,q)$$

Such an extended matrix of overlap coefficients cannot be estimated within the model and must be given as fixed input values.

Estimation of overlap coefficients

Overlap data were derived from North Sea IBTS survey data for the years 1991 to 2007 obtained from the ICES DATRAS database (http://datras.ices.dk/Home/default.aspx) as 'CPUE per length per statrec' for the respective predator species and prey species (Table 7.1). Survey data covering the whole North Sea were available for the 1st and 3rd quarter from the years 1991 to 2007 and for the 2nd and 4th quarter from the years 1991 to 1996. North Sea wide spatial overlap for all possible combinations between predator trophospecies (predator j of length class s; Table 7.2) and prey trophospecies (prey i of length class s; Table 7.2) populations were estimated. As a measure for spatial predator-prey overlap the Schoener (percentage) overlap index (Schoener, 1970) was chosen using the formula '1–0.5*(sum(abs(predator.pr-prey.pr),na.rm=TRUE))' where *predator.pr* and *prey.pr* represent the proportions of predator and prey trophospecies populations in each ICES rectangle at time *t* (year–quarter combination).

The resulting matrix of overlap coefficients was further transformed to meet the formula for food suitability, which uses overlap coefficients on a year-quarter-predator-prey basis without taking the size of predator and prey into account. As a first step for every year, quarter, predator, predator length and prey species combination a weighted mean over all prey length classes was calculated with the respective relative stomach content of the prey length class in the 1991 stomach dataset as weighting factor. This ensured that only combinations also observed in the stomach data were taken into account and that mainly eaten prey length classes influence the mean value to a larger extent. As a second step, a weighted mean was calculated over all predator length classes for each year, quarter, predator, and prey combination. The abundance of each predator length class in a certain year and quarter was taken as weighting factor. Age based abundance estimates were taken from the WGSAM key-run (ICES, 2008c). These estimates were transformed into length based estimates using age–length keys derived from IBTS survey samples and downloaded from the ICES DATRAS database (http://datras.ices.dk/Home/default.aspx).

The overlap matrix, however, was still incomplete. Overlap indices for the 2nd and 4th quarter were only available for the years 1991 to 1996. Data from theses years were used to carry out linear regressions between the different quarters for each predator species to determine the strongest relationships. The strongest relationships were used to extrapolate the matrix for the missing year-quarter combinations. In addition, for the interactions with sandeel as well as "Other Food" no spatial overlap indices could be calculated because survey information per ICES rectangle are either highly uncertain (sandeel) or not available (Other Food). For these prey types only seasonal overlap coefficients (so) were estimated inside the model. A higher availability of these prey species during the 2nd and 3rd quarter than during the 1st and 4th quarter of the year was assumed. For the remaining predators (i.e. bird species) spatial predator-prey overlap was assumed to be constant for all year-quarter combinations as in traditional multi species model approaches.

Hindcasts

The hindcasts to estimate the parameters needed for model predictions were based on the SMS key-run 2008 from the Working Group on Multi Species Assessment Methods (WGSAM; ICES, 2008c). However, the hindcast time-series was shortened to the time after the proposed regime shift in the late 1980s to base the predictions on the current ecosystem state. The default time-series 1981–1991 of stomach data were also shortened to include just the 1991 data (Hislop *et al.*, 1997).

The available input data were used to carry out three different types of hindcasts to allow for different types of forecasts. A single species hindcast utilizing constant natural mortalities from standard assessments (ICES, 2008a, ICES, 2008d) was carried out as well as a multi species hindcast with constant spatial overlap for all interactions and another one with variable spatial predator-prey overlap. For all three hindcasts 20 thousand MCMC simulations were carried out to estimate parameter uncertainties to be taken into account in the respective forecasts.

Forecasts

In all forecasts the current fishing mortalities were extracted from the official assessment reports (ICES, 2008a, 2008d) and given as input for 2008. From 2009 onwards, fishing mortalities were constant on the 2008 level for all species despite for cod. For cod a 25% reduction in fishing mortality from the 2008 level was assumed for 2009. Afterwards a constant fishing mortality of 0.4 was set as target, however, with an additional 20% constraint on the year-to-year variation of total allowable catches (TACs). This mimics the most important features of the agreed cod management plan from the European Commission (EU 2008). Ricker stock–recruitment relationships fitted to data after the regime shift were used to predict recruitment for all stocks despite for haddock. For haddock a geometric mean was used instead.

Two different multi species scenario forecasts were carried out for the years 2008 to 2020 utilizing the parameter estimates from the hindcast with variable spatial predator-prey overlap as input. In one forecast for the interactions with cod as prey the highest overlap index observed in each quarter between 1991 and 2007 was used and held constant over the forecast period. In the second forecast the lowest overlap index value was used and held constant. For all other interactions the overlap coefficients from 2007 were used and held constant in both forecasts. A single species and a multi species forecast assuming constant spatial overlap were also carried out as reference runs.

Results

Predicted recovery rates of cod were highly dependent on the type of forecast (Figure 7.1). Single species predictions gave the highest predicted SSB in 2020 of around 1.2 million tonnes (average from 20 thousand MCMC simulations) with a still increasing trend. All multi species forecasts predicted a lower recovery and density-dependent processes (i.e. cannibalism) prevented a further increase in SSB before 2020. However, also multi species forecasts came to very different results according to the assumption on future spatial predator-prey overlap. The forecast with the minimum observed spatial predator-prey overlap value during 1991 to 2007 for the interactions with cod as prey predicted a recovery of cod towards around 1 million tonnes on average in 2015. In contrast, the predicted average SSB in 2015 in the forecast utilizing the maximum spatial overlap value observed between 1991 and 2007 was less than 200 thousand tonnes. The forecast assuming constant predator-prey overlap gave results in between both extremes but was much closer to the forecast with maximum overlap values.

A prominent feature of multi species forecasts was that all other species were influenced by the recovery of cod. The higher the predicted SSBs for cod, the lower the predicted SSBs for its prey species in particular whiting, herring and Norway pout when fished with status quo fishing mortalities.

Conclusion

It could be demonstrated that information on large-scale predator-prey overlap can be included in existing multi species models. The ignorance of changes in spatial predator-prey overlap can lead to substantially biased results as shown for the recovery rates of cod. However, the ability to predict spatial predator-prey overlap is limited. In the current study only simple scenarios with different constant future spatial overlap values were possible. This is a field for future research. By understanding how fish change their large-scale distribution in response to climate, prey abundance and predator abundance, more realistic scenario forecasts may be possible and structural uncertainties arising from the current ignorance of changes in spatial predator-prey overlap in most multi species models may be reduced.

Table 7.1. Predator and prey species included in the spatial overlap coefficient calculations.

PREDATOR	PREY
Cod	Cod
Whiting	Whiting
Haddock	Haddock
Saithe	Herring
Grey gurnard	Norway pout

Table 7.2. Length classes as utilized in the overlap calculations.

