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Executive summary

In this seventh report of the pan-regional Working Group on Multispecies Assessment Methods (WGSAM), work focused on five (A, C, D, E, G) of the multi-annual ToRs and on a addressing a new ToR catalysed by discussions prior to the meeting.

The new ToR describes a process for the evaluation multispecies models and the criteria and standards considered (by WGMARS) necessary to make them acceptable for use in developing multispecies advice for management within ICES. This report presents a proposed process for accepting a new multispecies model as suitable model for providing inputs into management advice, and then a subsequent evaluation of a key run of that model for a particular Ecoregion. A component of the work on this ToR was the production of a series of briefing sheets, one for each multispecies model. These are intended to be used to communicate the approaches and capabilities of each model introduce and thus serve as a resource for researchers inside and outside seeking to understand multispecies models. The template for descriptions draws upon a similar template used for model briefing sheets for single species models (WKADSAM).

Based on their knowledge, participants provided an updated inventory of progress of multispecies models in ICES Ecoregions (ToR A), noting those regions where no information was available and pointing to the FP7 projects DEVOTES for a complementary overview.

There were no new Key Runs to report this year (ToR B), with progress on the Baltic Sea EwE Key run expected to be published during the next meeting. The concept of a Key Run is used to define the standards for acceptance of models suitability for use in multispecies advice (ToR NEW). This report describes what constitutes a Key Run for the SMS and LeMans models (ToRC). Previous reports (WGSAM 2011) have document the key run standard for EwE models.

Building on work started last year and developed further in WGECO, participants used WGECO criteria in applying their expert judgement to score the utility of proposed ecosystem indicators (ToR D). The finding of this will be taken forward in WGECO.

Work on ToR E further highlighted the need for a program of regular stomach sampling. This ensures that multi species and ecosystem models remain relevant, and is essential in order provide advice on the MSFD descriptor 4 regarding the structure and functioning of foodwebs. The ongoing study financed by the Commission to sample stomachs in the Baltic and North Sea in 2013 (MARE/2012/02) is expected to increase of the Baltic Sea stomach database by 150% and supply new data for three predators (1600 mackerel stomachs, 1600 grey gurnard stomachs, 800 hake stomachs). The report details methods for stomach analysis and data storage, plus an update of the Cefas- DAPSTOM database, which now has record in excess of 200,000 and is harmonized with the ICES 'Year of the Stomach' databases.

Responses to specific questions posed by the ICES community were addressed and reported back to the respective WG chairs and ICES secretariat.

In addition to updates on Key Runs of SMS and EwE models, work in 2014, (London, 20–24 October 2014) will focus on ToR H and F, where members of WGMIXFISH and WGMG will be invited to discuss synergies in the use of models to address mixed-

fisheries and multispecies issues, and on how output from different models can be usefully combined for ensemble-type provision of advice.

1 Opening of the meeting

The **Working Group on Multispecies Assessment Methods** (WGSAM) met met in Stockholm, Sweden, 21–25 October 2013. The list of participants and contact details are given in Annex 1. The Co-Chairs welcomed the participants including new members from Ireland and guests from Sweden. The Terms of Reference for the meeting (see section 1) 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 Maciej Tomczak for logistics during the meeting and Claire Welling of the ICES Secretariat for her continued support with the WGSAM SharePoint site.

1.2 Terms of reference

The Working Group on Multispecies Assessment Methods (WGSAM) chaired by Daniel Howell, Norway and Steven Mackinson, UK, met in Stockholm, Sweden, 21–25 October 2013 to:

Work on all ToRs. Focus on D, E, G (in bold) and Tor B restricted to Baltic EwE.

ToR A. Review **further progress** and report on key updates in multispecies and ecosystem modelling throughout the ICES region;

ToR B. Report on the development of key-runs (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and eco-system models for different ICES regions (including the Baltic EwE 2013).

ToR C. Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)

ToR D. Develop and compare foodweb and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)

ToR E. Report on progress on including new stomach samples in the ICES area in multispecies models

ToR F Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference

ToR G. Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)

New ToR – Operationalizing MS models

2 ToR A: Review further progress in multispecies and ecosystem modelling throughout the ICES region

The review of progress of multispecies models in ICES Ecoregions given below is not intended to be comprehensive and exhaustive. It reflects the knowledge available to the participants at the meeting and input from WGSAM who were not able to attend in person.

In addition to this overview, we refer the readers to a recent overview of modelling tools and applications prepared by the partners of the European Framework 7 project DEVOTES under Deliverable 4.1 http://www.devotes-project.eu/deliverables/

2.1 Ecoregion A: Greenland and Iceland Seas

Work is ongoing to incorporate newly developed methods for uncertainty estimation for Gadget that are based on a modified bootstrap. This work is currently in single species models, but could be extended to various modelling frameworks and to multispecies models such as those developed using Gadget.

In addition the Marine Research Institute of Iceland will participate in MareFrame, whose second objective is ".. to develop innovative assessment methods that address multispecies concerns resulting from biological interactions between species." On the Icelandic continental shelf comparisons will be made between various modelling techniques, including Gadget and Ecopath with Ecosym.

2.2 Ecoregion B: Barents Sea

Ongoing work

Work to develop the Atlantis and the SYMBIOSES end to end models is ongoing in the Barents Sea, but no updates were presented at this meeting.

Model comparison

A model comparison exercise for the Barents Sea was conducted. The models Gadget, STOCOBAR, EcoCod and Bifrost were compared, while wider ecosystem models NORWECOM and Atlantis were also discussed. The comparison was run comparing hindcast model fits to the data, and hindcast "what if" scenarios examining the impact on model outputs of different hypothetical fishing scenarios (F=0.2,F=0.4, F=0.7 and F=1.0).

Spatial overlap

A paper has been published examining the impacts on cod of changing spatial overlap between cod and capelin. The results indicate that increased availability of capelin to cod could lead to higher average cod biomasses, but also to more variability of the cod, with steeper increases and declines in biomass compared with the recent past. This is discussed in more detail under ToR G in Section 8.

STOCOBAR/CODCAB

Further development of the STOCOBAR model was related with implementation of year-to-year restrictions for changes in NEA cod TAC. It is allows to evaluate in multispecies context all elements of the current HCR for the Barents Sea cod, which include along with biological reference points also ±10% limits of changes in annual TAC. It was also modified the simulator of the temperature scenarios that are used in STOCOBAR model runs. Before it was possible to produce only scenario for development of the annual temperature on the Kola section in depth of 0-200 m, stations 3-7. Now it is possible to generate additional temperature scenarios, using available historical data from other sections with different temporal aggregation. The producing additional temperature scenarios are based on their statistical links with the basic temperature on the Kola section.

The extended variant of the STOCOBAR model, which includes age-structured capelin stock, was developed. It was named as the CODCAB model (**COD** and **CA**pelin in the **B**arents Sea). It simulates stock dynamics of cod and capelin in the Barents Sea, taking their interactions, fisheries and environmental impact into account. It is an age-structured and single-area model with 1 year time-step. Unlike the STOCOBAR in the CODCAB the recruitment function and fishing mortality are used for both cod and capelin. The growth and natural mortality of capelin are not process-simulated in the mode yet. The further work on development of this model will be continued. CODCAB is designed as a tool for prediction and exploration of cod and capelin stocks development and testing their HCLs.

2.3 Ecoregion C: Faroes

There is no progress to report on multispecies modelling in Ecoregion C this year.

2.4 Ecoregion D: Norwegian Sea

There is no progress to report on multispecies modelling in Ecoregion C this year.

2.5 Ecoregion E: Celtic Seas

2.5.1 Ecopath in the Celtic Sea

Work on modelling the Celtic Sea ecosystem and effects of fisheries and climate on Seabirds has been published in Dr Valentina Lauria's PhD thesis, with plans for work to be published in the primary literature. Cefas is working with Dr Lauria (University of Galway) to develop a Key Run model (expected at the earliest in 2014) has used GIS formatted environmental, ecological and fishery data to develop a preliminary a spatial 'Ecospace' model. The model is currently being tested through a process that will be used to help define Key Run standards for Ecospace applications.

2.5.2 Population-Dynamical Matching Model (PDMM) in the Celtic Sea

Shephard *et al.* (2013) compared the empirical time-series of the Large Fish Indicator (LFI) of the Celtic Sea with model simulations. The LFI indicator describes the proportion by biomass of a fish community represented by fish larger than some size threshold. From an observed peak value of 0.49 in 1990, the Celtic Sea LFI declined until about 2000 and then fluctuated around 0.10 throughout the 2000s. Simulations using the Population-Dynamical Matching Model (PDMM, Rossberg *et al.*, 2008, Fung *et al.*, 2013, Rossberg 2013) could reproduce the historical data with empirical fishing mortalities as input. They suggest that recovery in Celtic Sea fish community size-structure (LFI) could demand at least 20% reductions in fishing pressure and occur on decadal time-scales.

These findings naturally raise the question why community size structure is so sensitive and accumulates pressures over such long time-scales. This was addressed analytically by Rossberg (2012) and in PDMM simulations by Fung *et al.* (2013). The mechanisms leading to slow dynamics consistently identified in these studies are reciprocal direct feeding and competitive interactions between small and large fish, resulting in a suppression of the population growth of large fish by the populations of small fish, which are enhanced by a trophic cascade. Empirically, this mechanism manifests itself, for example, in the recent unexpectedly low recruitment of cod in the North Sea, which contributes to the weak, if any, recovery of the North Sea LFI in recent years (Fung *et al.*, 2012), despite substantial reductions in fishing pressures.

Models with a hard-coded non-linear stock recruitment relationship typically fail in reproducing the slow dynamics of community size structure (Shephard *et al.*, 2012). This leads to the question whether observed stock–recruitment relationships can be understood as emerging from the feeding interactions typically modelled in foodweb models, rather than being a phenomenon that needs to be hard-coded in models. This question was addressed by Rossberg *et al.* (2013). It turns out that in foodweb models that explicitly represent both the species size structure of the community and the intrapopulation size structure of each species, stock–recruitment relations quantitatively comparable to those observed emerge solely from feeding interactions among species. The predominant forms of the emergent relations are Ricker and Beverton–Holt as observed, and emergent distributions of steepness agree with those obtained from empirical datasets.

2.5.3 Irish Sea

A project to develop an ecosystem model for the Irish is currently being established at AFBI, Northern Ireland. The project is in an initial exploratory stage. Progress on the development of this model shall be reported to the next WGSAM meeting.

2.6 Ecoregion F: North Sea

2.6.1 North Sea SMS

As the historic sprat data from the North Sea were revised during the sprat benchmark in 2013 (WKSPRAT 2013), it was considered that the previously used coarse data did not provide accurate estimates of M for use in the single species assessment of sprat. Therefore, an alternative key run was produced using the revised sprat data. As the revision only considered data back to 1974, the key run was only performed from this date onwards. The new data changes natural mortalities slightly for ages 0 to 2, but increased M for age 3 (Figure 2.1). The temporal pattern remained unchanged for all ages.

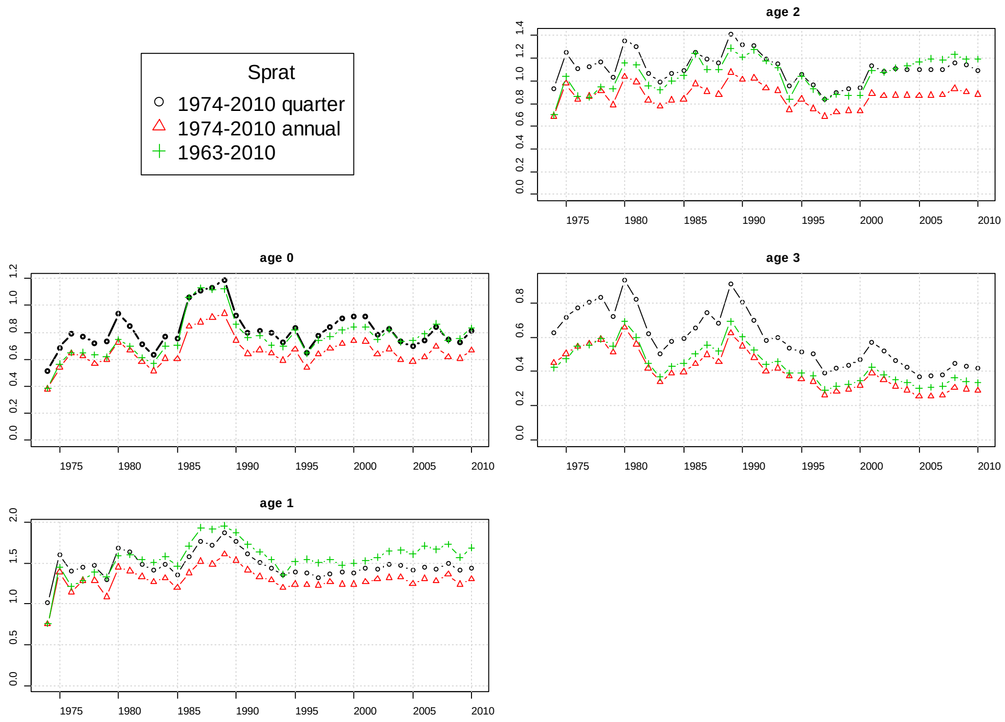

Figure. 2.1. Effect on sprat of changing input data. Green: 2011 key run. Red: new data but all yearly catches allocated to quarter 3 as was done in the 2011 key run. Black: New quarterly catches. Note that to obtain total natural mortality, a background mortality (M1) of 0.2 should be added to the values.

The North Sea SMS forecast module has been modified to account for correlation in recruitment success between species and autocorrelation in recruitment (lag 1 only). Trial runs have shown limited effects of including these new features on the forecasts. Further, the effect of changing the likelihood function of the stomach contents have been investigated, but this proved to have only minor effects on predictions.

2.6.2 Ecopath with Ecosim in the North Sea

Building on work previously reported in WGSAM, work has been published on tests of how well an ecosystem model of the North Sea could predict past trends in abundance of all ecosystem components, using two alternative approaches to model calibration (Mackinson 2013). Model findings confirm that changes in sea temperature and nutrient levels have a fundamental influence in the North Sea ecosystem (Figure 2.2). Importantly, the comparison between the alternative calibration approaches led to two important implications: (i) that the relative importance of fishing and environmental effects is likely to be interpreted differently depending on the calibration, and (ii) the contrasting model calibrations would give different responses to fishing policies. It raises questions about how to judge the credibility of an ecosystem model and what this means for the pursuit of operational and defensible tools to support the ecosystem approach to management. A conclusion is that best practice should: (i) adopt a dual approach where empirical and modelling work go hand-in-hand, and (ii) use data from multiple trophic levels (including plankton, benthos, fish (commercial and non-commercial), marine mammals and seabirds) to calibrate ecosystem models. Validation of ecosystem models requires data from biological components spanning different trophic levels. Thus efforts to maintain biological monitoring programmes and extend them to routinely sample more components of the ecosystem are important.

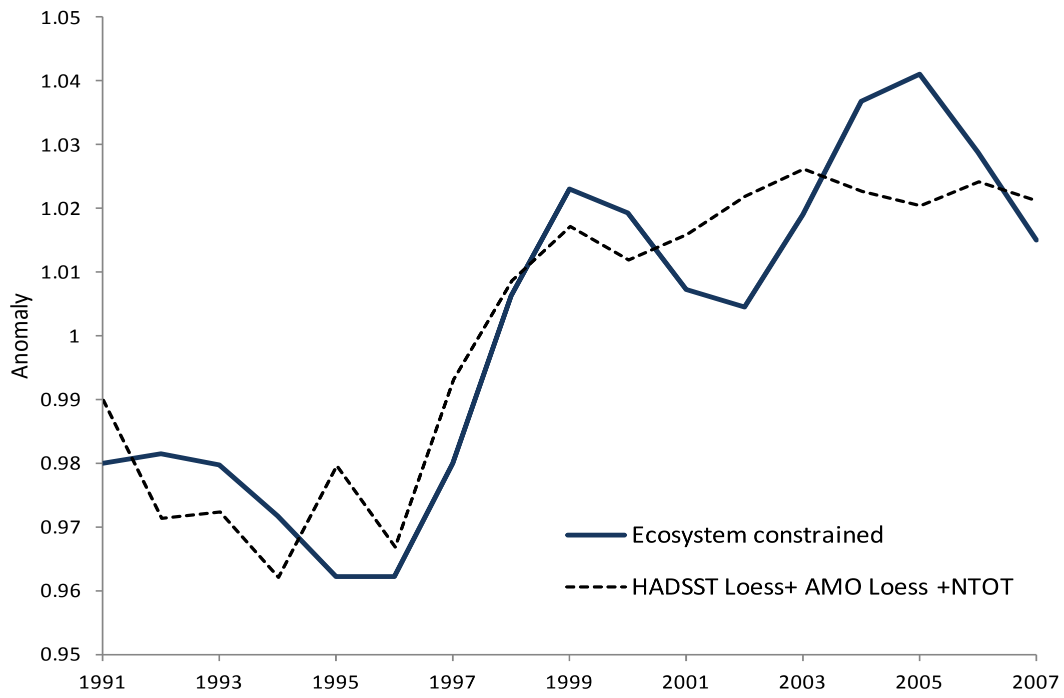

Figure 2.2. Combined environmental index and model estimated Ecosystem calibration primary production anomaly. [The figure shows that when the model calibration is constrained using components across multiple trophic levels (including plankton, benthos, fish (commercial and non-commercial), marine mammals and seabirds), strong evidence emerges from the model that temperature has system-wide impacts on the North Sea ecosystem. Consistent with empirical work, the information helps guide best practice in ecosystem modelling].

Consistent with ICES strategy for mixed fisheries and multispecies modelling (REF), expectations for ecosystem models to become useful operational tools is influencing the direction of developments in this area. Three particular areas of development on EwE modelling are (i) representation of fleet structure/ segmentation, (ii) validating modelled spatial distribution of fishing, (iii) evaluating impacts of uncertainty in model parameters.

(i) Representation of fleet structure/ segmentation (no updates beyond 2012 report)

(ii) Validating modelled spatial distribution of fishing

Building on the North Sea EwE model Key Run published in ICES WGSAM 2012, collaboration between Cefas and the University of Oslo has focused on work refining parameters, testing the methods for assigning functional groups to habitats and evaluate the model predictions of species and fleet distributions. A preliminary publication on the sensitivity analysis of Ecospace parameters (Romagnoni *et al.*, 2013) uses high-resolution spatial time-series of biomass (for 12 species of fish, data from ICES IBTS, 15 years) and effort (3 fleets, data from STECF, 5 years) for the North Sea (Figure 2.3) to evaluate predictions of the North Sea Ecospace model. Of the five model parameters tested for sensitivity, the most sensitive were found to be the Effective Power (a measure of concentration of fishing effort: for high values, fleet distribution is concentrated in profitable areas; for low values, fleet distribution is dispersed) and the Base Dispersal Rate. The work is intended for primary publication, with future investigating looking at the sensitivity of prediction to combined effects of ecosim and ecospace parameters.

(iii) Evaluating impacts of uncertainty in model parameters.

Being explicit about how parameter uncertainty influences model predictions of alternative harvest strategies is important because it affects how predictions are interpreted and what decisions might be made. Cefas has developed a routine for sampling Ecopath and Ecosim parameters and evaluating their impact on the outcomes of alternative management scenarios. The plug-in routine (which will be available for release within the EwE software in 2014 (Figure 2.3a)): (1) creates alternative ecopath and ecosim model parameterizations by sampling user specified parameter distributions, (2) sets harvest control rules (HCRs) based on reference points for commercial and conservation species, where targets for commercial species can be contingent upon conservation species. (3) evaluates performance alternative fishing strategies (a collection of HCRs) by predicting (i) the biomass of functional groups, (ii) the catch by fleets, (iii) indicators and estimating their associated uncertainty. A report and an example application are in draft form, and example output is shown in Figure 2.4.

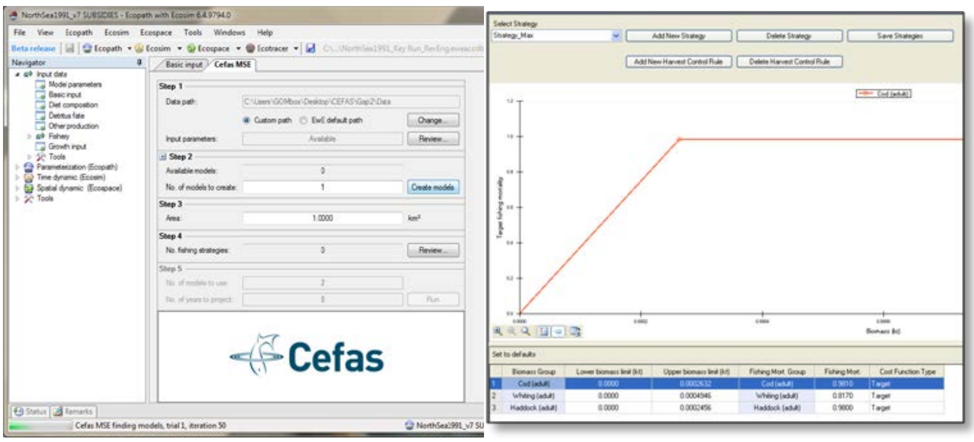

Figure 2.3. Examples screen shots of the tool for evaluation of management strategies, currently under development within the Ecopath with Ecosim software.

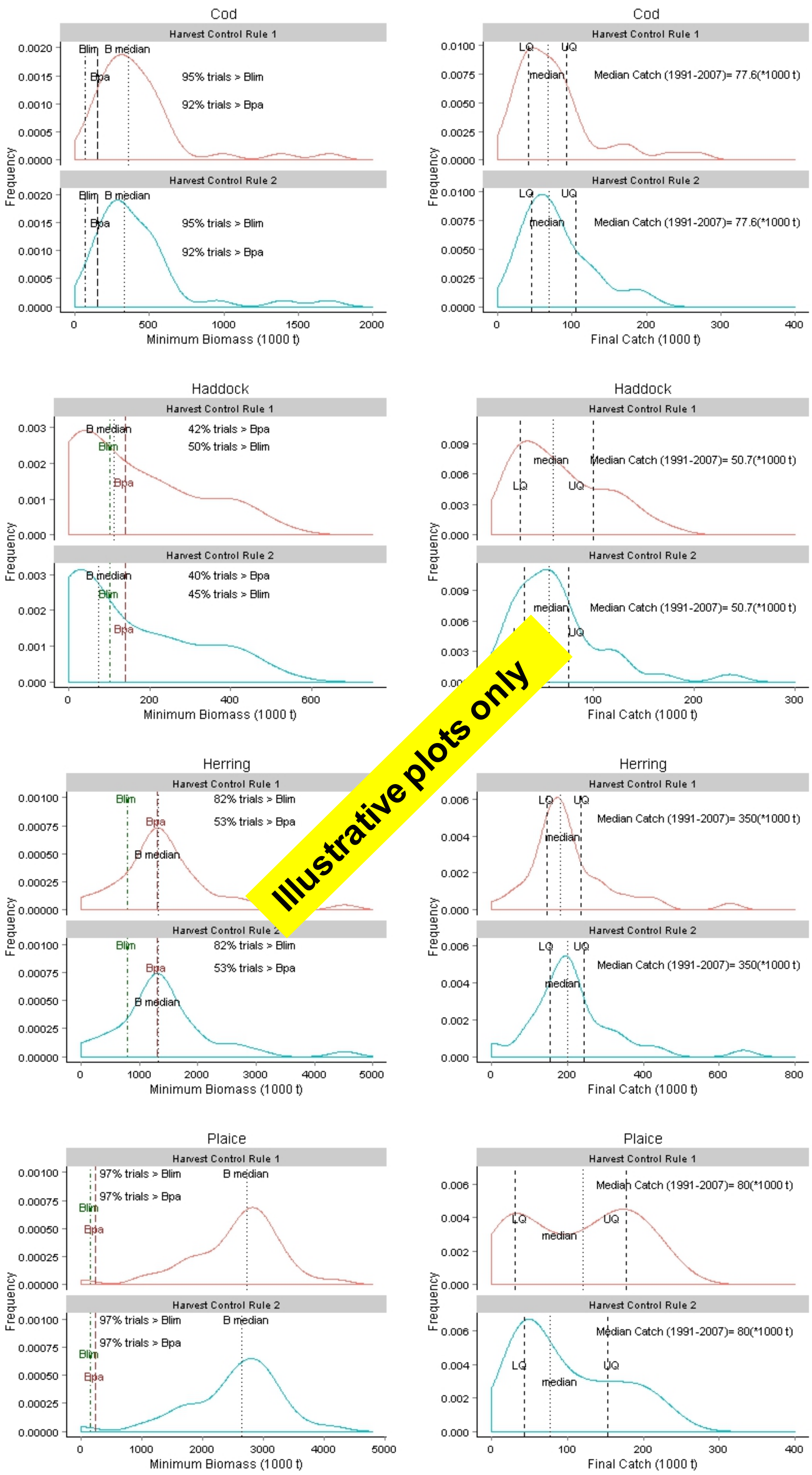

Figure 2.4. Illustrative examples of outputs where distribution of biomass and catch predictions for 2 harvest control rules are compared. NOTE: these are illustrative only, being used only to test the model and to develop thoughts on how to display the results.

