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Critical Interactions BEtween Species and their Implications for a PreCAUtionary FiSheries Management in a variable Environment - a Modelling Approach (BECAUSE)

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www.rrz.uni-hamburg.de/BECAUSE/

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Project objectives

The principle objective of this program is the identification and quantification of critical biological interactions between and within commercial target fish species and non-commercial top predators leading to a description of food web structures and the derivation of precautionary reference points for ecosystem oriented fisheries management. These precautionary reference points and limit values accounting for interacting mechanisms with the environment are necessary for the development of adaptive strategies in fisheries management. The overall objective can be broken down into the following list of more specific objectives:

Development of conceptual food web models and analysis of processes driving critical interactions

- Compilation of time series of spatial distribution of key predator and prey fish species in relation to environmental parameters.
- Estimation of enhanced consumption rate models and simple bioenergetic consumption models.
- Development of quantitative conceptual (spatially dis-aggregated) food web models, contrasting periods of different exploitation patterns and climatic /hydrographic situations.
- Formulation of spatial distribution/migration process models taking into account environmental variability.
- Parameterisation of enhanced functional response and prey selection process models, including predator/prey overlap.
- Development of coupled growth & maturation process models (including competition) taking into account environmental variability.

Improving multi - species assessment models

- Development of enhanced deterministic and stochastic multispecies models with process sub models from WP 1 implemented.
- Formulation of alternative, less data demanding multispecies models.
- Quantification of historical trophic transfer rates in critical interactions and historical stock sizes quantified by application of improved deterministic, stochastic and alternative multispecies models.
- Quantification of structural and parameter uncertainties in deterministic, stochastic and alternative multispecies models.
- Implementing enhanced multispecies models in other Case Studies than those in which they were developed, e.g. GADGET in Case Study areas Bay of Biscay / Iberian Peninsula and Mediterranean Sea as well as SMS in the Baltic.

Prediction of stock trends applying improved multi-species forecast models

- Construction and implementation of enhanced deterministic, stochastic and alternative multispecies forecast models.
- Performing short, medium- to long-term scenarios predictions with/without environmental processes affecting species interactions and recruitment utilizing multispecies forecast models.
- Comparing results and associated uncertainties in projections obtained by application of improved stochastic and deterministic models.
- Performing short, medium- to long-term prediction of effects of existing and alternative fisheries management strategies and technical measures on critical interactions and on stock dynamics.

Analysis of fisheries management implications

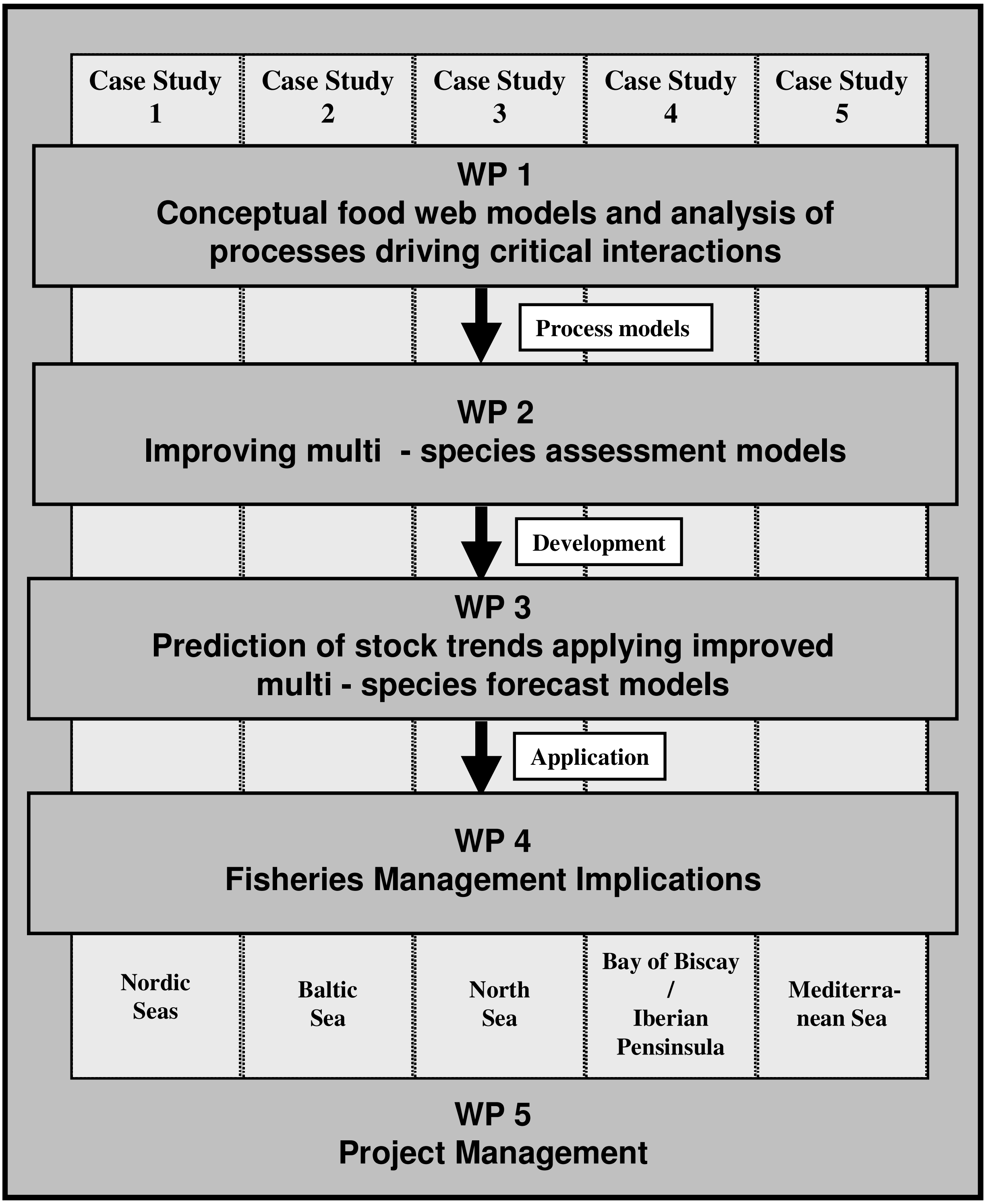
- Development of multispecies management evaluation tools.
- Evaluation of multispecies fisheries management strategies (e.g. biological reference points) considering identified critical biological links under variable environmental conditions.
- Evaluation of multispecies management strategies and technical measures that enhance the incorporation of environmental concerns with emphasis on the food web effects of stock recovery plans.
- Evaluation of multispecies fisheries management objectives (e.g. biological reference points, predator recovery plans) considering potential conflicts with ecosystem management objectives (e.g., biodiversity of higher trophic levels).

Project Participants

Participant name	Acronym	Country
Universität Hamburg (Coordinator)	UniHH	Germany
Fundacion AZTI	AZTI	Spain
The Secretary of State for Environment Food & Rural Affairs acting through the Centre for Environment Fisheries & Aquaculture Science	CEFAS	United Kingdom
Danish Institute for Fisheries Research	DIFRES	Denmark
Finnish Game and Fisheries Research Institute	FGFRI	Finland
The Scottish Ministers, acting through Fisheries Research Services Marine Laboratory	FRS MLA	United Kingdom
Marine Research Institute	MRI	Iceland
Leibniz-Institut für Meereswissenschaften an der Christian-Albrechts-Universität zu Kiel	IFM-GEOMAR	Germany
Institut Français de Recherche pour l'Exploitation de la Mer	IFREMER	France
Consejo Superior de Investigaciones Cientificas	CSIC-E	Spain
Institute of Marine Research	IMR - N	Norway
National Centre for Marine Research	NCMR	Greece
Sea Fisheries Institute	SFI	Poland
Dipartimento di Biologia Animale e dell Uomo - University of Rome La Sapienza	URom	Italy
University of St Andrews	UStAn	United Kingdom
Latvian Fish Resources Agency	LATFRA	Lativia
National Board of Fisheries, Institute of Marine Research	IMR-S	Sweden
Instituto Español de Oceanografía	IEO	Spain

Project Structure

Graphical presentation of the BECAUSE Work Package and Case Study components showing their interdependencies. The Case Studies evolve in parallel through Work Packages 1 - 4, all Case Studies have a common framework and the network of Work Packages 1-4 and Case Studies 1-5 is coordinated in the Project Management Work Package 5.



Expected end results

The project will deliver the following general end results, whereby the respective levels of detail inevitably will reflect the different data situations and system understanding in each Case Study area. Generally, in each Case Study the final project product will be a multispecies model addressing major species interactions including non commercial top predators and capturing the structure of the upper trophic community of the ecosystem, allowing to evaluate the impact of the fishery on these primary interactions and to derive biological reference points for an ecosystem oriented fisheries management.

Conceptual food web models of the intermediate to upper trophic levels of each Case Study area accounting for changes in i) fishing intensity and practise, ii) atmospheric forcing affecting the hydrography and iii) potential trends in other anthropogenic activities.

