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MariFish Joint Call Final Report

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Developing fisheries management indicators and targets (DEFINEIT)

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Please note that Partner 6 (Hellenic Centre for Marine Research, HCMR) was forced to withdraw from the project due to lack of funding.



2. Executive Summary

Project Summary

DEFINEIT produced the tools necessary to determine the optimal economic level of exploitation of North European marine fish resources, combining knowledge on species interactions, recruitment processes, vulnerable species and socio-economic aspects. Marine ecosystems consist of many species (including humans) affecting each other in complex ways and estimating the optimal exploitation level requires advanced mathematical models. These models estimate the response of the ecosystem to different levels of fishing. DEFINEIT constructed mathematical models of fish stock dynamics which explicitly took account of species interactions, vulnerable species and exploitation to allow estimation of the effect of different fishing management objectives on the marine ecosystem. These models were combined with economical models to predict the fishing effort require to reach the optimal yield and the effect of pursuing this yield on socioeconomic aspects. Geographically, the models covered a wide geographic area ranging from the Baltic Sea over the North Sea to the Barents Sea and Icelandic Seas.

Large fish, marine mammals and seabirds all eat fish. Therefore, increasing their numbers leads to increased predation on small fish. In DEFINEIT, we used multispecies models to investigate changes in predation and differences in distribution and the amount of alternative food. As the abundance of the primary food of predatory fish decreases, one might expect that growth of these predators decreases. However, in DEFINEIT, we have shown that the effect is often less than expected as predators increasingly use alternative prey sources. In the North Sea, the total amount of prey is often large enough to ensure that a considerable proportion of the predatory fish become saturated even when one prey type is only found in low densities. In contrast, a change in the distribution of Icelandic shrimps led to an increase in mortality as predatory cod aggregated in the areas of high shrimp densities and low density of alternative food. In the Barents Sea, DEFINEIT has shown that the abundance of alternative food changed considerably over time, alleviating problems with lack of the primary prey species, capelin.

To understand the effect of biological and climatic conditions on recruitment, DEFINEIT investigated both egg production and survival of larvae and juveniles. Both production and survival vary considerably between areas. DEFINEIT showed that the relative contribution of the four spawning grounds in the North Sea herring population changed completely over the past 40 years. For example, the eggs spawned at Orkney historically supplied up to 75% of all eggs spawned in the North Sea. This proportion has changed to less than 30% in later years, as the southern herring stock has recovered. The project also showed that several populations exhibit genetic differences on both regional and local scales and that as a result, sensitivity to fishing most likely differs between individual populations. Investigations of the importance of early life history in the formulation of year class strength of cod, herring and plaice revealed that year class strength is not formulated at the same point in the life history in all species or in different areas. The project further showed that the development in stock reproductive potential deviates significantly from that derived from the traditional estimates of Spawning Stock Biomass. In spite of this, reference points based on more appropriate estimators of egg production generally did not improve stock recruitment relationships.



To assess the effect of bycatch of non-target species, DEFINEIT worked towards identifying susceptible species using Ecological Risk Assessment. Sensitive species of sharks, rays and skates were ranked according to key biological and fisheries parameters. Their distribution and sensitivity to fisheries was investigated and advice given on precautionary management and maximum level of fishing effort consistent with sustainment of these species. Using size based models, DEFINEIT has shown that in the case where no species differences in selectivity beyond those induced by size exist, the maintenance of sensitive species is likely to incur a significant cost to fisheries.

DEFINEIT developed resource indicators combining economic, social and biological indicators to determine the optimal economic level of exploitation. The Maximum Economic Yield was calculated based on combined economic and multispecies models and is an indicator of how a fishery can be exploited in an economically optimal sustainable way. Adding species interaction decreased the estimates of Maximum Economic Yield relative to predictions not including species interaction. Hence, models not including species interactions are likely to overestimate the potential economic gains of the fishery by moving to Maximum Economic Yield. Evaluating the yield given the constraint that fishing mortality on vulnerable species should stay below sustainable limits did not result in large changes in profitability when species interactions were taken into account. A stochastic approach to economic indicators showed that to maximise the total Net Present Value of the fishery, fishing levels slightly higher than current are needed. However, maximising overall economic benefits will come at a trade-off as some of the stocks are likely to end up outside biological constraints. In general, removal of larger predatory fish is likely to benefit prey species and this result was consistent across all model types used. A method was developed to derive estimated of indicator suitability from individual or groups of stakeholders and this method was used to formalise the process of elicitation of uncertainties, from both experts and stakeholders, for Norwegian and Russian Herring in the Barents Sea.