See also comments in ToRE

2.6.3 tGAM the North Sea (with ref to Baltic and Black Sea also)

Cefas with collaborators from SAHFOS, University of Oslo, JNCC, University of Hamburg, Instituto Español de Oceanografıa (IEO), are developing a statistical model of the North Sea that links planktonic functional groups, fish stocks and drivers of change (temperature, fishing pressure; Lynam *et al.* in prep). A similar model has been developed for the Black Sea (Llope *et al.*, 2011) and a model for the Baltic Sea is in development (Blenckner *et al.* in prep). Using multidecadal time-series data only, the key links in the system are modelled and used to separate the confounding influences of climate and fishing (Figure2.5). Indicative results, intended for publication suggest (i) that climate forcing has a strong effect on the plankton that weakens as trophic level increases and (ii) fishing pressure has had such a strong effect on the spawning-stock biomass of fish species that climate effects have often been hidden or masked.

It is expected that the model will be used to evaluate the responsiveness of indicators (e.g. OSPAR pelagic habitat 'lifeform' indicators, trophic level of the fish community and landings and seabird productivity) to key foodweb links, climate change (sea surface temperature) and fishing pressure. Work will be fed directly to ICES WG Integrated Assessments of the North Sea (WGINOSE) and ICES WG Biodviersity Science (WGBIODIV; ICES, 2013).

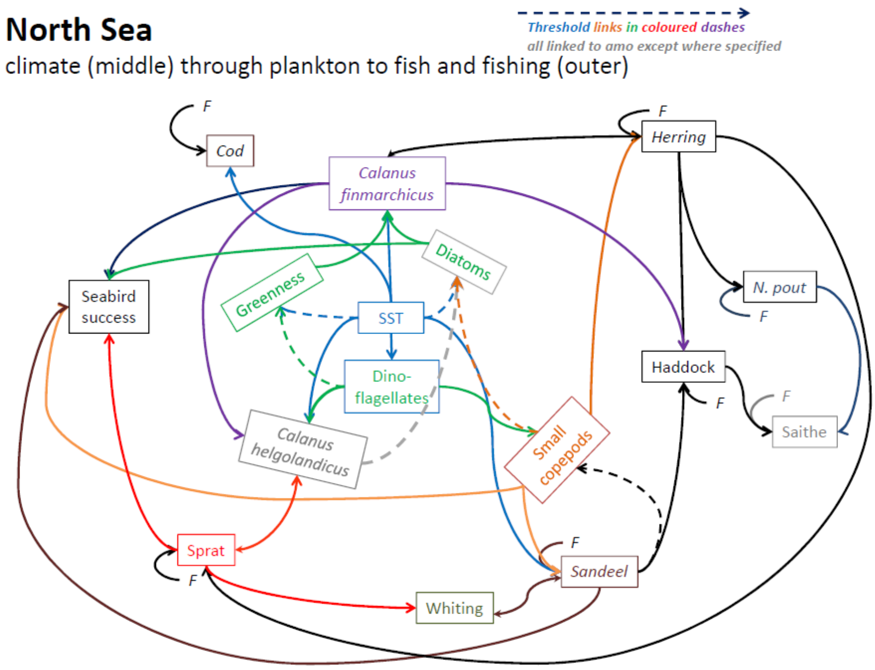

Figure 2.5. Statistical interaction web identified through tGAM analysis. Only significant signals given the data are retained by the model, therefore only a simplified view of the North Sea ecosystem is presented. This allows us to determine the important pathways in which climate (SST, sea surface temperature) and fishing pressure (F) alter foodwebs. The arrows show where the effect of one component on another is significant: the arrow emerges from the component that causes an effect on the population that the arrowhead points to. Here SST is shown to influence phytoplankton (green boxes), zooplankton (large copepods, i.e. two *Calanus* spp., and small copepods), sandeels and cod directly and this influence cascades through the interaction web. Phytoplankton have a direct effect on those groups that the green arrows point to etc.

2.6.4 Ecopath with Ecosim for the southern part of the North Sea

An EwE model for the southern part of the North Sea is developed at the Thünen Institute in Hamburg together with IMARES, Netherlands. The model is based on the Cefas North Sea EwE model but is restricted to ICES areas IVb&c to separate the shallow southern North Sea ecosystem with its specific fisheries from the northern part of the North Sea inhabiting a different species assemblage and fisheries. The focus in the model is on flatfish and brown shrimp but the model represents all parts of the ecosystem including cod, whiting, marine mammals and seabirds. The fishery is represented by the main fleets fishing in the southern part of the North Sea (demersal trawls and seines, beam trawls, shrimpers, gillnets…).

The parameterization of the Ecopath module (snapshot in time) has been finished and a balanced version is available. Biomass of the functional groups was estimated for areas IVb and IVc using assessments or input data to the Cefas North Sea model and IBTS data to make the split between the southern and northern part of the North Sea. Landings information was available from EuroStat. The distribution of landings over fleets was done according to latest information from the STECF database. The diet composition of predators in the southern part of the North Sea was estimated based on 1991 stomach data available for cod, whiting, haddock, gurnards, starry rays, mackerel and horse mackerel. It turned out that especially cod feeds on flatfish and brown shrimp to a larger extent in the southern part of the North Sea. Potential trade-offs between a successful cod recovery and yield in the flatfish and brown shrimp fishery will be evaluated. For this the time dynamic Ecosim part is currently under development. First results are available but further effort is needed to improve the fit to historic time-series (e.g. inclusion of environmental forcing on recruitment). The final aim is to use the model to give information on maximum yields under different weightings of ecological, economic and social constraints inside the EU project MY-FISH. Also a spatially disaggregated version of EWE (Ecospace) is envisaged to test the effects of spatial closures.

2.6.5 Ecopath with Ecosim in the Eastern Channel

Following the updates made in WGSAM 2012 report, the collaboration between Cefas and the University of Kent has led to a publication being submitted on evaluating the ecosystem and fishery effects of the size and location of marine protected areas derived from Marxan analysis (Metcalfe *et al.,* submitted). To investigate the potential trade-offs associated with adopting different spatially explicit MPA management strategies, we used Marxan and Ecopath with Ecosim software packages to determine: either (i) if strict no-take MPA networks justify the cost of their implementation; or (ii) whether MPA networks comprised of multiple zones with different management restrictions could achieve similar results.

2.6.6 Linking SMS to the output of the NPZD model EOCHAM-4 and species distribution models

The lower trophic level model ECOHAM-4 has been used to identify the most important drivers of fish recruitment per spawning-stock biomass. In 0.5 x 1 ° North Sea rectangles, passive drifters were started each day during the period 1980 to 2006 and measured parameters such as temperature, salinity, phytoplankton and zooplankton concentrations. Further, drift parameters like direction and distance were monitored. Thus for each starting rectangle a time-series of average conditions experienced by the drifters was generated. These time-series were split and the period 1980-1996 was used to identify significant correlations between R/SSB or zooplankton and the experienced Proxy series. From those correlations that still hold in the second half of the time-series (1997-2006) the best (highest r^2 in the resulting first and second correlation matrix) 15 proxies were chosen. For the forecast (2071-2099) the ECOHAM-4 was forced with a downscaled climate model projection and used the fore determined proxies to project R/SSB, phytoplankton and zooplankton abundance under this climate change scenario. The predicted changes in recruitment success (decreasing: Herring, Norway Pout, Whiting; increasing: Cod, Sandeel, Sole, Sprat) were transferred to the stochastic multispecies model (SMS) by modifying the stock recruitment relationships fitted in SMS hindcasts. By applying currently utilized F_{msy} proxies from single species assessments, species-specific stock sizes and yields were projected into the future. Interestingly and despite a slightly increased R/SSB trend for cod, the biomass of cod decreased in the modified projection (with the changed recruitment dynamic) in contrast to the normal (standard stock recruitment dynamics) SMS projections, mainly because alternative prey as Herring, Whiting, Haddock, and Norway Pout decreased and predation pressure on cod recruitment increased. Only species in the bottleneck or lower trophic positions like Sprat, Sandeel or flatfish like Sole and Plaice increased in abundance. It is planned to redo the analysis as better versions of ECOHAM-4 forecasts became available.

In the EU project VECTORS, the output of different species distribution models will be linked to SMS, primarily by modifying future predator-prey overlap based on the predictions of stock distributions under climate change scenarios. Due to the described linkages, the model framework can be used to evaluate climate change scenarios and consequences for future fisheries yield can be predicted. It is also possible to quantify structural uncertainties coming for m the usage of different species distribution models.

2.6.7 ATLANTIS model

Work on implementing Atlantis in the North Sea has continued in the FP7 project VECTORS to analyse potential impacts of management measures on the ecosystem and economy. Specifically, the effects of installing wind parks in the North Sea will be investigated, as well as various fishery closures and marine protected areas. The focus so far has been on the basic settings of the simulated areas (polygons) and basic parameterization. While parameterization has been generally finished the balancing of the model is still ongoing.

2.6.8 LeMANS in the North Sea

A size-structured North Sea fish community model has been further developed. The core of the model is derived from the Hall *et al.* (2006) model for the Georges Bank, as modified by Rochet *et al.* (2011) for the North Sea. Three major improvements have subsequently been made to this model:

a) The original Ricker formulation of the stock–recruit relationship has been replaced with a hockey-stick representation. The Ricker formulation i) resulted in cyclic behaviour of biomasses of long L-infinity stocks, and ii) resulted in an unrealistic response of community size spectrum to changes in fishing pressure.

b) By improving the speed of model execution, it has become possible to run large numbers of models covering a variety of parameter choices, allowing one to relax the assumption of a “best” parameter setting, test sensitivity of predictions to parameter choices, and to make probabilistic forecasts.

c) New estimates of total-stock biomasses for the North Sea from swept-area surveys (Simon Jennings, personal communication) have been used in the parameterization of the stock–recruit relationships.

The use of this model in exploring parameter and structural uncertainty associated with the North Sea fish community response to different levels of fishing pressure is discussed in ToR f).

2.7 Ecoregion G: South European Atlantic Shelf

2.7.1 Coupled ROMS–N2P2Z2D2+OSMOSE model in the Bay of Biscay

A hydrodynamic-biochemical ROMS-$N_2P_2Z_2D_2$ model has been coupled (one way) to an OSMOSE model in the Bay of Biscay by AZTI-Tecnalia. The ROMS model (Shchepetkin and McWilliams, 2005) is forced by detailed atmospheric, hydrologic and oceanic fields and it covers the entire Bay of Biscay. It has been coupled to the $N_2P_2Z_2D_2$ biogeochemical model taking into account ammonium, nitrate, 2 classes of phytoplankton, 2 classes of zooplankton and 2 classes of detritus.

The OSMOSE higher trophic level (HTL) model (Shin and Cury, 2001, 2004) attempts to simulate the dynamics of eight relevant species in the Bay of Biscay ecosystem: *Engraulis encrasicolus*, *Sardina pilchardus*, *Trachurus trachurus*, *Scomber scomber*, *Merluccius merluccius*, *Micromesistius poutassou*, *Thunnus thynnus*, and *Thunnus alalunga*. It models processes of growth, predation, reproduction, natural and starvation mortalities, and, in this case, uses the outputs of the lower trophic level (LTL) model ROMS-$N_2P_2Z_2D_2$ as prey fields.

A hindcast reference simulation has been undertaken using the prey fields from the 1998-2009 hindcast ROMS-$N_2P_2Z_2D_2$ simulation: small and large phytoplankton and zooplankton.

Effects of fishing activities and climate change related pressures have been analysed for different climatic and fishing scenarios under the framework of different EU projects (MEECE, FACTS and REPRODUCE).

2.7.2 Ecopath with Ecosim model for the French coast

An Ecopath model has been developed for the central shelf including ICES Divisions VIIIa and b between the 30-m and 150-m isobaths (Lassalle *et al.*, 2011). Shallower and deeper parts were excluded due to lack of data. The model represents a typical year in the period 1994 to 2005, i.e. before the collapse of the European anchovy and the subsequent five-year closure of the fishery for this species. Thirty-two functional groups were included in the model: 2 seabirds groups, 5 marine mammal, 9 fish, 8 invertebrate, 3 zooplankton, 2 primary producer, and 1 bacteria group, as well as discards from commercial fisheries and pelagic detritus. The 5 main pelagic forage fish species were given their own group while demersal fish were divided into 4 multispecies groups on the basis of their diets. In differing versions of the model, fishing activities have been represented as a single compartment or split into 3 fleets targeting small pelagic fish, demersal fish and invertebrates respectively.

An attempt was made to develop an Ecosim model for the same area. Fitting an Ecosim model to time-series data is a demanding process and here the preliminary results were not satisfactory. Consequently, other methods of validation were applied to this Ecopath model. First, descriptors of the trophic niche derived from Ecopath were compared to those obtained from stable isotope analysis performed on samples from the French continental shelf of the Bay of Biscay. Trophic level estimates were highly correlated. This independent test strengthened our confidence in the model validity (Lassalle *et al., In press*). Adding to this, the Ecopath model was also evaluated using a validation tool-box composed of three analyses (Lassalle *et al., In prep.*). The pedigree routine, the PREBAL procedure (Link, 2010) and a sensitivity analysis (Rochette *et al.*, 2009) all concluded to a model based on data of good quality (local origin) and coherent at the scale of the ecosystem.

In parallel, qualitative models of the French continental shelf of the Bay of Biscay were constructed. Qualitative models were particularly useful to test the effect of model structure uncertainties on model predictions. They display the sign, not the magnitude, of the interactions between compartments, here functional groups and fleets. To summarize, model variants were composed of seven functional groups or model nodes which were organized into two trophic chains, one pelagic chain and one bentho-demersal chain, coupled at different trophic levels and connected at the top by top predators (Lassalle *et al., In press*).

2.7.3 Gadget Modelling

Work has begun to produce a Gadget model for one or more species of dolphin in the Bay of Biscay. These models will be linked to the existing assessment model for southern Hake to add marine mammal predation to the model.

2.7.4 Foodweb Network model for the Portuguese waters

As a first approach for understanding the marine foodweb in Portuguese continental waters, the most relevant foodweb species and/or functional groups have been selected, based on habitat, ecological significance and fisheries relevance in Portuguese waters and identified significant pairwise trophic interactions from stomach content data. A Network Analysis has been used to depict foodweb topology properties focusing on the relationships between species. Knowledge of the trophic patterns and foodweb topology was used to identify key species and to assist in the development of foodweb indicators to support management decision on fisheries.

2.8 Ecoregion H: Western Mediterranean Sea

2.8.1 Ecopath with Ecosim in the Mediterranean

The Rank Proportion Algorithm (RPA; initially proposed by Link 2004 [Trans Am Fish Soc 133: 655–673]) was used to predict a diet composition of the blue cornet fish in the Bay of Calvi. The 'predicted' diet composition was input to an Ecopath with Ecosim (EwE) ecosystem model of the Mediterranean ecosystem, which was used to investigate consequences for other organisms and fisheries catches (e.g. Figure 2.6).

The ecosystem model predicted that increases in abundance of the non-native species led to positive outcomes for the fisheries. This is because the non-native species became an important food source for the predatory fish targeted by the fisheries in the Bay of Calvi region. The modelling also revealed indirect 'trophic cascade' effects, whereby the increased abundance of seabirds might result in a very dramatic decline of grey mullet. Such effects would be very difficult to predict using any other technique.

This 'toolkit' could be applied anywhere in the world, one example might be for risk assessment in the UK and especially for screening of species that have not yet arrived, but which might become highly problematic in future (e.g. the large predatory whelk *Rapana venosa* or the comb jellyfish *Mnemiopsis leidyi*.

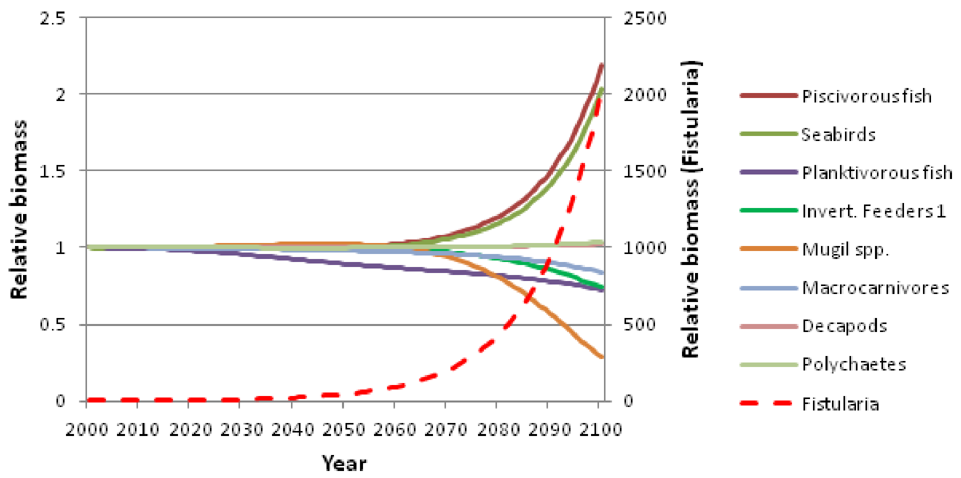

Figure 2.6. Simulated trajectory of F. commersonii population growth (red dashed line) under the 8%/year, v=10 scenario and resultant impact on the relative biomass of other fish and invertebrates in the foodweb.

2.9 Ecoregion I: Adriatic-Ionian Seas

There is no progress to report on multispecies modelling in Ecoregion C this year.

2.10 Ecoregion J: Aegean-Levantine

There is no progress to report on multispecies modelling in Ecoregion J this year. There were no participants present at the 2013 meeting from this Ecoregion.

2.11 Ecoregion K: Oceanic Northeast Atlantic

There is no progress to report on multispecies modelling in Ecoregion J this year. There were no participants present at the 2013 meeting from this Ecoregion.

2.12 Ecoregion L: Baltic Sea

2.12.1 Baltic Sea multispecies benchmark

The Baltic Sea underwent a benchmark of the major cod, sprat and herring stocks in 2013 aiming specifically at producing advice compatible with an Ecosystem Approach to Fisheries Management and multispecies interactions (WKBALT 2013). The benchmark included a review of the framework for providing multispecies advice suggested by WGSAM in 2012 and an elaboration of the framework to accommodate the specific requests from WKBALT experts. Further, biomass reference points applicable in both multispecies and single-species environments were estimated and used in the evaluation of candidates for F_{MSY} for each of the three species. These candidates were subsequently used to add a line to the catch option table in the assessment working group which contained the multispecies F_{MSY} of the specific species (WGBFAS, 2013).

2.12.2 Ecopath and Ecosim modelling for the Baltic

Progress at foodweb modelling on Baltic Sea based on Ecopath and Ecosim Baltic model publish by Tomczak *et al.,* 2012. An Ecopath with Ecosim Baltic Proper food–web model (BaltProWeb) was developed to simulate and better understand trophic interactions and their flows. The model contains 22 functional groups that represent the main food–web components. BaltProWeb was calibrated to long term monitoring data (1974–2006), covering multiple trophic levels and is forced by fisheries and environmental drivers. Our model enables the quantification of the flows through the food–web from primary producers to top predators including fisheries over time. The model is able to explain 51% of the variation in biomass of multiple trophic levels and to simulate the regime shift from a cod dominated to a sprat dominated system. Results show a change from benthic to more pelagic trophic flows. Before the reorganization macrozoobenthos was identified as an important functional group transferring energy directly from lower trophic levels to top predators. After the regime shift, the pelagic trophic flows dominated. Uncertainties and limitations of the modelling approach and results in relation to ecosystem-based management are discussed.

As stated at (Niiranen *et al.,* 2012) authors simulate for the first time how the combined changes in future climate, fishery, and nutrient loads may affect the Baltic Sea foodweb dynamics, using the open Baltic Sea Ecopath with Ecosim foodweb model BaltProWeb (Tomczak *et al.*, 2012). To ensure the usability of such projections, information about model capabilities and limitations, i.e. model uncertainty, is needed. Previously, only few uncertainty or sensitivity studies have been applied on Ecopath with Ecosim (EwE) models, regardless that EwE is a worldwide popular approach to simulate aquatic foodwebs EwE has some built-in model uncertainty routines. For example, probability estimates of all input data can be estimated, based on qualitative information about data reliability (pedigree tool). This information can then be used to build a mass-balance Ecopath model (Christensen and Walters, 2004). Also, a Monte Carlo routine is available for testing Ecosim model uncertainty and sensitivity to parameterization, or to optimize the Ecopath input for improved Ecosim model fit. However, at the time of this study these tools were not fully functional with models that accommodate age-structured groups (multi-stanza in EwE).

In this study (Niiranen *et al.*, 2012) a simplified model uncertainty and sensitivity analysis was applied on the BaltProWeb model. We use the term "model uncertainty" to describe the variation in the model results caused by the uncertainties, or variation, in the model input data and "model sensitivity" to describe the relative effect that a known change in a single input/forcing has on the model results. First, we identified the groups that the model is most sensitive to, defined uncertainty proxies for their model input biomasses and then studied resulting model uncertainty together with model sensitivity. Furthermore, the potential uncertainty under different future conditions was tested with different fishery and climate scenarios. In addition, we addressed model sensitivity to changes in environmental forcing, and studied the combinations of trophic control that were modelled as a result of model fitting to data.

At Niiranen *et al.,* 2013 authors used a new multimodel approach to project how the interaction of climate, nutrient loads, and cod fishing may affect the future of the open Central Baltic Sea foodweb. Regionally downscaled global climate scenarios were, in combination with three nutrient load scenarios, used to drive an ensemble of three regional biogeochemical models (BGMs). An Ecopath with Ecosim foodweb model was then forced with the BGM results from different nutrient-climate scenarios in combination with two different cod fishing scenarios. The results showed that regional management is likely to play a major role in determining the future of the Baltic Sea ecosystem. By the end of the 21st century, for example, the combination of intensive cod fishing and high nutrient loads projected a strongly eutrophicated and sprat-dominated ecosystem, whereas low cod fishing in combination with low nutrient loads resulted in a cod-dominated ecosystem with eutrophication levels close to present. Also, non-linearities were observed in the sensitivity of different trophic groups to nutrient loads or fishing depending on the combination of the two. Finally, many climate variables and species biomasses were projected to levels unseen in the past. Hence, the risk for ecological surprises needs to be addressed, particularly when the results are discussed in the ecosystem-based management context.

Tomczak *et al.* (2013) used modified Ecopath with Ecosim Baltic model to investigate Ecological Network Indicators of Ecosystem Status and Change in the Baltic Sea. Several marine ecosystems under anthropogenic pressure have experienced shifts from one ecological state to another. In the central Baltic Sea, the regime shift of the 1980s has been associated with foodweb reorganization and redirection of energy flow pathways. These long-term dynamics from 1974 to 2006 have been simulated here using a foodweb model forced by climate and fishing. Ecological network analysis was performed to calculate indices of ecosystem change. The model replicated the regime shift. The analyses of indicators suggested that the system's resilience was higher prior to 1988 and lower thereafter. The ecosystem topology also changed from a web-like structure to a linearized foodweb.

Biological ensemble modelling to evaluate potential futures of living marine resources (Gårdmark at al., 2013) was performed using set of models available for Central Baltic Sea. Here authors present one such approach, the ''biological ensemble modelling approach,'' using the Eastern Baltic cod (*Gadus morhua callarias*) as an example. The core of the approach is to expose an ensemble of models with different ecological assumptions to climate forcing, using multiple realizations of each climate scenario. Authors simulated the long-term response of cod to future fishing and climate change in seven ecological models ranging from single-species to foodweb models. These models were analysed using the ''biological ensemble modelling approach'' by which authors (1) identified a key ecological mechanism explaining the differences in simulated cod responses between models, (2) disentangled the uncertainty caused by differences in ecological model assumptions from the statistical uncertainty of future climate, and (3) identified results common for the whole model ensemble. Species interactions greatly influenced the simulated response of cod to fishing and climate, as well as the degree to which the statistical uncertainty of climate trajectories carried through to uncertainty of cod responses. Models ignoring the feedback from prey on cod showed large interannual fluctuations in cod dynamics and were more sensitive to the underlying uncertainty of climate forcing than models accounting for such stabilizing predator–prey feedbacks. Yet in all models, intense fishing prevented recovery, and climate change further decreased the cod population. That study demonstrates how the biological ensemble modelling approach makes it possible to evaluate the relative importance of different sources of uncertainty in future species responses, as well as to seek scientific conclusions and sustainable management solutions robust to uncertainty of foodweb processes in the face of climate change.

The work done by Lassalle *et al.,* (2013) aimed to provide a better understanding of how the structure and function of marine ecosystems and trophic control mechanisms influence their response to perturbations. Comparative analysis of Ecopath models of four Northeast Atlantic ecosystems was used to search for rules of thumb defining the similarities and differences between them. Ecosystem indicators, related to the ecology of species interactions, were derived from these models and compared. Two main questions were addressed. (i) What are the main energy pathways and mechanisms of control? (ii) Do these ecosystems exhibit the widespread and potentially stabilizing foodweb structure such that top predators couple distinct energy pathways? A strong bentho-pelagic coupling operated over the Bay of Biscay Shelf, while energy reached higher trophic levels mostly through pelagic compartments, in northern areas. Zooplankton was demonstrated to be trophically important in all ecosystems, acting as a regulator of the abundance of small pelagic fish. A latitudinal pattern in flow control was highlighted by this analysis, with a significant contribution of top–down effect at higher latitudes. This top–down control of the Baltic Sea, combined with the fact that this ecosystem did not exhibit the potentially stabilizing two-channel structure, suggested a non-stable environment.

2.12.3 Multispecies Integrated Stochastic Operative Model, MSI-SOM in the Baltic Sea

A new model, MSI-SOM, which suggests multispecies MSY reference points for the Baltic Sea was presented at the meeting. The model consists of three stochastic operative models (SOMs) for cod, sprat and herring stocks, respectively. Each SOM has numbers-at-age and weight-at-age as dynamic variables. The change in the dynamic variables is defined by a set of four functions: (i) a recruitment function, (ii) a weight-of-recruits function, (iii) a natural mortality function, and (iv) a body-growth function. Number of recruits is a function of spawning–stock biomass (SSB). These functions are estimated from data on weight-at-age and output from the official ICES assessment. For all functions the residual mean squares from fitting the models are added to the simulation models as an error. The precise form of these functions can change as the knowledge of ecological drivers or interactions develops, and new data becomes available.