Length class	Length (mm)
1	<100
2	100 – 149
3	150 – 199
4	200 – 249
5	250 – 299
6	300 – 349
7	350 – 399
8	400 – 499
9	500 – 599
10	600 – 699
11	700 – 799
12	800 - 999

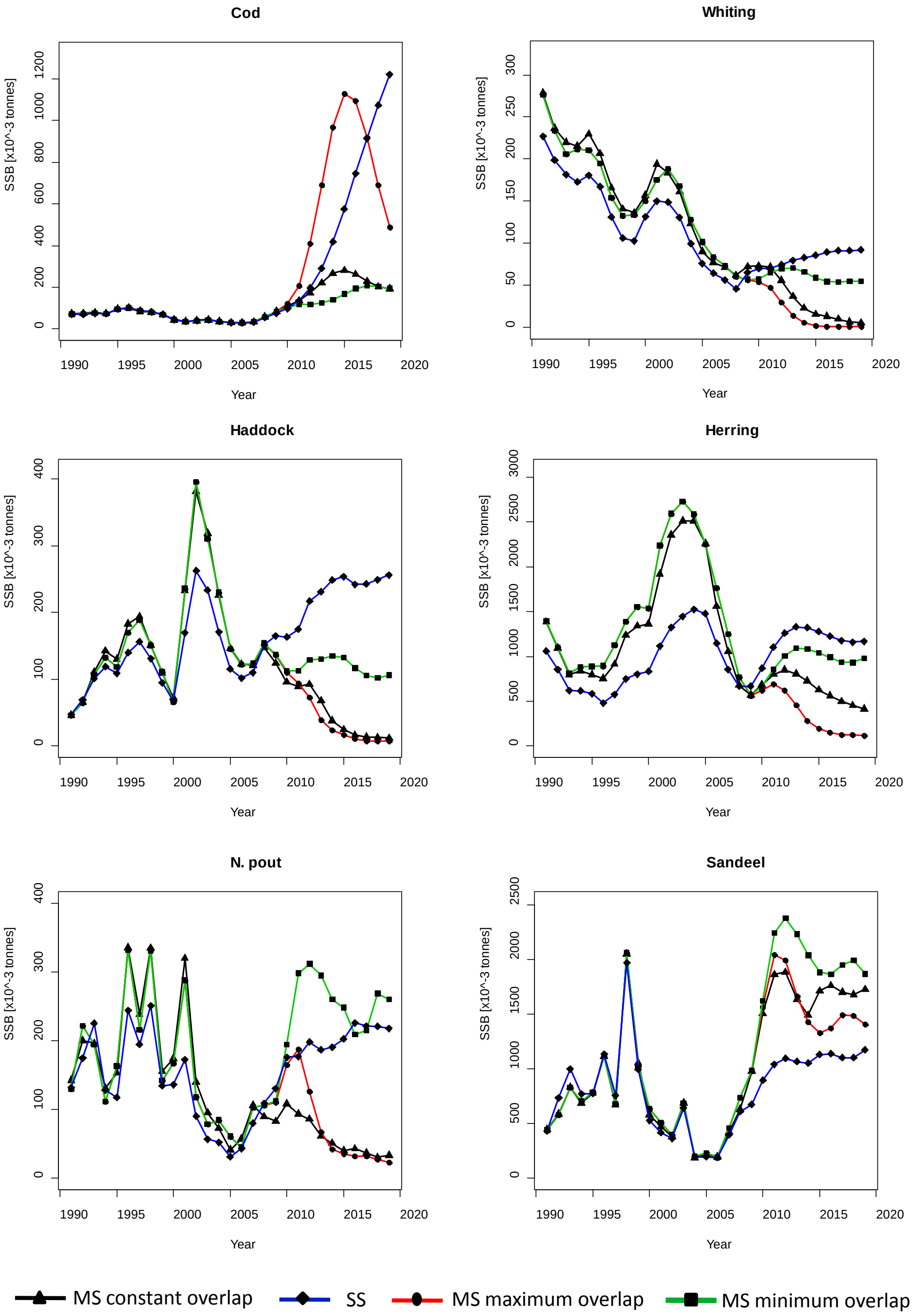


Figure 7.1. Trends in predicted SSB for different kinds of forecasts. "MS" stands for multi species forecast and "SS" for single species forecast. Maximum and minimum overlap refers to observed maximum and minimum spatial predator-prey overlap observed between 1991 and 2007 between cod and its main predators whiting, grey gurnard and cod itself (cannibalism).

7.2 Baltic

Decreasing prey-specific consumption rates at increasing overall prey abundance (i.e. 'negative-switching') can occur on the population scale solely due to overlap-dependent spatial variations in prey availability, *i.e.* without the individual predator altering preferences. Furthermore, as overlap changes occur in response to hydrographic fluctuations, predation mediates an effect of hydrographic changes on the prey population dynamics (Neuenfeldt and Beyer 2006).

Here WGSAM consider how individual functional response and spatial overlap can interact in accelerating the decrease in the instantaneous predation mortality rate at increasing prey abundance. It is shown that it is important for the prediction of prey population dynamics to know the functional response of individual predators beyond its functional form, especially regarding the concept of prey handling time and the response of the predators' search activity level to hunger. The Holling type 2 (Holling, 1959) and a simple active response model, (Chesson, 1984) are used as examples.

The overlap scenario considered is as follows: Prey population 1 occurs in the total predator population habitat, whereas prey population 2 occurs only in a limited part of the predator habitat. Habitat volumes of predator and prey is considered constant and predator-prey overlaps are for simplicity considered independent of habitat volumes. Focus is put upon f_1^* at variable overlap O_2 between the predator and prey population 2, *i.e.* it is investigated what happens to the *per capita* aggregated functional response for prey 1, when size changes of the stratum where prey 2 is additionally available for predator individuals.

Multiplying f_1* with the abundance P of the predator population, yields the total amount of prey 1 individuals consumed per unit time. The instantaneous predation mortality rate of prey 1 is given by $dN_1/dt=-(f_1^*)PN_1^{-1}$ (N_1 indicates the abundance of prey 1). Because P is considered constant the term $f_1^*N_1^{-1}$, expressing the relationship between consumed prey individuals per average predator individual and prey abundance, is here sufficient to describe predation mortality dynamics. The derivation of f_1^* for variable O_2 is given in Table 7.3.

Table 7.3. Local individual and per capita aggregated functional responses for prey 1 according to Holling type 2 and active response models.

$_1$: **individual functional response for prey 1 in stratum 2 (Fig.12);**

$_{10}$: **individual functional response for prey 1 in stratum 1 (1 is the only prey);**

$_1$*: **per capita aggregated functional response for prey 1**

$_2$* **per capita aggregated functional response for prey 2**

	Type 2	ARM (active response model)
f_1	$\alpha_1\rho_1(1+\alpha_1\rho_1h_1+\alpha_2\rho_2h_2)^{-1}$	$f_T\alpha_1\rho_1(\alpha_1\rho_1+\alpha_2\rho_2)^{-1}$
f_{10}	$\alpha_1\rho_1(1+\alpha_1\rho_1h_1)^{-1}$	f_T
f_1^*	$(1-O_2)f_{10}+O_2f_1$	

Unless explicitly mentioned, $\alpha_1=\alpha_2=0.5$ and $h_1=h_2=1$. Furthermore, f_T was set to 1, and ρ_2 was also set to 1 in the simulations.

Both in the Type 2 and the ARM functional responses, per capita predation rates decrease at increasing prey densities even if $O_2=1$:

ARM:

$$\frac{d}{dN_1}\left(\frac{f_1^*}{N_1}\right)=-\frac{1}{N_1^2}(1-O_2)f_T+O_2f_T\alpha_1\frac{-\alpha_1}{\{\alpha_1N_1+(1-\alpha_1)N_2\}}$$

Type 2:

$$\frac{d}{dN_1}\left(\frac{f_1^*}{N_1}\right)=(1-O_2)\alpha_1\frac{-\alpha_1h_1}{(1+\alpha_1N_1h_1)^2}+O_2\alpha_1\frac{-\alpha_1h_1}{(1+\alpha_1N_1h_1+(1-\alpha_1)N_2h_2)^2}$$

However, in the ARM at $O_2<1$ the decrease is more pronounced than at $O_2=1$ (eq. 6). If $O_2<1$ in the ARM, then the predators have exclusively prey 1 to obtain a constant amount f_T of consumed fish in a $(1-O_2)$-fraction of their dispersion volume. The *per capita* predation rate decreases at increasing prey 1 density at a rate that is inversely proportionate to N_1^2. Therefore, the effect is especially pronounce at $N_1<1$.