Project results were disseminated continuously during the project to both the scientific community, managers, stakeholders and the general public to ensure that results were used by the scientific community as well as in practical management. The project scientists in total participated in numerous expert groups under the International Council for the Exploration of the Sea and their work in these groups directly improved management advice for a range of stocks in the study areas. Further, DEFINEIT worked to facilitate the adoption of an Ecosystem Approach to Fisheries Management within the ICES area, in particular through the introduction of multispecies candidate reference points, through the advancement of science to assess climatic impacts on recruitment and enhance management of impacts on vulnerable species and through the development of methods to estimate socioeconomic effects of fisheries management objectives.



3. Final Report

Developments around the DEFINIET project which have affected results.

Since the project was started, there have been events outside the project which have affected the course of the project as well as the fulfilment of deliverables.

Firstly, the financial situation in Greece forced the Hellenic Centre for Marine Research to withdraw from the project in 2011. The withdrawal of HCMR led to changes in the project deliverables, as the proposed case study of the Mediterranean could no longer be completed. This affected the Aegean Sea contribution to deliverables 1.4.1 (Report on the definition of multispecies indicators), 1.4.2 (Report on methods to estimate multispecies limit and target reference points), 2.6.2 (Report on multi-species Schaeffer models fitted to the output of the different multispecies models), 3.2.2 (Report defining habitat areas and distribution of sensitive species and the overlap with fishing effort distribution in order to estimate susceptibility), 3.2.3 (Report on effort limits necessary to assure sustainable populations of non-target fish species), 4.3.1 (Report identifying appropriate economic indicators for practical responsive management systems), 4.4.1 (Report demonstrating the effects of using such economic indicators within practical responsive management systems), and all deliverables in WP 5. These deliverables were completed for the remaining geographic areas as planned in the project. In contrast to these deliverables, deliverable 1.2.1 (Report on multispecies models in the Aegean Sea) could not be addressed without the aid of HCMR and was not completed. The events and the project response to these events are described under WP6.

The second aspect affecting the project is the funding of a U.S./Canada/Norway joint project under CAMEO on using multispecies production models to compare ecosystems, an exercise similar to that originally planned under the DEFINIET task 2.6. To avoid duplicating their work with a smaller dataset, DEFINIET cooperated with the CAMEO workshop and increased the CAMEO database with data from the Baltic and North Sea.

A third and final aspect which has affected the project is the decision from the Commission to ask STECF for multispecies management plans for the Baltic Sea and mixed fisheries management plans for the North Sea. The Commission stated their intention to use the Baltic Sea as a model for multispecies management plans including species interactions and not to proceed with this in other areas. To achieve the highest impact of the project results and in particular the generic aspects, a Baltic Sea case study was introduced to the project and DEFINIET contributed significantly to the work in STECF and ICES on this topic.



WP 1: Biological interaction between species

The objective of WP1 was to construct multispecies models which specifically take account of prey availability and spatial overlap between predators and prey and of the technical interactions between catches of different species fishery, to use these models to develop multispecies indicators of the sustainability of fishing and to provide the model basis needed in WPs 2, 3 and 4 in order to provide an improved overall understanding of optimal ecosystem management.

In **task 1.1**, the project has produced enhanced multispecies models by including new predator-prey relationships and the models of fishing fleets. In the North Sea, the focus was on creating stomach content likelihood routines for the SMS model in order to be estimate prey consumption. In the “Gadget” models in use in Norway and Iceland, stomach content likelihood functions already existed, and effort was placed on improving the time series of non-modelled “other food”. Predator-prey spatial distribution was investigated in all three areas, improving the models ability to reconstruct spatially and temporally varying predation mortalities. Technical interactions were investigated in Icelandic waters, where an interaction between prey availability to predators and fishing pressure was identified in the shrimp fishery.