The most recent versions of the functions are estimated from data and assessment output for herring in 2009 (ICES, 2009) and cod and sprat in 2011 (ICES, 2011). For cod, recruitment was also influenced by the reproductive volume (RV), i.e. the water volume with salinity and dissolved oxygen required for cod egg survival (Vallin and Nissling, 2000). Hence, the system is influenced by the declining salinity in the Baltic Sea observed since the 1980s (Hänninen, Vuorinen and Hjelt, 2000). The weight of recruits is a function of parental weight, i.e. linking the weight to succeeding cohorts (Geffen, 2009). The natural mortality of herring and sprat increases with cod SSB, and provides the top–down regulation of the system (Casini *et al.*, 2008). The bottom–up regulation is established by the growth of cod depending on the clupeid SSB. Cod body growth is regulated by a sigmoidal growth as a function of weight. The growth is also negatively influenced by the cod SSB, perhaps as a result of depletion of clupeid abundance within the year. Herring and sprat body growth decreased markedly during the late 1980s, as estimated by year-specific growth parameter common for all age classes for both species. The body growth of these two species is modelled as a von Bertalanffy type of growth, with declining growth rates as body weight increases. There is some evidence that this change in growth is due to decline in salinity (Holmgren *et al.*, 2012). The fishing mortality is regarded as independent on the stocks, i.e. no limitations on F across species due to mixed fisheries. Although the pelagic fishery is mixed to some degree, the species ratios can be changed with targeted fishing.

In simulations representing the current state of the environmental drivers, the erratic nature of RV in the Baltic Sea is modelled with values drawn from a gamma distribution fitted to data from 1981 to 2010. This distribution accounts for the reduction in the peaks of RV evident in the time-series from the periods before and after 1981. For growth in herring and sprat, the current low growth rates were accounted for by taking an average over the last ten years of the estimated year-growth parameter.

The joint BMSY analysis is conducted by solving SSB at MSY (BMSY) for one species while stepping through a range of constant SSBs of the other species. Herring and sprat turned out to have additive impact on cod growth, herring having an effect 3.4 times stronger than sprat. This enabled the use of a weighed SSB sum of the clupeids, here measured in herring SSB equivalents. The joint MSY is here presented as the intersection between BMSY-isolegs (lines along which a stock is fished at MSY) plotted in the phase portrait of biomass for clupeids and cod (Figure 2.7). The joint BMSY analysis can be conducted with or without stochastic noise added.

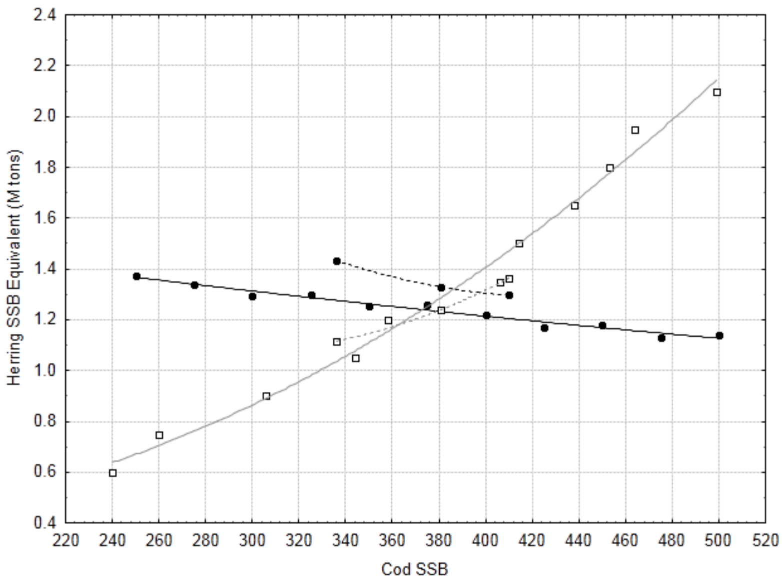

Figure 2.7. BMSY-isolegs for cod (open squares) and clupeids (closed circles) in terms of herring SSB equivalents (sprat SSB weighed by its impact on cod in relation to herring). The solid lines represent the results from the deterministic simulations and the dashed lines the stochastic simulations. The intersection of the fitted polynomials indicates the SSBs at which joint MSY for cod and clupeids are defined.

The resulting BMSY-isolegs of the deterministic simulations intersects at BMSY ~ 374 t tons for cod and ~ 1.24 M tons of total clupeid BMSY in herring equivalents (Figure 2.7). This gave for cod an FMSY=0.57, for herring FMSY=0.19, and for sprat FMSY=0.25. Stochastic simulations were run to confirm the results and verified that the isolegs intersects in the vicinity of where the deterministic simulations intersect (Figure 2.7). The SSB varies in long cycles, with decades or sometimes a century of very low abundances. With the current SSB fluctuations, the mean yields vary even after rather long simulations (about 30 000 years) leaving some uncertainty in the FMSY estimate, and the exact location of the crossing point in the joint BMSY analysis.

The result points out the state of the three dominating species in the Baltic Sea at which they simultaneously are at BMSY, which is not the same as a joint FMSY, which does not exist for the system with the model in its current format (unpublished). The presented FMSY, associated yields, SSBs and trigger points only apply to the system being in the MSY state described. To apply the proposed FMSY on the current cod stock without the use of a harvest control rule, will most likely prevent it from recovering to BMSY. The analysis does not provide a strategy for how to move the stocks to the state where they are capable of producing MSY. The proposed joint multispecies MSY is conditional on the estimated resilience of the stocks. Although these are based on ICES data and up-to date knowledge of stock biology and environmental drivers, resilience is sensitive to density-dependent processes and our knowledge of these will improve with new science.

It should be noted that the proposed multispecies MSY is solved as $BMSY_i | BMSY_j > 0$ for all *i* and *j*. This means that all stocks can coexist at MSY given that all other stocks are at MSY. This differs from the alternative MSY-objective to maximize total MSY of all species, which leads to eradication of all stocks except the ones on the lowest trophic level when based on biological considerations only (Gislason, 1999).

Currently the model is updated with data from 2012 and results from the 2013 benchmark workshop on Baltic multispecies assessments (ICES, 2013). The model is updated from using the results of MSVPA to using SMS results for estimating multispecies interactions.

2.13 Ecoregion M: Black Sea

There is no progress to report on multispecies modelling in Ecoregion M this year. There were no participants present at the 2013 meeting from this Ecoregion.

2.14 Ecoregion: Canadian Northwest Atlantic

There is no progress to report on multispecies modelling in Ecoregion N this year. There were no participants present at the 2013 meeting from this Ecoregion.

2.15 Ecoregion: US Northwest Atlantic

2.15.1 Pilot Project: 10 Species Georges Bank Multispecies Assessment

A project has been started at the National Marine Fisheries Service, Northeast Fisheries Science Center. The goals are to:

- Develop a prototype multispecies assessment for a ten species system on Georges Bank with environmental covariates.
- Develop multiple models of varying degrees of complexity, and evaluate performance in a Management Strategy Evaluation setting.
- Adopt a multimodel inference strategy using model averaging and model envelopes to represent results.
- Identify key indicators to complement model results and approaches.

The development of operating and tactical models and other tools to be used in the assessment process are mostly done. The validation (described more below) of the tactical models has begun on simulated data, and is ongoing. The gathering of the data for the models and other analyses is mostly complete.

The ten species to be assessed are: Atlantic cod, haddock, silver hake, redfish, goosefish, yellowtail flounder, winter flounder, spiny dogfish, winter skate, Atlantic herring, and Atlantic mackerel.

Two modelling packages are in development. The data needs are biomass time-series by length, catch time-series (landings and discards) by length and gear type, food habits data by length (to inform interaction strengths), and environmental covariates (both regional such as temperature and salinity, and broad scale such as the NAO index).

2.15.2 Hydra (Multispecies Length Based Operating Model)

This is a model currently under development which will be a spatial multispecies and length structured model that uses reproductive biology, environmental covariates on growth, maturity, and fecundity, harvest, and predation. It currently runs in simulation mode only, but will have likelihood or Bayesian parameter estimation through the ADMB software package which it is being developed in. The spatial aspect is also not currently completed. As such, this model is being used to generate the simulated datasets to validate the other methods with. Example outputs in Figure 2.8.

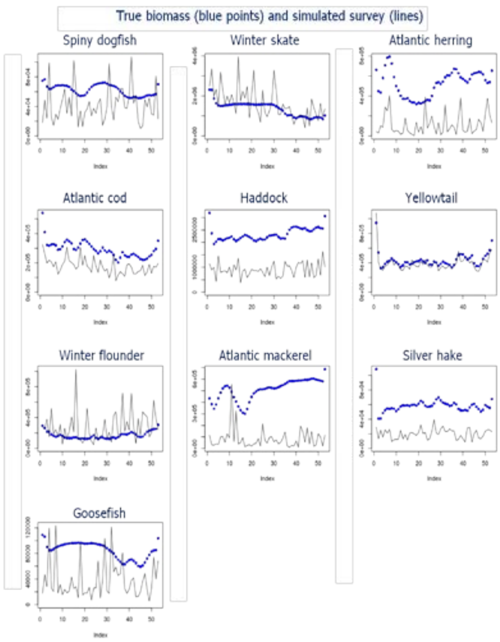

Figure 2.8. Example outputs from Hydra running as a simulation model. The ten species in the system each have outputs of true biomass (the blue dots) and simulated survey including catchability and error considerations (the thin solid lines).

2.15.3 Kraken (Multispecies/Aggregate Surplus Modelling Package)

Kraken is a surplus production modelling package that is designed to provide multiple functional forms for growth (e.g. linear, logistic), predation (e.g. Type I, II, III), competition (e.g. between species, between groups), and exploitation (e.g. total catch, catchability and effort, exploitation rate). Covariates on growth and carrying capacity are included, as are process and observation errors on growth and exploitation (in this case, simulating lack of complete compliance with management regulations). The fitting routine currently is a genetic algorithm, but more traditional methods such as maximum likelihood will be coded.

Validation of a form of this model has begun, using Hydra's simulated outputs. The model form is:

$$\frac{dB_i}{dt} = r_i B_i - \sum_{1}^{j} \alpha_{ij} B_j - C_i$$

where B_i is biomass for species i, r_i is the intrinsic rate of growth for species i, C_i is catch on species i, and α_{ij} is the interaction coefficient between species i and j. The interaction coefficient also occurs between species i and itself, indicating the density-dependent effect on a species (similar to the effect of carrying capacity). Estimation results on perfectly known biomass outputs from Hydra are shown in Figure 2.9. The primary source of interactions in this Hydra run was predation on small pelagics, and parameter estimation was done both with species interactions included, and without. Species like spiny dogfish and Atlantic cod were well estimated using the genetic algorithm with no species interactions, and species like Atlantic herring and Atlantic mackerel had an improved fit when parameters were estimated with species interactions included.

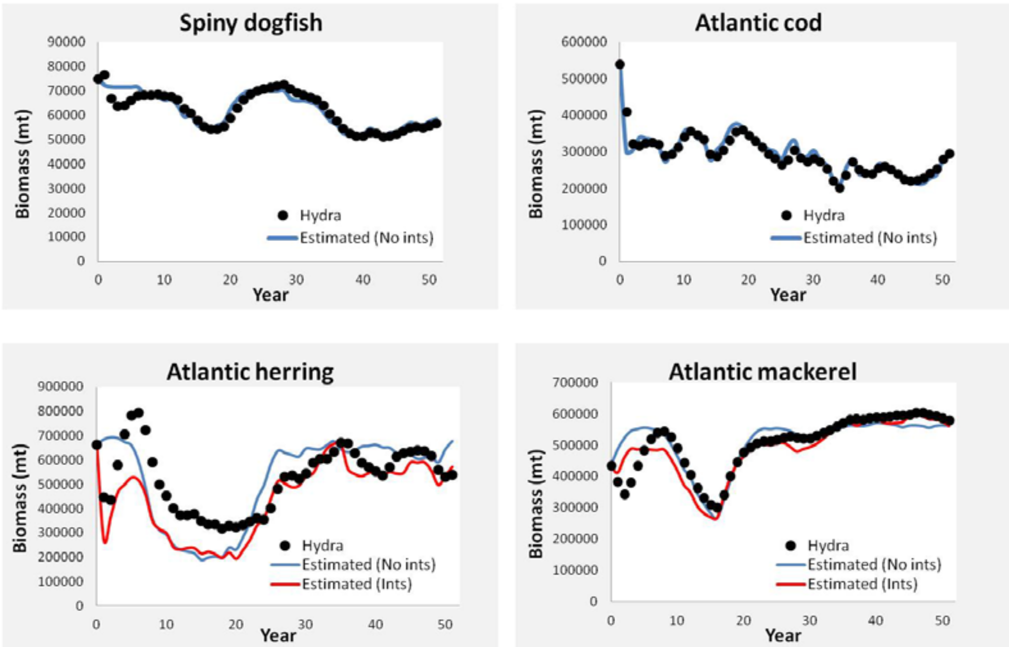

Figure 2.9. Example estimations using the Kraken model described. The black dots are the true outputs from Hydra, the blue line in all the plots is the estimated line assuming no species interactions, and the red line is the estimated line assuming species interactions.

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

3.1 Baltic Sea EwE

EwE Baltic Sea key run was not perform at WGSAM meeting 2013, and has been postpone for next year. Published Central Baltic Sea EwE model (Tomczak *et al.*, 2012) has been tested to produce key-run. However, way how the current model is design and calibrated (structure, data used and time span; see Tomczak *et al.*, 2012) better suite model for ecological analysis, flows estimations and food-web processes understanding then fisheries multispecies analysis. As suggested, model improvement in direction to full fill key-run goals, required changes in structure towards more fisheries oriented model with more fishing fleets related to DCR, fishing effort driven and additional exploitable fish stocks included.

4 ToR C: Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs) ToR C. Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)

4.1 Key runs

In order to facilitate incorporating multispecies model output into the ICES advice giving process, so called 'key runs' have been developed, initially for the "SMS" model. A 'key-run' refers to a model parameterization and output that is accepted as a standard by ICES WGSAM, and thus serves as a quality assured source for scientific input to ICES advice. For comparison see section 9 on evaluating and accepting new multispecies models.

The description of what this standard should look like for different models is the focus of this ToR. In general terms, a key-run describes and makes accessible the model outputs for a case study of a particular ecosystem. It contains consistent outputs, together with documentation and information on inputs. Prime purposes of a key run include:

a) Demonstrating the utility of a particular model formulation in a controlled environment and thereby building confidence that this formulation is appropriate to use in providing advice.

b) Assisting with the development of multi-model approaches by providing a "standard" set up to aid understanding of different model frameworks, and a worked example of the results that can potentially emerge.

Key runs are typically run every three years, or alternatively, 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.

In addition to the key run procedure developed for SMS, EwE (WGSAM 2009, 2011) and Gadget-type forward simulation population models, work has been ongoing to extend the format to handle other types of model. At this year's meeting a format for extending the process to include the "LeMANS" size structured model was considered.

4.2 Summary of key run procedure for SMS models

The SMS and Gadget key runs conducted in WGSAM have addressed and reviewed the following aspects of the model application and output:

1 Overview/summary of the model.

Around 5 lines of summary of the model type followed by a short (around half a page) summary of the additions/changes in the described current application.

2 Input data.

Input data sources are reviewed carefully by the group to ensure that the best available data is used in the model fitting. Examples of input data reviewed could be survey data, commercial catch data, weight at age, biomass of external predators, diet and consumption data. The rationale for decisions made by the group is documented.

3 Model settings.

Settings of the models are described along with the background for deciding the final key run configuration. Examples could be size preference parameterized or new species added.

4 Key run summary sheet.

Table 1 lists an example of a key run sheet for the North Sea SMS.

Table 1. North Sea SMS key run summary sheet. From WGSAM (2011).

Area	North Sea
Model name	SMS
Type of model	Age-length structured statistical estimation model
Run year	2011
Predatory species	Assessed species: Cod, haddock, saithe, whiting Species with given population size: North Sea mackerel, western mackerel, North Sea horse mackerel, western horse mackerel, grey gurnard, starry ray, fulmar, gannet, great black backed gull, guillemot, herring gull, kittiwake, puffin, razorbill, grey seal, harbour porpoise
Prey species	Cod, haddock, herring, Norway pout, sandeel, sprat, whiting
Time range	1963-2010. Model output for 1963-1973 is considered less reliable due to poor quality of catch data of mainly the forage fish before 1974.
Time-step	Quarterly
Area structure	North Sea
Stomach data	Fish species: 1981, 1985, 1986, 1987, 1991 Grey seals: 1985, 2002 Harbour porpoise: Decadal 1985, 1995, 2005
Purpose of key run	Making historic data on natural mortality available
Model changes since last key run	Inclusion of sprat, grey seal and harbour porpoise
Output available at	http://www.ices.dk/reports/SSGSUE/2011/WGSAM/SMS_summary.csv
Further details in	Report of the Working Group on Multispecies Assessment Methods 2011

5 Results of model fitting.

This section will contain aspects of model fitting investigated to achieve the final run. Examples include Log likelihood, plots of observed and predicted observations and trials with other settings such as alternative food size selection or time-series of other food included.

6 Comparison with other runs.

Examples of content in this section include comparisons with previous key run and comparison with single species assessments.

7 Model output

Frequently produced output includes biomass eaten by predators, estimated predation mortalities (M2) and predation mortalities by source (partial M2).

4.3 Developing a LeMans Key Run

What is a LeMans key-run?

A LeMans 'key-run' refers to the use of a LeMans model whose allowable parameter set has been chosen so that it can replicate observed ICES stock biomasses to an acceptable degree, i.e. a calibrated ensemble model. The procedure is shown in schematic form in Figure 4.1.

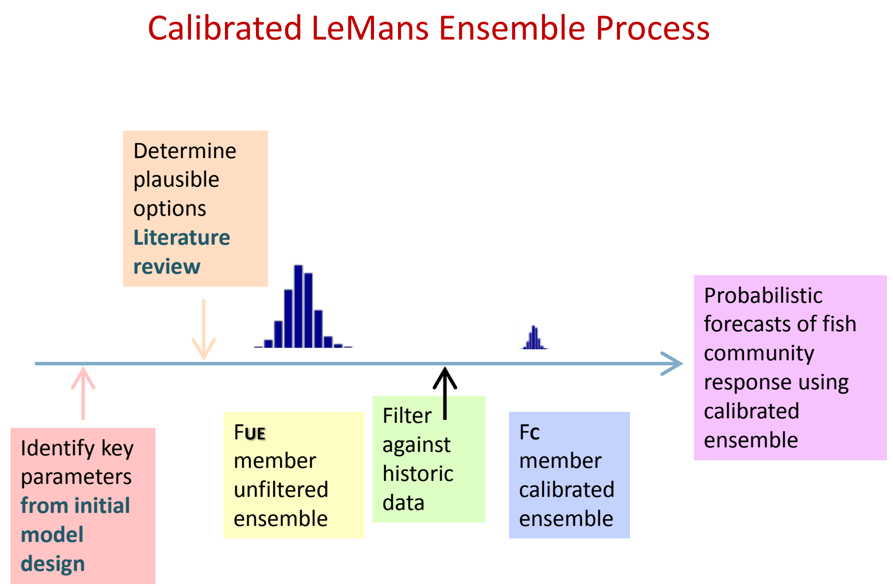


Figure 4.1. Outline of "LeMans" modelling process.

Essential components of the key-run are:

- an acceptable basic LeMans configuration.
- an agreed set of key parameters to be varied in generating the model ensemble.
- plausible initial ranges of parameters to construct the unfiltered ensemble.
- appropriate screening data in the form of maximum and minimum observed stock biomasses for a defined period.
- an emergent ensemble of model runs which conform with observed data to an accepted level of tolerance. The ensemble should be large enough for generating meaningful probability statistics.

Quality control issues

- The underpinning LeMans model framework should be published and/or its quality established using clear criteria.
- The parameter choices made in the initial ensemble should be clear and justifiable.
- The data used to constrain the model should be specified and available for inspection.
- The robustness of the emergent ensemble to the screening process should be demonstrated.

Standard format for results

Given the large amount of data generated by an ensemble approach, the required outputs need to be carefully specified. Generation of risk indicators and probabilistic output will require information to be stored for each valid ensemble member, inflating the data requirement by order 100. Potentially outputs could include biomasses of model stocks, fish community indicators, natural and fishing mortality by size and stock.

Results are typically output as (very large) text or .csv files.

5 ToR D: Develop and compare foodweb and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)

In 2012, WGSAM produced a list of potential foodweb indicators. The indicators were suggested only for areas where WGSAM considered that advice could be provided based on the expertise in WGSAM, specifically about setting reference levels based on model predictions. Further details on the specific aim of the different indicators can be found in WGSAM 2012.

Guidelines for evaluating indicators were produced at WGECO 2013 based on a suggestion from WGBIODIV 2013; WGSAM used these guidelines to evaluate the proposed indicators using expert judgement. Criteria 3 from WGECO was further detailed compared to the original proposal into 3a: Acceptable signal to noise (importance score 2) and 3b: Accurately determined using technically feasible and quality controlled methods (importance score 1). Of the original list, the proposed indicators 'amplitude of trophic cascades in size spectra', 'non-"linearity" of size spectrum', 'size at first sexual maturation', which may reflect the extent of undesirable genetic effects of exploitation (secondary indicator) and 'mean weight at age of predatory fish species from models' were not included in the evaluation. The former two were considered to be at an explorative stage at present. The latter two can potentially be included in multispecies models but would require more knowledge of parameterization and the functional relationships than is currently available in the group. The indicators and their justification and the models capable of addressing each indicator can be found in Table 5.1. Table 5.2 shows the criteria which were used to score the indicators.

The scoring of the different indicators can be seen in Table 5.2 and the total score in Table 5.3. Table 5.1 also gives details of which model currently in use at WGSAM would potentially be able to provide the necessary information.

WGSAM thought that the process of summing weighted scores did not reflect that some of these criteria refer to essential properties. Such essential properties included in the opinion on the group Criteria 3a (signal to noise ratio acceptable) and Criteria 6 (responsive to human pressure). To reflect that these criteria were considered essential, a second screening was performed by WGSAM by multiplying the total score by the score of Criteria 3a (signal to noise ratio acceptable) and Criteria 6 (responsive to manageable human pressure) except pressure indicators which receive a score of 0 at Criteria 6 and therefore only interaction with Criteria 3a was applicable. This in effect up-weighted the criteria that the group considered critical in a practical indicator. The final rating of the indicators thus reflected WGSAM's opinion that the group is capable of providing advice when these criteria are met.

Table 5.4, shows that although the majority of the indicators achieve reasonable scores in total, only a few are considered to have both a strong signal to noise ratio and are responsive to management. However, in many cases, the scores on these two criteria was based on expert opinion alone and it is likely that some of the indicators may exhibit response to pressures or have a higher signal to noise ratio, given more thorough investigation. It is therefore recommended by WGSAM that the proposed indicators foodweb indicators are further investigated by WKFOOI to determine particularly their signal to noise ratio and their response to human pressures.

Table 5.1. Description of the proposed indicators, which MSFD indicators they relate to, a brief explanation, and a list of the models currently in use in WGSAM which could potentially provide the necessary information.

Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Gini-Simpson diversity index (species dominance) of large fish and of small fish by biomass.	1.7.1 Population abundance and or biomass, as appropriate and 4.3 Abundance/distribution of key trophic groups/species	Measures community change. Responds to fishing, because sensitive of abundance of the few most abundant species.	SMS for assessed species, EwE, Gadget but misses important biomass of e.g. polar cod
Gini-Simpson dietary diversity of each fish species	1.7.1 Composition and relative proportions of ecosystem components (habitats and species) and 4.3 Abundance/distribution of key trophic groups/species	Measures community change. Responds to fishing, because sensitive of abundance of the few most abundant species.	SMS for assessed species, EwE, potentially also Gadget.
Indicator proposed by WGSAM			
Gini-Simpson dietary diversity of each fish species from models North Sea	4.1.1. Performance of key predator species using their production per unit biomass (productivity)		SMS for assessed species, EwE, Gadget potentially.
Pelagic biomass/demersal biomass from models	1.7.1. Composition and relative proportions of ecosystem components (habitats and species) and	Measure changes in community structure as an indicator of the distribution of energy in the ecosystem.	EwE, Gadget, SMS and Stocobar pelagic/demersal for assessed species.
fish biomass/benthos biomass from models	1.7.1. Composition and relative proportions of ecosystem components (habitats and species)	Measure changes in community structure as an indicator of the distribution of energy in the ecosystem.	EwE, Gadget, SMS and Stocobar pelagic/demersal for assessed species.