Enhanced process sub-models on i) prey selection, ii) individual consumption rates, iii) growth rates, iv) maturation process and v) stock recruitment relationships to be included in multispecies models. These sub-models will be spatially structured and environmentally sensitive whenever necessary and possible.

Improved statistically based multispecies hind-, now- and forecasting models incorporating all major predator/prey interactions identified and constructed sub-models, being able to handle parameter uncertainty and thus providing confidence measures for the output.

By application of these enhanced multispecies models, quantification of consumption by relevant predators and predation mortality of important prey species including measures of the uncertainty of the estimates, taking into account fisheries activities and changes in environmental conditions, will be delivered This in some cases includes the modelling of feed back mechanisms of prey availability and consumption on growth, maturation and offspring production.

Likely and worst case scenarios of local environmental variables necessary to drive constructed sub-models on prey selection, individual consumption, growth rates, maturation and stock recruitment relationships, to be implemented in medium- to long-term multispecies forecast models.

Prediction of likely effects of changes in patterns of exploitation by the fishery on first order species interactions and quantification of uncertainties associated with these effects, considering likely and worst case environmental scenarios. Develop a risk management based approach to managing the consequences of such effects.

Evaluation of present fisheries management objectives (e.g. biological reference points) considering identified critical biological links under variable environmental conditions. Test of alternative fisheries and ecosystem management reference points and harvest control rules (including closed areas and seasons), considering also conflicting objectives in fisheries and ecosystem management.

Multispecies models accommodating spatial heterogeneity and environmental variability to be implemented into fisheries management evaluation tools. These tools will be utilized to evaluate various fisheries and ecosystem management actions on stock development both of the targeted fish stock and non commercial top predators.

Intentions for use and impact

One of the major management problems addressed by BECAUSE are the ecosystem effects of stock recovery plans for heavily overfished top predators such as cod and whiting. Most of our shelf ecosystems are characterised by a strong reduction of top predators over decades and a parallel increase in landing of the main prey fish species. It has been estimated by the Multi-species working group of ICES that the decrease in mackerel and cod stocks in the North Sea has led to corresponding reduction in fish predation in the order several 100.000 tonnes to more than a million tonnes consumed fish per year. A large part of this released prey fish production was channelled into industrial as well as into human consumption fisheries. The inherent risk of a stock recovery scenario of the major top predators is that the prey fish production is insufficient to supply the combined food requirements of the growing predator population, the fisheries on its prey and the dependent wild life populations such as sea birds and marine mammals. Such an effect has actually been observed in the Barents Sea when a recovering cod stock impacted severely on the capelin stocks in the mid 80s and the mid 90s. In both periods the capelin stock collapsed with dramatic implications in the ecosystem including cod, marine mammals and sea birds. Similar problems can be expected in the Baltic, where an industrial fishery developed in recent years characterised by very low cod stocks. Also the North Sea and Iberian shelf may experience such indirect effects as stock recovery plans come into force.

Policy purpose and strategic impact

The project will explain the state and dynamics of clearly distinguishable first-order interactions between targeted commercial fish species and non-commercial top-predators in major European Sea areas. It will include a description of responses in these interactions to exploitation and environmental change as well as the derivation of precautionary reference points and limits to be used in an ecosystem oriented fisheries management. The successful implementation of the project will have several important impacts for the European Union, for international partners such as ICES and the General Fisheries Commission for the Mediterranean (GFCM), for the marine research community, for key stakeholder groups such as fishing and fish processing industry, environmental groups and for the marine environment itself. These benefits and impacts include:

Global commitments

Worldwide ecosystem services, are estimated to be worth over 30 Trillion $ per year. In the EU, this includes the harvesting of over 6.2 Million Tonnes / year (1999) due to fishing operations. Overfishing and global change threatens these services and to preserve them requires the development of appropriate management strategies on a global and community wide level.

Policy focus

BECAUSE directly addresses the policy priority set out by the EU Commission. The key objective in BECAUSE is to enhance the integration of environmental issues into the common fisheries policies, as stipulated under Article 6 of the Treaty and reflected in the Action Plan to integrate environmental protection requirements in the CFP reform. The Commission promotes a progressive adoption of an ecosystem-based approach to fisheries management.

Ecosystem-based fisheries management

The need for an ecosystem approach to management of European marine ecosystems and their resources has been clearly identified (OSPAR Quality Status Reports 2000; HELCOM Periodic Assessments of the state of the Marine Environment of the Baltic Sea; Water Framework Directive for coastal regions, Reykjavik Declaration on Responsible Fisheries, Green paper on CFP). Until recently, there has been a tendency that fisheries management and conservation issues were treated separately. Ecosystem based management strategies seek to develop a holistic & integrated approach. This has been identified as a major research priority for the EU (IPTS-JRC 2000 Mega-challenge 2, Sustainable development) and is supported at the highest political levels (e.g. Ministerial Bergen Declaration 2002). Project results will further help to identify data gaps which are needed to be filled to fully implement the ecosystem approach to fisheries management, thus helping in the revision of the current European data collection regulation (DCR).

Work performed and results achieved

Case Study specific achievements of immediate management relevance

Nordic Seas

Gadget has now been developed to the stage where it can be and has been used for assessing stocks in data-poor and data-rich situations. Estimates of uncertainty in multispecies models have been greatly enhanced. Simulation models have clearly shown that traditional methods of closing small areas (e.g. 1-2 statistical rectangles in the North Sea or around Iceland) are very unlikely to have any effects.

The historical Gadget multispecies (minke whale- cod – capelin-herring) model for the Barents Sea was fit to the survey, catch and stomach content data for the period 1985-2004 (Lindstrøm et al. 2007). This model was then adapted for forward simulations running 20 years into the future (2005-2024), in order to use it as a tool for investigating management strategies. In order to make this change the fishing levels and recruitment levels for the next 20 years needed to be predicted. This was done by including stock-recruitment functions and harvest control rules for cod and capelin. It is assumed that the recruitment pattern in the period 2005-2024 is the same as in the period 1985-2004. This assumption is also made for herring, which is not yet fully dynamically modelled within this Gadget model. The extended model covers the period 1985-2004 as a hindcast, and projects forwards between 2005 and 2024.
First, a base case run was made, using the present harvest control rules for cod and capelin. The results of these runs were in line with the historical stock size and stock fluctuations. Then a number of scenarios were runs, exploring e.g. the following issues:

- Increasing or decreasing fishing mortality of cod and capelin
- Increasing the mesh size in the cod fishery
- Increasing or decreasing cod recruitment.

As expected, an increasing cod stock led to a decreasing capelin stock, and vice versa. The effects of cod abundance on capelin abundance were found to be much stronger than the effects of capelin on cod. This is because effects of capelin abundance on cod growth/maturation are not included. The effect of capelin fishery on capelin abundance was found to be small. The consumption per whale was hardly affected by the changes in cod and capelin abundance seen in these scenarios.

The Barents Sea case study has allowed the development of new methodologies for modelling consumption by cetaceans based on stomach content, blubber thickness, bioenergetic modelling and prey availability data collected at different spatial scales. The historical scenarios do not suggest that whales have a strong negative impact on commercial stocks. Thus, there is no scientific evidence that culling of minke whales is needed to conserve fish and there is not a conflict between the imperatives of fisheries management and conservation of minke stocks. Instead, whales may have a slight positive effect on capelin because the predation on cod by whales reduces the cod stock which in turn reduces the predation pressure on capelin.
This result is an example of the importance of indirect effects in multi-species systems: cod are not a preferred prey of the whales and generally are not consumed in great quantities, but though this trophic link, the whales may have their most important impacts. Such effects can only be explored in multi species models, e.g. conclusions about whale impacts on herring are misleading, unless the dynamics of the other prey species are taken into account. Indirect effects will be missed entirely by single species models. The potential impact of different management strategies on whale food availability was also evaluated. The results was that whales got enough food in all the analysed scenarios.

Most areal closures in Icelandic waters to date have been short-term or small areas. Simulation results indicate that this is unlikely to provide any real benefits in terms of fishery management.

Simulations were undertaken to investigate the effects of closed areas. These emphasize fleet dynamics (using economic modelling) and migrations of single species, but the results imply that only very large areas should be considered when contemplating using areal closures as management measures.

Baltic Sea

SALMON

An artificial intelligence (AI) -based application of neural network (NN) and genetic algorithm (GA) techniques to estimate run size and escapement of Atlantic salmon (Salmo salar) into three spawning rivers in the northern Baltic Sea has been explored. The results suggest that in 2003, when the run size in the coastal waters was high, escapement in the two main rivers was far above established goals. In 2004, escapement dramatically decreased although run size was average. In 2005 and 2006, run size was small but escapement goals were achieved mainly due to higher proportion of wild salmon in the run. In the smaller river, escapement goals were not achieved in any of the years estimated. Run size in the coastal waters in 1994-2006 correlated well with previous year's post-smolt survival and with off-shore 'run size' (abundance) in the southern Baltic feeding grounds. That is, run size in the coastal area is predictable with reasonably high confidence.

Hence, to better assure adequate escapement and at the same time to optimize coastal harvesting, the regulations could be agreed yearly, perhaps some six months prior the opening of the fishing season (when all the necessary information is available.