In consequence, increases of N_1 are amplified in the ARM at $O_2<1$, especially when N_1 is initially small. Here it becomes important to distinguish between the traditional functional response experiments with simultaneous encounters and the sequential encounters in the field. Especially, if N_1 is measured in number of schools per unit volume then a situation where the individual predator has less than 1 encounter per unit time is realistic. Also the density of prey individuals can well be less than 1.

Also in the type 2 functional response model the *per capita* predation rate decreases faster at increasing N_1 if $O_2<1$, however, not at such a high rate as in the ARM. Yet, a greater decrease rate of *per capita* predation at low but increasing N_1 can be observed, if h_1 in the type 2 model is high, corresponding to a (long) handling time (for example during digesting a meal consisting of several prey specimen after school encounter) during which the predator individual would not search for new prey.

Overlap hence influences the number of consumed prey individuals per average predator individual and prey abundance (Figure 7.2), thereby decoupling predation mortality from predator and prey abundances. These effects are more pronounced in the ARM (Figure 7.2 B and D).

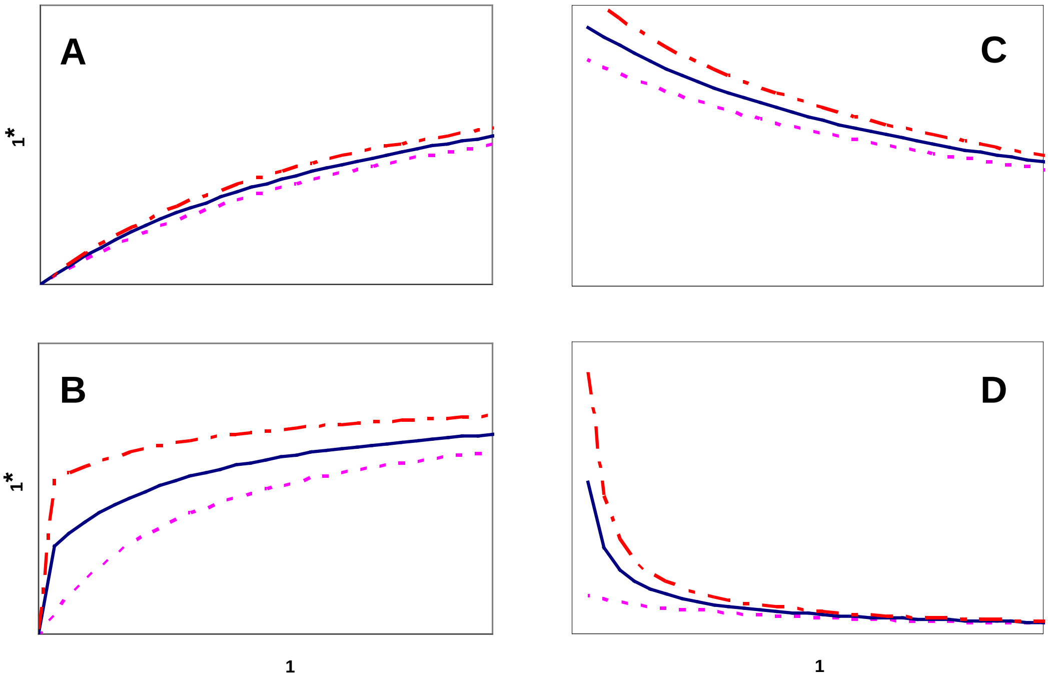


Figure 7.2. Aggregated per capita functional response $_1$* type 2 (A) and ARM (B) and number of consumed prey individuals per average predator individual and prey abundance $_1$*/ $_1$ for Type 2 (C) and ARM (D). The dashed lines show the functional response and predation rate at $_1$= $_2$=1, i.e. at complete mixing of predator and prey populations. The solid lines, in contrast, reflect functional response and predation at $_1$=1, and $_2$=0.7, i.e. in a situation where 30% of the predator habitat contain prey 1 only. The dash-point lines reflect $_1$=1 and $_2$=0.4.

7.3 Barents Sea

Predatory interactions in the Barents Sea with special emphasis on cod and capelin; preliminary results.

Capelin is a key forage fish for several apex predators, such as cod (Carscadden and Vilhjalmsson, 2002), in the Barents Sea ecosystem. As much as 1/3 of the total biomass consumption, on average, by cod comprising of capelin (ICES, 2009a). The dietary importance of capelin is reflected in the demographic parameters of cod; liver condition index (e. g. Sandeman *et al.*, 2008), individual growth (Jørgensen 1992) and fecundity (Kjesbu *et al.*, 1998) are all positively influenced by capelin abundance. Thus, one would expect that the spatial distribution of cod and capelin also coincide.

The spatial variability of cod prey consumption as well as the geographical overlap between cod and capelin has been investigated.

Spatial and temporal consumption pattern

Cod stomach content data are collected throughout the year by Norwegian and Russian vessels (Dolgov *et al.*, 2007). Cod display a clear seasonal feeding pattern with respect to capelin. Predation consumption is higher during winter and autumn compared with spring and summer (Figure 7.3).

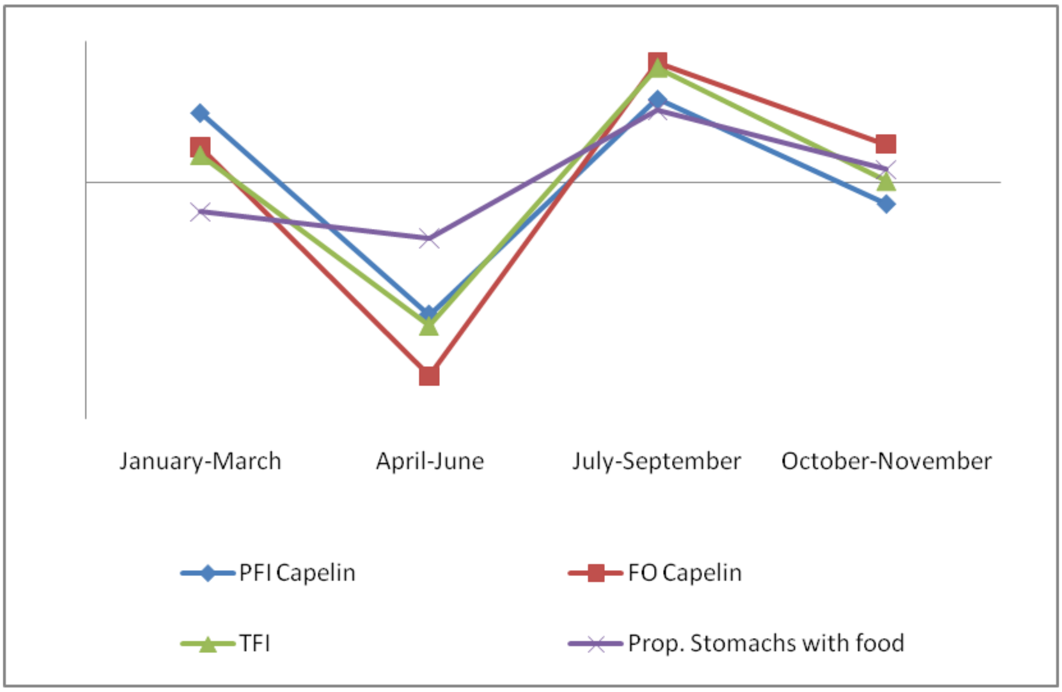


Figure 7.3. Seasonal feeding pattern of 2003–2008. The data are taken from the Joint IMR-PINRO stomach database. TFI is total filling index and PFI is partial filling index.