Indicator proposed by WGSAM	**MSFD Indicator (or attribute)**	**Brief explanation (see Section below for methods)**	**Which model currently run by WGSAM can provide this information.**
Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Average Trophic Level (TL) of community	1.7.1. Composition and relative proportions of ecosystem components (habitats and species) and 4.3 Abundance/distribution of key trophic groups/species	Measure of state of how the energy in the foodweb is distributed.	EwE without further information, Gadget, SMS and Stocobar for assessed species given estimates of TL.
Mean TL of the catch	1.7.1. Composition and relative proportions of ecosystem components (habitats and species) and 4.3 Abundance/distribution of key trophic groups/species	Measure of state of how the energy in the foodweb is distributed.	EwE without further information, Gadget, SMS and Stocobar for assessed species given estimates of TL.
Fishing mortality (F)	3.1.1 Primary indicator: Fishing mortality (F)		Gadget, SMS and Stocobar for assessed species
Community F (catch/biomass)	3.1 Level of pressure of the fishing activity		EwE for all, Gadget, SMS and Stocobar for assessed species
Ratio between catch and biomass index (hereinafter catch/biomass ratio)	3.1 Level of pressure of the fishing activity		EwE for all, Gadget, SMS and Stocobar for assessed species
Spawning-stock biomass (SSB)			Gadget, SMS and Stocobar for assessed species

Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Secondary indicator: Biomass indices			Gadget, SMS and Stocobar for assessed species
Performance of key predator species using their production per unit biomass (productivity)	4.1.1 Performance of key predator species using their production per unit biomass (productivity)		Gadget, SMS and Stocobar for assessed species
Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Total (F+M) fish species, in practice only assessed stocks.	1.3.1 Population demographic characteristics (e.g. body size or age class structure, sex ratio, fecundity rates, survival/mortality rates) and 4.1.1 Performance of key predator species using their production per unit biomass (productivity)	Management must respond to changes in F+M, not only F.	Gadget, SMS, EwE, Stocobar
Natural mortality of fish species, in practice only assessed stocks.	1.3.1 Population demographic characteristics (e.g. body size or age class structure, sex ratio, fecundity rates, survival/mortality rates) and 4.1.1 Performance of key predator species using their production per unit biomass (productivity)	Management must respond to changes in F+M, not only F.	Gadget, SMS, EwE, Stocobar

Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Mean weight at age of predatory fish species from data	4.1.1 Performance of key predator species using their production per unit biomass (productivity)	Measure of condition of predators relating to food availability	SMS (Baltic, North Sea potential), Gadget (potential), Stocobar (cod only)
Loss in secondary production resulting from fishing. (L index)	4.1.1 Performance of key predator species using their production per unit biomass (productivity)	Responds predictably to disturbance of community by fishing mortality, but also to changes in primary productivity.	EwE
Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Mean transfer efficiency for a given TL or size.	4.1.1 Performance of key predator species using their production per unit biomass (productivity)	Important for transport of energy to higher trophic levels.	EwE, size spectra potentially
Average recruitment anomaly	4.3 Abundance/distribution of key trophic groups/species	Information on food available to higher trophic levels in ecosystem.	Gadget, EwE for modelled species, SMS similar, Stocobar for cod. Size spectra model potential. All require decisions on lower and upper cut-off.
Slope of size spectra	3.3.1 Proportion of fish larger than the mean size of first sexual maturation and 4.2 Proportion of selected species at the top of foodwebs	Responds predictable to disturbance of community by fishing mortality. Non-“linearity” characterizes trophic efficiency. Trophic cascades, because minima can lead to species loss.	Gadget, SMS, Stocobar with mean length-at-age for cod: yes for slope and non-linearity of size spectra

Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Cumulative distribution of biomass over TL: slope and inflection point	4 Foodweb descriptor	Responds predictable to disturbance of community by fishing mortality.	EwE (North Sea, Baltic potential, Adriatic potential)
LFI	3.3.1 Proportion of fish larger than the mean size of first sexual maturation and 4.2 Proportion of selected species at the top of foodwebs	Responds predictable to disturbance of community by fishing mortality. Non-"linearity" characterizes trophic efficiency. Trophic cascades, because minima can lead to species loss.	Gadget, SMS, Stocobar with mean length-at-age for cod: yes for slope and non-linearity of size spectra
Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
95%-tiles of length of individuals in fish community	3.3.1 Proportion of fish larger than the mean size of first sexual maturation and 4.2 Proportion of selected species at the top of foodwebs		Gadget for modelled species, SMS similar, Stocobar for cod. Size spectra model potential. All require decisions on lower cut-off.
LSI	3.3.1 Proportion of fish larger than the mean size of first sexual maturation and 4.2 Proportion of selected species at the top of foodwebs		Gadget for modelled species, SMS similar. Size spectra model potential. All require decisions on lower cut-off.

Indicator proposed by WGSAM	MSFD Indicator (or attribute)	Brief explanation (see Section below for methods)	Which model currently run by WGSAM can provide this information.
Total biomass of small fish	4.3 Abundance/distribution of key trophic groups/species	Information on food available to higher trophic levels in ecosystem.	Gadget, EwE for modelled species, SMS similar, Stocobar for cod. Size spectra model potential. All require decisions on lower and upper cut-off.
Community biomass of pelagic, forage, demersal, benthos and total	4.3 Abundance/distribution of key trophic groups/species	Measure of where and how the biomass in the ecosystem is distributed	EwE all groups and Gadget, SMS and Stocobar for assessed species.

Table 5.2. Criteria scoring from WGECO (ICES, 2013) to evaluate the performance of "common indicators" proposed by OSPAR to support implementation of the MSFD at subregional and regional scale. The 16 criteria are grouped into five main categories, and the principle characteristic of each indicator's performance examined by each criterion is given. The *importance* weightings, and their associated scores, assigned by WGBIODIV to each criterion are shown, as are the guidelines for assessing the level of *compliance* of each indicator against each criterion. Pale blue cells indicate criteria not contributing to WGBIODIV's analytical assessment of the performance of the OSPAR "common indicators". In the *compliance* guidelines column, criteria automatically given a zero *compliance* score if the indicator was deemed to be a "pressure" indicator (criterion 1) are highlighted.

Criterion No.	Category	Characteristic	Criterion	*Importance* Weighting	*Importance* Score A	Guidelines for *Compliance* Assessment. Score B
1	Type of Indicator	State or pressure	Is indicator a "pressure" indicator being used for want of an appropriate "state" indicator?			Fully met (1): indicator is a "state" indicator; Not met (0): indicator is actually a "pressure" indicator.
2	Quality of underlying data	Existing and ongoing data	Indicators must be supported by current or planned monitoring programmes that provide the data necessary to derive the indicator. Ideal monitoring programmes should have a time-series capable of supporting baselines and reference point setting. Data should be collected on multiple sequential occasions using consistent protocols, which account for spatial and temporal heterogeneity.	Core	3	Fully met (1): long-term and ongoing data from which historic reference levels can be derived and past and future trends determined; Partially met (0.5): no baseline information, but ongoing monitoring or historic data available, but monitoring programme discontinued, however potential to re-establish the programme exists; Not met (0): data sources are fragmented, no planned monitoring programme in future.
3	Quality of underlying data	Indicators should be concrete	Indicators should ideally be easily and accurately determined using technically feasible and quality assured methods, and have high signal to noise ratio.	Core	3	Fully met (1): data and methods are technically feasible, widely adopted and quality assured in all aspects, signal to noise ratio is high; Partially met (0.5): potential issues with quality assurance, or methods not widely adopted, poor signal to noise ratio; Not met (0): indicator is not concrete or

Criterion No.	**Category**	**Characteristic**	**Criterion**	***Importance* Weighting**	***Importance* Score A**	**Guidelines for *Compliance* Assessment. Score B**
						doubtful; noise excessively high due either to poor data quality or the indicator is unduly sensitive to environmental drivers
4	Quality of underlying data	Quantitative vs. qualitative	Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments.	Desirable	2	Fully met (1): all data for the indicator are quantitative; Partially met (0.5): data for the indicator are semi-quantitative or largely qualitative; Not met (0): the indicator is largely based on expert judgement.
5	Quality of underlying data	Relevant spatial coverage	Data should be derived from a large proportion of the MSFD subregion, at appropriate spatial resolution and sampling design, to which the indicator will apply.	Core	3	Fully met (1): spatially extensive monitoring is undertaken across the subregion; Partially met (0.5): monitoring does not cover the full subregion, but is considered adequate to assess status at subregional scale; Not met (0): monitoring is undertaken across a limited fraction of the subregion and considered inadequate to assess status at subregional scale.

Criterion No.	Category	Characteristic	Criterion	*Importance* Weighting	*Importance* Score A	Guidelines for *Compliance* Assessment. Score B
6	Quality of underlying data	Reflects changes in ecosystem component that are caused by variation in any specified manageable pressures	The indicator reflects change in the state of an ecological component that is caused by specific significant manageable pressures (e.g. fishing mortality, habitat destruction). The indicator should therefore respond sensitively to particular changes in pressure. The response should be unambiguous and in a predictable direction, based on theoretical or empirical knowledge, thus reflecting the effect of change in pressure on the ecosystem component in question. Ideally the pressure-state relationship should be defined under both the disturbance and recovery phases.	Core	3	**IF CRITERION 1 IS SCORED 0 THEN THE SCORE MUST BE 0**. Otherwise: Fully met (1): the indicator is primarily responsive to a single or multiple pressures and all the pressure-state[1] relationships are fully understood and defined, both under the disturbance and recovery phases of the relationship; Partially met (0.5): the indicator's response to one or more pressures are understood, but the indicator is also likely to be significantly influenced by other non-anthropogenic (e.g. environmental) drivers, and perhaps additional pressures, in a way that is not clearly defined. Response under recovery conditions may not be well understood; Not met (0): no clear pressure-state relationship is evident.
7	Management	Relevant to MSFD management targets	Clear targets that meet appropriate target criteria (absolute values or trend directions) for the indicator can be specified that reflect management objectives, such as achieving GES.	Desirable	2	Fully met (1): an absolute target value for the indicator is set; Partially met (0.5): no absolute target set for the indicator, but a target trend direction for the indicator is established; Not met (0): targets or trends unknown.

[1] **Here the term pressure-state relationship is used in the sense described by Piet *et al*. (2007): e.g. fishing *pressure* (fishing mortality rate [*F*]) – *state* of the stock (stock biomass [*B*]).**

Criterion No.	Category	Characteristic	Criterion	*Importance* Weighting	*Importance* Score A	Guidelines for *Compliance* Assessment. Score B
8	Management	Relevant to management measures	Indicator links directly to management response. The relationship between human activity and resulting pressure on the ecological component is clearly understood.	Desirable	2	**IF CRITERION 1 IS SCORED 0 THEN THE SCORE MUST BE 0**. Otherwise: Fully met (1): both response-activity and activity-pressure relationships[2] are well defined - advise can provided on both the direction AND extent of any change in human activity required and the precise management measures required to achieve this; Partially met (0.5): response-activity and activity pressure relationships are not well understood, or only one of the relationships is defined, but not the other, so that the precise changes in pressure resulting from particular management actions cannot be predicted with certainty; Not met (0): no clear understanding of either relationship, so that the link between management response and pressure is completely obscure.
9	Management	Comprehensible	Indicators should be interpretable in a way that is easily understandable by policy-makers and other non-scientists (e.g. stakeholders) alike, and the consequences of variation in the indicator should be easy to communicate.	Desirable	2	Fully met (1): the indicator is easy to understand and communicate; Partially met (0.5): a more complex and difficult to understand indicator, but one for which the meaning of change in the indicator value is easy to communicate; Not met (0): the indicator is

[2] **Here the terms response-activity relationship and activity-pressure relationship are used in the sense described by Piet *et al*. (2007) and Greenstreet *et al*. (2009); e.g. management *response* (total allowable catch) – fishing *activity* (days-at-sea), and fishing *activity* (days-at-sea) – fishing *pressure* (fishing mortality rate [*F*]).**

Criterion No.	Category	Characteristic	Criterion	*Importance* Weighting	*Importance* Score A	Guidelines for *Compliance* Assessment. Score B
						neither easy to understand or communicable.
10	Management	Established indicator	Indicators used in established management frameworks (e.g. EcoQO indicators) are preferred over novel indicators that perform the same role. Internationally used indicators should have preference over indicators used only at a national level.	Desirable	2	Fully met (1): the indicator is established and used in international policy frameworks; Partially met (0.5): the indicator is established as a national indicator; Not met (0): the indicator has not previously been used in a management framework.
11	Management	Cost-effectiveness	Sampling, measuring, processing, analysing indicator data, and reporting assessment outcomes, should make effective use of limited financial resources.	Desirable	2	Fully met (1): little additional costs (no additional sampling is needed); Partially met (0.5): new sampling on already existing programmes is required; Not met (0): new sampling on new monitoring programs is necessary.
12	Management	Early warning	Indicators that signal potential future change in an ecosystem attribute before actual harm is indicated are advantageous. These could facilitate preventive management, which could be less costly than restorative management.	Informative	1	**IF CRITERION 1 IS SCORED 0 THEN THE SCORE MUST BE 0**. Otherwise: Fully met (1): indicator provides early warning because of its high sensitivity to a pressure or environmental driver with short response time; Not met (0): relatively insensitive indicator that is slow to respond.

Criterion No.	Category	Characteristic	Criterion	*Importance* Weighting	*Importance* Score A	Guidelines for *Compliance* Assessment. Score B
13	Conceptual	Scientific credibility	Scientific, peer-reviewed findings should underpin the assertion that the indicator provides a true representation of variation in the ecosystem attribute in question.	Desirable	2	**IF CRITERION 1 IS SCORED 0 THEN THE SCORE MUST BE 0**. Otherwise: Fully met (1): peer-reviewed literature; Partially met (0.5): documented but not peer-reviewed; Not met (0): not documented or peer-reviewed literature is contradictory.
14	Conceptual	Metrics relevance to MSFD indicator	For D1 and D6, metrics should fit the indicator function stated in the 2010 MSFD Decision document. This requirement can be relaxed for D4 indicators because the Decision document stipulates the need for indicator development in respect of this Descriptor (but any newly proposed D4 indicators must still fulfil the overall goals stated for D4).	Core	3	Fully met (1): the metric complies with indicator function; Not met (0): the metric does not comply with indicator function.
15	Conceptual	Cross-application	Metrics that are applicable to more than one MSFD indicator are preferable.	Desirable	2	Fully met (1): metric is applicable across several MSFD indicators; Not met (0): no cross-application.
16	Indicator suites	Indicator correlation	Different indicators making up a suite of indicators should each reflect variation in different attributes of the ecosystem component and thus be complementary. Potential correlation between indicators should be avoided.	Desirable	2	Fully met (1): the indicators are uncorrelated; Partially met (0.5): correlation between some indicators; Not met (0): all indicators are correlated.

Table 5.3. Foodweb indicators proposed and evaluated by WGSAM. Values in italics are based on output from size based models (ToR f).

Indicator proposed by WGSAM	C1	C2	C3a	C3b	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Descriptor 1 - Biological Diversity																	
Gini-Simpson diversity index (species dominance) of large fish and of small fish by biomass.	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	0	1	0	1
Gini-Simpson dietary diversity of each fish species from stomachs Barents Sea	S	1	0.5	1	1	1	0	0	0	0	0	0.5	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from stomachs Baltic Sea	S	1	0.5	1	1	1	0	0	0	0	0	0.5	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from stomachs (other areas)	S	0	0	0	1	1	0	0	0	0	0	0.5	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models Barents Sea	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models Baltic	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models North Sea	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models Bay of Biscay	S	1	0.5	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Pelagic biomass/demersal biomass from models	S	1	1	1	1	1	0.5	0	0.5	1	0	1	0	1	1	0	1
fish biomass/benthos biomass from models	S	1	0.5	1	1	1	0.5	0	0.5	1	0	1	0	0	1	0	1
Average Trophic Level (TL) of community	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	1	1	1	0.5
Mean TL of the catch	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	1	1	1	0.5
Indicator proposed by WGSAM	C1	C2	C3a	C3b	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Descriptor 3 - Populations of commercially exploited fish and shellfish																	
Fishing mortality (F)	P	1	1	1	1	1	0	1	0	1	1	1	0	0	1	0	1
Community F (catch/biomass)	P	1	1	1	1	1	0	0	0	1	1	1	0	0	1	0	1
Ratio between catch and biomass index (hereinafter catch/biomass ratio)	P	1	0.5	1	1	1	0	0	0	1	1	1	0	0	1	0	1
Spawning-stock biomass (SSB)	S	1	1	1	1	1	0.5	1	0.5	1	1	1	0.5	1	1	0	1
Secondary indicator: Biomass indices	S	1	0.5	1	1	1	0.5	0.5	0.5	1	1	1	0.5	1	1	0	1
Descriptor 4 - Foodwebs																	
Performance of key predator species using their production per unit biomass (productivity)	S	1	1	1	1	1	0.5	1	0.5	1	1	0.5	1	1	1	0	1
Total (F+M) fish species, in practice only assessed stocks.	?	1	1	1	1	1	0.5	0	0.5	1	0	1	1	0	1	0	0.5
Natural mortality of fish species, in practice only assessed stocks.	S	1	1	1	1	1	0.5	0	0.5	1	0	1	0	0	1	0	0.5
Mean weight at age of predatory fish species from data	S	1	1	1	1	1	0.5	0	0.5	1	0.5		0	0	1	0	1

Indicator proposed by WGSAM	C1	C2	C3a	C3b	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Loss in secondary production resulting from fishing. (L index)	?	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	0	1	0	1
Gini-Simpson dietary diversity of each fish species from stomachs Barents Sea	S	1	0.5	1	1	1	0	0	0	0	0	0.5	0	0	1	1	1
Indicator proposed by WGSAM	C1	C2	C3a	C3b	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
Gini-Simpson dietary diversity of each fish species from stomachs Baltic Sea	S	1	0.5	1	1	1	0	0	0	0	0	0.5	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from stomachs (other areas)	S	0	0	0	1	1	0	0	0	0	0	0.5	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models Barents Sea	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models Baltic	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models North Sea	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Gini-Simpson dietary diversity of each fish species from models Bay of Biscay	S	1	0.5	1	1	1	0	0	0	0	0	1	0	0	1	1	1
Mean transfer efficiency for a given TL or size.	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	0	1	0	1
Average recruitment anomaly in forecast	S	0	0	1	1	1	0	0	0	1	0	1	0	0	1	0	1
Average recruitment anomaly in hindcast	S	1	1	1	1	1	0	0	0	1	0	1	0	0	1	0	1
Slope of size spectra	S	1	1	1	1	1	0.5	0	0.5	0.5	0	1	0	1	1	0	0.5
Cumulative distribution of biomass over TL: slope	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	1	1	0	0.5
Cumulative distribution of biomass over TL: position of inflection point.	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	1	1	0	0.5
Indicator proposed by WGSAM	C1	C2	C3a	C3b	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16
LFI	S	1	0	1	1	1	0.5	1	0.5	1	1	1	0	1	1	0	0.5
95%-tiles of length of individuals in fish community in surveys	S	1	0.5	1	1	1	0.5	0	0.5	0.5	0	0.5	0	1	1	0	0.5
95%-tiles of length of individuals in fish community in models	S	1	0.5	1	1	1	0.5	0	0.5	0.5	0	1	0	0	1	0	0.5
LSI	S	1	0	1	1	1	0.5	0	0.5	1	0	0.5	0	0	1	0	0.5
Total biomass of small fish hindcast	S	1	1	1	1	1	0.5	0	0.5	1	0	1	0.5	1	1	0	1
Total biomass of small fish forecast	S	1	1	1	1	1	0.5	0	0.5	1	0	1	0.5	1	1	0	1
Gini-Simpson diversity index for predators and prey	S	1	1	1	1	1	0.5	0	0.5	0	0	1	0	0	1	0	1
Gini-Simpson dietary diversity of each fish species in models	S	1	1	1	1	1	0	0	0	0	0	1	0	0	1	0	1
Community biomass of pelagic, forage, demersal, benthos and total	S	1	1	1	1	1	0.5	0	0.5	1	0	1	0	1	1	0	1
Average Trophic Level (TL) of community	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	1	1	1	0.5
Mean TL of the catch	S	1	0.5	1	1	1	0.5	0	0.5	0	0	1	0	1	1	1	0.5

LSI: proportion of biomass belonging to species larger than a certain Linf threshold. LFI: proportion of biomass of individuals larger than a certain L threshold.

Table 5.4. Final score of the different indicators. Indicators with a total score/max score between 0.5 and 0.75 are in yellow, indicators with a total score/max score>0.75 are

Indicator proposed by WGSAM	Total score/max score	WGSAM Score
Descriptor 1 - Biological Diversity		
Gini-Simpson diversity index (species dominance) of large fish and of small fish by biomass.	0.57	0.14
Gini-Simpson dietary diversity of each fish species from stomachs Barents Sea	0.51	0.00
Gini-Simpson dietary diversity of each fish species from stomachs Baltic Sea	0.51	0.00
Gini-Simpson dietary diversity of each fish species from stomachs (other areas)	0.37	0.00
Gini-Simpson dietary diversity of each fish species from models Barents Sea	0.57	0.00
Gini-Simpson dietary diversity of each fish species from models Baltic	0.57	0.00
Gini-Simpson dietary diversity of each fish species from models North Sea	0.57	0.00
Gini-Simpson dietary diversity of each fish species from models Bay of Biscay	0.54	0.00
Pelagic biomass/demersal biomass from models	0.71	0.36
fish biomass/benthos biomass from models	0.63	0.16
Average Trophic Level (TL) of community	0.66	0.16
Mean TL of the catch	0.66	0.16
Descriptor 3 - Populations of commercially exploited fish and shellfish		
Fishing mortality (F)	0.92	0.92
Community F (catch/biomass)	0.63	0.63
Ratio between catch and biomass index (hereinafter catch/biomass ratio)	0.60	0.30
Spawning-stock biomass (SSB)	0.84	0.42
Secondary indicator: Biomass indices	0.79	0.20
Mean maximum length across all species found in research vessel surveys	0.54	0.00
95% percentile of the fish length distribution observed in research vessel surveys	0.54	0.14
95% percentile of the fish length distribution observed in models	0.57	0.14
Descriptor 4 - Foodwebs		
Performance of key predator species using their production per unit biomass (productivity)	0.83	0.41
Total (F+M) fish species, in practice only assessed stocks.	0.66	0.33
natural mortality of fish species, in practice only assessed stocks.	0.63	0.31
Mean weight at age of predatory fish species from data	0.63	0.31

Loss in secondary production resulting from fishing. (L index)	0.57	0.14
Gini-Simpson dietary diversity of each fish species from stomachs Barents Sea	0.51	0.00
Gini-Simpson dietary diversity of each fish species from stomachs Baltic Sea	0.51	0.00
Gini-Simpson dietary diversity of each fish species from stomachs (other areas)	0.37	0.00
Gini-Simpson dietary diversity of each fish species from models Barents Sea	0.57	0.00
Gini-Simpson dietary diversity of each fish species from models Baltic	0.57	0.00
Gini-Simpson dietary diversity of each fish species from models North Sea	0.57	0.00
Gini-Simpson dietary diversity of each fish species from models Bay of Biscay	0.54	0.00
Mean transfer efficiency for a given TL or size.	0.57	0.14
Average recruitment anomaly in forecast	0.43	0.00
Average recruitment anomaly in hindcast	0.57	0.00
Slope of size spectra	0.66	0.33
Cumulative distribution of biomass over TL: slope	0.60	0.15
Cumulative distribution of biomass over TL: position of inflection point.	0.60	0.15
LFI (proportion of biomass of individuals larger than a certain L threshold)	0.74	0.00
95%-tiles of length of individuals in fish community in surveys	0.60	0.15
95%-tiles of length of individuals in fish community in models	0.57	0.14
LSI (proportion of biomass belonging to species larger than a certain Linf threshold) survey	0.54	0.00
LSI (proportion of biomass belonging to species larger than a certain Linf threshold) model	0.57	0.00
Total biomass of small fish hindcast	0.73	0.36
Total biomass of small fish forecast	0.73	0.36
Gini simpson diversity index for predators and prey	0.60	0.30
Gini-Simpson dietary diversity of each fish species in models	0.51	0.00
Community biomass of pelagic, forage, demersal, benthos and total	0.71	0.36
Average Trophic Level (TL) of community	0.66	0.16
Mean TL of the catch	0.66	0.16

6 ToR E: Report on progress on including new stomach samples in the ICES area in multispecies models

A program of regular stomach sampling is needed not only to ensure that multi species and ecosystem models remain relevant but also to advise on the MSFD descriptor 4 regarding the structure and functioning of foodwebs. The stomach sampling currently ongoing is sporadic in many ecoregions and improvements are necessary in these areas to enable estimation of e.g. natural mortality. Further, a longer term perspective is also needed for the monitoring of foodwebs (e.g. changes in diet of predators over time, see ToR d).

6.1 Stomach tender project

The ongoing study financed by the Commission to sample stomachs in the Baltic and North Sea in 2013 (MARE/2012/02) will provide an expected increase of the Baltic Sea stomach database by 150% and supply new data for three predators (1600 mackerel stomachs, 1600 grey gurnard stomachs, 800 hake stomachs). Further details can be found in WGSAM 2012.

The project has provided insight into potential challenges when sampling on existing surveys, most dominantly in areas such as the North Sea where a large range of fish species must be sampled for biological characteristics such as age and maturity. The IBTS surveys in 2013 have both been challenged by periods of inclement weather, limiting the time available to process catches to the absolute minimum. In this situation, it was not always possible to obtain the targeted number of stomach samples as task funded directly under the DCF which take precedence over added tasks such as stomach sampling. On some research vessels, this problem can be addressed partly by increasing the number of staff members, but this is not possible on all vessels and also represents an unnecessary added cost in cases where the weather on the entire survey is fair.

6.2 Methods for analysing stomachs and uploading stomach data to the ICES stomach database

A detailed manual with best practices in stomach contents sampling has been published as 'Manual for ICES Stomach sampling projects in the North Sea and Baltic Sea' (ICES, 2010). Stomach sampling analysis and database format should follow this manual where possible. ICES hosts the joint ICES stomach database, and data in the agreed format can be sent by e-mail to Anna Osypchuk (anna.osypchuk@ices.dk). Questions related to the ongoing Baltic stomach sampling should be placed to the project coordinator, Bastian Huwer (bhu@aqua.dtu.dk).