APPLICATION OF MULTI SPECIES MODELS

For the Baltic Sea cod-herring-sprat SMS model, four predictive scenarios were investigated. The predation and recruitment parameters were estimated based on different parts of the available time series in the four scenarios. The same harvest control rules (corresponding to those presently in use for the three stocks) was used in all cases. The choice of periods for estimating these parameters had a considerable effect on the results, and strong multispecies interactions (including cod cannibalism) were seen in the model results. It does not seem to be possible to have high stock levels of predator and prey simultaneously. The results also shows that adding uncertainty requires lowering the fishing mortality in order to meet the objective of keeping SSB above B_{lim} with a high probability:

HCR evaluations of two different environmental scenarios were done using the SMS package. Input data were derived from the final assessment by WGFAS in 2007. This assessment includes un-reported illegal landings and discards.

Simulations were done using two stock-recruitment models. One ("low recruitment level") fitted to the most recent observations of SSB and recruitment, corresponding to a period of unfavourable recruitment conditions, another ("high recruitment level") fitted to the full time series.

For both environmental scenarios we tested scenarios, with or without an assessment uncertainty of 0.35 CV with and without an assessment bias of 1.2 (consistent overestimation of stock by 20%) as well as with and without implementation bias of 1.2 (catch consistently 20% higher than advised).

All simulations show a decline in yield already with the first 10% reduction in F or 15% reduction in TAC in 2008. This is caused by the relatively high recruitment of the 2003 year-class carrying relatively high catches in 2006 and 2007, while in 2008 and especially from 2009 onwards lower recruitment of following year-classes affects the yield negatively. Due to the same reason, an increase in SSB takes place earliest in 2010.

The conducted simulations show that the harvest control rule tolerates an assessment CV of 0.35, in fact applying only this moderate assessment uncertainty would allow a target fishing mortality of ca. 0.4.

Adding additionally either an assessment bias of 1.2 (consistent 20% overestimation of the stock) and an implementation uncertainty of 0.1, or an implementation error of 1.18 and implementation uncertainty of 0.1, creates the limiting conditions at which the harvest control rule can be considered precautionary. At present a 20% assessment bias is not obvious from previous assessments, however the present implementation bias for the stock is considerably higher. The TAC has since 2000 been regularly overshooten by ca. 30%. The harvest control rule was not robust against such implementation failures.

The low stock-recruitment relationship applied in the simulations on the other hand is a conservative assumption, and higher recruitment allows slightly higher target F. At a high recruitment scenario the TAC constraint of 15% does, however not appear to be optimal, a relaxation to 30% may improve the speed of recovery and reduce variability in stock size, yield and fishing mortality. However, before advising on this, consultations with the stakeholders should be held and more simulation runs exploring this option should be conducted.

The "cost" of a high cod biomass is an increased predation on sprat and herring. With cod recruitment at the level observed in the most recent years (option "baseline" and "low cod recruitment") a sustainable fishery of herring and sprat is possible using the suggested HCR. Cod recruitment at the high level in combination with the agreed management plan for cod will however result in a too high predation on the clupeid to allow any fishery. Dependent on the stock recruitment relation used for the clupeid, the stock will either go extinct or be reduced to a very low level.

North Sea

LOCAL STUDIES ON SANDEELS AND MAMMALS

A localised field study was carried by Cefas between spring 2004 and autumn 2006, and data were collected to investigate multispecies interactions sandeels and their predators from a heavily fished area and a lightly fished area to the west side of the Dogger Bank.

Generally, the diet 'flexibility' and ability to substitute diet shortfalls with other prey items suggests that predatory fishes of the Dogger Bank are perhaps less crucially dependent on local sandeel abundance than, e.g., seabird colonies of Scotland. This is supported by other research showing that predatory fish tend to be generalist feeders and hence less reliant on a particular prey resource. However, our investigations revealed that when predators' consumption of sandeels was high they generally showed better condition indices, thus growth and reproduction of predators could be directly influenced directly by the availability of sandeels as prey. This underlines the importance of a healthy sandeel population for the commercially important predatory fish species of the Dogger Bank. Sandeel–predator-condition links appeared strongest for lesser weever and plaice; intermediate for whiting and haddock; and weakest for grey gurnard and mackerel (and perhaps cod but data were extremely limiting).,

An in-depth analysis of field data collected over the 1997-2003 period from a study site located in the Firth of Forth was carried out. Their findings showed that the biomass of cod, whiting and haddock declined slowly over the study period. There was no evidence of any beneficial effect of the sandeel fishery closure on the abundance or biomass of any of the three gadoid predators. The sandeels consumed by the gadoid predators consisted almost entirely of 0-groups. There was little evidence to suggest that the diets of the three gadoid predators were in anyway related to the variation in the densities of their prey and daily food intake rates were largely unaffected by variation in the abundance of prey. There was no indication that the closure of the sandeel fishery had any effect on gadoid condition.

Interactions between marine mammals and their main fish prey were investigated for the North Sea. Biochemical analyses of feeding preferences in marine mammals were carried out in a related project by Cefas and showed that porpoise and common seal have a relatively similar diet among individuals of the same species. The isotope signature of porpoises was consistent with a diet dominated by low trophic level fish species, especially sandeels and sprat. Seals isotope signature indicated a diet of larger fish, and less reliance on sandeels and sprat, confirming older observations that common seals preferentially consume demersal fish such as whiting and plaice. A methodology was developed and implemented for estimating the spatial distribution of the prey species for the grey seal, the most important marine mammal predator in the study area. Grey seal diet was estimated from scats collected on haul-outs on the coast of England and Scotland, and the availability of fish to the seals was estimated using Generalised Additive Models applied to International Bottom Trawl Survey data, together with models of seal movement based on telemetry data. These results were used to predict the way in which prey consumption and seal induced prey mortality might vary with prey abundance.

APPLICATION OF MULTI SPECIES MODELS

A Stochastic age-length based Multispecies model (SMS) was developed for the North Sea. SMS includes "other predators" i.e. predators for which the stock numbers are assumed know from external sources. Data on stock abundance mean weight and diet have been collated for the fish species: Horse mackerel, Mackerel, grey gurnards and Raja radiata from ICES stock assessment, survey CPUE data and ICES stomach samples. Similar data have been collated for nine species of seabirds. Data on population numbers of grey seals and consumption have been updated. SMS has been extended to use values for spatial/temporal overlap between predators and preys.

A forecast sub-model to SMS has been developed. Fishery mortality for projections can be fixed throughout the forecast period or derived dynamically from trigger values (e.g. SSB or recruitment). Constrains on annual changes in TAC, SSB or F can be added and an overall maximum TAC or F can be specified as well. Specific management plans (e.g. real time monitoring of sandeel) are also implemented. Wide-ranging testing of the SMS forecast software has been made through application of the SMS hindcast and forecast model in single species assessment and Harvest Control Evaluations (e.g. Norway pout (ICES 2007/ACFM:39, Sandeel (ICES 2006/ACFM:35), Baltic cod and Blue whiting (ICES 2006/ACFM:34).

A direct modelling of environmental processes affecting species interactions and recruitment has not been included in the model. Instead, possible outcome of environmental changes can be simulated from input on likely changes in stock distribution and overlap of predators and prey species. Environmentally driven changes in recruitment can likewise be simulated by changes stock recruitment model and its parameters.

A management evaluation tool has been developed on top of SMS which model the biological processes and stock projection. This addition simulates the effect of uncertainties in assessing the stock and uncertainties in implementing the management measures, e.g. a TAC, which makes it possible to evaluate the success rate (e.g. the probability of the true SSB > Blim) of the applied management measure.

Simple HCRs in a multi species context that can be applied to all stocks were tested for their sensitivity towards climate influence as well as uncertainties in assessment and implementation. Following rules were applied.

1. The stock size should reach Bpa as fast as possible
2. The year to year variation in F is not allowed to exceed +/- 15 %
3. The maximum fishing mortality allowed (Fcap) is Fpa

With the help of these HCRs the following scenarios were evaluated.

1. HCRs for cod only
2. HCRs for cod only with an assumed reduced productivity of the stock under global warming conditions
3. HCRs for cod only with an assumed maximum assessment and implementation error of +/-30%
4. HCRs for cod only with an assumed bias in assessment of 30% due to an overestimation of the cod stock size.
5. HCRs for cod only with an assumed bias in assessment and implementation of 30% (overestimation of the stock size and underestimation of the fishing mortality applied).

6. HCRs for all forage fish (herring, Norway pout, sandeel)

7. HCRs for all gadoid predators (cod, whiting, haddock, saithe)

Scenario 1: The HCRs did work and lead to a recovery of the cod stock. After 2017 an average equilibrium was reached at the Bpa level. The necessary fishing mortalities to sustain this equilibrium, however, could not be estimated with sufficient precision. This was caused by high parameter uncertainties especially for recruits. The 95% interval for sustainable fishing mortalities was between 0.3 and 0.65. More certain, however, was the estimation of the fishing mortality needed to ensure a fast recovery of the cod stock: in 2010 this fishing mortality was around 0.3.
As observed in other scenarios the recovery of the cod stock was predicted to increase the predation mortalities of all prey stocks. Whiting, haddock, herring and Norway pout where not able to sustain the fishing mortalities of 2006 anymore and to decrease below Blim until 2030 with high probability (> 60%). Only sandeel was predicted to reach levels above Bpa with nearly 100% probability. This was due to reduced predation mortalities from the haddock and whiting stocks.