As seen in Figure 7.4, there is a major heterogeneity in use and consumption of prey by cod (50–75 cm) in the Barents Sea. Cod in the northern and northeastern Barents Sea, which primarily feed upon capelin and polar cod, appear to have higher consumption rates than cod in southern and central parts of the Barents Sea.

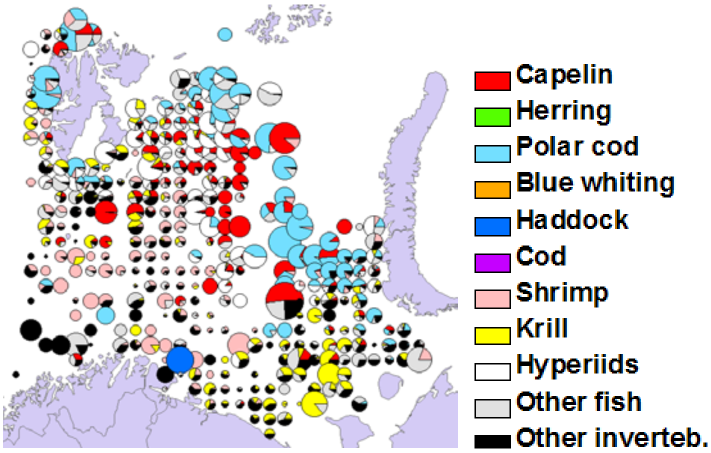


Figure 7.4. Pie chart of cod consumption 2003–2008 averaged over 50x50 km grid cells for cod 50–75 cm. The size of the pies is proportional to total consumption in the grid cell.

Cod-capelin overlap

Acoustic data on capelin abundance and bottom-trawl data on cod, sampled during ecosystem surveys in August-September 2003–2008, were used to calculate the overlap between three length groups of cod and capelin. The spatial resolution of the analysis was 2500 km^2.

The overlap index proposed by Woillez *et al.* (2009), was used to estimate spatial overlap. The method involves the use of non-centered correlation for local abundance and the global index of collocation as an index at the population scale:

$\text{GIC} = 1 - (\text{CG prey-CG predator})^2/(\text{CG prey-CG predator})^2 + \text{I prey} + \text{I predator})$

where *CG* is the center of gravity, and *I* is the inertia, that is the variance in the location of individuals in the population, estimated as:

$$CG = \frac{\sum_{i=1}^{N} x_i s_i z_i}{\sum_{i=1}^{N} s_i z_i} \qquad I = \frac{\sum_{i=1}^{N} (x_i - CG)^2 s_i z_i}{\sum_{i=1}^{N} s_i z_i}$$

Where zi is sample value at position xi and si is the area of influence which is the area made up by points in space that are closer to each sample than to other samples. The global index of collocation varies between 0 (no overlap) and 1 (max overlap).

The global index of collocation estimated from the ecosystem survey is preliminary and should be treated with caution (Figure 7.5). Nonetheless, the results indicate that: (1) there is annual variation in spatial overlap between cod and capelin, and (2) large cod match the distribution of capelin better than small cod in August-September. It should be emphasized that the area of influence was set to 1 for each data point for simplicity, but because the sampling is not regular, this may have caused a bias. Also, the estimated global index of collocation is calculated from the Inertias and the center of gravities which are sensitive to high density values.

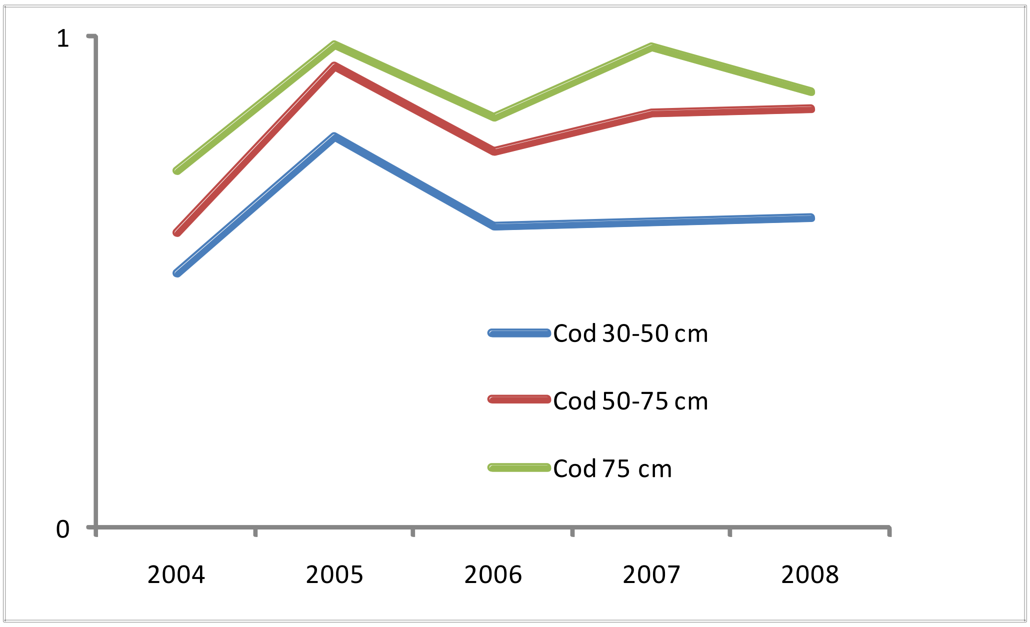


Figure 7.5. Annual estimates of the capelin–cod overlap, using the overlap index by Woillez (2009), in August-September 2003–2008.

Future work

We aim to quantify the functional and aggregative response of cod towards their prey at various spatial scales combining stomach content data and geographical distribution of predator and prey from the ecosystem survey. We further aim to explore the sensitivity of the overlap index with respect to high prey density values and area of influence.

8 Tor F. Methods for estimating consumption and diet composition in multispecies models

Many multi species / community models have been developed to gain knowledge of community behaviour as well as for the use in resource management, particularly management strategy evaluations; one of the key underlying processes in these models 'consumption'. In this ToR, three topics on consumption are dealt with: the estimation of historical total consumption, the estimation of diet composition and the prediction of consumption in the multispecies models. As estimating consumption rate out of stomach content data alone is prone to errors, some comments are given on how these could be introduced and possibly be corrected for.

8.1 Estimation of consumption

Different methods have been suggested for estimating total food consumption. Most of these can be summarized into 6 different types, as listed below. An overview of these methods, including key-literature and their general mathematical description is given in Table 8.2.

Consumption can be estimated in numerous manners, often based on:

- Weight of the stomachs in relation to weight of the fish (%BW)
- Daily ration, where this accounts for the amount of food consumed per day, similar to %BW but not necessarily corrected for body weight.

- The ratio between Q and B, Q representing the ingested amount of food and B representing the species' biomass (Also known as C/B method)
- Evacuation rate. This methods combines the knowledge of the relationship between average stomach content, evacuation rate and average consumption to estimate consumption rates
- An assumption on functional response. This models the relation between preys ingested by a predator depending on the availability of the prey.
- Bioenergetic methods. These methods estimate the food intake as the sum of the expenditures on metabolism, excretion, growth and reproduction.

This overview has been constructed based on generic attributes of methods that estimate consumption. Within the different ecoregions several multispecies and ecosystem models are used. Their approaches for estimating consumption are derived from the basic types listed above. Most tend to utilize some form of evacuation rate model or functional response.