6.3 Update of DAPSTOM database

Work has recently been completed (at Cefas; as part of the EU Euro-Basin project) updating the 'integrated database and portal for fish stomach records' (DAPSTOM v 4.5). As part of MARE-2012/02 the taxonomy in DAPSTOM and the ICES 'Year of the Stomach' databases have been harmonized by cross-referencing NODC, Aphia/Worms and TSN codes making the databases interoperable. An additional c30,000 records have been added to DAPSTOM from project partners (Ifremer, IMR, Marine Institute-Ireland, MRI, Cefas) including 20,720 records of pelagic species. As of September 2013, the total number of records in the DAPSTOM database is 207,907

(237,617 individual stomachs) from 184 predator species sampled during 1836 - 2012. The largest proportion of samples come from the North Sea (62%) followed by Celtic Sea (11%), Irish Sea (10%), Spitsbergen and the Barents Sea (5%), Norwegian Sea (2%) Greenland Sea (2%) and other areas (7%). All records are available via the DAPSTOM data portal: www.cefas.defra.gov.uk/fisheries-information/fish-stomach-records.aspx.

6.4 Update of Celtic Sea Blue Whiting GADGET submodel

Within the Euro-Basin project Cefas and Ifremer have committed to revisiting the blue whiting submodel of an existing 3 species 'GADGET' model for the Celtic Sea developed under the FP5 project DST[2] (ended 2004). Updates of the existing model include using recent survey and catch datasets (from ICES stock assessment reports), implementation of 3 areas (south, central, north) with migration among these regions and implementation of growth and recruitment functions that take account of climate variability (Figure 6.1).

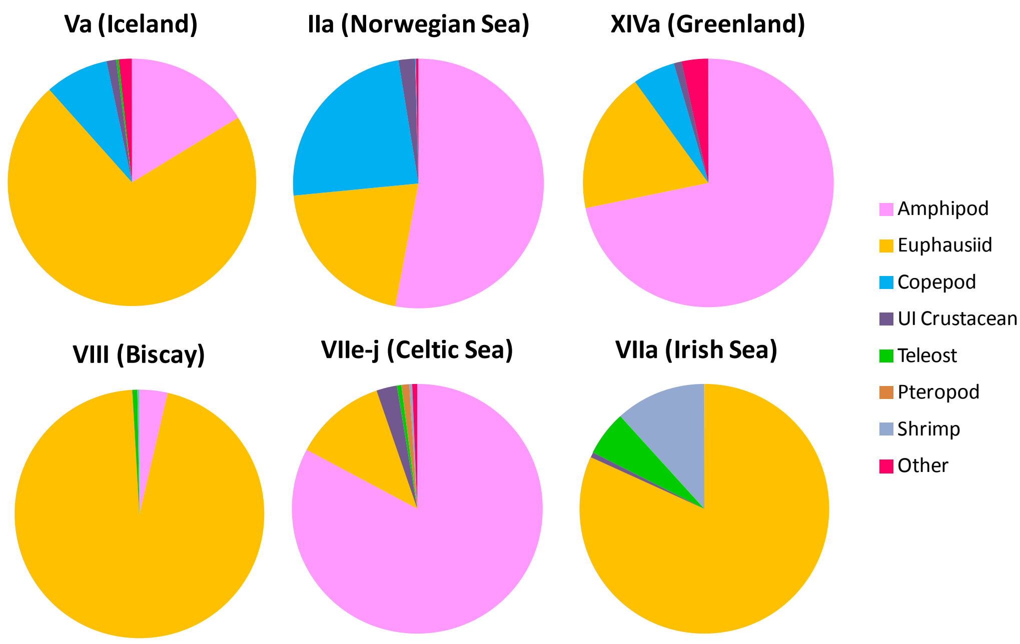


Figure 6.1. Stomach content analysis of Blue Whiting from DAPSTOM.

The revised model has been developed for the time period 1984 – 2011, with quarterly time-steps. Ten age classes (1-10) and $M = 0.2$ at all ages. Growth is derived according to a von Bertalanffy growth function with 16 length classes (from 9-41cm). Key data sources include landings data for each region and quarter, commercial and survey catches by length for each region, an age-length key (numbers by length and age) within survey and fishery catches and a survey index for each region (EVHOE-south, IBWSS-central, IESSNS-north). Using the estimated number of individuals in each area, by quarter and length class the total quantity of food (euphasiids/amphipods) consumed is calculated assuming 'gastric-evacuation' equations developed for cod feeding on krill (Temming and Herrmann, 2003). Investigation of the blue whiting stomach content records from DAPSTOM has revealed substantial regional variation across the geographic range, with euphausiids dominating in Iceland, the Irish Sea and Bay of Biscay, whereas hyperiid amphipods dominate in Greenland, the Norwegian Sea and Celtic Sea – in terms of absolute prey numbers (Figure 6.1). Copepods (mainly *Calanus finmarchicus*) were an additional important prey item in the Norwegian Sea and shrimps (in particular *Pasiphaea sivado*) were commonly observed in stomachs from the Irish Sea.

6.5 Historical diets, foodweb dynamics and climate change in the Barents Sea

As part of a Cefas data archive project ('Trawling Through Time'), *c*23,000 records of cod and haddock diet have been digitized from the Barents Sea around Spitsbergen (spanning 1930–1959). These historic stomach samples were initially collected by UK Ministry of Agriculture, Fisheries and Food (MAFF) scientists on board commercial vessels. At this time the UK fisheries represented >80% of cod catches in the Barents Sea. Subsequently during 1949–1973 MAFF commissioned the RV Ernest Holt as a dedicated research vessel to monitor the Arctic fishing grounds. To date, the project has completed digitalization of logbooks (but not length composition) and historic stomach samples up to 1959.

Preliminary analysis of the historic stomach contents with cod size shows selection patterns, in which amphipods dominate the contents of smaller size classes <10cm, replaced by krill (euphausiids) which initially increase and then decline with cod length, replaced by fish species in cod of >90cm (Figure 6.2). Initial analysis, by year demonstrates the ability to track strong year classes of prey species (cf. 1953 – strong Capelin year; Figure 6.2 and Figure 6.3), although further data checks and re-examination using Generalized Additive Models (GAM) will be carried out in the next few months. Cod populations in the Barents Sea are currently larger, than at any other time in the last 50 years. The last time that large populations existed in this region was in the late 1940s/early 1950s – i.e. the time covered by the MAFF/Cefas data series. It is hoped that analyses of the historic data, and contrasts with recent information, will help to provide insights into how such populations can be sustained as well as possible links (via feeding relationships) to climatic variables. In addition, the intention is to compare the resulting time-series with similar data collated by Russian authors, for the same period (from 1947 onwards).

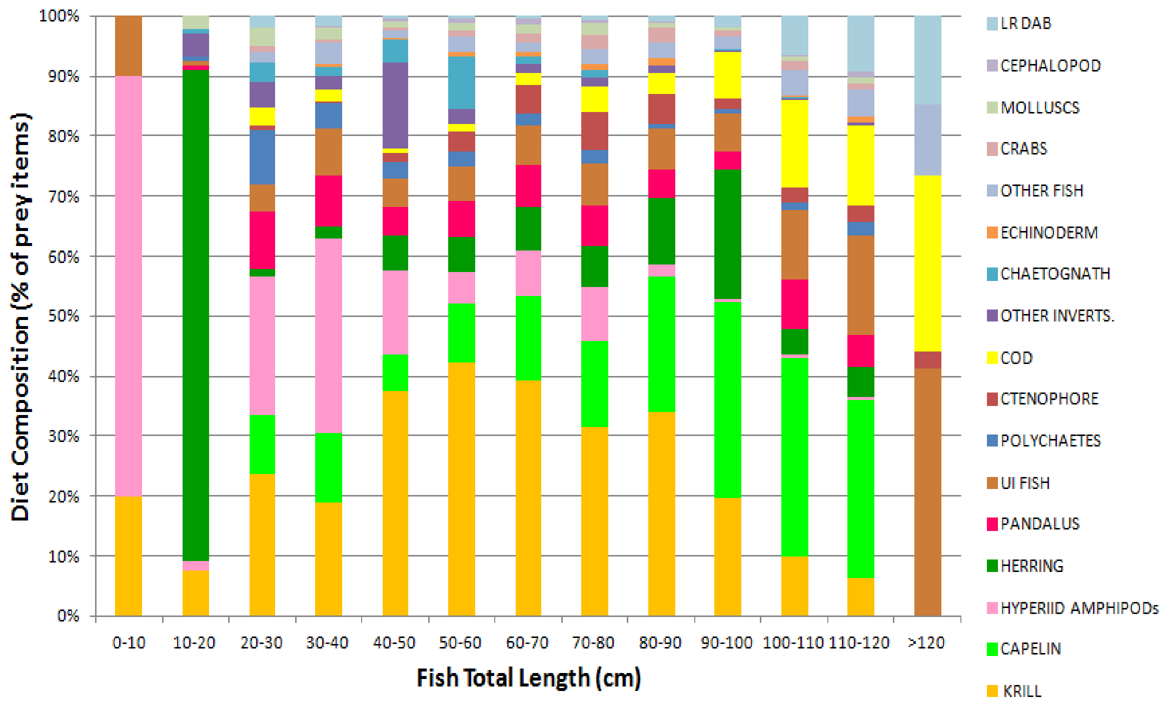


Figure 6.2. Historic (1936 – 1956) analysis of Barents Sea Cod stomach contents by cod length.

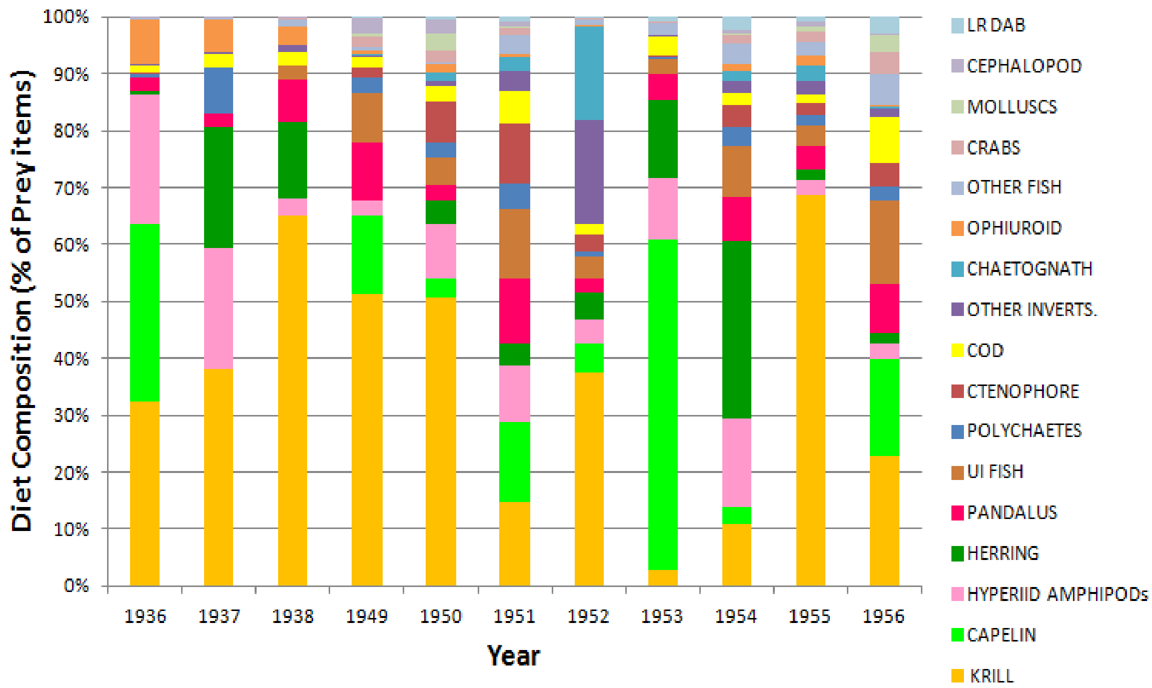


Figure 6.3. Historic (1936 – 1956) analysis of Barents Sea Cod stomach contents by year.

6.6 References

Temming, A., Herrmann, J. P. 2003. Gastric evacuation in cod: prey-specific evacuation rates for use in North Sea, Baltic Sea and Barents Sea multispecies models. Fish Res., 63: 21–41.

7 ToR F: Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points

7.1 Introduction

With demands from governments that fisheries management become more ecosystem centred, there is a push to include more species and environmental interactions into stock assessment models at both the strategic and tactic level. At the strategic level this involves using multispecies or ecosystem models to evaluate the overall behaviour of the system in response to different pressures (including fishing). On the tactical level, the inclusion of multispecies considerations into the assessment quota setting procedure may be desirable for some stocks. However there are important practical and theoretical considerations relating to the complexity of ecosystem or multispecies models that make implementing this difficult. On the theoretical side, the models are often complex and highly parameterized, making it difficult to ascertain how reliable the results should be considered. On the practical side, there are relatively few people skilled in these complex models when compared to the number of single species stock assessment scientists. Furthermore the time requirements to prepare these models is much higher than for single species models, and the optimization time required may fit poorly with traditional assessment timetables. This tension is, to some extent, being resolved in fisheries science today by a pragmatic approach of incorporating the minimum degree of extra complexity possible into single species stock assessment models in order to gain the desired improvement in ecological realism. There are several such approaches, which are in different stages of being incorporated into the advice giving process. Presented here is an overview of the current state-of-the-art in ICES for using multispecies modelling to give insights into MSY and inputs into annual quota giving advice. There follows several preliminary studies around the implications of moving further in the direction of multispecies management. One presents long-term implications of moving from current management to multispecies MSY. A second study presents an approach for examining the inherent uncertainties of such models, and the implications of that uncertainty on choices of FMSY and the utility of different community indicators.

7.2 Current state-of-the-art of multi species advice in ICES for MSY

A successful implementation of the ecosystem approach to fisheries needs information beyond what single species assessment models can deliver. ICES WGSAM deals with various multi species (e.g. SMS, Gadget) and ecosystem models (EWE, Atlantis) that can be used to either inform single species assessments or to supplement the traditional single-species advice. However, one big challenge is to move the often complex outputs from being interesting to a small group of specialists to being more widely useful and facilitate their incorporation into actual advice and management. During recent years ICES WGSAM has tried to condense and simplify the output from multispecies and ecosystem models to provide information on natural mortalities and foodweb indicators. Specific work has been carried out on MSY in a multispecies and ecosystem context to identify trade-offs between species but also on how to present the complicated results to stakeholders.

The complex trade-offs resulting from predator-prey interactions can be presented in a graph as used in the ICES advice on multi species considerations for Baltic fish stocks (Figure 7.1). The information in the graph can be further condensed to just give information on what interactions are most important (Table 7.1). Although the currently used format has been perceived positively by stakeholders, further progress could be achieved in standardizing the graphs to be able to compare the outputs from different models. It is maybe also possible to come up with plots that are more intuitive for stakeholders to understand. WGSAM will further work on this as it is most important to get stakeholders involved in the decision-making progress. Simulations can only delimit the space for sustainable exploitation within acceptable good environmental status (close to MSY). However, inside this space stakeholders have to decide on trade-offs and acceptable risk levels.

In general, multi species advice should include information on stock, community and foodweb indicators. Time-series of relevant indicators should be made available in electronic format to be used by single species assessment working groups (e.g. natural mortality trajectories). There should be advice on important interactions in the ecosystem and on trade-offs in yield between different species. Finally, combinations of precautionary fishing mortalities producing close to MSY yield should be identified. First examples of ICES advice on multi species considerations were produced for the Baltic and North Sea fish stocks in 2013.

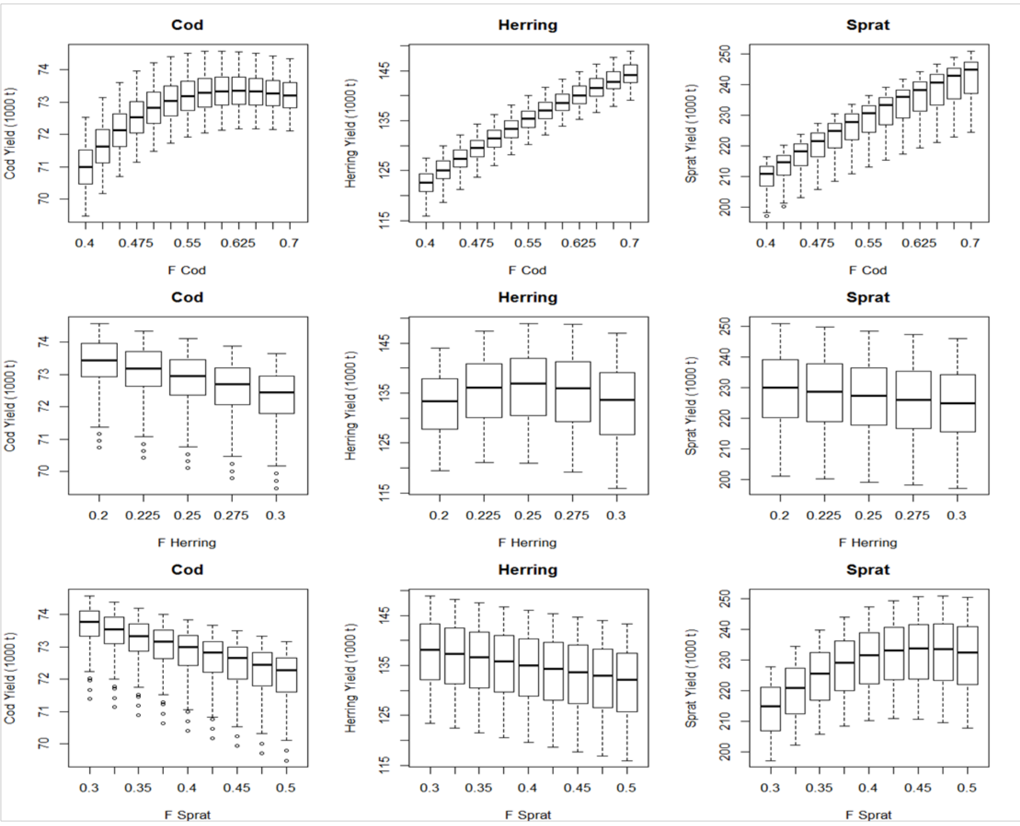


Figure 7.1. Yield of (from left to right) cod, herring and sprat as a function of (top to bottom) target F on cod, herring and sprat. The graph by species shows the distribution of yields for any given F shown on the X-axis, taking into account the range of Fs for the other species. Recruitment is deterministic in the simulations.

Table 7.1. Importance of changes in fishing mortality (rows) on yield (columns). Dark shading indicates high importance, light indicates low importance.

F\Yield	Cod	Herring	Sprat
Cod			
Herring			
Sprat			

7.3 Current state-of-the-art of multi species advice in ICES for quota setting

Examples of methods and case studies

The first approach is the custom one, shown here for Barents Sea capelin. Capelin are surveyed in the autumn, and the proportion maturing at that time is calculated. The fish then swim south to spawn and die the following spring. Fishing is conducted on their migration with an escapement rule, requiring a 95% for the SSB to remain above a set “safe” level. It was recognized early in the development of the fishery that estimating the significant cod predation between the time of the survey and the time of the fishery was one of the key challenges facing the assessment. Fortunately there is an extensive annual collection of cod stomachs, giving direct data on cod predation on capelin. This time-series of stomach datasets, together with the assessed biomass of cod is given as inputs to an extended single species model (“SeaStar”), which directly calculates the consumption mortality. As uncertainty is required by the Harvest Control Rule (HCR), the model also calculates this uncertainty. This procedure was first conducted for stock assessment in 1990.

The second approach is the generic one applied in the Baltic Sea and North Sea. Here there are issues regarding limited time-series of stomach contents, meaning that computing consumptions requires more modelling than in the previous example. The approach taken here is to run a multispecies (“SMS”) model every few years. This model provides partial natural mortalities, which are then input into the annual single species (“SAM” statistical catch-at-age model) assessments. This enables the annual assessments to be run without spending much extra time at the Working Group, but while accounting for the main multispecies interactions.

A final example is for the Barents Sea cod. Here the assessment is a straight single species “XSA” model. This stock has high levels of cannibalism, however most of the cannibalism occurs before the fish enter the fishery, so the stock assessment is able to ignore this. However the HCR requires a three year projection to be made, and year classes that are cannibalised in the assessment year will have entered the fishery within those three years. The forecast therefore uses an extension of the XSA methodology where an extra “fleet” is constructed after the XSA has been optimized. This fleet represents the age-dependant cannibalism, and is constructed from the XSA population of predatory cod and the stomach content database giving per cod consumption. The XSA is then re-optimized and the process is run to convergence. This allows the existing assessment model to produce

Discussion

The key feature in all of these approaches is pragmatism; producing the desired result with the minimum level of extra effort in the assessment cycle. Each approach has strengths and weaknesses. The custom approach gives a high level of flexibility and consistency, at the cost of development time and of making the assessment model more complex. The generic approach of importing partial mortality values streamlines the assessment process, but raises issues over the consistency of mortality values between different models, and renders the multispecies part a "black box" to many participants. The extension of the XSA model described here is ad hoc and case specific, but allows for extra realism for a relatively low investment of time. It should be noted that both of the Barents Sea examples presented here rely on the availability of high quality stomach (diet composition) data. In all of these cases there is no feedback from prey to predator. This enables major simplifications in the modelling procedure to enable the work to fit within the assessment framework. However, it also limits the range of pressures that can be modelled.

In all of these cases it is important that the signal of the predation effects outweigh the noise, such that significance of predation on the modelled populations can be detected. As noted previously, good quality diet composition data are key data for ensuring that the impact of predation is modelled well. The goal is the make the assessment "less wrong" than by ignoring the variable predation, and as long as the signal is sufficiently clear then it is likely that all of the approaches outlined here will achieve that goal. It is also clear that a "one size fits all" approach is not suitable – such an approach would result in too much energy being spent in some stocks and too little in others. In all of the cases here the work was tailored to the specific needs of that assessment, depending on biology, data availability and management requirements. An important precursor to including multispecies considerations into quota setting advice is therefore an analysis of what are the key drivers that need to be considered.

7.4 Optimizing fishing effort to achieve FMSY while simultaneously considering possible climate effects in the North Sea

Many fishing fleets catch a range of commercial species and multiple fishing mortality targets exist for assessed species. Current F_{msy} targets cannot be achieved simultaneously through changes in fishing effort alone. Recent work (Lynam and Mackinson in prep, Cefas) explores the objective solution to the problem of optimizing effort reductions in order to reach as close as possible to the fishing mortality targets for eight species of fish in the North Sea. To explore the effect of such a fishing strategy on the ecosystem, a foodweb model (EwE Key run, ICES, 2011) is projected forward, with and without climate forcing, and the direct fishing impact of the fleets and the indirect impacts propagated through the foodweb are evaluated. Many 'winners' arise through reduced fishing, including cod and herring, but other species such as haddock, whiting and megrim 'lose', their biomasses declining as a result of predation by the ascending predatory species, which include cod, saithe and seals. Preliminary results (Figure 7.2), to be examined in more detail, suggest that climate change has a strong effect on some groups (e.g. haddock) but little impact upon others (herring). The knock-on foodweb effects of climate change are important to consider in long-term management plans aiming to reconcile multiple objectives and faced with many trade-offs.

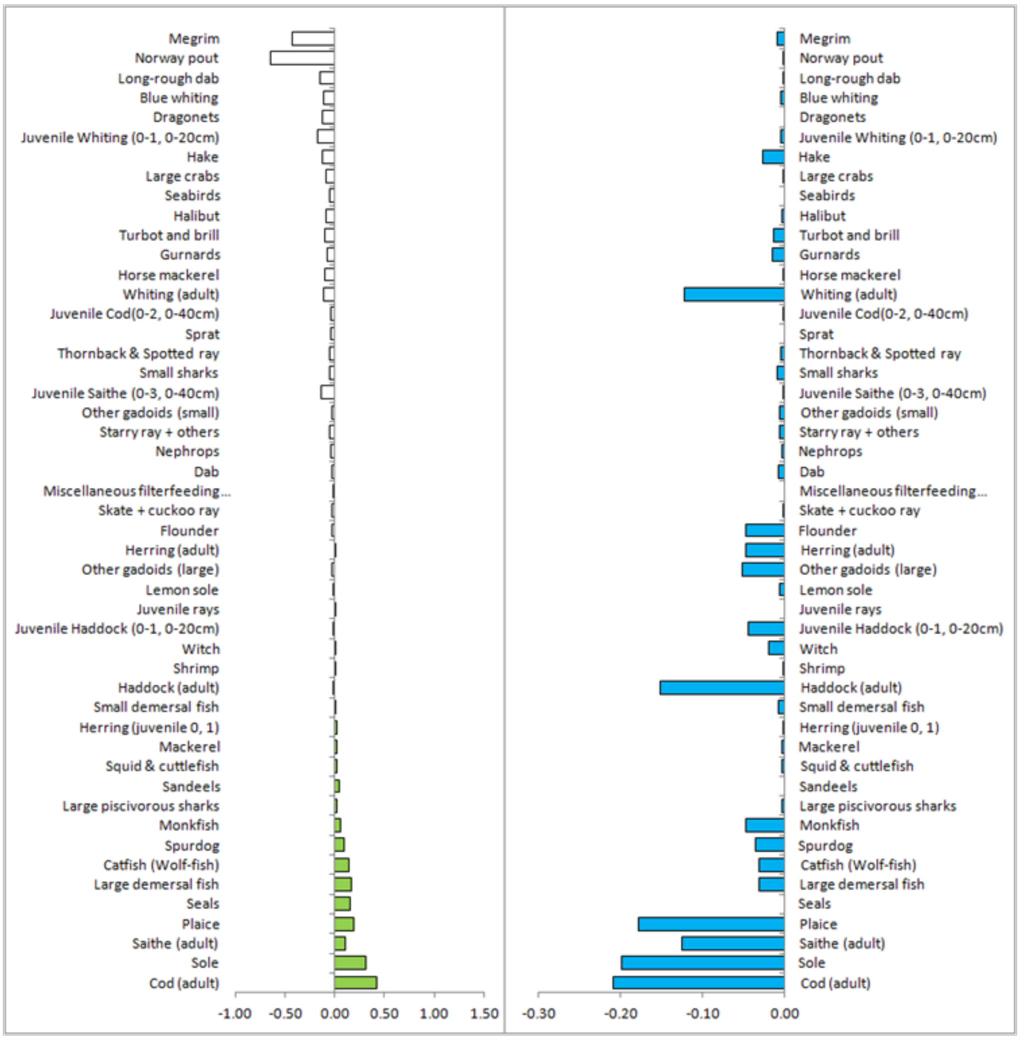


Figure 7.2. Preliminary results: Winners (green bars) and losers (white bars) in terms of percentage change in biomass in 2030 given percentage decreases in fishing mortality (blue bars) consistent with optimal fishing effort by fleet and including climate change effects.