Scenario 2: The HCRs were not found to be sensitive towards a climate induced decrease in productivity of the cod stock. Only the fishing mortalities required to reach Bpa were lower than in scenario 1. The fishing mortality to sustain an equilibrium at Bpa was below 0.4 on average in the climate change scenario. In scenario 1 the cod stock can sustain a fishing mortality of 0.5 on average.

Scenario 3: The recovery of the cod stock with the help of the HCRs was generally not at risk due to the assumed +/- 30% implementation and assessment errors. The uncertainties of the predicted stock development and fishing mortalities required to recover the cod stock, however, increased considerably.

Scenario 4: When the size of the cod stock was overestimated by 30% it was predicted to recover, however, with a probability of around 90% in 2030 not to the level of Bpa. The fishing mortalities calculated by the HCRs were too high since the cod stock was assumed to be in a better shape than it was in “reality” - due to the assessment bias.

Scenario 5: An additional underestimation of the fishing mortality by 30% compared to scenario 4 led to a further reduction of the predicted cod SSB. The average “true” applied fishing mortality reached 0.65 due to the implementation bias, although a fishing mortality between 0.4 and 0.5 on average was predicted to lead to an equilibrium at Bpa level in scenario 1.

Scenario 6: The implementation of the HCRs lead to a recovery of especially sandeel and herring. While sandeel was predicted to be above Bpa with a high probability (>80%), the recovery of herring was not that pronounced. The probability to be under Bpa was still around 60% in 2030. Norway pout was not able to recover in 50% of the 10000 MCMC simulations, even when the fishing mortality was close to zero. In contrast, the parameter uncertainties for this stock, however, were so large that in 40% of the cases the stock was predicted to be well above Bpa. In an indirect way the HCRs for forage fish had also a positive effect on predator stocks. Due to the Holling type II functional feeding response, the increasing stocks of sandeel and herring led to reduced predation mortalities for cod and whiting. The relative stomach contents of cod and whiting prey decreased since their relative abundance in the sea decreased due to the recovery of the other prey stocks. This effect led to a moderate recovery of cod towards 80 thousand tonnes on average when fished with 2006 fishing mortalities. Whiting recovered towards 200 thousand tonnes on average.

Scenario 7: When the HCRs were applied to all gadoid predators only cod was predicted to recover. All other stocks suffered from the increasing predation mortalities from the cod stock. Even when fished with HCRs whiting and haddock were predicted to stay below Bpa with a high

probability (> 80%). For haddock, however, this result may be unrealistic. Due to the assumption of a geometric mean as the stock recruitment function, the extreme large recruitment events which are typical for this stock were not taken into account - since it is up to date impossible to predict when such events will occur.
For other prey stocks as Norway pout and herring the HCRs for the gadoid predators have also a negative effect. Due to the increasing predation mortalities the stocks are predicted to collapse with a high probability under current fishing mortalities. Only the sandeel recovery was robust against the implementation of several parallel predator HCRs since haddock and whiting were predicted to not recover, even when fished with very low fishing mortalities.

Conclusions
The simple HCRs for cod led to satisfying results and a recovery of the cod stock under these HCRs was predicted to occur with high probability. The HCRs itself were thereby quite robust against changes in the productivity of the cod stock as well as assessment or implementation errors.
The problem with such HCRs was in fact, that the fishing mortalities needed to ensure a recovery were sensitive towards changes in the productivity of the cod stock or assessment and implementation errors.
Although a recovery under the rule of a maximum inter-annual change of +/-15% occurred in all cases, the estimation of the absolute target fishing mortality was associated with high levels of uncertainty. An additionally simulated assessment and/or implementation bias prevented the recovery of cod towards Bpa. The reason was in the wrong perception of the status of the stock.
When evaluating HCRs in a multi species context it became obvious that the recovery of predator stocks will cost productivity of the prey stocks due to increasing predation mortalities. The general trends were stable, although the predictions were highly uncertain especially due to weak stock recruitment relationships. In the current situation where a number of prey stocks are in critical shape in the North Sea (e.g., whiting, herring, sandeel, Norway pout), recovery plans for predators as cod have to be evaluated with care. Traditional single species management plans may lead to unwanted impacts on these prey stocks. It may be more effective to rebuild the prey stocks first before adding additional predation pressure on these stocks. Once the forage fish stocks have been rebuild, the recovery of predators will be most likely accelerated. As long as a Holling type II functional feeding response is an appropriate assumption, juvenile predators are eaten less the more alternative prey is available to the adult predators
Whether the recovery of the cod stock may lead to a food limitation for marine mammals depends highly on the future stock development of other predator stocks, as e.g. mackerel. A recovery of cod alone is most likely not able to cause a collapse in forage stocks as herring and sandeel. If the whole North Sea ecosystem changes to a state where more than one predator stock exert a high predation pressure, however, the danger of a collapse in important prey fish stocks becomes evident especially if fisheries management does not take such changes in predation pressure into account (as it is currently the case!). In the current North Sea ecosystem state non-assessed predator species as mackerel, horse mackerel and grey gurnard play an important role. An ecosystem based management should therefore no longer focus exclusively on the traditional predator species as cod, haddock and whiting, but also on improving the knowledge and data situation for so far more or less ignored predator species. E.g., the limited availability of data on abundance, distribution and diet of the western mackerel stock in the North Sea lead to high uncertainties in the mid-to long-term forecasts and any estimation of future predation mortalities can only be achieved with wide confidence limits. Here only field work, i.e., routine sampling & process studies, can help to better parameterize our models and provide more meaningful results.

APPLICATION OF SIZE SPECRTRUM MODELS

Alternative less data-demanding size-based models were developed by Cefas to investigate the following processes: food dependent growth and mortality (driven by predators consuming smaller prey); the effects of benthic-pelagic coupling and prey quality on community size structure; the effect of spatial processes and movement on pelagic community size-structure (Castle *et al*. in prep); and the dynamics of a single "cod-like" species coupled with the overall community size-spectrum. They provided an alternative tool for answering questions related to the effects of fishing on the structure of ecosystems and can complement traditional single-species, multispecies and more complex modelling approaches for addressing ecosystem-based fisheries management questions.

The size-based models developed by Cefas were used as an alternative approach to test the consequences of recent historic exploitation patterns on the size-structure of the North Sea ecosystem as a whole. The resultant size spectra including recent levels of fishing were closer to the large-scale patterns of the observed data than the baseline model scenario results for fish and benthic infauna community size spectra observed in the North. A range of primary production input values was tested, representing mean, minimum and maximum annual estimates. Higher levels of primary production appeared to buffer the effects of fishing, whereas lower levels resulted in truncated size spectra that were more susceptible to fishing. Fishing increased the slope of the pelagic fish size spectrum, whereas the indirect effect of prey release on the benthic size spectrum resulted in shallower slopes for the benthic spectrum. Compared with unexploited baseline, and under mean levels of primary production, there was an 88% reduction in the biomass of large fish between 1 and 4 kg, a 99% reduction of fish 4-16 kg and a 100% reduction of fish 16-66kg.

The recent exploitation pattern over the period 1990-2003 was also applied to species plus background size spectrum model. This was applied to cod and the pelagic predator size spectra to determine levels of reduction that would be caused by fishing compared to the unexploited baseline size spectra. Initial tests showed that fishing resulted in a reduction in the density of large predators in the pelagic fish community and an increase in the density of cod and benthic detritivores. Although these results demonstrate some of the knock-on effects that can be typically experienced in fished ecosystems, the results are preliminary.

The coupled size spectrum and the cod-background community size spectrum models were used to test various fisheries management scenarios under different environmental conditions. A North Sea Ecopath model completed under another project by Cefas was used to evaluate different fisheries management scenarios with a focus on the North Sea sandeel fishery. A comparison of the effects of these management scenarios with results from the size-based models was carried out.

Evaluation of the ecosystem impacts of size-selective exploitation patterns in the coupled size spectrum model relative to unexploited reference levels showed that increasing fishing mortality resulted in size spectrum slopes decreasing from –1 to –3 for the range of fishing patterns and plankton conditions examined. This is consistent with the range of slopes reported for heavily fished ecosystems. Applying the same area closure used in the EwE scenario resulted in a greater abundance of small fish with the largest positive impacts cascading to predators sized between 0.1 and 1 kg. Different prey quality had a small effect on the biomass and abundance of size classes, with lower benthic prey quality scenarios resulting in marginally larger reductions (by about 1-2%) in large fish across all of the scenarios. Further work on the effects of prey quality is required to fully evaluate the management implications of removing high energy prey (such as sandeels and other fish species) on predators

Further work is required to be able to understand the full range of dynamics possible from different models and from potentially conflicting, management objectives. Model cross-comparison and validation will be undertaken along with investigation of a broader range of management objectives and scenarios related to predator recovery plans and the development of EAF reference points. This is work that will be carried forward by ICES Working Groups and ongoing EU projects (e.g. PROTECT, UNCOVER, IMAGE, MEECE).