The work on *improving modelling of changes in food abundance* (Deliverable 1.1.1) on consumption has focused on two areas: estimating variable consumption and improving the description of the abundance of other food. In the North Sea, work on improving the modelling of changes in food abundance on consumption has focused on estimating variable consumption and estimating predation by marine mammals. The work on the effect of prey abundance on consumption focused on the development of a new likelihood formulation compatible with the data format required to estimate variable consumption. Consumption was re-estimated using state-of-the-art techniques and the saturation level as a function of temperature described for the gadoid predators in the North Sea (contact Anna Rindorf, ar@aqua.dtu.dk, for further details). Consumption of a given prey was generally higher in areas with high density of that prey but the increase in consumption was insufficient to retain a constant mortality rate at all densities. Instead, mortality rate decreased with density giving small fish a survival advantage if they aggregate. The likelihood of the observed stomach contents has been formulated to allow the estimation of food selection parameters in a statistic catch at age model such as the multispecies model used for the North Sea (contact Peter Lewy, pl@aqua.dtu.dk, for further details). The consumption of fish by marine mammals was investigated in cooperation with the FACTS project (contact Anna Rindorf, ar@aqua.dtu.dk, for further details). The investigation revealed that harbour porpoise and grey seal were likely to have a far greater effect on the temporal development in natural mortality than adjustments caused by varying the abundance of other food or the food intake of fish predators. Therefore, all efforts on improving the North Sea SMS were focused on producing a database of harbour porpoise diet composition covering three decades and the entire North Sea. Further, data on the diet composition of grey seals were assembled and the population size of both marine mammals estimated to allow the temporal development in the predation impact to be estimated and included in the North Sea SMS key run in 2011 (WGSAM 2011). The key run showed a substantial increase of natural mortality of particularly cod and whiting. The change in temporal pattern of cod natural mortality was particularly marked for age 3 cod in the last 10 years, coinciding with the increase in unallocated mortality of cod. The change in the temporal pattern for whiting was particularly marked for younger ages leading to changes in relative recruitment. This change in relative recruitment has serious implications for the estimation of limit reference points (WGNSSK 2012). The new natural mortalities were used subsequently in the cod, haddock, whiting and herring assessments in the North Sea. The effect was a reduction in the estimated unallocated mortality of cod and a



substantially altered historical pattern of whiting and herring (HAWG 2012, WGNSSK 2012, WKPELA 2012).

In the Barents Sea, the work on modelling effects of changes in the amount of alternate prey has focused on producing improved time series of availability of the non-modelled “other food” in the multi-species models of the Barents Sea in conjunction with the FACTS project. This is important for improving the modelling of the mortality induced on prey and the variability of the food supply available to the modelled predators. The existing Gadget model directly models the interactions between minke whales, cod, capelin, herring and from age 1 and upwards, and has included a time series of krill biomass. However, data on fluctuations in other prey species and on 0-group fish biomass was previously not included in the model. A time series of the biomass of 0-group fish in the Barents Sea was produced and described in Eriksen *et al.* 2011. The improved knowledge of 0-group fish together with estimates of biomass for a number of species (haddock, polar cod, blue whiting, shrimp, redfish, and an improved krill timeseries) was used in the construction of more realistic “other food” within the multispecies model and hence to improve our estimates of natural mortality of fished species (contact Bjarte Bogstad, bjarte.bogstad@imr.no, for further details). The variability of different species abundances in the Barents Sea is particularly important due to the influence of capelin abundance on top predators. There have been three capelin collapses since the mid 1980s. During the first of these significant impacts were observed on top predators, especially cod. Condition factor and maturation were both adversely affected. During the subsequent collapses the cod suffered much less, and this appears to be due to increased abundance of suitable other foods. Thus, the improved species abundance series both improves the hindcast portion of the model, and allows greater flexibility in modelling “what if” scenarios of multispecies interactions in the face of changing conditions in the Barents Sea. In Icelandic waters there was also focus on generating a time series of examining the available data to establish the feasibility of generating “other food” time series for the different modelled predators (contact Höskuldur Björnsson, hoski@hafro.is, for further details).

Work on *modelling spatial overlap between predator and prey* (Deliverable 1.1.2) has been conducted in all three major areas.

The North Sea SMS model has been adapted to produce estimates of local natural mortality in subareas to account for changes in distribution (contact Morten Vinther, mv@aqua.dtu.dk). However, just before the final runs were performed, the Commission signalled that they would consider the effect of spatial overlap and multispecies MSY reference points only in the Baltic Sea but not in the North Sea until after the successful implementation in the Baltic Sea. At this point, continuing work in the North Sea would have meant that the project would not have had an influence on management until long after the final report. To achieve the maximum impact of the results in the project both now and in the future, it was therefore decided to estimate the effect of spatial distribution on natural mortality in the Baltic Sea. The Baltic Sea SMS and North Sea SMS have the same core, and the changes to the model core intended for estimating effects of spatial distributions could be used directly to model the Baltic Sea as distribution of fish had been estimated in the FACTS project. The results showed that there are large changes in natural mortality between subareas, both in terms of the absolute level and in terms of the temporal development. Natural mortality in the Bornholm Basin is now close to or at the historic maximum due to the large cod stock, which is concentrated in this area in contrast to previous large cod stocks which had a much wider distribution (contact Morten Vinther, mv@aqua.dtu.dk). The resulting model was used in the ICES workshop on integrated/multispecies advice for Baltic fisheries (WKMULTBAL). However, it was decided not to use the spatial version of the model for forecast, as the use of a fixed distribution key produced forecast problems (WKMULTBAL 2012). To solve these, it will be necessary to



produce a migration model which can be used to describe the exchange of fish between subareas in a dynamic way.