7.5 Using the LeMANS North Sea fish community model to analyse parameter and structural uncertainty

A size-structured North Sea fish community model has been further developed. The core of the model is derived from the Hall *et al.* (2006) model for the Georges Bank, as modified by Rochet *et al.* (2011) for the North Sea. Three major improvements have subsequently been made to this model:

a) The original Ricker formulation of the stock–recruit relationship has been replaced with a hockey-stick representation. The Ricker formulation i) resulted in cyclic behaviour of biomasses of long L-infinity stocks, and ii) resulted in an unrealistic response of community size spectrum to changes in fishing pressure.

b) By improving the speed of model execution, it has become possible to run large numbers of models covering a variety of parameter choices, allowing one to relax the assumption of a "best" parameter setting, test sensitivity of predictions to parameter choices, and to make probabilistic forecasts.

c) New estimates of total-stock biomasses for the North Sea from swept-area surveys (Simon Jennings, personal communication) have been used in the parameterization of the stock–recruit relationships.

A model ensemble of "valid" variants of LeMans has been developed and used to make probabilistic forecasts that could be used in risk-based decision-making. The process of generating the ensemble is shown schematically in Figure 7.3.

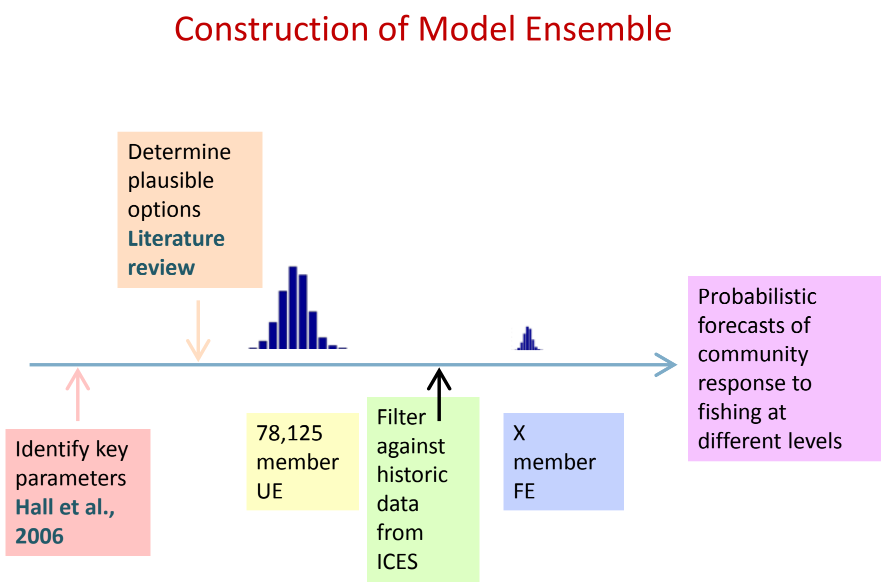


Figure 7.3. Schematic showing the manner in which the probabilistic forecasts (the filtered ensemble or FE) have been generated from the unfiltered ensemble (UE) spanning the 78,125 possible plausible parameter choices.

Expert judgement was used to set plausible values or treatments for 7 key variables (recruitment fertility and carrying capacity, L infinity, energy required per unit growth of predator, size of predation window, diet matrix, and natural mortality) in the LeMans model environment. Each one of these was allowed to take one of 5 values consistent with data, giving 5**7 or 78,125 variants consistent with expert judgement (the unfiltered ensemble or UE). Each of these variants was then assessed for its ability to reproduce average stock biomasses to within a factor of 2 for all 9 assessed North Sea stocks (Norway pout, sandeel, herring, sole, whiting, plaice, haddock, cod, and saithe). The subset consistent with stock data (the filtered ensemble or FE) was then used to make probabilistic predictions of community response to different fishing scenarios.

FE outputs are expressed as conditional probability distributions (e.g. for cod biomass under historic fishing pressure, Figure 7.4).

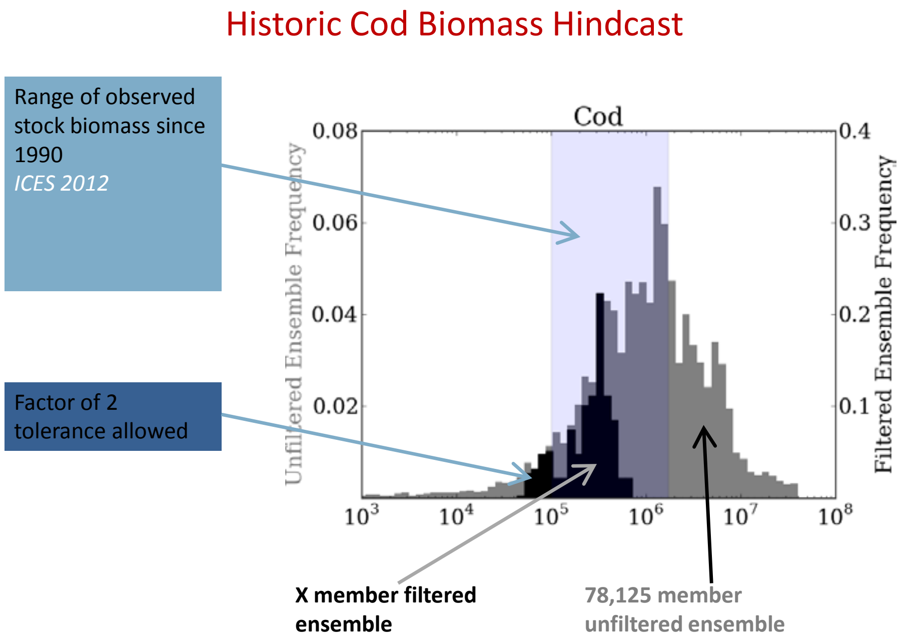


Figure 7.4. Probability hindcast of cod biomass under historic fishing.

The impact on the fish community of fishing each stock at various multiples of single species F-MSY estimates was estimated for the filtered ensemble of LeMans models that passed the data screening test. Results were then used to address the following questions:

1) Is it safe to fish the North Sea community at single species F-MSY estimates?

2) Does this achieve a good overall yield?

3) Can various fish community indicators distinguish between desirable and undesirable levels of fishing?

We found that fishing at the single species F-MSY estimates was in general safe, with only a 5% chance of witch stock collapse. Overall yield was also relatively high at > 90% of the maximum among the scenarios considered here. Figure 7.5 shows the signal to noise ratio for 2 putative ecosystem indicators, the large fish indicator or LFI and size spectrum slope.

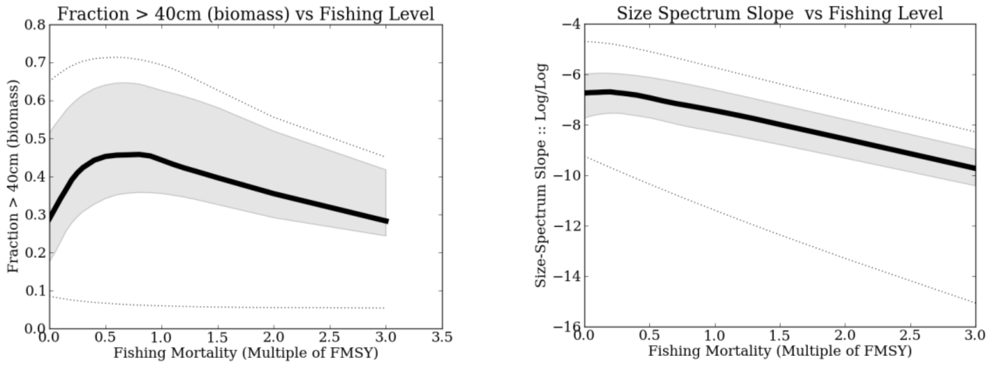


Figure 7.5. Relationship between a) LFI, and b) size spectrum slope and fishing pressure. The dark line is the ensemble mean response. The grey shaded region represents the 50% confidence range (25-75%) and the area between the upper and lower lines is the 90% confidence range (5-95%).

In order to be useful for management the indicator must be able to distinguish between desirable states (F<F-MSY) and undesirable states (F >> F-MSY). From Figure 6.5 it can be seen that neither of these indicators is able to do this, though the size spectrum slope has a better signal to noise ratio than the LFI and other things being equal would be the preferred indicator of the two if one of them was to be chosen. However in practice, we know something additional about the LFI, namely information about its actual value during the recent past. Incorporating this extra information might further constrain uncertainty and thereby improve the signal to noise ratio of the LFI. Whether this effect is sufficient to allow the LFI to be useful in management remains to be investigated.

7.6 On the need for a multi-model approach

Introduction

Currently multispecies advice is provided for the Baltic via the SMS model, and indicative advice is also provided for the North Sea. Such advice is conditional both on the parameter choices made in SMS and elements of the model structure (physical assumptions, assumptions about the important elements of the system to be modelled etc.). Whereas parameter uncertainty can be readily addressed within a single model framework, it is much more difficult to do this for structural uncertainty.

Here we present some evidence that structural uncertainty is potentially important, and therefore that we should be making use of more than one model when making multispecies projections to provide a more formal assessment of uncertainties associated with the model structure or structures we have used.

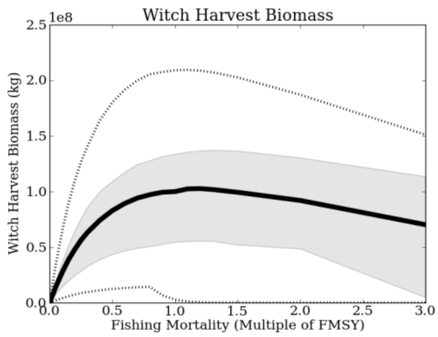
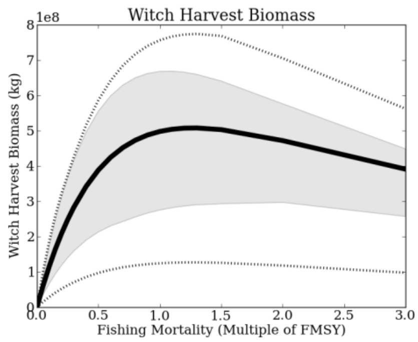
Sensitivity to the Number of Interactive Stocks

We explored the potential sensitivity of results to the number of interactive stocks in a model using an ensemble of LeMans models in which parameter uncertainty was already represented explicitly. In the baseline case (L21), we used the LeMans North Sea model which has 21 fish stocks, all of which can potentially interact with each other. Results were compared with a 9 stock version (L9), in which the nine assessed North Sea stocks (Norway pout, sandeel, herring, sole, whiting, herring, haddock, cod, and saithe) were allowed to interact with each other via predation as in L21, but the 12 non-assessed stocks were subject only to the model's background mortality.

For both L21 and L9, an unfiltered ensemble (UE) of 78,125 members spanning plausible parameter choices was generated, which was then tested against historic biomass data for the 9 assessed stocks. A subset of these models that was able to reproduce these biomasses to within a factor of 2 (the filtered ensemble or FE) was then used to generate projections of fish community response for both L21 and L9. More details on the method used can be found in ToR A: section 2, LeMans modelling in the North Sea.

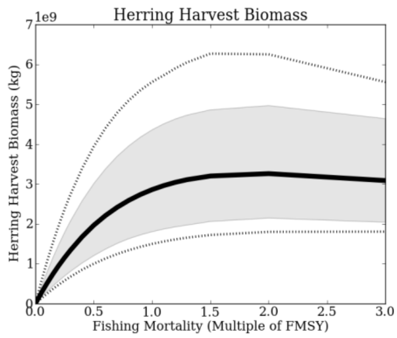
21 STOCK LEMANS MODEL (L21)	9 STOCK LEMANS MODEL (L9)
• 21 stocks, all potentially interacting with each other • 21 stock multispecies model	• 9 assessed stocks interactive: Norway pout, sandeel, herring, sole, whiting, plaice, haddock, cod, saithe • 12 non assessed stocks present but not interacting • 9 stock multispecies in parallel with 12 single stock models

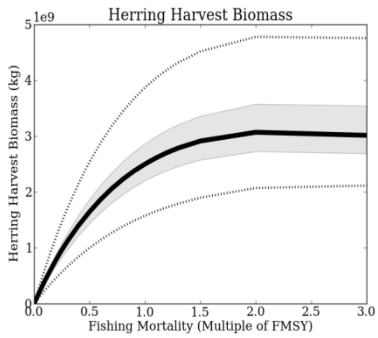
We then investigated how the stock biomasses and fish community indicators varied with fishing pressure, taking into account both parameter uncertainty and the number of interactive stocks (9 or 21). Some results are shown below. For all of these plots, the thick line represents the ensemble mean response, the grey band shows the 50% confidence interval (25–75%) and the area between the upper and lower lines is the 90% confidence interval (5-95%):

21 STOCK LEMANS	9 STOCK LEMANS
	

The projected witch yield is much lower in 21L than 9L, and there is a risk of stock collapse (increasing from 5% at F-MSY to 25% at 3x F-MSY), which is absent from 9L. This shows that where it occurs, witch stock collapse is caused by increased predation from the other stocks rather than a direct response to higher fishing. Of course it is not surprising that there are qualitative differences between 21L and 9L for witch as the stock is treated differently in the two cases.

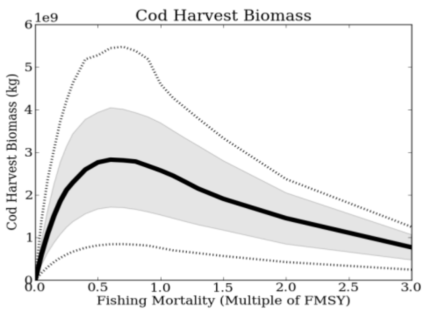
21 STOCK LEMANS	9 STOCK LEMANS

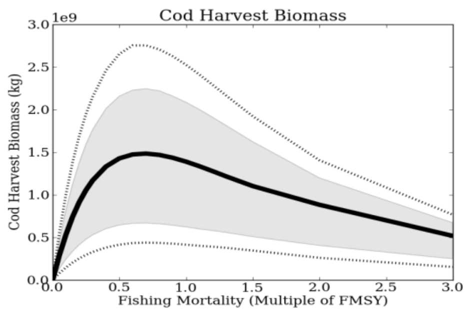




In the case of herring, the response is qualitatively similar in 21L and 9L, and the ensemble mean yield is virtually identical in the two cases, but the parameter uncertainties are much greater in 21L than 9L, although they have been generated using the same methodology. Thus our level of confidence depends not only on parameter choices, but also on issues of model structure.

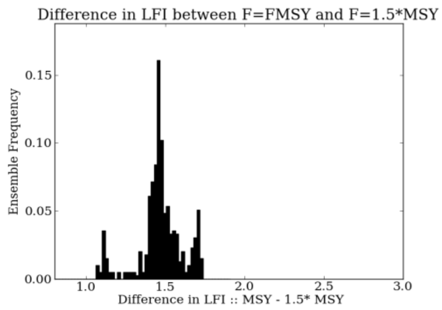
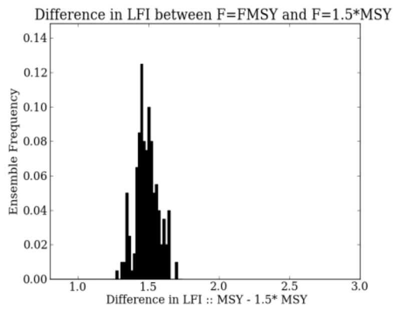
21 STOCK LEMANS	9 STOCK LEMANS





In the case of cod, qualitative behaviour is similar, but both the mean yield and uncertainties are sensitive to the structural change, being higher in 21L than 9L.

We also looked at the behaviour of the LFI and size spectrum slope. In the case of the latter, again we found greater levels of uncertainty in 21L than 9L. For LFI we looked at the relative change in the value at F~F-MSY and F~3xF-MSY.

21 STOCK LEMANS	9 STOCK LEMANS
	

Here we found that there is a more complex relationship in 21L than 9L. Behaviour at F=F-MSY is less of a guide to how the index might behave at 3xF-MSY in 21L than 9L, suggesting that the system dynamics is less complex in 9L than 21L and that some possible modes of system response are missing.

7.6.1 On evaluating structural model choices

In this case 21L is clearly superior to 9L, as it contains additional explicit multispecies interactions within the same general framework and with the same assumptions. So in this case we have an objective reason to prefer the results of 21L to 9L. However, in general it will not be obvious a-priori that one model structure is "better" than another, and in this case it makes sense to construct a "multi-model" ensemble using models with different structural elements and assumptions. Whereas the details of constructing such an ensemble may not be trivial, it should provide the best vehicle for investigating structural uncertainty. If results are common to all members of such an ensemble, we would be able to say they are robust (or more robust) to structural uncertainties and this should greatly enhance their credibility.

7.7 References

Lynam, C., and Mackinson, S. in prep. Exposing trade-offs in North Sea mixed fisheries management: ecosystem effects and the importance of climate.

Hall, S. J., Collie, J. S., Duplisea, D. E., Jennings, S., Bravington, M., and Link, J. 2006. "A length-based multispecies model for evaluating community responses to fishing". Canadian Journal of Fisheries and Aquatic Sciences, 63: 1344–1359.

Rochet, M-J., Collie, J. S., Jennings, S., Hall, S. J. 2011. "Does selective fishing conserve community biodiversity? Predictions from a length-based multispecies model", Canadian Journal of Fisheries and Aquatic Sciences, 68: 469–486.

8 ToR G: Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)

In principle, area structure can be implemented at a variety of scales into multispecies models indirectly via overlap factors or directly through incorporation of spatial structure into the model. However there are rarely data available on a sufficient spatial and temporal resolution to fully parameterize the distribution of fish on a fine spatial and temporal scale. There is therefore a tension between the level of realism desired in modelling spatial processes and the data available to support that modelling. Work is ongoing in this field, and a number of recent studies relate to this issue. WGSAM had intended to compare the approaches taken different areas (the Barents Sea, the North Sea and in the Baltic), however updated spatial work from the Baltic was not presented at the meeting, so only recent work from the Barents Sea and the North Sea is considered here. In both regions the spatial overlap was estimated externally and imported into the models, and in scenario modelling the future cod biomass was shown to be highly sensitive to the effects of differing degrees of predator-prey overlap.

A recent study has been conducted analysing changing cod-capelin overlap in the Barents Sea (Howell and Filin, in press), and predicting the likely outcomes for the stock trends and fisheries if the overlap change were to continue. It is known that there has been a long-term trend to more northerly distributions for both species and a greater degree of overlap, and that there are significant interannual variations. As part of this study, two different models (Gadget and STOCOBAR) were used to account for model uncertainty in the results. STOCOBAR is not area structured, and therefore used a varying overlap factor to account for the changing availability of capelin as prey for cod. Gadget does have spatial structure, and was therefore able to model the overlap directly. However, while there is good knowledge of the overlap during the Ecosystem Cruise conducted in September each year, there is little knowledge of the exact distributions and overlap for the rest of the year. Consequently Gadget used a quasi-area based approach, where the Barents Sea was divided into two regions (one northerly and Arctic water dominated, and one more southerly Atlantic water dominated region). These regions were not geographically defined, but allowed to move as the environmental conditions shifted, but scenarios were run with greater percentages of cod entering the northerly region. The results of comparison indicated that both approaches were able to capture the increased food availability for cod, and consequently predict lower overall cannibalism levels based on higher prey availability. This led to higher average biomasses of cod, but also greater instability in the cod population when a higher biomass of cod coincided with a period with little capelin. The inclusion of explicit spatial structure allowed for modelling a secondary cause of reduced cannibalism due mostly large cod moving north, thus reducing the overlap between cannibalistic and cannibalized cod. In both models the changing overlap was estimated externally and set as fixed input values.

The importance of taking into account spatial predator-prey overlap in estimating recovery potentials of North Sea cod has been demonstrated in an analysis with the multi species model SMS (Kempf *et al.*, 2010). As SMS is a one area model, the spatial dynamic of predator-prey interactions had to be implemented in an indirect way via overlap indices. SMS models predation mortality on the basis of food suitability and consumption. In the predation submodel the suitability coefficient (S) is as measure for predator preferences times 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 (but constant over years) overlap coefficient *so(i,j,q)* for each predator prey species combination:

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

In contrast to the standard SMS version the overlap coefficients were 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 because of over-parameterization problems and must be given as fixed input values.

Overlap data were derived from North Sea IBTS survey data for the years 1991 to 2007 obtained from the ICES DATRAS database as 'cpue per length per statrec' for the respective predator and prey species. North Sea wide spatial overlap for all possible combinations between predator entity (predator j of length class s) and prey entity (prey i of length class s) populations was estimated. As measure for spatial predator-prey overlap, the Schoener (percentage) overlap index (Schoener, 1970) was chosen, using the formula:

$$1 - 0.5 \sum_{m=1}^{n} \left| predator.pr - prey.pr \right|$$

where *predator.pr* and *prey.pr* represent the proportions of the North Sea wide predator and prey entity populations in each ICES rectangle *m* at time *t* (year–quarter combination). The resulting matrix of overlap coefficients was further transformed to meet the input requirements for SMS, 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 overlap coefficient 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 consumed prey length classes influence the mean value to a larger extent. As a second step a weighted mean overlap coefficient was calculated, this time 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 the weighting factor. The resulting 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 these years were used to carry out linear regressions between the different quarters for each predator species to determine the strongest relationships. The strongest relationships between neighboring quarters were used to extrapolate the matrix for the missing year-quarter combinations. As a result, multispecies hindcasts with variable overlap showed to some extent different recruitment dynamics for cod and whiting compared to the standard SMS run with constant overlap. The recovery potential of North Sea cod was highly influenced by assumptions on future spatial overlap between cod and its predators.

8.1 Reference

Kempf, A., Dingsør, G. E., Huse, G., Vinther, M., Floeter, J., and Temming, A. 2010. The importance of predator–prey overlap: predicting North Sea cod recovery with a multispecies assessment model. ICES Journal of Marine Science, 67: 1989–1997.

9 ToR NEW: Model evaluation and acceptance process.

WGSAM has received a request to evaluate a new multispecies model for use in advice. It is likely that as the ICES community moves towards integrated ecosystem assessments the number of modelling tools and the number of regions in which they are used will increase. WGSAM therefore proposes a formal procedure by which such new models could be "accepted" into the ICES advice process.

WGSAM suggests that there is a distinction to be made between accepting a modelling framework / tool (e.g. SMS) as suitable for giving possible advice (or inputs to advice) and accepting a particular model implementation relevant to region (e.g. the SMS of North Sea stocks). The acceptance of a particular implementation falls within the scope of the periodic acceptance of "key runs" which WGSAM already conducts for the North Sea and Baltic Sea. These key runs form an agreed standard that can be used to provide inputs to the single-species assessment models, or can be further developed by other researchers. Accepting a modelling tool is, however, a new topic for WGSAM, separate from the key run process. WGSAM recommend that the acceptance of a new key run from a previously untested modelling tool follows a two-step process: (1) the ability of the modelling tool to produce suitable outputs for use in advice, (2) the specific implementation for a particular region. These two steps should not be combined in a single meeting in order to avoid overloading WGSAM.

WGSAM provides a possible forum for evaluating and accepting new models, and subsequently new key runs for use in the advice-giving process. In order to facilitate this process there are a number of requirements that the model must satisfy:

- The modelling tool must have been through a peer review process, and the results of this review be made available to the group. This could be via a peer reviewed publication or via a specific ICES-organized review of the model.
- The model should be fully documented, with the documentation easily accessible.
- The model authors should have completed a summary sheet outlining the model structure, capabilities and limitations. A template for such a sheet is given in 9.1, and examples presented in Annex 5.
- Outputs should be available to test the model performance in a realistic setting. This could be in the form of demonstration of fit to historical data, a self-test of fitting to "data" output from the model, or in the form of fitting to other "known" datasets.
- When run, "unfished" (F=0 for all stocks), the model should not predict the elimination of stocks known to have been present at the onset of fishing.

When the above information is available a subgroup from WGSAM could evaluate the modelling tool, its documentation and the presented performance statistics in advance of the WGSAM meeting. A report from this subgroup would then form the basis of a discussion on whether the group would endorse the modelling tool. If so, then a specific model realization could go forward to the "key run" process, specified in section 4. One benefit of having members of WGSAM conduct this evaluation is that it would provide a level of competence and understanding of the model for the key run process.