APPLICATION OF ECOPATH WITH ECOSIM MODELS

Cefas carried out evaluation of the ecosystem-effects of various fisheries management scenarios. Evaluation of the broad scale impacts of alternative sandeel management scenarios using the EwE model specified using data from the Dogger Bank, revealed that the ‘release’ of sandeel competitors, could help sustain population of predators (including fish, seabirds and marine mammals) that were initially negatively impacted by fisheries depleting stocks of sandeels. Increasing TAC to 1 million tonnes generally had negative effects, whilst seasonal closure appeared to provide no benefit at all because the abundance of juvenile sandeels is mostly governed by the abundance of zooplankton. Area closures had the widest ranging positive impacts to sandeels, their predators and fisheries.

Closure of the entire North Sea to sandeel fishing has strong positive effects for the sandeel predators and the fisheries dependent upon them. It is also strongly beneficial for sprat (a competitor), which are taken as a by-catch of the sandeel fishery. Predators benefit from the increased abundance of both. This type of response is the rationale that has supported the development of forage fish management plans in the USA, the principal goal of which is to conserve stock of small fish important to top predators (e.g. herring in Washington and Alaska, small pelagic fish in Florida), i.e. to create the right forage conditions for predators so that their populations are more likely to thrive.

COD NEPHROPS INTERACTIONS

The management implications of the Cod-Nephrops interactions were based on empirical data analyses in the Skagerrak and Kattegat did not have a analytical nature. Biological reference points for *Nephrops* have not been proved possible under the ICES precautionary approach framework. Furthermore, *Nephrops* are not covered by management plans containing targets (relating to biomass or fishing mortality). The recover of the cod stocks (both in terms of biomass and size structure) can have an effect on *Nephrops* population. The potential recover of other demersal fish, predator of *Nephrops* (as pollock and ling), needs also to be considered in management. Increasing temperature and frequency of hypoxic condition periods at bottom increase the vulnerability of *Nephrops* (especially females) to both fishing gears and predators. Thus, natural mortality should be adjusted accordingly in an analytical assessment. Increasing biotic production due to eutrophication and high level of discards from commercial vessels could keep high the *Nephrops* production even in case of increased predation mortality.

SANDEEL DISAPPEARANCE, SNAKE PIPEFISH APPEARANCE, IS THAT NORMAL AND WHAT DOES IT MEAN FOR SEABIRDS ?

The structure and function of marine ecosystems may be regulated through 'bottom-up' effects, where the amount of primary production, often thought to be under climatic control, determines the abundance at higher trophic levels, or through 'top-down' effects of predators on lower trophic levels. Recently, there has been strong interest in when and where each of these mechanisms is most. The dominant type of regulation in a specific ecosystem clearly has major implications for resource management and for inferring causes of observed changes in ecosystem components.

Most species of seabirds in the North Sea suffered widespread reproductive failures in 2003, 2004, 2005 and 2006. The most severe problems, including total failures of some species, occurred in Shetland and Orkney in the northernmost part of the North Sea, but in 2004 exceptionally low breeding success was also observed in colonies along the E coast of Britain. Although bad weather during the chick-rearing period was partly to blame at some colonies, the main proximate cause of the breeding failures was a lack of high-quality food. Most seabirds in the North Sea feed mainly on sandeels *Ammodytes marinus* during the breeding season. Since the 1970s, sandeels have been the dominant mid-trophic pelagic fish in the North Sea, and around Shetland no other high-lipid prey fish occur in sufficient densities to support successful breeding of most piscivorous seabirds. There is thus little doubt that the observed seabird breeding failures were linked to low availability of high-quality sandeel prey. Further evidence for the bad state of North Sea sandeel stocks comes from the large-scale industrial fishery: during the 1990s annual landings were 600,000-1,100,000 t, but in 2003 and 2004 they fell to around 300,000 t, and the fishery was closed completely by the European Commission from 15 July 2005.

Recruitment to sandeel stocks in the southern North Sea has been shown to be negatively affected by high winter sea temperature. Recruitment was extremely low in 2002 and in most subsequent years. It thus seems obvious to link the problems that sandeel stocks, and in consequence breeding seabirds have experienced since 2003 to global climate change, and such a connection has indeed been made, and widely publicized. However, there is as yet no published evidence to show that high sea temperatures caused the observed sandeel recruitment failures since 2002, and the exact mechanism through which climate affects sandeel recruitment remains unclear. While climate-driven bottom-up control of sandeel abundance is a plausible scenario, other explanations are possible and should be considered.

Specifically, a ‘new’ source of possible top-down control has reappeared in the North Sea since 2000. Herring *Clupea harengus* stocks have increased from less than 100,000 t in the late 1970s to 2 million t in 2004, a level not seen since they were reduced dramatically by overfishing in the 1960s. Rather little effort has so far been put into evaluating the possible top-down impact of predatory fish that consume sandeel larvae.

Sandeels and herring are both schooling pelagic fish feeding mainly on zooplankton, and both can be extremely numerous in seas of NW Europe. Herring feed extensively on sandeel larvae in spring, and on other zooplankton. Herring are pelagic throughout their lives, but sandeels have a more complex life cycle. Adults spend most of the year buried in sand, and only emerge to feed in daylight hours of late spring/early summer, and to spawn in midwinter. The pelagic larvae hatch in early spring, and after metamorphosis around May the 0-group fish establish a diurnal rhythm similar to that of adults. They continue feeding until mid or late summer, accumulating lipid stores to overwinter. Sandeels are dependent on suitable sandy sediments, and adults are only abundant in areas where such sediments are common. Although managed as if a single North Sea stock, sandeels show pronounced population structuring within the North Sea, whereas the more nomadic herring belong to one large stock, the North Sea autumn-spawning herring. Young herring predominantly develop in the southern and eastern North Sea, whereas adults concentrate in the northwest for much of the year.

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

Further south in the North Sea, off SE Scotland and NE England, sandeels are also the main prey of most seabird species. In contrast to Shetland, other fish prey are also available, and in particular young clupeids (mainly sprat *Sprattus sprattus*) are taken in some years by seabirds. However, few adult herring occur in this part of the North Sea. There are no long-term data on sandeel abundance in this area, but during the 1990s local sandeel biomass was reduced by an industrial fishery, and this was associated with low breeding success of black-legged kittiwakes on the Isle of May in the Firth of Forth. Frederiksen *et al* used Continuous Plankton Recorder data to develop an index of sandeel larval abundance, and this index was positively correlated with breeding success of four seabird species in the following year. The sandeel larval index was also strongly positively related to the abundance of phyto- and zooplankton, suggesting strong bottom-up control. In 2004, breeding success was exceptionally low for most seabird species on the Isle of May, despite sandeel larvae being abundant in the spring of 2003. Detailed studies showed that the energy content of both sandeels and sprat fed to seabird chicks in 2004 was extremely low, indicating poor food availability for the fish. Data from chick-feeding puffins and CPR samples also indicate that the size-at-date of both larval, 0 group and older sandeels has declined substantially since 1973, although it is unclear what is the exact cause of this decline. There is thus evidence that both abundance and quality of seabird prey is under bottom-up control in this region, and this is likely to have affected seabird breeding success.

Sandeel spawning stocks mainly consist of 2-year old fish, and are thus expected to be influenced by the strength of recruitment with a 2-year lag, although in fact variable proportions of 1-year old fish spawn too, and this cohort may greatly exceeed the abundance of older age-classes so should not be assumed to be trivial. Fishery-based estimates of sandeel SSB in the North Sea 1983-2004 were negatively correlated with herring SSB two years previously ($r = -0.54$, $P = 0.0099$), indicating the possibility of top-down control. However, there was no correlation between North Sea sandeel SSB and the CPR-based index of sandeel larval biomass off E Scotland two years previously ($r = -0.10$, $P = 0.67$). This lack of correlation may reflect differences in spatial scale of the variables: the larval index is specific to one sandeel aggregation off E Scotland, whereas the SSB estimates fail to account for population structure within the North Sea and may be primarily determined by conditions on the main fishing grounds in the central North Sea.

It is noteworthy that the recent decline in sandeel abundance in the North Sea shows a very strong regional patterning, with the greatest decrease in sandeel abundance at Shetland and off southern Norway, but with much smaller decreases towards the southern North Sea. This change is clearly evident in fishing activity too – catches of sandeels have been drastically reduced on the Norwegian grounds in the northern North Sea, but much less reduced on the Dogger Bank for example. Thus, an interpretation of the likely causal mechanism for the decrease of sandeels since 2003 must take this spatial pattern into account. This pattern is at least consistent with what might be predicted if top-down control by predatory fish was important. Adult herring are distributed predominantly in the northwest North Sea, and so impact of their increased stock biomass would likely be most evident in the northwest and least evident in the south. It seems unlikely that warming seas would result in the sandeel decline being most in the northwest, where sea temperature is largely determined by Atlantic water inflow, whereas in the southern North Sea the temperature is more strongly affected by climate-related heat input into the water. There should be scope for investigation into the pattern of temperature change of the areas of the North Sea in relation to this clear spatial pattern in sandeel decline.