Diverse methods have been employed over the years to calculate food consumption of fish. Palomares and Pauly, in several papers, have provided allometric equations incorporating growth parameters, water temperature, morphological variables and food type (Palomares and Pauly, 1989; Pauly, 1989; Jarre *et al.*, 1991; Christensen and Pauly, 1993) (see Table 8.1). These models, although giving relatively imprecise estimates (Jarre *et al.*, 1991), have been widely applied in order to obtain reasonable values for use in ecological models, e.g. they are increasingly being used to generate input parameters for Ecopath models, especially for species where detailed laboratory experiments have not been carried out.

The fish feeding model MAXIMS, developed by the International Centre for Living Aquatic Resource Management (ICLARM) (Jarre-Teichmann *et al.*, 1990; Jarre *et al.*, 1991; Richter *et al.*, 1999), has also been widely applied over the past decade (Richter *et al.*, 1999; De Silva *et al.*, 1996) and the model has been shown to be mathematically robust when artificial variability was introduced into a theoretically perfect dataset (Richter *et al.*, 1999). This approach makes use of stomach content weights measured throughout a day/night cycle in the wild, as well as assumed gut evacuation rates.

Various methods have been developed to estimate in situ food consumption by fish based upon the volume of stomach contents and gastric evacuation rate (Elliott and Persson, 1978; Jobling, 1986; Persson, 1986). An ICES working group (ICES, 1991b) compared food consumption computed using the standard gastric evacuation rate model (based on Daan, 1973) and two alternative models (dos Santos, 1990; Bromley, 1991). The three models produced differences of up to 200% in estimates of total food consumption by the North Sea cod population.

An alternative approach to the estimation of consumption is bioenergetics modelling based on the basic physiological principles of energy partitioning. With bioenergetics models, food consumption is estimated from individual fish growth rates. Several models have been developed for marine species, including cod (Ursin, 1979; Kerr, 1982). However, such models have been used mainly in studies of freshwater fish (e.g. Kitchell *et al.*, 1977; Helminen *et al.*, 1990; Hansen *et al.*, 1993).

Size-at age data are routinely collected for commercially important species, which are then used to fit parameters of a growth function, such as the von Bertalanffy growth function (VBGF; von Bertalanffy 1938). Although the VBGF is most commonly used simply as a descriptive model of growth, the descriptive VBGF is actually a based on a simple mass balance equation similar to those underlying bioenergetic models (e.g.

Paloheimo and Dickie 1965; Ursin 1967). Thus, in theory, parameters of the VBGF can be used to estimate fish consumption rates (Pauly, 1986). Pauly (1986) and Temming (1994) illustrate how the VBGF can be used in concert with data on growth efficiency to estimate fish consumption rates. Essington et al (2001) evaluated the accuracy of VBGF-derived consumption rates by performing a meta-analysis and sensitivity testing of VBGF assumptions. The precision of the VBGF depended on statistical characteristics of the size-at age data used to parameterize the model. When data indicate decelerating growth, consumption rates were estimated with good precision, otherwise consumption estimates were poorly defined. The authors conclude that VBGF can be a useful tool for estimating fish consumption rates, but potential biases and precision of these estimates should be evaluated on a case-by-case basis.

8.1.1 Estimation of consumption by real-time fish behaviour

Rather than relying on models of gut evacuation and filling to estimate food consumption rates among fish, another approach has attempted to estimate food consumption by simply counting the number of bites taken by a fish each day, to calculate 'daily ration'. This approach has been used extensively by researchers working on coral reef fish, and often involves following individual animals and recording behaviour patterns throughout the day, sometimes making use of electronic data-capture devices. This approach requires some estimate of the quantity (mass) of material ingested in a single 'bite', but is more direct than back-calculating from the weight of semi-digested material in the stomach. The approach has been successfully applied to estimate daily consumption among herbivorous reef fish e. g. parrotfish and the damselfish (see Bruggemann *et al.*, 1994; Polunin and Klump, 1989), however the approach is much harder to apply in hostile environments (such as the North Atlantic) where protracted scuba-diving is unfeasible and for animals that forage over a larger area (i.e. most commercial fish within the ICES area).

One important development in recent years has been the emergence of data-storage tags (DSTs) that can be attached to animals in the wild, and which record the number of discrete 'feeding events' remotely. Scientists have developed a modification of the Cefas G5 archival tag (see Metcalf *et al.*, 2009) incorporating an inter-mandibular angle sensor (IMASEN) that had previously been used with penguins in which jaw movements were measured by monitoring the relative distance between a small Neodymium disc magnet and a Hall-effect magnetic field sensor. The new tag has a maximum data logging frequency of 30 Hz, a sensor resolution of 12 bit and a memory of 16 MB, sufficient to store 96 hours of data when logged at 30 Hz. The flexible data logging capabilities of the G5 DST allow the tag to be programmed so that feeding trials can be extended over several months by programming the tags to log data for short periods (e.g. 1 hour) on separate, predefined, occasions. In laboratory studies with Atlantic cod, jaw movement data were obtained during ventilating, yawning, coughing and, in one fish, during feeding. The results indicate that these different types of jaw movement can readily be discriminated and analysis suggests that feeding events should be detectable at lower data logging frequencies (e.g. 10 Hz).

8.1.2 Estimation of predicted consumption

Many recent model developments focus on size based approaches where species identity is substituted for generic life-history characteristics. In these models, a predefined predator-prey biomass ratio defines 'who-eats-who' rather than a list of combinations saying so. Another group of models predicts consumption according to an assumed functional response, where consumption is driven by the abundance of preys according to a fixed relationship. Although these models are in need of real data on 'who-eats-who', to estimate predator-prey biomass ratio's, they do not incorporate functions for estimating consumption as defined in Table 8.2. Hence, in most of these models consumption is modelled through predation mortality. Summing predation mortality per predator species is a proxy for consumption. Most multispecies assessment models assume constant consumption (SMS in the North Sea and Baltic Sea configuration, Gadget in the Barents Sea configuration). An overview of these current modelling approaches and their general mathematical description on consumption / predation is given in Table 8.2.

Table 8.1. Allometric equations with have been used to calculate the consumption/biomass (Q/B) ratio of fish, and estimates obtained for the damselfish (from Pinnegar, 2000).