It should be stressed that this proposed procedure is reliant on pre-existing peer reviews of the modelling tool. Without such reviews being available, WGSAM would not be able to conduct an evaluation in a timely manner or within the resources available. It should also be noted that this procedure does not extend to reviewing the code of the model directly, rather the stated algorithms governing the model and the model performance on the test datasets are the criteria on which acceptance would be based. The procedure and criteria developed here are, in large part, comparable to similar systems being developed in the United States for incorporating ecosystem modelling into management (e.g. Townsend *et al.*, 2008).

Resource implications

Although this process has resource implications for WGSAM, the workload is likely to remain manageable provided that the number of models to approve remains low, with respect to other tasks, and that the group's members are able to devote time to pre meeting evaluation. If the workload grows then it could rapidly exceed the capacity of WGSAM to handle. The capacity of WGSAM to evaluate periodic key run updates may also be exceeded if a large number of key runs for different models and regions need updating.

9.1 Model summary sheets (see Annex 5)

WGSAM considers that a brief description of the multispecies models in a common format would be valuable for introducing a new modelling tool to WGSAM or into the advice process. They would also be useful in facilitating understanding and comparison of the models, and for informing the choice of appropriate model for a new region or to address future issue. We recommend that ICES maintains a library of summary documentation for models in use in assessments within the ICES area. Such summary sheets have been developed for single species models by 'WKADSAM' in 2010 (ICES, 2010), and this report documents a template Figure 9.1 and examples for multispecies models for Gadget, SMS, OSMOSE, OSMOSE-ROMS-NPZD coupled model, Ecopath with Ecosim, STOCOBAR, LeMans, and MSI-SOM (Annex XX). The template resembles the format used for single species models, with a number of extensions to account for the other aspects of multispecies models. The aim here is to summarize the modelling tool in general, rather than a specific implementation (which is better done in a key run sheet). However, this distinction will be clearer for generalized "modelling toolbox" approaches than for custom designed models for a specific system.

Multispecies model summary sheet template (Complete sheet should not be more than two sides).

Figure 9.1. Template for the multispecies model summary sheet.

Model Name	Name
Contact details	Name of contact institute and/or contact e-mail, web address of model if possible
Category	From the 2007 FAO report: Whole ecosystem and dynamic system models (e.g. Atlantis, Ecopath), Minimum realistic models (e.g. SMS), Individual-based models (e.g. OSMOSE), Bioenergetic models
Generalized/custom	Model only developed in one region OR generalized modelling toolbox?
Model Type	Brief description of model, including equilibrium, deterministic or stochastic, process or regression-based. Do not include equations or detailed model structure, just an overview
Data used	List input data types e.g. fleet, surveys, age, length, stomachs, tags, environmental data, F, mortality, consumption rates, life-history parameters.......
Key model assumptions	Underlying simplifying assumptions
Time-step	Time-step of the model
Spatial Structure	Spatial Structure of the model
Estimated parameters	Parameters estimated. e.g. Growth parameters, Beverton–Holt recruitment, Annual deviation of recruitment, fishing selectivity,...
Outputs	Outputs of the model. e.g. stock numbers, biomass, M2s, catches,...
Model tuning	How is the model tuned? e.g. Statistical fit to data, values from literature
Uncertainties	How is uncertainty handled in the model and model outputs
Model accessibility	Open or closed source? Model website? Available on request?
Documentation	Describe level of documentation. Give reference to where documentation can be acquired.
Program language	Specify. Also if it possible to build models without programming? Is there a GUI?
Accepted WGSAM key run	Is there one or more accepted WGSAM key runs for the model?
Main purposes	What is the model good at?
Main limitations	What is the model less suited for? What other restrictions are there?
Examples where the model has been applied	Examples of implementations of the model
Peer review reference	References to papers and/or model reviews

9.2 References

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Annex 1: List of participants

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Annex 2: Agenda

ICES Working Group on Multispecies Assessment Methods (WGSAM),

Baltic Sea Centre, Baltic NEST Institute, Stockholm, Sweden, 21–25 October 2013.

Monday AM

- Agree Agenda and confirm contributions from participants
- **WCSAM feedback (DH, AK).**

ToR A. Report on further progress and key updates in multispecies and ecosystem modelling throughout the ICES region

PM

ToR B. Report on the development of key-runs. Report on the Baltic Sea EwE (MT)

New ToR – Operationalizing MS models (SM, DH, AR)

- Discussion – Operationalizing multispecies models for advice in management:

i) Role of WGSAM

ii) Benchmarking and standards

Tuesday AM and PM

New ToR – Operationalizing MS models … continued

Address specific requests from other WGs: briefing sheet for herring and sprat, plaice issue (See table at end of agenda)

Wednesday AM

ToR D. Develop and compare foodweb and ecosystem indicators (e.g. from the MSFD) and advice produced by multispecies key runs

(Using indicators and key run from North Sea key runs in 2012, Venice. (AR, SM, AK))

PM

ToR E. Report on progress on including new stomach samples in the ICES area in multispecies models (AR and others)

PLUS Request on stomach sampling

ToR G. Compare methods used to include spatial structure (predator prey overlap) in multispecies prediction models (DH and AF)

Thursday AM

ToR F Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points; DH, SM, AR)

PM

Work on Report/ extra requests

Friday: Reflect on ToRs and make final changes to the text.

- Decide date and location WGSAM 2014
- Work on Report

AR – Anna Rindorf; SM- Steven Mackinson; DH – Daniel Howell; AK – Alexander Kempf; MS – Moritz Staebler; MC- Maciej Tomczak;

Table 1. External requests from other working groups

ID	Request	WGSAM Action
104	WGSAM encouraged to enter a dialogue about the generation of an overview "top–down" briefing sheet, characterizing the current state of predatory and competitive influences of other species on the dynamics of herring and sprat in the Greater North Sea and Celtic Sea.	Look at WGOOFE sheets to see what is required. After new ToR
60	11. WGBIFS recommends that WGSAM provides detailed information on how to work up the Cod stomach samples and provides a database for storing the data.	Address at same time with ToRE. Confirm that methods for working up samples were published in WGSAM 2012, section 5.5. Where necessary advise on where to seek other relevant sampling protocols / either existing of from the project leaders. Consider WGSAM role. (AR, BB)
116	According to WGNSSK estimates, the North Sea is currently ongoing a plaice outburst without precedent. However, plaice is not included in multispecies models, so the consequences of this outburst on the North Sea ecosystem are unclear and would potentially require additional focus	WGSAM to consider advice on the changes in the predation mortality of plaice (North Sea) on its prey and consequences for predators of plaice. This might best be done in 2014 when updated key run models are done, thus capturing changes in abundance of plaice. (propose A. Kempf to lead): After New ToR
117	WGBFAS recommend MULTBAL to have annual updated SMS and not only every 3rd year.	Discuss with ToR B (AR)

Annex 3: WGSAM terms of reference for the next meeting

The **Working Group on Multispecies Assessment Methods** (WGSAM) chaired by Daniel Howell, Norway and Steven Mackinson, UK, will meet in London, 20–24 October, 2014.

ToR descriptors

ToR	Description	Background	Science Plan topics addressed	Duration	Expected Deliverables
A	Report on **further progress** and key updates in multispecies and ecosystem modelling throughout the ICES region	This ToR acts to increase the speed of communication of new results across the ICES area	Use codes	3 years	Reports on further progress and key updates for internal use in WGSAM as well as externally.
B	Report on the development of **key-runs** (standardized model runs updated with recent data, producing agreed output and agreed upon by WGSAM participants) of multispecies and ecosystem models for different ICES regions (including the Baltic EwE 2013, Barents Sea 2014, North Sea EwE 2014, North Sea SMS 2014, Baltic Sea SMS 2015 and others as appropriate)	The key runs provide information on natural mortality for inclusion in various single species assessments	Use codes	3 years	Output of multispecies models including stock biomass and numbers and natural mortalities for use by single species assessment groups and external users.
C	Where possible, develop standards for 'Key Runs' of other modelling approaches (e.g. Size spectra, TGAMs)	This work is aimed at expanding the key runs to include methods not currently suited for providing this type of information.	Use codes	3 years	Key run standards for use under ToR b and externally

D	Develop and compare **foodweb and ecosystem indicators** (e.g. from the MSFD) and advice produced by multispecies key runs (preferably together with WGFE and WGECO)	Foodweb and ecosystem indicators are increasingly demanded in management, paricularly through the implementation of the MSFD. To be succesful, the ToR requires a supporting ToR in WGECO and/or WGFE	Use codes	3 years	Foodweb indicators and advice on their development under different fisheries management scenarios (as part of multispecies advice) for WGECO, other ecosystem groups and single species assessment groups
E	Report on progress on including **new stomach samples** in the ICES area in multispecies models	WGSAM actively works for obtaining new stomach sampling programmes and incorporating the data from these programmes in multispecies models.	Use codes	3 years	New stomachs are included in the models to enhance the quality of deliverables under ToR b.
F	Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (**MSY related and other biological reference points**)	Multispecies reference points such as those related to MSY and the effect of environmental changes on these reference points is a key point in multispecies advice.	Use codes	3 years	Multispecies advice will be provcided wherever possible based on key runs developed under ToR B. Uncertainties in models will be taken in to account.
G	Compare methods used to include **spatial structure** (predator prey overlap) in multispecies prediction models (preferably together with WGIPEM)	Spatial structure is increasingly taken into acount in retrospective multispecies modelling. Methods are currently developed in several groups and a comparison of these methods would facilitate the future development. To be succesful, the ToR requires a supporting ToR in WGIPEM		3 years	Report on joint activities together with WGIPEM for use as basis of future work in WGSAM, WGIPEM and other groups addressing spatial concerns.

H	Work towards providing ecosystem advice consistent with species and technical interaction in mixed fisheries (preferably together with WGMIXFISH)	Currently, ecosystem advice on mixed fisheries and mutlispeciesissues are parallell and not coordinated. This coordination is of great importance to avoid inconsistencies. To be succesful, the ToR requires a supporting ToR in WGMIXFISH	3 years	Joint multispecies-mixed fisheries ecosystem advice for use in single species assessment groups. Where models are used as a basis for advice, effects of model uncertainties will be taken into account.

Summary of the Work Plan

Member contributions to any of the ToRs will be accepted in any year, but where possible, effort will be made to focus WG activities on particular ToRs as proposed below:

Year	Work
Year 1	Work on all ToRs. Tor B restricted to Baltic EwE. Focus on D, E, G
Year 2	Work on all ToRs. Tor B restricted to Barents Sea Gadget, North Sea EwE 2014 and North Sea SMS. Focus on B, C, H
Year 3	Work on all ToRs. Tor B restricted to Baltic Sea SMS. Focus on F, H

Plans for 2014

ToR H: Work towards providing ecosystem advice consistent with species and technical interaction in mixed fisheries.

In 2014, WGSAM will invite WGMIXFISH (and possibly WGMG) members to discuss synergies in the use of models to address mixed-fisheries and multispecies issues. In particular, the discussion will focus on the level of fleet aggregation in multispecies models and how outputs on fishing mortality from multispecies models might be useful to feed into mixed-fisheries models.

Building on this initiative we hope to have representation of WGSAM members at WGMIXFISH meetings in 2014.

ToR F: Explore the consequence of multispecies interactions and environmental factors in practical multispecies advice for fisheries management (MSY related and other biological reference points)

d) In 2014 the group will outline suggestions on how output from different models can be usefully combined for ensemble-type provision of advice. This will be built upon in future years.

Supporting information

Priority	The current activities of this Group will lead ICES into issues related to the ecosystem effects of fisheries, especially with regard to the application of the Precautionary Approach. Consequently, these activities are considered to have a very high priority.
Resource requirements	The research programmes which provide the main input to this group are already underway, and resources are already committed. Depending on the requirements for advice, additional resource might be required to undertake ToR H since the resource needed to shape the research into ICES advice and communicate it is likely to be more substantial than research projects can provide.
Participants	Approx 20. Expertise in ecosystem, modelling and fish stock assessment from across the whole ICES region.
Secretariat facilities	None.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	ACOM, most assessment Expert Groups
Linkages to other committees or groups	WGMIXFISH, WGDIM, WGBIFS, IBTSWG, WGECO, WGFE, WGINOSE, WGIAB, WGNARS, WGIPEM, most assessment Expert Groups, most EGs in the regional Seas Programme. STECF Ecosystem Approach WG.
Linkages to other organizations	

Annex 4: Recommendations

1.WKFooWI should examine the work on conducted on foodweb and ecosystem indicators, presented in section 5.	WKFooWI
2. A possible procedure for accepting first new multispecies models and subsequently key runs for specific Ecoregions is presented in Section 9 of the report. WGSAM recommends that this be considered by ACOM.	ACOM
3. The multispecies modelling summary sheets (section 9 and annex 5) should be considered by WGMethods, in light of the single species model summary sheets produced by WKADSAM. We further recommend that a library of both single- and multispecies modelling summary sheets be made available on the ICES website.	WGMG, ICES

Annex 5: Multispecies model summary sheets

Introduction

As suggested under ToR new (above), WGSAM has designed a template for summarizing multispecies models. Presented in this appendix is a template for such multispecies modelling summary sheets, followed by 8 different worked examples for the models available at WGSAM 2013.

Multispecies model summary sheet template (Complete sheet should not be more than two sides)

Model Name	Name
Contact details	Name of contact institute and/or contact e-mail, web address of model if possible
Category	From the 2007 FAO report: Whole ecosystem and dynamic system models (e.g. Atlantis, Ecopath), Minimum realistic models (e.g. SMS), Individual-based models (e.g. OSMOSE), Bioenergetic models
Generalized/custom	Model only developed in one region OR generalized modelling toolbox?
Model Type	Brief description of model, including equilibrium, deterministic or stochastic, process or regression-based. Do not include equations or detailed model structure, just an overview
Data used	List input data types e.g. fleet, surveys, age, length, stomachs, tags, environmental data, F, mortality, consumption rates, life-history parameters.......
Key model assumptions	Underlying simplifying assumptions
Time-step	Time-step of the model
Spatial Structure	Spatial Structure of the model
Estimated parameters	Parameters estimated. e.g. Growth parameters, Beverton–Holt recruitment, Annual deviation of recruitment, fishing selectivity,...
Outputs	Outputs of the model. e.g. stock numbers, biomass, M2s, catches,...
Model tuning	How is the model tuned? e.g. Statistical fit to data, values from literature
Uncertainties	How is uncertainty handled in the model and model outputs
Model accessibility	Open or closed source? Model website? Available on request?
Documentation	Describe level of documentation. Give reference to where documentation can be acquired.
Program language	Specify. Also if it possible to build models without programming? Is there a GUI?
Accepted WGSAM key run	Is there one or more accepted WGSAM key runs for the model?
Main purposes	What is the model good at?
Main limitations	What is the model less suited for? What other restrictions are there?
Examples where the model has been applied	Examples of implementations of the model
Peer review reference	References to papers and/or model reviews

Model Name	Ecopath with Ecosim (EwE) and Ecospace.
Contact detail	Cefas
Generalized/custom	Generalized toolbox
Category	Dynamic whole ecosystem model
Model Type	Ecopath is a mass-balance model quantifying interactions among predators and prey in marine foodwebs (Christensen and Walters, 2004). Species or functional groups, ranging from plankton, to fish, and marine mammals. Landings and discard compositions of fishing fleets, together with detail of their economic performance, enables consideration of mixed fisheries issues simultaneously with multispecies issues. Ecosim (Walters *et al.*, 1997) provides a dynamic simulation frame work to evaluate the direct and indirect effects of fisheries and environmental change on ecosystem components. Ecospace (Walters *et al.*, 1999) extends Ecosim capabilities to account for spatial dynamics of species and fishing fleets. Using versioning control systems and a modular 'plug-in'approach, the software is under continuous development by several institutes around the world. Some recent developments include modules on parameter uncertainty analysis, Management Strategy Evaluation, Network analyses, Layer-based spatial modelling (Habitat capacity model) and tools for evaluation of MSY in a multispecies context.
Data used	Ecopath – foodweb description data for each species/functional group: • Biomass (t/km2) • Production/Biomass (y-1) • Consumption/Biomass (y-1) • Diet composition (%) • Catches, specified as landings and discards for each fleet • Fleet economics: landed values, including fixed and variable fishing costs • Biomass accumulation rates For multistanza groups • VBGF-k • Weight at maturity and W∞ Ecosim - calibration data (those in bold are used to drive model dynamics, others used as data for fitting model predictions to during parameters estimation): • **Fishing Mortalities (F)** • **Relative fishing effort for each fleet** • **Primary production anomalies (annual)** • Biomasses absolute • Biomass relative (from stock assessments, surveys) • Catch • Mean weights • Total mortality (Z) Ecospace – data for specification of spatial distributions • 'Habitat' layers (e.g. depth, substrate) • Environmental condition layers (e.g. temperature, salinity) • Fishing costs • Dispersal rates • Advection and migration patters

	• Location of protected areas
Key model assumptions	Ecopath: equilibrium ecosystem (mass balanced), where biomass accumulation is included the system is not in steady-state, but still adheres to mass-balance. Ecosim: • Use of mass-balance results (from Ecopath) for parameter estimation • Forging arena theory (Walters and Martell 2004) as the foundation for representing predator prey interactions and its effect on the foodweb dynamics. • Includes biomass dynamics for key ecosystem groups, using a mix of differential and difference equations. • Multi-stanza life stages for important components (a simplified ontogenetic structure) that includes structure by monthly cohorts, density- and risk-dependent growth • For multistanza groups, stock–recruitment relationships are an 'emergent' property of competition/predation interactions of juveniles. • Variable speed splitting for efficient modelling of the dynamics of both 'fast' (phytoplankton) and 'slow' groups (whales); Ecospace: • Habitat capacity model links species distributions with environmental conditions • Fleet distribution linked to sailing and distance weighted costs, but can be overwritten with data (e.g. inverse VMS effort)
Time-step	Monthly time-step internal calculation with annual average output. Can be modified.
Spatial Structure	Made explicit in Ecospace – resolution depends on specific application and data
Estimated parameters	Depends on specific EwE framework application for given ecosystem but usually for: Ecopath – Ecotrophic Efficiency, for multi-stanza groups -B and Q/B for other than leading multistanza, Respiration and Assimilation rates. Ecosim – vulnerability(v) ; PP anomaly
Outputs	Ecopath – Mortalities (F; M2) consumptions, trophic flows, transfer efficiency, trophic levels (for group, for catch); foodweb indices i.e. omnivore Index, ecosystem indicators. Ecosim –outputs per group or fleet - Biomasses; Mortality rates (F; M2), Consumptions; diet compositions, catches , electivity (standardized forge ratio), MSY, ecosystem indicators
Model tuning	Ecopath – data from literature values, other models, fields surveys, monitoring data, empirical relationship, values manual tune to balanced model within ecologically reasonable range. Ecosim - Marquardt non-linear search algorithm used to to search for vulnerabilities that minimize the weighted sum of squared differences (SS) between log reference and log predicted biomasses.
Uncertainties	Sensitivity analysis for Ecopath parameters • Pedigree – formal way to describe level of trust in input data • Monte Carlo Makarov Chain routine in Ecosim to evaluate effect of Ecopath parameter uncertainty on the model fit to data • New routine (release in 2014) estimate impact of Ecopath and Ecosim parameter uncertainty on possible representations of the ecosystem and performance of management strategies.

Documentation	Available with software and online (Christensen *et al.*, 2005)
Model accessibility	Open Source (www.ecopath.org) source code available on request with version control via SVN
Program language	MS.NET, software package with GUI
Peer review reference	Walters *et al.* 1997, Walters *et al.* 1999, Walters *et al.* 2000, Christensen and Walters 2004, Plagányi and Butterworth 2004, Walters and Christensen 2007.
Accepted WGSAM key run	North Sea updated 2011 (ICES, 2011)
Main Purposes	Ecopath: Mass-balance of system, typology and foodweb structure analysis, trophic flow analysis, Ecological Network Analysis, comparative ecology. Ecosim: Medium (<10 years) and long-term strategic simulation of fisheries-ecosystem interactions and fisheries and climate effect on foodweb, evaluation (screening) of alternative management options. Ecospace: Evaluation of spatial management strategies and changes in environmental conditions on the distribution of species and fishing activity.
Main limitations	Short-term simulation and forecast (1-3 years), introducing seasonality, dynamic/mechanisms at lower trophic levels/microbial loop not well represented. Although representation of multiple life stages is possible, the majority of foodweb components are included as one compartment without age structure.
Examples in ICES Ecoregions	Some live examples include: North Sea, central Baltic Sea, Channel, West coast of Scotland, Celtic sea, Scotian shelf, Gulf of Maine, Georges bank. More examples are given in WGSAM 2007 review on modelling in ICES ecoregions
References	Christensen, V. and C. J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172:109-139. Walters, C., Pauly, D. and Christensen, V. (1999) Ecospace: Prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. Ecosystems, 2, 539_554. Walters, C., Pauly, D., Christensen, V. and Kitchell, J. F. (2000) Representing density-dependent consequences of life history strategies in aquatic ecosystems: EcoSim II. Ecosystems, 3, 70_83. Walters, C., Christensen, V. and Pauly, D. (1997) Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Reviews in Fish Biology and Fisheries, 7, 139_172. Walters, C. and V. Christensen. 2007. Adding realism to foraging arena predictions of trophic flow rates in Ecosim ecosystem models: Shared foraging arenas and bout feeding. Ecological Modelling 209:342-350. Walters, C., Martell, S.J.D, 2004. Fisheries Ecology and Management. Princeton University Press, N.J. 448 pp. Plagányi, É.E., and Butterworth, D.S., 2004. A critical look at the potential of Ecopath with Ecosim to assist in practical fisheries management. African Journal of Marine Science, 26: 261–288.

Model Name	Gadget (The Globally applicable Area Disaggregated General Ecosystem Toolbox)
Contact details	http://www.hafro.is/gadget, gadgethelp@hafro.is
Category	Minimum Realistic Model
Generalized/custom	Generalized toolbox
Model Type	Age-length structured, multi-area, multifleet forward simulation, process-based fisheries model. Species can be split into multiple "stocks", either actual stocks, or split by maturity or gender. Processes modelled are: growth, maturation, mortality, fishing level and selectivity, predation level and selectivity. Typically a choice of functions available for each process, with parameters estimated within the model.
Data used	Fleet total and survey data: by total catch, length, age, age and length; stomach contents, tagging data, cpue, and environmental data. Can potentially take parameters for consumption levels, prey preferences, fleet selection, growth and maturation from literature or external optimization if data unavailable. Can use variable levels of aggregation (e.g. wider length categories for the largest fish) in a dataset.
Key model assumptions	Assumes that all fish of a given ageand length are identical. Pure Markovian model, no "memory". Harvest Control Rule (HCR) assumes accurate up-to-date assessment of stock.
Time-step	User defined. Typically monthly or quarterly.
Spatial Structure	Single area or simple area structure. Models with low single digit numbers of areas are most tractable
Estimated parameters	All modelled processes (see "model type", above) can be estimated with one set of parameters for all years, annual factors, or blocks of parameters or trends through time
Outputs	Numbers and mean weight of fish in each age-length category in the population, in each "stock", in each fleet and in each survey. Predation by predator and prey age and length category. All outputs are for each time-step, and can be summarized with user-defined levels of aggregation.
Model tuning	Least likelihood fit to a weighted sum of datasets. Two optimization routines (wide area and local search) included.
Uncertainties	Model produces single run without uncertainty estimates. Multiple runs can be used to examine the parameter space around the optimum.
Model accessibility	Open source with online documentation, at http://www.hafro.is/gadget
Documentation	Available at http://www.hafro.is/gadget
Program language	Program in C++. Models are built in series of text files, no GUI
Accepted WGSAM key run?	No
Main purposes	Multispecies and/or mixed fisheries models where a small number of species and/or areas need modelling. Models where biological realism is desirable Models (single and multispecies) where age reading data is problematic.

Main limitations	Not well suited to detailed area structure or complex foodwebs. Complex modelling tool with a steep learning curve and high demands on model development time. For predation models a time-series of "other food" must be supplied to each predator. Can model fishing effort and HCRs, but assumes accurate and up to date knowledge of stock size.
Examples where the model has been applied	Theoretical multispecies in the Barents Sea(cod – capelin –herring - minke whale - harp seal), and Iceland. Bay of Biscay anchovy with climate drivers Assessment single species models: Barents Sea redfish, Southern Hake, Icelandic Tusk proposed Barents Sea Greenland Halibut Mixed fisheries assessment model, Mozambique Sofala Bank prawns
Peer review reference	Frøysa, K. G., Bogstad, B., and Skagen, D. W. 2002. Fleksibest - an age length structured fish stock assessment tool with application to Northeast Arctic cod (*Gadus morhua* L.). Fisheries Research vol 55: 87-101. Howell, D., and Bogstad, B. 2010. A combined Gadget/FLR model for management strategy evaluations of the Barents Sea fisheries. ICES Journal of Marine Science 67:1998-2004. Lindstrøm, U., Smout, S., Howell, D. and Bogstad, B. 2009. Modelling multispecies interactions in the Barents Sea ecosystem with special emphasis on minke whales, cod, herring and capelin. Deep Sea Research Part II: Topological Studies in Oceanography 56: 2068-2079.