Ecosystem control of the North Sea food web is likely to be complex and this is illustrated in Frederiksen et al. (2007) where they suggest relationships that may drive sandeel abundances in different parts of the North Sea. While there is some evidence of a top-down effect of herring on sandeels, herring abundance may itself be influenced by several factors, including top-down, bottom-up and direct climatic effects. Human fisheries have exerted a strong top-down control on herring stocks, which were reduced to a fraction of their previous abundance. It seems likely that plankton abundance will affect both growth and survival of herring larvae and recruitment to the spawning stock. For the Norwegian spring-spawning herring stock, recruitment is affected by oceanographic conditions determining retention and drift of larvae. It is possible that herring also exert top-down control of zooplankton abundance, and community composition, in the North Sea, as has been observed in the Baltic Sea and inferred in the Norwegian Sea. The abundance and phenology of both phyto- and zooplankton is strongly influenced by climatic factors. A full understanding would at least need to include the effects of other predatory fish (e.g. mackerel *Scomber scombrus* and cod *Gadus morhua*), the abundances of which have been severely reduced in the North Sea by overfishing. It is likely that both top-down and bottom-up processes operate simultaneously in the North Sea, with top-down processes potentially being more important at some times and in some areas (such as around Shetland in recent years) than in others.

In the last few years, seabirds have been recorded carrying snake pipefish to feed to chicks at many colonies in the northwestern North Sea. These fish are very poor as seabird food as they contain low lipid levels, but more importantly they are very difficult for chicks to swallow and to digest. Indeed, many snake pipefish have been found dropped by adult seabirds when unable to feed them to their chicks. These fish may represent a “last resort” by parents trying any possibility to keep starving chicks alive. For this reason, the fact that seabirds did not feed snake pipefish to their chicks in these colonies before 2002 may simply reflect the fact that abundances of preferred fish prey, such as sandeels, were much higher than they have been in the last few years. Nevertheless, the novel sight of seabirds trying to feed starving chicks on snake pipefish represents an indicator of severe change in their available prey-base. It is unclear why snake pipefish numbers have apparently increased, and whether that change in ecosystem structure also relates to the decrease in abundance of sandeels.

One important implication of the possibility that sandeel abundances in North Sea stocks is influenced by top-down impacts of predatory fish is that the "normal" state of the North Sea ecosystem may be one where herring and large gadoids dominate, controlling sandeel abundance at low levels (as apparently in the period before the 1960s). The increase in sandeel abundance in the 1970s to 1990s may simply represent a short-term perturbation of the system caused by the removal of most mackerel, herring and gadoids, and so removing top-down control of sandeel abundance. The high breeding success of North Sea seabirds fuelled by abundant stocks of sandeels from the 1970s to the 1990s, and high rates of population growth of most seabird species in the North Sea during that period, may therefore by also a response to an abnormal perturbation of the ecosystem. Seabird ecologists working around the North Sea have mostly developed careers during this phase of high breeding success and population growth of seabirds. This may not be the "norm" against which seabird breeding failures of the period after 2003 should be evaluated. Rather, the high rates of increase during a period of abnormally high abundance of sandeels might be seen as an abnormal phenomenon. It may be that seabird populations in the North Sea were more "normal" in the period before the 1960s, but unfortunately there are few data on their numbers, breeding success or ecology from that time period.

Bay of Biscay / Iberian Peninsula

HAKE CANNIBALISM AND SPATIAL PREDATOR PREY OVERLAP

Spatio-temporal behaviour of hake on the eastern continental shelf of the Bay of Biscay was analysed using geostatistical means (i.e. aggregation curves and spatial selectivity index). Kriging distribution maps are available for hake age group 0. On the eastern continental shelf of the Bay of Biscay, hake age 0 concentrations are generally stable in size and spatial location. Hake age 0 densities vary according to the strength of the year-class and high density areas represent the same proportions of biomass and of total occupied area. Maps for other hake age groups were achieved as well as for prey species such as horse mackerel and blue whiting. For the southern stock, European hake is considered the main predator and maps were created for this species as also for its key prey, i.e. horse mackerel and blue whiting.
The spatial distribution between hake and its main preys was calculated per length group to create spatial overlap indexes. Environmental variability at mesoscale is known from the coastal area to the middle of the continental shelf (especially river discharge) while the outer part of the shelf is less variable. Blue whiting lives in the outer part of the shelf while anchovy and horse mackerel inhabit the inner part. Hence the spatial distribution of horse mackerel and anchovy may be more variable. On the eastern continental shelf of the Bay of Biscay, hake age 0 concentrations are generally stable in size and spatial location. The temporal variability of spatial distribution is too low to look for a relationship with environmental variability. Global and local spatial overlap indexes between hake age groups showed great temporal variability, explaining the temporal variability of hake cannibalism observation.

APPLICATION OF MULTI SPECIES MODELS

Five models were implemented in GADGET for the two sub areas of the CS4, i.e. Bay of Biscay (Bob) and Atlantic shelf of the Iberian Peninsula (IP). In March 2005, it was decided to split the modelling work according to the current division into two management areas for hake, i.e. the Northern hake stock partly distributed in the Bay of Biscay, and the Southern hake stock distributed on the Atlantic shelf of the Iberian Peninsula. This approach gave the possibility to compare the outputs of the first GADGET implementations to stock assessments made by the ICES Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and Megrim (WGHMM).
The aim was to fit single species hake models for both areas, to link each model with single species models of other species interacting with hake in order to create multispecies models and afterwards to merge both multispecies models to obtain a general model for hake. However the difficulties and the delays encountered to achieve the first step of the implementation in GADGET did not allow to implement a general and multispecies hake model.

Southern hake (Iberian Peninsula)

First, a single species model for hake of the Iberian Peninsula (IP) was implemented by IEO using survey and commercial data provided by Spain and Portugal. This model covers the same area as the Southern Hake stock assessed by the ICES working group, so it was possible to compare the GADGET model outputs to those of the ICES WG assessment to check the suitability of the input data. The comparison provided a reasonable consistency between both models.

Then, a model of predation of hake by hake (cannibalism) was added to the single species model. The implementation of this trophic process was made possible by the information provided by Velasco in 2007 (Fran Velasco from IEO, PhD 2007). Velasco's information filled a crucial gap in the food web data.

The achievements include a function defining the maximum consumption by length in kJ per month, a suitability function describing the size relationship between hake as predator and hake as prey, the prey energy content and the proportion of hake in the hake diet. These are the minimum information required by GADGET model in order to implement a trophic process. The existing models are very basic and there is a need for the future to include changes according to the hake size, the area, the season and the year. Nevertheless, it is the first time that an assessment model of that area includes trophic interactions.

The current Iberian Peninsula GADGET model has several limitations. Data of good quality were scarce before 1994 to initialise the model. Area allocation was not possible for the commercial data. Only one area was considered in the current model although area differentiation, based on country (Spain - Portugal) or gear, could be possible in the future.

Generally, multispecies models are implemented in GADGET by linking two or more single species models through a trophic relationship. During this project, it was not possible to collect sufficient data to develop appropriate single species models for other species like blue whiting or horse mackerel and the time spent to develop hake models was longer than expected. Indeed, blue whiting and horse mackerel stocks are spatially widely distributed with many countries implied in their exploitation. In the absence of models for hake preys species in IP, the only option to set a trophic model was the cannibalism.

So, the IP cannibalistic hake GADGET model was a single species model where a cannibalism process was added. Trends for SSB, F and recruitment are similar in both models, with and without cannibalism. The recruitment estimated from the cannibalistic model was about six times higher than in single species model. SSB and F levels were similar. This may be explained by the existing differences in the age structures between both models, with high recruitment and high mortality in model with cannibalism. The adjustments of both models were bad at the beginning of the time series.

To compare both model (with and without trophic process) predictions and to evaluate the effect of the addition of the trophic process, two different projections until 2020 have been simulated under different management strategies:

(i) the specifications of the Hake Southern stock recovery plan and
(ii) different levels of constant fishing mortality multipliers.

The results showed that at short term there were not differences in SSB or yield between both models. In the medium term the cannibalistic model gave a slower recovery of the SSB and also less yield than the single species model. In the long term the cannibalistic model achieved lower SSB levels than the single species model.

The main conclusion of the work performed is that the cannibalism process should be incorporated into the currently used assessment model, as it gives a more pessimistic view of the recovery possibilities and future yield of hake Southern stock in the medium and the long term.

However, it must be taking into account that the present implementation of the trophic process (cannibalism) is very elementary with certain assumptions, which were not realistic like constant proportions of stomach content independent of the predator size, of the time or of the area. In awaiting a better model, it can be affirmed that it is important to take account of the cannibalism in the assessment models to get a better overview of the capacities of recovery of the hake stock.

Northern hake (Bay of Biscay)

The target species in this case study were identified as follows: hake as the top predator; anchovy, horse mackerel and blue whiting as its most relevant preys.