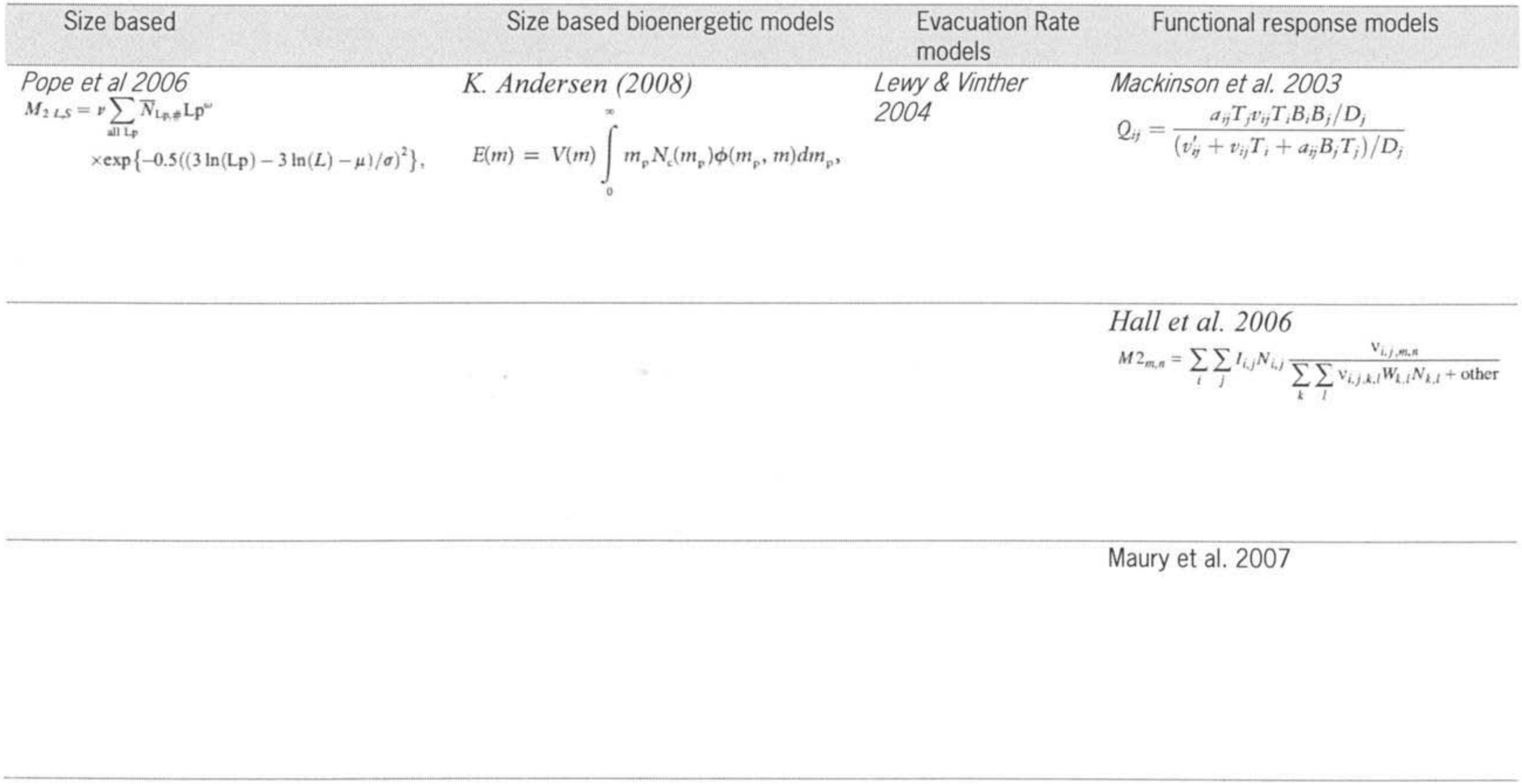
Reference	Equation	Q/B (year^{-1})
(Palomares and Pauly, 1989)	$\ln Q/B = -0.1775 - 0.2018 \ln W\infty + 0.6121 \ln T + 0.5156 \ln A + 1.26F$	10.83$^{\#}$
(Jarre ., 1991)	$\log_{10} Q/B = 4.885 - 1309.139(1/T^{1}) + 0.423\log_{10} A + 0.285\log_{10} D - 0.111\log_{10} W\infty - 0.445\log_{10} P$	4.38
(Pauly ., 1990)	$QB = 10^{6.37} * 0.0313^{Tk} * W\infty^{0.168} * 1.38^{Pf} * 1.89^{Hd}$	11.35
(Christensen and Pauly, 1993)	$QB = 3.06 * W\infty^{0.2018} * T^{0.6121} * A^{0.5156} * 3.53^{Hd}$	10.85
(Palomares and Pauly, 1998)	$\log Q/B = 7.964 - 0.204\log W\infty - 1.965T_k + 0.083A + 0.532h\ 0.398d$	10.27
(Palomares, 1991)	$\log Q/B = 0.261 - 0.1651\log W\infty + 0.7591\log T + 0.4051\log A + 0.530h + 0.466d$	10.75
(Pauly, 1989)	$\log_{10} Q/B = -0.102 + 0.444\log_{10} T - 0.115\log_{10} W\infty + 0.427\log_{10} A + 0.577\log_{10} D - 0.464\log_{10} P$	6.94

$W\infty$=52.404g, $T = 18.112$°C, $T_k = 3.434$, = **k**, A= 1.76, $h = 0$, $d = 0$, $Hd = 0$, F=0, $Pf = 1$, $D = 2.799$, $P = 0.336$, # Q/B converted from % per day.

Table 8.2 Estimation of historical consumption.

% BW	Daily ration	C/B (aka Q/B) ratios	Evacuation Rate models	Functional response models	Bioenergetics models
Straskraba et al., 1966 $\frac{\text{Total stomach contents weight}}{\text{Total fish weight}} \times 100.$	*Bajkow 1935* $D = \bar{A}(24/n).$	*Palomares & Pauly 1998* $\log Q/B = 7.964 - 0.204 \log W_\infty - 1.965T' + 0.083A + 0.532h + 0.398d$	*Pennington 1985* $C = \frac{\rho}{N} \sum_{i=1}^{N} S_i^a$	*Holling 1959* $F = \frac{bN}{1 + bt_hN},$	*Karjalainen et al. 1997* $C=(C_{max}Pf(T))=(G+(Rf(T)A)+((C-F)S)+U));$
Smyly 1952 $\frac{\text{Total stomach contents weight}}{\text{Total fish weight}} \times 100.$	*Boisclair & Sirois 1993* $D = \bar{F} \cdot R \cdot 24.$ $F = \frac{DT \cdot 100}{W}.$	*Pauly 1986* $\frac{Q}{B} = \frac{3K \int_{t_r}^{t_{max}} \frac{(1 - \exp(-Kr_1))^2 \cdot \exp(-(Kr_1 + Zr_2))}{1 - (1 - \exp(-Kr_1))^{b}} dt}{(A_1 + A_2 + A_3 + A_4)}.$	*Elliot & Persson 1978* $C_t = C_{max} - ae^{-bt} \quad a = C_{max} - S_0$ $S_t = S_0e^{-Rt} + e^{-Rt} \int_0^t abe^{(R-b)x}dt$ $= S_0e^{-Rt} + \frac{abe^{-Rt}}{b-R}(1 - e^{(R-b)t}).$		*Sainsbury 1986* $R = \int_{\tau=0}^{\tau=T_m} \alpha dt = \alpha T_m.$ $S_r = \left[\frac{\alpha}{c} + \frac{(cS_r - \alpha)}{c} e^{-cT_m}\right] e^{-c(T_{24} - T_m)}$ $S_r = \frac{\alpha(e^{-c(T_{24} - T_m)} - e^{-cT_{24}})}{c(1 - e^{-cT_{24}})}.$
	Pinnegar et al. 2007 $R_d = J1 \times (T_{f1} - T_{t1}) + J2 \times (T_{f2} - T_{t2}).$	*Trudel et al. 2000* $\frac{dC}{dt} = (\alpha \cdot C_d \cdot I) - (E + G + K)C$	*Eggers(1977)* $C = 24 E S\gamma$ $E = \alpha \beta T$		Jodzis & Innes 1992 $dC/dt = C[-T + (1 - \delta)J(R)]$

Table 8.3. Predicted consumption.