Model Name	LeMans ensemble North Sea model
Developing Institute	Cefas
Region of Applicability	North Sea
Category	Size-based fish community model
Model Type	LeMans is a size-structured fish community model of the North Sea, representing 21 stocks or ~98% of fish biomass.
Data used	F by stock and size class. Initial estimates of abundance by species/size, life-history traits, ICES S-R database for S-R parameters, total-stock biomasses from swept-area survey data. Stomach datasets.
Key model assumptions	Predation mortality is governed by size and diet matrix. • Deterministic von Bertallanfy growth. • Growth and recruitment are not food-limited. • Recruitment is a hockey-stick function • Life-history traits are based on L∞, except for length at maturity • Length partitioned into 32 equal classes of 5cm. • Fish recruited to the model at an average size of 2.5cm. • The impacts of lower and higher trophic levels than the fish community can be ignored.
Time-step	Limited by the requirement that all length/stock combinations grow by no more than one length class per time-step. Currently ~0.25 years.
Spatial Structure	None
Estimated parameters	• Recruitment initial slope and breakpoint • Senescence mortality • Growth efficiency, midpoint and width of lognormal predation window. A wide variety of possible combinations of these are assessed (see uncertainties).
Outputs	Biomasses, numbers, mortalities and catches of the 21 fish stocks by length class. 11 fish community indicators
Model tuning	Initial parameter choices come from the literature. These are tuned to produce stock sizes under historic fishing for 9 assessed stocks within a factor of 2 of observations.
Uncertainties	The model is explicitly probabilistic. Using Bayesian methodology each of 7 key parameters is given one of 5 possible values, generating an ensemble of 78,125 variants which are equally probable a-priori. Each of these variants, which pass screening against ICES stock data, is assigned an equal weight and used to generate an ensemble prediction. In this way parameter uncertainty can be rigorously evaluated.
Model accessibility	Via Cefas
Program language	Python
Peer review reference	The initial model design is based on Hall *et al.* (2006) updated by Rochet *et al.* (2011) for the North Sea. A manuscript describing the variant employed here should shortly be submitted for publication.
Accepted WGSAM key run	No

Purposes	• Investigating uncertainties and for use in supporting risk-based decision-making regarding medium to long-term management of a fish community. • Exploring the longer term consequences for the fish community of fishing at single species F-MSY estimates. • Investigating the signal to noise ratio and hence utility of fish community indicators. • Investigating the interactions between biology and mixed fisheries and risk/reward trade-off for idealised fleets (for liaison with WGMXFISH)
Limitations	The model • Cannot be used in assessment of Marine Protected Areas or to answer questions requiring spatial information. • Is not able to address questions relating to impacts of environment or marine mammals/birds on the fish community. • Is not suitable for tactical quota-setting due to parameterized stock recruitment. • Evaluate ecosystem impacts apart from fish community dynamics. • Evaluate situations where food-dependent growth is an important factor.
Examples	None
References	Hall, S. J., Collie, J. S., Duplisea, D. E., Jennings, S., Bravington, M., and Link, J. 2006. A length-based multispecies model for evaluating community responses to fishing. Canadian Journal of Fisheries and Aquatic Sciences, 63: 1344–1359. Rochet, M.-J., Collie, J. S., Jennings, S., and Hall, S. J. 2011. Does selective fishing conserve community biodiversity? Predictions from a length-based multispecies model. Can. J. Fish. Aquat. Sci., 68: 469–486.

Model Name	Multispecies Integrated Stochastic Operative Model, MSI-SOM
Contact details	University of Skövde, Systems biology research centre.
Category	Minimum realistic multispecies model
Generalized/custom	Custom application
Model Type	The model contains three stochastic operating models (SOMs) modelling cod, herring, and sprat in the Baltic Sea main basin. The Stochastic Operative Models (SOMs) are stochastic age-based models with Number At Age (NAA) and Weight At Age (WAA) as dynamic variables. The SOM-functions determining the changes in NAA and WAA are both process based and regression based. The Maximum Sustainable Yield (MSY) analyses performed are equilibrium based.
Data used	Data: cod WAA, herring WAA, sprat WAA, salinity, temperature, reproductive volume From assessments: cod NAA, herring NAA, sprat NAA, cod Spawning-stock biomass (SSB), herring SSB, sprat SSB, cod fishing mortality (F), herring F, sprat F, herring predation mortalities, sprat predation mortalities
Key model assumptions	The model is only relevant within the historical ranges of the parameters/variables since the SOM-functions are fitted to historical data. To estimate cod predation mortalities on clupeids outputs from other multispecies assessment models are used for further statistical analyses. The different multispecies assessment models used so far are Multispecies Virtual Population Analysis (MSVPA) and Stochastic Multispecies Model (SMS). The MSY analyses are based on scenarios of environmental states and are equilibrium based.
Time-step	Yearly
Spatial Structure	No spatial structure
Estimated parameters	Growth parameters for clupeids (6), and cod (5). Recruitment parameters for clupeids (4), and cod (3) Mortality parameters for clupeids (32), and cod (0) Weight of recruits parameters for clupeids (4), and cod (2)
Outputs	Primary outputs of the model are MSY reference points for cod, herring, and sprat in the Baltic Sea.
Model tuning	The SOM-functions are parameterized through fitting of historical data and output from multispecies assessments.
Uncertainties	The residual mean squares of each fitted SOM function are added as an error (in the form of the variance of an error with normal distribution) to each function in the model. The model can produce estimates of the variability of the reference points.
Model accessibility	Open source. Code is given out at request.
Documentation	Not documented.

Program language	R library. There is no Graphical User Interface (GUI) or possibility to build models without programming.
Accepted key run	No accepted Key run.
Main purposes	The result points out the state of the three dominating species in the Baltic Sea at which they simultaneously are at the biomasses that produces MSYs (BMSY).
Main limitations	The resulting fishing mortalities leading to MSY (FMSYs), associated yields, SSBs and trigger points only apply to the system being in the MSY state described. To apply the proposed FMSY on the current cod stock without the use of a harvest control rule which reduces F when the SSB falls below a threshold will most likely prevent it from recovering to BMSY. The analysis does not provide a strategy for how to move the stocks to the state where they are capable of producing MSY. The resulting BMSYs are not the same as having a solution with one F for each species that simultaneously produces MSY.
Examples where the model has been applied	The complete model has not been applied anywhere. The herring and sprat SOMs have individually been used to produce single species FMSY reference points in the Baltic Sea main basin (herring and sprat) and the Bothnian Sea (sprat) through ICES.
Peer review reference	Currently not reviewed.

Model Name	OSMOSE (Object-oriented Simulator of Marine ecOSystem Exploitation)
Contact details	http://www.meece.eu/library/osmose.html yunne-jai.shin@ird.fr
Category	Individual-based Model (IBM)
Generalized/custom	Generalized model with flexible configurations depending on ecosystem properties and structure, and scientific objectives of each case study
Model Type	OSMOSE is a process based spatial multispecies individual-based model which focuses of piscivorous fish species. This model assumes opportunistic predation based on spatial co-occurrence and size adequacy between a predator and its prey (size-based opportunistic predation). Age and size structured model. Stochastic model because all individual trajectories/variability inherent to all IBMs.
Data used	- Life-history parameters for predation (maximum ration of food for predators, critical threshold of predation efficiency), growth (Linf, K, t0 - von Bertalanffy parameters; Fulton condition factor; allometric parameters of the Length-Weight relationship), reproduction (relative fecundity, age/size at maturity), lifespan and mortality sources (additional mortality rate-other than explicit predation estimated by model; starvation – maximum starvation mortality rate; fishing – annual fishing mortality) - Migration data if migratory species are included - Distribution map of species by age: forced spatial dynamics of fish
Key model assumptions	The model assumes size-based opportunistic predation dictated by spatio-temporal co-occurrence, maximum ingestion rate, min/max threshold for predator size/prey size ratio.
Time-step	Two weeks
Spatial Structure	2D horizontal resolution. 0.15x0.15 degrees (depending on the case study). There will be a spatial version available soon.
Estimated parameters	Larval additional mortalities and plankton accessibilities (Genetic algorithm – Versmisse, 2008, PhD thesis; Duboz *et al.* 2010. Ecol.Model., Oliveros et al., in prep.)
Outputs	State variables and derived indicators at different aggregation levels (schools, age/size class, species, community): • Biomass, numbers and catches (x,y,t, by school, age/size class, species) • size-based indicators (mean and max size for each species, size at age, size spectrum, diversity spectrum) • trophodynamic indicators (TL distribution per species, mean trophic level of species, trophic spectrum, diets matrices per size/age/species)
Model tuning	Once the model is parameterized with published or documented values, unknown parameters are inverse estimated by an automatic calibration algorithm, by confronting the model output to time-series of observed biomass and catches. The calibration algorithm is an evolutionary algorithm which uses likelihood-based objective functions (Duboz *et al.*, 2010, Oliveros *et al.* in prep.)
Uncertainties	Sensitivity analysis has been undertaken but it is case-dependent (Ferrer 2008). No automatic algorithm is provided for rigorous SA and UA.

Model accessibility	MODEL http://www.meece.eu/library/osmose.html http://www.meece.eu/documents/deliverables/WP2/D2.3.pdf CODE: https://svn.mpl.ird.fr/osmose/code
Documentation	http://www.meece.eu/library/osmose.html Will be released in 2014 on www.osmose-model.org
Program language	JAVA. 2D on workstations, cluster required for calibration of the model (R-package coded for the evolutionary algorithm).
Accepted WGSAM key run?	NO
Main purposes	Evaluate fishing pressure or climate change (when coupled with an hydrodynamic – biogeochemical model) effects on the system
Main limitations	stochastic model : several runs per configuration is needed, and this renders the calibration complex.
Examples where the model has been applied	Southern Benguela-South Africa Northern Humboldt-Peru (implemented) Strait of Georgia-Canada (implemented) Gulf of Mexico - US (implemented) Adriatic Sea (MEECE project) Aegean Sea (MEECE project) North Sea (in project) Bay of Biscay (MEECE project) Gulf of Lions-France (ongoing) Eastern English Channel (ongoing) Sine Saloum - Senegal (ongoing) Gulf of Gabes (in project)
Peer review reference	Shin, Y.-J. and Cury, P. 2001. Exploring fish community dynamics through size-dependent trophic interactions using a spatialized individual-based model. Aquat. Living Resour. vol. 14, pp. 65-80. Shin, Y.-J. and Cury, P. 2004. Using an individual-based model of fish assemblages to study the response of size spectra to changes in fishing. Can. Jour. Fish Aquat. Sci. vol. 61, pp. 414-431.

Model Name	Coupled ROMS-N2P2Z2D2 + OSMOSE model (Biogeochemical (BGC) model of the Regional Ocean Model System + Object-oriented Simulator of Marine ecOSystems Exploitation)
Contact details	ROMS-NPZD: http://www.romsagrif.org/; ftp://ftp.legos.obs-mip.fr/pub/romsagrif/DATA_ROMS/papers/BGCmodel.pdf ROMS-NPZD + OSMOSE: http://www.meece.eu/documents/deliverables/WP2/D2.3_2011.pdf
Category	Whole ecosystem and dynamic system model
Generalized/custom	Generalized toolbox with different configurations depending on ecosystem properties and objectives of each case study
Model Type	The ROMS-N2P2Z2D2 + OSMOSE coupled models simulate the system, from hydrological and biogeochemical processes up to main fish species dynamics. The hydrographical- BGC model contains nitrate, ammonium, 2 phytoplankton, 2 zooplankton and 2 detritus groups. Both phyto and zooplankton groups are size based structured and their biomasses are calculated by the ROMS- N2P2Z2D2 model in order to provide food to the higher trophic levels. The coupling process can be configured one way (off –line configuration) or two ways (on-line configuration), which in addition to force the higher trophic level species, gets some feedback mortality from them to the lower trophic level compartments.
Data used	Temperature, salinity, circulation, nutrients, Chl-a for low trophic level (LTL) model. Life-history parameters, spatial distribution of species by age, migration data (case study dependent) for fish species in high trophic level (HTL) model
Key model assumptions	LTL model: Lotka-Volterra-derived predation. Ingested food affects zooplankton growth rate (numerical response) HTL model: see OSMOSE summary sheet
Time-step	LTL model: 20 minutes HTL and Coupled model: Two weeks
Spatial Structure	LTL: 3D resolution HTL:2D horizontal resolution Case study dependent.
Estimated parameters	LTL: Temperature, salinity, currents, stratification, phyto and zooplankton biomasses and spatial distributions, Chl-a, Primary Production, Nutrients distribution. HTL: see OSMOSE summary sheet
Outputs	LTL: Growth (nitrogen uptake, grazing, respiration, excretion, egestion), mortality, sinking. HTL: see OSMOSE summary sheet
Model tuning	LTL: Forced by HTL: see OSMOSE summary sheet
Uncertainties	HTL: see OSMOSE summary sheet
Model accessibility	Coupled MODEL http://www.meece.eu/library/osmose.html http://www.meece.eu/documents/deliverables/WP2/D2.3.pdf CODE: https://svn.mpl.ird.fr/osmose/code
Documentation	ROMS-NPZD: http://www.romsagrif.org/; ftp://ftp.legos.obs-mip.fr/pub/romsagrif/DATA_ROMS/papers/BGCmodel.pdf ROMS-NPZD + OSMOSE: http://www.meece.eu/documents/deliverables/WP2/D2.3_2011.pdf Annex 3- D4.1 DEVOTES Project

Program language	LTL: Fortran HTL: JAVA. 2D on workstations, cluster required for calibration of the model (calibration algorithm in R). Dialog between models: netCDF files
Accepted WGSAM key run?	No
Main purposes	LTL: – Assessing fluxes of matter – Estimation of primary production (plankton dynamics) and identification of forcing factors HTL: Studying the effects of fishing on species and community dynamics (size-based, species-based indicators)
Main limitations	LTL: overly simple BGC model depending on the characteristics of the ecosystem. HTL: see OSMOSE summary sheet
Examples where the model has been applied	Bay of Biscay (MEECE project – Species: Engraulis encrasicolus, Sardina pilchardus, Trachurus trachurus, Scomber scomber, Merluccius merluccius, Micromesistius poutassou, Thunnus thynnus, and Thunnus alalunga)
Peer review reference	ROMS: Shchepetkin, A., and J.C. McWilliams, 2005: The Regional Oceanic Modeling System: A split-explicit, free-surface, topography-following-coordinate ocean model. Ocean Modelling, 9, 347-404. Shchepetkin, A.F., and J.C. McWilliams, 2003 : A method for computing horizontal pressure-gradient force in an ocean model with a non-aligned vertical coordinate. J. Geophys. Res., 108, C3, 3090, doi:10.1029/2001JC001047. NPZD: Steele, J., 1974. The structure of marine ecosystem. Harvard University Press, Cambridge, MA, 128pp.. Fasham, M., Ducklow, H., McKelvie, S., 1990. A nitrogen-based model of plankton dynamics in the oceanic mixed layer. Journal of Marine Research 48, 591–639. Sarmiento, J.L., Slater, R.D., Fasham, M.J.R., Duclow, H.W., Toggweiler, J.R., Evans, G.T., 1993. A seasonal three-dimensional ecosystem model of nitrogen cycling in the North Atlantic euphotic zone. Global Biogeochemical Cycles 7, 417–450. HTL-OSMOSE Shin, Y.-J. and Cury, P. 2001. Exploring fish community dynamics through size-dependent trophic interactions using a spatialized individual-based model. Aquat. Living Resour. vol. 14, pp. 65-80. Shin, Y.-J. and Cury, P. 2004. Using an individual-based model of fish assemblages to study the response of size spectra to changes in fishing. Can. Jour. Fish Aquat. Sci. vol. 61, pp. 414-431. Coupling: Travers M., Shin Y.-J. 2009. Spatio-temporal variability in fish-induced predation mortality on plankton. A simulation approach using a coupled trophic model of the Benguela ecosystem. Progress in Oceanography. doi:10.1016/j.ecolmodel.2009.08.016 Travers M., Shin Y.-J., Jennings S., Machu E., Huggett J.A., Field J., Cury P. 2009. Two-way coupling vs. one-way forcing of plankton and fish models to predict ecosystem changes in the Benguela. Ecological Modelling, 220: 3089-3099.

Model Name	SMS
Contact details	DTU-Aqua (mv@aqua.dtu.dk)
Category	Minimum realistic ecosystem model
Generalized/custom	Generalized Toolbox
Model Type	SMS (Lewy and Vinther, 2004) is a stock assessment model including biological interaction estimated from a size dependent food selection function with internally estimated parameters. Parameter estimation is by maximum likelihood and the variance/covariance matrix is obtained from the Hessian matrix.
Data used	• Input data by year, quarter, species, age: Surveys, catch, weight in catch, weight in the stock, proportion mature, residual natural mortality (M1), consumption rates, abundance of non-modelled predators. • Input data per year, quarter, species, length class: relative stomach contents, ALK and LAK for stomach data years • Additional input: Environmental covariates can also be included. If the interactions take place in separate areas, the distribution of predators and prey across areas must be input data and other input data must be per area.
Key model assumptions	• Diet selection follows a Holling type II functional feeding response. • The size preference of predators is constrained uniform (but other types are possible (e.g. lognormal)). • “Other Food” is assumed to be constant in time. • Prey preference and overlap assumed to be constant within an area as a default, but predator-prey overlap can vary seasonally, temporally and spatially. • Consumption rates and weight at age assumed to be constant (but can be made variable leading to variable weight at age if underlying relationships exist). • Redistribution of fish between areas when run spatially occurs instantaneously at the beginning of a quarter. • Survey catchability assumed to be constant over externally defined periods. • Residual mortality (M1) assumed constant
Time-step	Quarter
Spatial Structure	One to 5 areas, more if sufficient data are available.
Estimated parameters	Catchability (per survey, species, age), vulnerabilities (per predator-prey), size selection parameters (if used), F (year, season and age effect), stock–recruitment parameters (e.g. Beverton–Holt, Ricker, Hockey stick, constant)
Outputs	Stock numbers, SSB, TSB, M2, M, F, Z, catch, biomass eaten, partial M2s, weight in catch and stock, consumption rates . All outputs are by year, quarter, species and age:
Model tuning	Statistical fit to data (negative log likelihood); 4 objective functions (catch, survey, stomachs, stock–recruitment)
Uncertainties	Uncertainties estimated from the Hessian matrix or from MCMC simulations
Model accessibility	Open source. Available upon request from Morten Vinther (mv@aqua.dtu.dk)
Documentation	Lewy and Vinter 2004, ICES CM 2004/ FF:20

Program language	ADMB model builder, Input and Output processed with R
Accepted key run	Accepted keyruns for the North Sea and Baltic
Main purposes	Multi species and single species stock assessments Estimation of M2s to be used in single species assessments Estimation of partial M2s to be used in the identification of important predators Estimation of MSY in a multi species context MSE testing of HCRs
Main limitations	No representation of bottom–up effects from lower trophic levels beyond correlations between environmental factors and recruitment, no fleet submodel, no implementation error in the assessment in the MSE loop, not suitable for evaluations of spatial closures
Examples	North Sea: variable M2s in the assessments of cod, whiting and herring; Advice on multi species considerations for North Sea stocks Baltic: M2s in the assessments of cod, herring and sprat; Advice on multi species considerations for Baltic stocks
Peer review reference	WKMULTBAL 2013

Model Name	STOCOBAR
Contact details	PINRO, Anatoly Filin filin@pinro.ru
Category	Minimum realistic multispecies models
Generalized/custom	Custom application
Model Type	Age-structured, forward simulated, process-based, stochastic model. Describes stock dynamics of cod in the Barents Sea, taking into account trophic interactions and environmental influence. It includes cod as predator on up to eight prey items. The simplest version of the model species composition includes 3 categories of cod prey items: capelin, own young (cannibalism) and other food. Recruitment function is used for cod only. The model is able to produce stochastic temperature scenarios for future runs. 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. Impact assessment of ecosystem factors are based on «what if» scenarios.
Data used	Cod individual weight in stock, length, fatness (hepatosomatic index) and maturation from survey; weight in catch from fleet, initial abundance and fishing mortality by age from VPA assessment; cod stomachs content, Kola section annual temperature, Fbar, Fpa, Blim for cod, natural mortality for cod at age 4 and older, total-stock biomass of capelin from Captool assessment.
Key model as-sumptions	The cod stock dynamics is described through modelling growth, feeding, maturation, recruitment, natural mortality (including cannibalism) and fishing mortality. The model can run with or without including temperature in cod recruitment equation. The capelin stock projections are based on statistical approach only. The following assumption are used: • a proportion of prey species in a predator's ration reflects the proportion of these species in the sea; • maximum consumption by fish depends on their body weight and environment temperature; • a coefficient of proportionality between real and maximum consumption by a predator is the function of available food; • growth of fish is a function of initial body weight and body length, water temperature and ration expressed as energy units; • maturation rate of cod is determined first of all by their linear growth and fatness.
Time-step	One year
Spatial Structure	Single area is the Barents Sea
Estimated parameters	Parameters are estimated for modelling of cod consumption, growth and maturation rate, Ricker recruitment equation and annual deviation of cod recruitment-at-age 1.
Outputs	Cod stock numbers by age, individual weight, individual length, maturity ogive, fishable stock biomass, spawning-stock biomass, cannibalism mortality, catches, capelin consumption by cod, total capelin stock biomass.
Model tuning	Statistical fit to historical data
Uncertainties	Residues on cod recruitment-at-age 1 and stochastic temperature scenarios and capelin stock projection are used in multple model runs.
Model accessibility	Model is available on request from filin@pinro.ru
Documentation	Model structure described (see peer review reference), other documentation not currently available

Accepted WGSAM key run?	No
Main purposes	The model is suitable for long-term simulations aimed to evaluate of HCR for cod and consequences of climate change scenarios on cod stock dynamics and fishery.
Main restrictions	The model is less suitable for short time prognosis.
Examples	Theoretical studies on evaluation impact of capelin abundance in the Barents Sea on cod rebuilding strategy, impact of temperature on cod recruitment, estimation of relation between cod cannibalism and capelin stock size, evaluation consequences of climate change in the Barents Sea for cod-capelin relation, cod stock dynamics and its MSY.
Program language	Delfi. There is a GUI. The simple variant of the model (deterministic simulation) may be built without programming in Exceel sheet.
Peer review reference	Howell, D., Filin, A. A., Bogstad, B., and Stiansen, J.E. 2013. Unquantifiable uncertainty in projecting stock response to climate change: Example from NEA cod. J. Marine Science. DOI:10.1080/17451000.2013.775452

Annex 6. Requests and Responses

ID	Request	WGSAM Action
104	WGSAM encouraged to enter a dialogue about the generation of an overview "top–down" briefing sheet, characterizing the current state of predatory and competitive influences of other species on the dynamics of herring and sprat in the Greater North Sea and Celtic Sea.	Please see the multispecies advice for the North Sea produced in WGSAM 2012 and published as draft advice. This draft can perhaps be used for discussion in HAWG 2014, as WGSAM in October 2014 will make a new key run for the North Sea and update the multispecies advice accordingly and therefore could potentially provide more or different information. WGSAM is in a dialogue with WGHAWG chairs to clarify if this is sufficient.
60	11. WGBIFS recommends that WGSAM provides detailed information on how to work up the Cod stomach samples and provides a database for storing the data.	A detailed manual with best practices in stomach contents sampling has been published as 'Manual for ICES Stomach sampling projects in the North Sea and Baltic Sea' (ICES, 2010). Stomach sampling analysis and database format should follow this manual where possible. ICES hosts the joint ICES stomach database, and data in the agreed format can be sent by e-mail to Anna Osypchuk (anna.osypchuk@ices.dk). Questions related to the ongoing Baltic stomach sampling should be placed to the project coordinator, Bastian Huwer (bhu@aqua.dtu.dk).

ID	Request	WGSAM Action
116	According to WGNSSK estimates, the North Sea is currently ongoing a plaice outburst without precedent. However, plaice is not included in multispecies models, so the consequences of this outburst on the North Sea ecosystem are unclear and would potentially require additional focus	WGSAM to consider advice on the changes in the predation mortality of plaice (North Sea) on its prey and consequences for predators of plaice. WGSAM is currently not able to address this request effectively. It requires knowledge of the stomach contents of plaice and inclusion in a model to investigate the consequences for its prey but also to quantify the competition with other species for food. However, consequences for the predators of plaice could be addressed in future through modification of the SMS Key run. The predation impact of predators (e.g. cod) on plaice can be quantified in SMS by treating plaice as individual prey species (currently only available to predators via the "Other Food" pool). Information from a Southern North Sea EwE model will be also available in 2014 to quantify the consumption of plaice by its predators but also to evaluate negative effects on other stocks due to competition for food. As very first indication of the importance of plaice as prey for cod, the relative stomach content in the 1991 stomach dataset used to parameterize the southern North Sea Ecopath (ICES area IVb and c) was 3.3% for adult cod (age 3-8) preying on juvenile plaice (age 0-2). In the stomachs of juvenile cod hardly any plaice was found. The current stomach contents after the plaice outbreak are unknown due to lack of data but model estimates will be available next year.
117	WGBFAS recommend MULTBAL to have annual updated SMS and not only every 3rd year.	The multispecies advice (including natural mortalities) is currently updated every 3 years, though indicators which can be produced directly by the assessment group can be updated annually and included in forecast (e.g. total biomass of pelagic and demersal fish). The group investigated the WKBALT (2013) study of what the consequences would be of updating the natural mortalities every year with the Eastern Baltic Sea SMS. Due to the pronounced retrospective pattern in the assessment of Eastern Baltic cod, an annual update would introduce retrospective patterns in the natural mortality of the prey stocks. This will have severe effects on the estimated recruitment. As a result, it was decided that it was more appropriate to extrapolate M using e.g. three year average than to update M every year which would transfer excessive noise between species.