In Icelandic waters an attempt has been made to produce probability distributions of the capelin stock size (contact Höskuldur Björnsson, hoski@hafro.is, for further details). This has traditionally been rather uncertain, since the measurement errors are compounded by the fast migration of the stock, and the predation mortality caused by cod eating migrating capelin. The distributions of capelin and cod before the migration starts are reasonably well known, but the actual spatial overlap during the migration is not well determined. The analysis indicates that the uncertainty in the acoustic measurement is larger than that resulting from the predation mortality. The methods employed here treating one predator and one prey could be applied to the cod-capelin interactions in the Barents Sea. Given the longer migration time in the Barents Sea, the predation mortalities could be more significant. The method could also be extended to a system with multiple predators.

In the Barents Sea, two potential areas of spatial influence on ecosystem dynamic were examined during the project. The first was the overlap between juvenile herring and capelin larvae, which has been suggested as a controlling factor on the recruitment success of capelin. This is discussed further under task 2.6. This interaction was not found to be a reliable predictor of capelin recruitment strength (contact Daniel Howell, daniel.howell@imr.no, for further details). Although high herring in some years were associated with poor capelin recruitment, in other years good recruitment was observed despite high herring abundance in the Barents Sea. The second focus was to update the model to allow for the changing overlap between cod and capelin in the northern Barents Sea. Historically the region containing polar cod (a forage fish, *Boreogadus saida*) and the capelin feeding grounds in the north and northeastern Barents Sea have been almost devoid of cod. However, with warming waters and retreating ice cover recent surveys have documented appreciable quantities of cod expanding their range into these waters (AFWG 2012). Although relatively modest at present, if this expansion continues it could have major implications for the dynamics of the Barents Sea. For the capelin, the cod expansion could represent a new predation pressure, while the cod could find significant new food sources. The North East Arctic cod in the Barents Sea is currently near record biomass levels, with SSB at a historical high (AFWG 2012), and thus the question of the carrying capacity for cod becomes an important issue in the Barents Sea. This is therefore an important improvement in the model capacity to study the impacts of climatic changes in the Barents Sea.

Work on *including technical interactions in multispecies models* (Deliverable 1.1.3) was conducted in Icelandic waters and attempted in North Sea waters. An interaction was found in Icelandic waters where heavy fishing pressure on shrimp was leading to increased predation of shrimp by cod. Increased fishing pressure seems to have resulted in reduced shrimp schooling behaviour. This in turn has caused shrimp to become more available for predation by cod, leading to increased predation mortality on the shrimp (contact Höskuldur Björnsson, hoski@hafro.is, for further details). This has important implications for management, where the total mortality caused by fishing shrimp is rather higher than would be expected if this mechanism were excluded. It also has implications for modelling ecosystem dynamics, since prey suitability for the cod is not constant, but rather depends on shrimp fishing pressure.

After requesting information on quarterly and fleetbased catches for the North Sea from the mixed fisheries working group under ICES for two subsequent years and receiving the reply that it was not possible to deliver these data, it was agreed to use only the fleet model already available to



the partners, namely that used by FOI in WP4. This model would be built directly on the production model and would not require information on fleet composition to be built in for the historic period.

In **task 1.2**, the project planned to develop a multispecies model of the Aegean Sea. This deliverable has been dropped due to withdrawal of the Hellenic institute from the DEFINEIT project.

In **task 1.3**, the project aimed to compare the utility of the improved multispecies models to the current multi- and single- species models in order to identify whether additions to the models significantly change our perception of historic ecosystem status and dynamics.

In the North Sea progress on acceptance of annually varying natural mortalities in stock assessments led to a focus on comparing different multispecies models. In the Barents Sea the improved other food series has improved modelled recruitment, while examination of other possible drivers of recruitment indicated no significant relationship. In Iceland the improved modelling has led to a better understanding of the relationship between the capelin survey and the actual population size.