Size based	Size based bioenergetic models	Evacuation Rate models	Functional response models
Pope et al 2006 $M_{2\,L,S} = \nu \sum_{\text{all Lp}} \overline{N}_{\text{Lp},\#} \text{Lp}^{\omega} \times \exp\{-0.5((3\ln(\text{Lp}) - 3\ln(L) - \mu)/\sigma)^2\},$	*K. Andersen (2008)* $E(m) = V(m) \int_0^\infty m_p N_c(m_p) \phi(m_p, m) dm_p,$	*Lewy & Vinther 2004*	*Mackinson et al. 2003* $Q_{ij} = \frac{a_{ij} T_j v_{ij} T_i B_i B_j / D_j}{(v'_{ij} + v_{ij} T_i + a_{ij} B_j T_j)/D_j}$
			Hall et al. 2006 $M2_{m,n} = \sum_i \sum_j I_{i,j} N_{i,j} \frac{\nu_{i,j,m,n}}{\sum_k \sum_l \nu_{i,j,k,l} W_{k,l} N_{k,l} + \text{other}}$
			Maury et al. 2007

8.1.3 Error in consumption estimations

Estimation of consumption from stomach sampling is subject to potential error. The methods require information not only on stomach contents but also on the parameters describing evacuation. Furthermore, the estimation of $\frac{1}{N}\sum_{i=1}^{N} S_i^{\alpha}$ requires information on the stomach content in individual stomachs as $\left(\frac{1}{N}\sum_{i=1}^{N} S_i\right)^{\alpha} \neq \frac{1}{N}\sum_{i=1}^{N} S_i^{\alpha}$ when α is equal to 0 or 1. In all other cases, estimating $\frac{1}{N}\sum_{i=1}^{N} S_i^{\alpha}$ as $\frac{1}{N}\sum_{i=1}^{N} S_i^{\alpha}$ introduces a bias in the estimation increasing estimated consumption by as much as 60% (Rindorf and Lewy, 2004).

Diet composition is also potentially biased when estimated from stomach contents. Usually, diet composition is estimated from the proportions present in stomach contents. However, the proportions present do not necessarily represent the consumed proportions as differences in evacuation rates (Andersen, 2001) or differences in the prey composition in individual stomachs may lead to differences. Not accounting for these may lead to biases in the order of -80% to +100% (Rindorf and Lewy, 2004). This problem applies equally to studies estimating total consumption from e.g. Q/B relationships and then distributing this on prey items using observed proportions in the stomach content (e.g. the approach used in models such as EwE).

9 New stomach sampling program

In last year's report, we stated the need for implementing new stomach sampling programs. To work towards this, WGSAM formulated a ToR with the purpose of estimating costs of such programs (ToR g). However, at this year's meeting, it was considered that the main factor delaying the implementation of new stomach sampling programs was the lack of availability of external funding. WGSAM agreed that this problem can only be alleviated through a joint action by ICES and national and international funding agencies. To request the support of SCICOM for such a joint action, WGSAM formulated the following letter to SCICOM:

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 and to predict 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 ICES Working Group on Multi-species Assessment Methods (WGSAM) includes scientists from throughout the ICES Ecoregions and has expertise on a range of ecosystem modelling approaches used in addressing research and management questions. It is the principal forum servicing requests for information on species interactions (e.g. what MSY means in a multispecies context).

Based on their review of the status of ecosystem models, the group considers that the lack of up-to-date information on 'who eats who' and how this has changed makes it increasingly difficult to provide adequate advice in some regions. There is an obvious danger when models using patchy or grossly out-of-date information are used to make future predictions.

The last comprehensive investigation of species interactions in the North Sea and Baltic was conducted 20 years ago and consequently such information is unlikely be representative of what a very different ecosystem is now. Since the early 1990s, major changes in ecosystems have occurred, including shifts in benthic communities, plankton and fish communities. WGSAM is now tasked, on a regular basis, to provided updated estimates of predation mortality for inclusion in single-species stock assessments (e.g. in the Barents Sea, Baltic and North Sea), but this is becoming a challenging task because of the lack of recent information of the diet composition of predatory fish. No model can provide reliable predictions unless it is calibrated with up to date information. In the absence of recent data, the modelling work may continue but the accuracy and relevance on the predictions made will deteriorate accordingly.

Therefore, WGSAM asks ICES to support the WGSAM initiative to, begin the process of collecting food composition data on existing surveys in the North Sea, the Baltic, and other areas where such data are not at present collected regularly, and assists WGSAM in contacting both the ICES delegates, National and International funding agencies and National Institutes to obtain the necessary funding for this ecosystem survey.

10 Additional request: WKSHORT asks WGSAM to attempt to generate an estimate of predation on sprat in the North Sea based on stomach content data and predator food requirements

During the WKSHORT meeting in 2009 (ICES, 2009d), an attempt was made to make a benchmark assessment of North Sea sprat. It was found that the creation of an acceptable stock assessment was not possible at the present time. Current analyses of the available data do not provide adequate information for an assessment, and the absolute level of the stock is very uncertain. Any additional information on stock levels is thus important to obtain, and WKSHORT asked WGSAM to attempt to generate an estimate of predation on sprat in the North Sea based on stomach content data and predator food requirements.

This was done in the following way for the 'years of the stomach' 1981 and 1991, based on the 2007 MSVPA key run:

Consumption sprat (year) = sum(predatorspecies, age ,quarter) * Npred(predatorspecies, age, quarter) * TotconsPerPred (predatorspecies, age, quarter)* PropSpratInDiet (predatorspecies, age, quarter)

The results for 1981 and 1991 are given in Tables 10.1 and 10.2. In both years the total sprat consumption by the MSVPA predators was between 400 and 500 thousand tonnes. Whiting is the main predator, but cod, mackerel, horse mackerel and seabirds are also important.

Table 10.1. Predator consumption of sprat in the North Sea in 1981. 1000 tonnes

Predator	quarter 1	quarter 2	quarter 3	quarter 4	Total
Cod	47.9	16.6	8.3	3.2	**76.0**
Haddock	4.8		0.3		**5.1**
Whiting	126.9	9.9	33.0	75.3	**245.2**
Western mackerel		0.0	0.0		**0.0**
North Sea mackerel		1.5	7.9	1.5	**10.9**
Saithe (Pollock)	3.7	0.1		0.0	**3.8**
Fulmar	7.6	2.7		11.6	**21.9**
Great black-backed gull	0.8	0.4	0.4	2.9	**4.6**
Guillemot	7.3	1.1	2.8	15.2	**26.4**
Gannet		1.3	1.4		**2.6**
Herring Gull	2.6	1.2	0.4	4.2	**8.5**
Kittiwake	11.8			13.2	**25.0**
Puffin		0.6	0.5		**1.0**
Razorbill	0.8	0.6	0.2	0.5	**2.1**
Total	**214**	**36**	**55**	**128**	**433**

Table 10.2. Predator consumption of sprat in the North Sea in 1991. 1000 tonnes.

Predator	quarter 1	quarter 2	quarter 3	quarter 4	Total
Cod	6.2	0.8	3.2	2.2	**12.5**
Haddock		0.01			**0.01**
Whiting	64.8	35.5	55.1	28.0	**183.4**
Western mackerel		4.0	0.1	141.2	**145.3**
North Sea mackerel		2.8	0.3	3.9	**7.0**
Saithe (Pollock)			0.1		**0.1**
Grey gurnard		0.3	1.9	0.3	**2.6**
Horse mackerel		1.1	41.5	14.6	**57.3**
Fulmar	7.2	2.5		10.9	**20.6**
Great black-backed gull	0.8	0.4	0.4	2.8	**4.3**
Guillemot	7.3	1.3	3.2	15.3	**27.1**
Gannet		1.7	1.6		**3.3**
Herring Gull	2.5	1.2	0.4	4.0	**8.1**
Kittiwake	10.8			12.0	**22.8**
Puffin		0.7	0.7		**1.4**
Razorbill	0.9	0.6	0.2	0.4	**2.2**
Total	**100**	**53**	**109**	**236**	**498**

In addition to the analysis using stomach data from the two ICES 'Years of the Stomach' in 1981 and 1991 (above), a preliminary investigation was carried out using the DAPSTOM database of stomach content records, which is completely independent of the ICES datasets (Pinnegar, 2009). The DAPSTOM database contains information from 182 individual research cruises, spanning the 116 year period between 1893 and 2009. In addition it includes records for 104 fish species (as opposed to the 8 included in the ICES dataset), allowing a wider view of potential predators on sprat in the North Sea.