Hake and anchovy data have been compiled from AZTI (commercial data) and Ifremer (commercial and survey data) recurrent sampling programs carried out in this area. Data for demersal and pelagic target species exploited in ICES Sub-divisions VIIIabd and provided by ICES working groups were also stored in the data warehouse. Catches and survey data for horse mackerel and blue whiting were also provided by IEO and Ifremer.

Commercial data for horse mackerel were not reliable in the Bay of Biscay and no data have been available through the ICES Working Group on the Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy (WGMHSA) since 2000. Similar problems occurred with the widely distributed blue whiting stock. The difficulties to capture the dynamics of stocks so widely distributed as hake, horse mackerel and blue whiting at the scale of the Bay of Biscay were underestimated. Big difficulties were encountered when setting up a parametric statistical model (GADGET model) because of the lack of suitable data for the Bay of Biscay.

Finally, sufficient data were only available to implement single species GADGET models for hake and anchovy. Relevant diet and consumption data for hake (Velasco, 2007) were available close to the end of the project and have allowed to link the two single species hake and anchovy models. However, these models still have limitations.

There were trend discrepancies between hake GADGET model outputs and ICES WGHMM results related to F, biomass, spawning stock biomass and recruitment. The Northern hake model implemented in GADGET for the Bay of Biscay did not capture the dynamic of the whole hake Northern stock. This is because the spatial scale used for the hake GADGET model was the Bay of Biscay (ICES Divisions VIIIabd) while the hake Northern stock assessed by the ICES WGHMM extended from the south of Bay of Biscay (boundary between France and Spain) until the Norwegian coast.

Like for hake, a single species model was set up for anchovy. Unfortunately, it was not possible to understand why the model gave a bad fit to the data.

A predation relation of hake on anchovy has been added to link the two single species models and to implement a multispecies model in GADGET. As for IP hake, data provided by Velasco (2007) were determinant to establish a simple model of consumption (consumption not depending on predator and/or prey lengths, season, area, year).

Despite these limitations the multispecies model was run, the results for hake showed a very variable F during most of the period and a decreasing trend during the last five years. Biomass steadily declined until 1997-1998 and then slowly increased, these results are not so different from those obtained with hake single species model or the ICES WG assessment. The range of the values obtained for anchovy for F, biomass and recruitment were considered as unreliable.

At the beginning of the BECAUSE project, traditional ageing of hake was questioned from tagging experiments developed by Ifremer. Age readings differ by a factor of 2. The confirmation of the overestimation of the age of the hake came late during the project in 2006.

A simulation of a twice faster growth pattern was run by the ICES WG. Results showed that the absolute levels of estimates of fishing mortality and stock biomass of stock assessment were affected while overall trends were very similar. However, a stock with such a higher growth rate would be more reactive to changes in fishing levels which would affect catch forecasts and advice.

The new hake growth model was implemented in the GADGET hake model and results were as anticipated, i.e. trends were similar to the ones obtained with the previous one and the range of values was different. The same growth model implemented in the multispecies model showed very different results with opposed trends.

Predictions carried out with the multispecies model, using the “traditional” hake growth model, showed that current fishing mortality will allow a similar level of hake catches in short, medium and long term. A small increase of fishing mortality will produce at short term more landings but also a quick decline of the SSB. Similar results were obtained for catches using the new hake

growth model but SSB declined when fishing at current F. However, it must be noticed that, in the later case, the characteristics of the hake population were not realistic.
It is possible to say nowadays that there is a parameterized GADGET model for hake eating anchovy in the ICES sub-division VIIIabd. However, this preliminary multi-species model is not yet reliable enough to be used as a management evaluation tool and cannot yet be used as an alternative in the current assessment of the hake Northern stock.

Mediterranean Sea

TYRRHENIAN SEA - LIGURIAN SEA

A basic GAGDET model was built for hake in the Tyrrhenian Sea. The model has a quarter time aggregation and time span of 11 years (1994-2004). The conceptual model simulated two stock components that represented small and large hake separately. The whole fish population included five year classes with age4 as plus-group. 1 cm length aggregation. Fish passed from small to large through maturation at a fixed length of 40 cm; it ensured that the large fish component was represented only by mature hake. The values of the von Bertalanffy equation assumed a fast-growth hypothesis. A single recruitment event was modelled in the second quarter of the year. Fishing level was fixed at the value of 2.5 (high fishing pressure). Fisheries effect was simulated through two fleets: the main one represented commercial trawlers and was controlled by a gamma suitability function, the second and less important was governed by a constant function. The first fleet fished the small fish component (fish <40 cm) that actually represents most of total landings, while the second fleet caught only large hake (fish >40 cm) and represented a multitude of actual gears (the tail of trawlers selectivity on large hake, gillnets of different mesh size). The hake model was a deterministic model, but it was possible to include stochasticity into the projection part of the simulation modelling a probability distribution of the recruitment process. Although the lack of a long time series, residuals of recruitment were approximated by a normal distribution that was chosen as the most appropriate for forward projections. Thus, recruitment was simulated to fluctuate around the mean level of the previous 11 years (1994-2004) with a defined standard deviation. The model was fitted to 2 survey time series and landing data.
The basic model was enhanced by adding several processes, as e.g. cannibalism, double recruitment, enhanced maturation.
A 2-areas model was built for the Tyrrhenian and Ligurian sea. No migration of fish was simulated because although movement of fish between the two areas is theoretically possible no specific data were available. The dynamics of the two stocks were related by a certain number of assumptions like different size but shared pattern of recruitment, a fishing pressure approximately 1.4 times higher in the Tyrrhenian than in the Ligurian. Stock behaviour was quite similar in the two areas, but a higher number of medium size and large fish were predicted in the Ligurian, in agreement with the data. A more stable SSB was predicted in the Ligurian with a reduction of only 5-10% in the period 1996-2004, while an almost 40% decrease in the Tyrrhenian in the same time period. Also the assumption of a shared recruitment dynamic revealed the ability of the model to get the common features in the recruitment observed in the two areas (recruitment peaks in 1998 and 2002) with the advantage of a reduced number of parameters (more parsimonious model).

The GADGET model was chosen for the development of a multispecific model for hake in the Mediterranean. Although the trophic interactions between hake and its prey have been analysed and quantified in WP1, the lack of a systematic data collection on small pelagic fish in the Tyrrhenian-Ligurian area (no acoustic or pelagic surveys are currently enforced) did not allow to build dynamic models for sardine and anchovy. Single species model for prey are needed in GADGET to evaluate prey-predator interaction in a dynamic fishery context.
Thus, the available data were used to develop a GADGET single-species model for hake, ready to be implemented including critical interaction with small pelagic fish, as soon as biological data will be accessible. At the moment the only trophic interaction simulated in GADGET was cannibalism.
Several scenarios were built simulating different management measures: reduced fishing level, variations in gear selectivity. In all the scenarios the same management strategies were

implemented in both the Tyrrhenian and the Ligurian area and differences in the dynamic of the two stocks were discussed also respect the scenario without new management startegies.

A positive result of the current modelling approach was the ability to successfully include a fast growth rate into the simulated stock dynamics. The consequences of assuming an almost half growth rate in most of the previous stock assessment models have not been fully considered but can be easily supposed. Even if very simple and based on relatively strong assumptions, these Gadget models could be more reliable in some aspects than other assessment models exactly because the growth assumptions are closer to the real fish growth. Another interesting result came from the recruitment model implementation that well agreed and confirmed the two recruitment event per year that allowed a back-calculation of the spawning peaks in autumn and late winter. The other implemented models did not provided the expected results or not enough data or sub-process specific analysis were available for their objective evaluation. Thus, moderate levels of cannibalism could be expected for hake in the Tyrrhenian area, but their effects on the stock dynamics cannot yet be assessed due to lack of suitable diet data.

The lack of long time series landing data was by-passed defining a fishing level parameter that was intended to be proportional to the landings as implemented in Gadget. Comparison of different fishing level scenarios helped us to partially solve the problem, looking for the best fitting model, but also to the model that behaved more closely to the general knowledge that we have of the studied fish stock. This involved the use of estimations from a geostatistical model for comparison. A very high level of exploitation was found to be the most reliable for the current stock in the Tyrrhenian, and the calculated fishing mortality values perfectly agreed with the values independently obtained end of the 1990s.

A comparison of the management scenarios shad light on the important and positive consequences that a moderately modified selectivity pattern would have on the stock dynamics, both in terms of biomass and landings. Contrary from what could be expected a reduction in the fishing impact, simulated by either a lower fishing level, by closed areas or by a more selective fishing pattern, was not followed by lower landings. The amount of catch was predicted to remain almost invariant reducing the fishing level of 5% or with closed areas that would preserve 20% of recruits, while simulations forecasted a moderate increment with alternative trawler selection pattern.

The self-executing rules of Reg. EC 1626/1994 established a minimum mesh size of trawlers of 40 mm and a minimum fish size to protect hake juveniles at 20 cm. Actually hake much smaller than the minimum legal size are landed and discards can represent a high proportion of total landing and are not easy to be estimated.