During the life of the project, *comparisons of historical patterns when using single species and multispecies natural mortality* (Deliverable 1.3.1) have been performed by a number of ICES benchmark and working groups. However, as the use of annually variable multispecies natural mortalities has become more widely accepted in North Sea assessments, the focus on comparisons of temporal development using constant and variable natural mortalities has decreased. Instead, focus has shifted to the large difference between assessments using different key runs.

In the Barents Sea an analysis was conducted of the importance of including multispecies dynamics for modelling Northeast Arctic cod. The cod are highly cannibalistic, with an inverse relationship observed between cannibalism and the abundance of alternative food in the form of capelin. Since data on fish too young to have entered the fishery (below age 3) is rather noisy, the impact of cannibalism can have a large impact on our understanding of cod recruitment. A series of experiments was run using the Gadget model to examine the difference between ignoring cannibalism entirely, including cannibalism but with no other dynamic prey sources, including cannibalism with dynamic other prey, and including the new improved “other food” time series as well as modelled prey. The results indicate that the variability in modelled cod recruitment is sensitive to the inclusion of different prey sources, and highlights the importance of ecosystem effects in our understanding of recruitment (contact Daniel Howell, daniel.howell@imr.no, for further details).

Work on examining *the differences between new and current multispecies models on the perception of historical stock dynamics* (Deliverable 1.3.2) was conducted in all three areas.

The large difference between assessments using different key runs was examined by WGSAM (WGSAM 2012) in preparation for the North Sea herring benchmark (WKPELA 2012) and by the working group on the assessment of the demersal stocks in the North Sea and Skagerrak (WGNSSK 2012). Whereas the analysis of herring natural mortality showed reasonably consistent temporal patterns, this was not the case for cod and whiting (WGNSSK 2012). This result highlights the conflict induced by the need for stable estimates of natural mortalities from SMS induced by the increased use in single species assessment and the need to continue model development and improvement. A particular aspect of model improvement is the continued addition of emerging predators, which is likely to continue in the future as new predators become abundant in the North Sea as a result of e.g. climate warming (Perry et al. 2005).

In the Barents Sea model, significant effort was placed in improving the flexibility of the Gadget model to take in more detailed recruitment process equations arising from WP2. However, as



no such relationships were identified this represents an improvement on which further work can be built rather than one which has an impact on the existing model results. Equally, explicitly modelling spatial overlap resulting from cod distributional changes has also not materially affected perception of historical stock dynamics, as the change in cod migration behaviour is a recent phenomenon. However, this will be used in the future to investigate the possible effects of the continued spread of the cod stock on the ecosystem dynamics of the Barents Sea. In contrast, the improved food series in the multispecies model has had an impact on our understanding of cod recruitment dynamics (contact Daniel Howell, daniel.howell@imr.no, for further details). The impacts resulting from model improvements at the level of fishable stock biomass for the different species (cod, capelin and herring) have been rather minor, as the models are tuned to extensive datasets for these ages. The implications for the mortality on young fish are more pronounced, and emphasises that in conducting stock projections the total abundance of prey species (not just modelled species) is important.

In Icelandic waters the modelling of the relative importance of predation mortality and uncertainties in the measurement of capelin biomass (contact Höskuldur Björnsson, hoski@hafro.is, for further details) indicates that the measurement error is the most important source of uncertainty.

In **task 1.4**, the project has used the knowledge gained during Task 1 and Task 2 to identify relevant multispecies indicators, and to suggest methods for estimating multispecies reference points. A workshop was conducted to share knowledge between case study areas and produce a document outlining principles for selecting relevant indicators for a particular ecosystem along with suggested methods for estimating reference points, where there is sufficient data to permit this (Deliverables 1.4.1 and 1.4.2). The results emphasized that such reference points and target values need to be chosen and evaluated in conjunction with the choice of management regime and targets for the mixed fishery system (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further details).

WP 2: Developing stock-recruitment models

The aim of WP2 was to improve the understanding of processes determining variability in recruitment. Specifically, the main patterns of recruitment variability over time were to be identified, and the importance of spatial structuring, variations in reproductive potential, and processes in the early life-history evaluated. Finally, the consequences of these processes for the provision of appropriate management advice were to be assessed.

In **task 2.1**, DEFINEIT addressed the main causes of variation in recruitment patterns between stocks through a meta-analysis of a wide variety of stocks.