The search yielded information on 12 predators that are recorded as consuming sprat (Table 10.3), although the vast majority of records were for cod and whiting. When converted to an estimate of 'frequency of occurrence' however, comparatively few cod stomachs (3.2%) and whiting stomachs (2.1%) were found to contain sprat, and a much larger proportion of common skate, hake, thornback ray and saithe were found to contain this prey item. These predators are much less abundant than either cod or whiting and so the total quantity of sprat consumed by these predators would be much less, and in addition, some of the records of predators eating sprat were from surveys in the early years of the 20th Century (for example the data on common skate were collected on research cruises in 1903 and 1904), and these species are no longer found in the central and southern North Sea.

Table 10.3. Proportion of sprat in the diet of various predators in the North Sea, taken from the DAPSTOM database.

	RECORDS	OCCURRENCES	STOMACHS	% F OF O	% OF DIET	PREY ITEMS
(EUROPEAN) MACKEREL	7	7	564	1.2	0.2	3617
COD	334	162	5071	3.2	1.2	26170
COMMON SKATE	1	1	6	16.7	12.5	8
EUROPEAN HAKE	1	1	6	16.7	12.5	8
GREY GURNARD	7	7	4962	0.1	0.1	9250
HADDOCK	26	23	3909	0.6	0.1	23839
HERRING	4	1	198	0.5	0.1	4067
SAITHE	48	15	288	5.2	2.7	1776
SANDEELS	2	2	250	0.8	0.1	1988
SPURDOG	1	1	123	0.8	0.3	326
THORNBACK RAY (ROKER)	2	2	24	8.3	0.3	579
WHITING	505	336	16312	2.1	2.0	25652

11 Answers to requests made by WGSAM 2008 to other groups

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

According to a reply dated 9 July 2009 from the Chair of BEWG, Steven Degraer, BEWG proposes to address this issue in 2010.

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

WGSAM acknowledges the reply of WGWIDE to the request to report on the proportion of horse mackerel and mackerel stock which are represented in the North Sea in each quarter of the year. WGSAM found both the statement to use the distribution of catches and the referenced paper (Cunningham *et al.*, 2007) very useful and will consider both methods before the next North Sea SMS key run.

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

Excerpts from the answer from the ACOM Chair, Mike Sissenwine, dated 24 June 2009: "This issue is one of the reasons why ICES needs to reconsider the framework for its advice, and meetings are planned so that ACOM can focus on these issues. Years ago, trophic interactions were less important in terms of ICES advice because the fishing mortalities for most species were so high, it was clear that they should be reduced, even if it was not clear by how much. Now that Fs are lower, and management is moving towards F_{msy} as a target, trophic interactions are much more relevant in advice.

ICES appear to have the following options:

1) Acknowledge potential multispecies effects, but advice based on single species assessments.

2) Advised based on plausible multispecies model predictions, although the reliability of such models is unknown. In fairness, the reliability of singles species models in the face of obviously "real" trophic interactions is also unknown.

3) Consider a more robust approach that attempts to balance numbers 1 and 2.

4) Frame an adaptive management approach that might address the issue of the reliability of predictions.

Mostly, ICES applies number 1. I do not sense that there is a consensus to move to number 2 except perhaps under special circumstances. I don't know how to pursue numbers 3 and 4, but I think we need to try. Perhaps they are a worthwhile challenge for the WGSAM."

WGDIM

The following is an extract from the WGDIM 2009 report (ICES, 2009f) (provided by Neil Holdsworth, ICES Data Centre):

> **ToR f – Year of the Stomach**
>
> 'work towards making the ICES 'Year of the Stomach' datasets for North Sea and Baltic more readily available to the ICES community. This will require the creation of a standardized and quality-controlled version of the data including an updated look-up key for prey codes.
>
> **Background;** A request had been received from WGSAM asking for help from WGDIM to recover data collected by the Year of the Stomach Project (1981 to 1990). This data are not held centrally or available easily, the task is to create a single dataset, QC check the data then publish it.
>
> **Progress;** The Data Centre has collated what is thought to be the complete dataset; it consists of 1.4 million observations from 11 countries, breaking down further into 8 predator species and 854 prey codes. The prey codes are in NODC format and need conversion to ICES compatible form. The conver-

sion has highlighted a code issue; 47 NODC codes do not appear in the ITIS species list.

It is not clear if the dataset compiled by DC contains all the records for the project. Data summaries have been made available online to allow expert review. (http://ecosystemdata.ices.dk/stomachdata/index.htm)

During the meeting a subgroup discussed progress and agreed to liaise with N Daan. Niels is considered to be a leading authority on the project and is likely to be able to confirm the expected number of records may be able to supply any missing ones and could provide guidance on the prey code conversion.

Contact will also be made with the contributing countries to ascertain the completeness of the ICES dataset and whether it (the ICES dataset) is the only digital version available.

There is now cooperation between Carlos Pinto in the data centre and Ingeborg Deboois (Chair of WGBEAM and member of WGDIM). They plan to meet in November and March 2010 to work on the North Sea data. The analysis of the data are taking longer than first thought as we have to be sure we have all the records from all the possible sources, however we believe we're making good progress.

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Annex 2: WGSAM terms of reference for the next meeting

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 ecosystem 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 food web 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'

Longer-term aspirations (possible ToRs for future years)

Linking biogeochemical/hydrodynamical models to foodweb models

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

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

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

Improve quantification of the role of top predators (marine mammals, seabirds, large pelagics) in the ecosystems

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 apply to all three thematic areas (Understanding Ecosystem functioning, Understanding Interactions of Human Activities with Ecosystems and Development of options for sustainable use of ecosystems).

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)

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.

WGMIXFISH: Provide quarterly data on catch-at age by fleet in the North Sea for the longest period possible.

WGSAM will report by 15 November 2010 (via SSGSUE) for the attention of SCICOM and ACOM.

Supporting information

Priority	Multispecies assessment modelling is essential to the development of viable long-term management strategies.

Scientific Justification	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 2009 meeting 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. 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 b, d and g). 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 2010 WGSAM meeting the group will work towards implementing new stomach sampling programmes throughout the ICES area in 2011 by reviewing protocols, pursuing new funding opportunities and gathering institutional support (ToR c). 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 2010 WGSAM will consider how such issues might be modelled using the various approaches available and familiar to WGSAM participants. A major component of the current ICES/JRC process to define indicators of 'Good Environmental Status' for the forthcoming EU Marine Strategy Framework Directive, concerns the identification and parameterization of indicators that reflect marine 'foodwebs'. In 2010 WGSAM will investigate ways to communicate results from multispecies and ecosystem models to decision-makers, including development of foodweb indicators and visualization techniques. This fits with the priority identified in the ICES Science Plan, concerning "Effective communication of research results for inclusion in the advisory work at the strategic as well as the operative level". Other priority research areas that have been highlighted in the ICES Science Plan and which will be addressed by WGSAM at its 2010 meeting include: biodiversity and the health of marine ecosystems (ToRs f and g); top predators (marine mammals, seabirds, and large pelagics) in marine ecosystems (ToR b), Impacts of fishing on marine ecosystems (ToR h), Marine living resource management tools (ToRs b, d and h).

Resource requirements	–
Participants	Approx 20. Expertise in ecosystem, modelling and fish stock assessment from across the whole ICES region.
Secretariat facilities	None
Financial	No financial implications
Linkage to advisory committees	ACOM
Linkage to other comities or groups	AMAWGC, WGRED, WGECO, SGMAS, WKEFA,WGMIXFISH, most assessment Expert Groups
Linkages to other organizations	–

Annex 3: 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. WGMIXFISH: Provide quarterly data on catch-at age by fleet in the North Sea for the longest period possible.	WGMIXFISH