Assumptions on the similarity between the two areas were probably too strong to appreciate differences in the outputs. If some biological parameters like growth can be reasonably shared, probably more careful consideration should be done about natural mortality, time of recruitment and fleet composition in the Tyrrhenian and in the Ligurian area. Also the assumption of a similar length composition of landing seemed evidently to be too strong and disaggregated data would be needed required. Although shared features could be found in the two adjacent areas, for instance in the recruitment pattern, the two modelled stocks would require a stronger characterisation in terms of model setting and landing data likelihood components.

The lack of data on the migration of recruits as well as of mature fish between the Tyrrhenian and Ligurian convinced us of not to include any migration model because its results would have been evaluated by too subjective considerations. Although theoretically possible, also in relation to the oceanographic features of the two areas and of the Corsica Channel, no tagging experiment was carried on in the area. Mark and recapture of fish would be probably one the most effective way of directly demonstrating the existence of such migration process between the two basins and its evaluation would have a great impact on the definition of Mediterranean hake sub-stocks and on their management.

Commercial landing data are the fundamental source of information for catch based stock assessments but also for the development of multispecies models where fleets are, together with other marine species, competitors of the same resources. Long time series of landing data are lacking in the Italian fishery context, as well as in most of the Mediterranean, but the few years of data available represent precious information that should be more carefully considered and fully utilised.

On the other side there are certain kinds of information and data aggregation levels that are really lacking but which would be necessary for a multispecies and multifleet modelling. Total landings should be always available for single species, especially for the commercially most valuable species. The biomass or number of fish caught should be disaggregated by fishing gear, or groups of gears, when the species is targeted by different fisheries that exploit different size components of the stock.
Even if the Mediterranean is quite unique for its complexity in terms of interaction between many species and the fisheries components, the trophic system into which hake represents the predator can be very much simplified and for many aspects compared with that observed in the north-eastern Pacific. Small pelagic fish like anchovies (*Engraulis encrasicolus*) and sardines (*Sardina pilchardus*) represent the main preys of hake in the Tyrrhenian-Ligurian area. During a well defined pre-maturing phase hake migrate on the continental shelf to feed of small pelagics that constitute 80-90% of its diet. Along the west coasts of US and Canada, *Merluccius productus*, *Engraulis mordax* and *Sardinops sagax* constitute a similar system. To develop a multispecies model in the Mediterranean at least a simple dynamic model of small pelagics should be built. This would mean the use of biological and landing data on anchovy and sardine that at the moment are not available.
Actually in the Tyrrhenian-Ligurian area no pelagic survey is carried out and no data are available on the length distribution of anchovy and sardine from commercial landings.
In the study area quite good information about hake juveniles are available from the two annual trawl survey MEDITS and GRUND. It has been proven that the selectivity of trawler steeply decrease for hake larger than 25-30 cm resulting in a strong underestimation of large hake. For fish >40 cm trawler catchability is so low that annual variations in the number of fish caught during the survey risk to be strongly influenced by stochastic effects. At the moment no other experimental survey is carried on with gears that could specifically target large hake (i.e. gillnets, acoustic survey, etc.). Coupled with a limited data collection of gillnet landings (Reg. CE 1543/2000) this unbalanced sampling effort of the stock produced a great lack of knowledge and data available on mature fish.
More experience with Gadget is actually required. Although the indubitable potentialities of this modelling toolbox, great effort was needed to implement each model.
The Mediterranean area also suffered the lack of a previous long experience on stock assessment and population dynamic modelling. This was not only related to the fact that a certain time was required to learn how to use the data warehouse and Gadget, but also to the lack of ready estimations (i.e. initial population) to build a Gadget model, to the lack of outside Gadget assessments that could be used to evaluate results.
The integration of a spawners-recruits relationship within the model would provided an important implementation especially in terms of forecasts. But to formalise the reproductive potentialities of the mature fish stock is not always easy or possible. Other components of the system, internal (density dependent mechanisms) and external (oceanographic processes at different scale) to the stock, can play a key role into the recruitment process and success.
We have started just now to understand the effects of the environment on the hake recruitment fluctuation in the Mediterranean and which are the driving forces on the survival rate of recruits and in the renewal process of the stock, but a lot of work still need to be done for an appropriate and useful modelling.
Another way of interaction between large and small hake could be represented by cannibalism. Incorporating dynamic cannibalism could be of great importance for a correct interpretation of some of the alternative management scenarios presented above. For instance, considering the important variations in the SSB that were predicted with some management strategies, there would be the risk to overestimate the size of the stock available for fisheries.
Although many studies have focused on hake in the Mediterranean, the knowledge of many aspects of the life cycle of this species are still fragmentary and poorly understood, both from a geographic and biological point of view. Questions concerning many processes and aspects of its biology are not well known.
Among the main gaps of knowledge there is the lack of definite proof on the existence of sub-stocks within the Mediterranean basin and the presence of natural barriers. From a theoretical and also practical point of view, it is very difficult and also not so meaningful to model a fish stock of which we don't know boundaries and spatial structure. We also ignore the dynamics of

migration of larvae and adults and the role played by certain recruitment areas on the local and large scale for the renewal of the stock.

EASTERN MEDITERRANEAN SEA

The first key run of GADGET in the Eastern Mediterranean Sea has indicated that less than 40% of the total biomass was removed from the North Aegean Sea due to fishing. If the model estimations are trustworthy then the population seems under no immediate threat in the short and mid-term. This is particularly important because fish from ages 1 to 5 years make up 95% of the commercial trawl catches (mean of 2002–2006). Thus, this represents an essential step towards an accurate assessment of the status of the Aegean stock.The more complex model used to assess the population, included the partition in two sub-populations (adults-juveniles) and the effect of cannibalism.Results of this model suggest that the adult stock is, more or less, in a steady state just above 2.000 tonnes in the last 15 years.

The juvenile stock estimation fluctuates between 3 and 7 thousand tonnes annually, mainly due to the large effect of the recruitment component used in the juvenile population model. Taking into account the length distributions of commercial catches, it is likely that the adult population is most affected from fishing mortality. Although fish less than 3 years of age comprise the 70% of the catch in numbers, they add up to only 30% of the catch in kg. So, 70% of the landings in weight consist of hakes removed from the adult stock. Since the biomass of juveniles is estimated to be at least double of that of adults, it becomes clear that the removal of hakes due to fishing is more detrimental for the adult stock.

Cannibalism as demonstrated from the model outputs was a negligible parameter in the population dynamics of hakes in the North Aegean. However, data from stomach content analysis have shown that hake > 15 cm prey on juvenile hake but this is strongly affected by the month of the year, i.e. from 0% to up to 78.4% during the recruitment months (August and May). No direct comparisons could be made due to the fact that stomach content analysis indicates strong monthly seasonality on cannibalism, whereas the model time step was a quarter.

Plan for using and disseminating the knowledge

Section 1 - Exploitable knowledge and its use

This default section was made to only present exploitable results, defined as knowledge having a potential for industrial or commercial application in research activities or for developing, creating or marketing a product or process or for creating or providing a service.

- nothing to report.

Section 2 – Dissemination of knowledge

PEER-REVIEWED PUBLICATIONS

1. Asseburg, C. John Harwood, Jason Matthiopoulos & Sophie Smout (UStAn) 2006: The functional response of generalist predators and its implications for the monitoring of marine ecosystems. In: Top predators in marine ecosystems: their role in monitoring and management" (I.L. Boyd, S. Wanless and K. Camphuysen eds.) Cambridge University Press, ISBN-13: 9780521612562. pages 262-275.

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15. Ehrich, S., Adlerstein, S., Brockmann, U., Floeter, J., and 11 other authors.: 20 years of the German Small-Scale Bottom Trawl Survey (GSBTS) (UniHH 2007): Senckenbergiana maritima, 37 (1) 13-82.

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1. Asseburg, C. (UStAn) 2004: The functional and numerical responses of marine predators, and their implications for monitoring. Management of Marine Ecosystems: Monitoring Change in Upper Trophic Levels. 22nd April 2004, Zoological Society of London.

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6. The project web site was established in March 2004 http://www.rrz.uni-hamburg.de/BECAUSE/
7. A BECAUSE brochure, giving a short overview on the projects objectives, tasks and participants, was produced (n = 500) by UniHH and distributed to all contractors for further distribution.

DOWNLOADABLE PROJECT INFORMATION AND PRESENTATIONS

Three presentation on trophic interactions and their significance for North Sea fisheries assessment:, as well as on the North Sea Cod recovery plans considering multispecies effects were published on the web site. There also the project flyer can be downloaded. (http://www.rrz.uni-hamburg.de/BECAUSE/content/project_publications.html)

The BECAUSE project flyer was created by UniHH and professionally printed in 500 copies. The flyer was distributed among the project partners at the Brest meeting for further distribution to interested parties outside the project.

PLANNED PUBLICATIONS

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19. Lewy, P. and Vinther, M. (2008). A stochastic age-length-structured multi species model applied to North Sea stocks. In prep for Canadian Journal of Fisheries and Aquatic Science.

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21. Poulard, JC, Blanchard, F. Spatial dynamics of hake (Merluccius merluccius) in the bay of Biscay and species interactions.

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