The *main causes of variation in recruitment patterns between stocks* (Deliverable 2.1.1) were investigated in an analysis of empirical stock-recruitment time series (contact Axel Rossberg, axel.rossberg@cefas.co.uk, for further details). Depensatory population dynamics, also known as Allee Effect, denotes a decrease of the per-capita growth rate of a population with decreasing population size. Understanding depensatory population dynamics of commercially exploited fish species, if they exist, may be important for determining the safe biological limits of exploitation. The reason is that, starting from the population size below which depensation sets in, a population will become vulnerable to instability and extirpation not only under a fixed quota-, but also under a fixed effort management policy. Strong depensatory dynamics can inhibit recovery of a stock even under a moratorium on exploitation.

While several mechanisms that lead to depensation are known or have been demonstrated in laboratory or field studies, depensatory dynamics themselves are generally difficult to observe. A



landmark empirical study of depensation by commercially exploited fish has been conducted by Myers et al. (1995). The study is based on the analysis of empirical stock-recruitment time series. It concludes that for most time series the data are insufficient to allow any conclusions. The database upon which this study had relied has recently been update and extended (<http://www.mscs.dal.ca/~myers/welcome.html>). The full updated database containing 775 stock-recruitment time series was analysed, closely following the methodology of Myers et al. (1995). As Myers et al. (1995), we found that the majority of time series in the database is insufficient for firm conclusions: Among the time series with a clear signal is that of spring-spawning Icelandic herring, which is the one giving the clearest signal of depensation in the analysis by Myers et al. (1995). Depensation in the other two candidates identified by Myers et al. (1995) could not be confirmed with the extended data.

Of note is the comparatively large number of Clupeiformes. However, the proportion of Clupeiformes (7 out of 30) is not significantly larger than the proportion of Clupeiformes in the entire database (15.7%, $p=0.09$), even when disregarding multiple testing. Statistically more powerful analyses would therefore be required to arrive at specific conclusions regarding depensatory population dynamics by Clupeiformes.

There was thus no solid empirical support of for depensatory population dynamics, and the data furthermore provide evidence that depensation is generally absent. This is not entirely surprising, because fish efficiently mitigate the problem of mate-finding at low population sizes by regularly converging at well-defined spawning grounds for this purpose. This conclusion implies that an ecological foundation for the concept of a limiting stock size B_{lim} would have to be sought in other mechanisms than depensation. The concept of a limiting fishing mortality F_{lim} is more easily motivated. Without depensation, populations are characterized by a well defined mean population growth rate at low abundances, and F_{lim} is simply the fishing mortality that reduces this rate to a value below zero. For management, this implies a reason for preferring F_{pa} as a precautionary reference point over B_{pa} . Of course, a thorough discussion of the relative merits of the two types of reference points would take several other lines of reasoning into account.

In **task 2.2**, species specific genomic markers (single nucleotide polymorphism) were screened in samples of spawning herring, spanning the North Sea and adjacent areas to identify stock sub-structure.

A study on *the population sub-structure of North Sea herring* (Deliverable 2.2.1) showed that the components have different dynamics and that the relative proportions of the components have changed over time (Payne, 2010). The sum of the fitted abundance indices across all components proved an excellent proxy for the biomass of the total stock, even though the model utilizes information at the individual component level. The Orkney–Shetland component appears to have recovered faster from historic depletion events than the other components, whereas the Downs component has been the slowest (Deliverable 2.2.2). The research was designed to examine the spatial dynamics of the early life history stages of this species and provide information for the spatial management of this stock. The index (SCAI) is now used in the Herring Assessment Working Group for the Area South of 62° N under ICES (WKPELA 2012).

The population structure in North Sea herring was also assessed using SNP analysis for samples of spawning herring from the North Sea and adjacent areas in the Northeast Atlantic (Limborg et al. 2012). A landscape genomic analysis approach was used to produce maps of genetic relationships among herring populations. We analysed a total of 18 samples spanning local spawning locations representing major basins and presumed populations in the northeast Atlantic (Figure 1).



Based on data for the 18 samples we determined large-scale genetic relationships among populations using a Bayesian clustering approach to identify 1) the most likely number of overall population groupings and 2) the respective relationship of each population sample to such groupings. The clustering analysis using information for all SNP markers suggested four main regional population clusters, that overall corresponded with samples collected in respectively 1) the North Sea and west of the British Isles, 2) the North Sea/Baltic Sea transition zone, 3) the Baltic Sea and 4) the Northeast Atlantic. The detection of a highly distinct Northeast Atlantic cluster is novel, as no genetic marker study has previously been able to clearly differentiate between herring from this region and those in the North Sea.

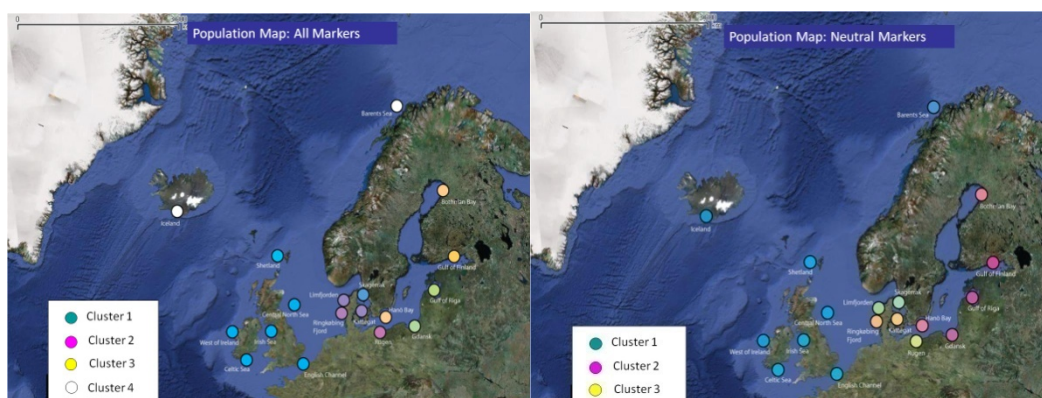


Figure 1. Genetic relationships among geographic samples, as determined from 281 SNP markers (265 neutral and 16 ‘outlier’ SNPs combined, left panel) and from 265 neutral SNP markers (right panel). The colour of each dot represents the sample’s genetic profile in relation to the four (for all SNPs) and three (for neutral SNPs) clusters.

Overall, levels of genetic differentiation among regional groupings were app. four times higher than levels of differentiation among local populations within regions, and all comparisons between pairs of samples between any of the four regions exhibited statistically highly significant differentiation. Nonetheless, local populations *within* regions sometimes also exhibited (low, but statistically significant) genetic differences, showing that structure was also evident among local populations within regional groupings. In contrast to this, when comparing pair-wise population differentiation using only information for neutral markers, only three pair-wise comparisons out of a total of 36 were statistically significant (at $P < 0.05$) within regional clusters. The genetic structure detected with the applied SNP markers allow for determination of regional and in some cases local population origin of individuals sampled in mixed stocks.

Population substructure in cod in the North Sea was examined applying SNP analysis to population samples spanning the North Sea. The analysis is reported in two manuscripts that are currently in development (contact Jakob Hemmer-Hansen, jhh@aqua.dtu.dk, for further details). The first study identified three genetically distinct groups within the North Sea, of which spatial modelling suggested that the North-eastern North Sea population is less productive and most vulnerable to fishing. The second study identified genetic differentiation among populations in candidate genes, e.g. genes associated with growth. These results show that spatial considerations need to be incorporated into fisheries management of North Sea cod in order to avoid unintended depletion of local population units exhibiting functional divergence.

Work on *quantifying the contribution of population sub-structure to recruitment variability* (Deliverable 2.2.2) has focused on drift modelling of autumn and winter spawned herring larvae in the North Sea. The results indicate the extent of drift from the spawning grounds, generally in an easterly direction to the principal nursery areas in the eastern North Sea. The studies also highlight



the ingress of herring larvae from the neighbouring management area to the north and east (namely VIa North. This will have consequences for the perception of the IBTS 0-ring survey (known as the MIK index) which is used as an indicator of recruitment in the North Sea herring stock.

In **task 2.3**, the variability in the production of spawning products is identified. Based on existing data, factors such as age structure, sex structure, fecundity at age, maternal effects, spatial structure, maturity ogives, growth and adult mortalities which contribute to SRP variability are examined. It was then investigated whether estimates of SRP improve our understanding of the relationship between stock size and recruitment.

The use of Total Egg Production, instead of Spawning Stock Biomass (SSB) in a Stock Reproductive Potential (SRP) to recruitment relationship (Deliverable 2.3.1) was investigated for North Sea cod, plaice and herring and Norwegian Spring Spawning herring and Barents Sea cod. The objective was to find improved predictors of recruitment for input to the assessment process. These studies examined the egg production at the stock level using stock specific characteristics. Spatial considerations were studied for North Sea Autumn Spawning herring using the acoustic survey data. Here the spatial distribution of lengths, weights and conditions of herring in July was used in conjunction with a model for fecundity to estimate the Total Egg Production for the stock based on its spatial distribution (contact Thomas Brunel, thomas.brunel@wur.nl, for further detail). The trends in the time series for Total Egg Production and the estimate of Total Egg Production based on the spatial distribution of the stock were very similar but there were some important differences between the two series. Total Egg Production based on the spatial distribution was consistently higher (around 10%) than Total Egg Production for the first 4 years, but lower in 2009 (approximately 10%). Using information on the spatial variability in reproductive traits in North Sea herring thus led to substantial differences in the estimation of the reproductive potential of the stock compared to when average values are used for these traits. The use of one or the other of these measures of Stock Reproductive Potential would have important implications in term of stock management and alter the perception of the historical variations of the stock and affect parameters of the stock recruitment relationship, and thereby potentially on the reference points used for managing the stock. In species such as plaice there are large changes whereas species such as herring the differences can be minor (contact Richard Nash, richard.nash@imr.no, for further detail). As pointed out elsewhere, the linking of recruitment with SSB or even SRP (Deliverable 2.3.2) is going to be noisy at healthy stock sizes as many factors can affect the survival of the different life stages between the eggs and the recruiting juveniles (see reports covering Paulik diagrams (Nash 1998; Nash and Dickey-Collas 2005; Nash and Geffen 2012) or contact Richard Nash, richard.nash@imr.no, for further detail).

In **Task 2.4**, key processes from spawning to recruitment (Deliverable 2.4.1) were examined in two ways, firstly through the construction of Paulik diagrams and secondly through field studies, mainly on Norwegian Spring Spawning herring. Paulik diagrams were constructed for a number of stocks e.g. North Sea and Norwegian spring spawning herring, Northeast arctic, North Sea, Irish Sea and Baltic cod, and North Sea and Irish Sea plaice. The data illustrate the importance of early life history in the formulation of year class strength, indicate that year class strength is not formulated at the same point in the life history i.e. species and to a certain extent stock specific and can vary between years. The Paulik diagram approach highlighted the complexity of processes which occur in the early life history and the relative importance of processes occurring in the juvenile stage (Nash and Geffen, 2012). The conclusion was that more consideration of the dynamics of juveniles and nursery grounds needs to be incorporated in population modelling and fisheries management. The combination indicated the highly dynamic nature of early life history dynamics and the importance of understanding that natural mortality rates are not static. It was also apparent that influential



mortality rates can be in different parts of the life cycle in different species and the location of the influence can vary inter-annually through the life cycle. The underlying causes of the relationships between stock and recruitment were also explored using fully structured trophic models (contact Axel Rossberg, axel.rossberg@cefas.co.uk, for further details). Here the importance of trophic relationships in density dependent processes is highlighted.

A number of studies have concentrated on herring (both North Sea autumn spawners NSAS and Norwegian Spring spawners NSS). In the case of NSAS the growth rate of larvae prior to and post the reduction in recruitment (year 2000) was examined (Payne et al 2013). It appears that growth rate has reduced and this suggests that feeding conditions have changed and a reduction in available prey may be the principal cause of the reduction in productivity of this stock. However, size selective predation may be a cause although this would require selection for larger, faster growing larvae which is counter to the generally accepted theories.

The field studies of recruitment processes concentrated on Norwegian Spring Spawning (NSS) herring. For any field study there is a necessity to carefully examine the field procedures and this was done through modelling work on the effect of survey design. The direction of the survey i.e. north to south or south to north can have an effect on the perception of the abundance (Stenevik et al 2012). Disruptions to the survey e.g. stoppages due to factors such as bad weather can also affect the perception of abundance. The differences in abundance can have a fundamental influence on stock assessments since these indices are used as indicators of spawning stock biomass. The spatial extent and utilisation of spawning grounds is a function of stock size and can have a fundamental influence on the levels of recruitment. Over the years there have been considerable changes in the historical usage of spawning grounds (contact Richard Nash, richard.nash@imr.no, for further detail). These data will be combined with our data on the hatching distributions (for the whole stock shown here in Fig. 3). Thus we will be able to determine the relative contributions of each spawning ground to the stock dynamics.

The relative contribution of functional genomic variation, environmental conditions experienced and physiological trait variation during early life history stages (Deliverable 2.4.2) was investigated in a study reporting on relationships between environmental conditions on spawning/first larval stage locations and functional genetic variation, estimated using single nucleotide polymorphism (SNP) markers in Atlantic herring in the North Sea and adjacent areas (Limborg et al. 2012). Simulation based analyses were used to evaluate the relative importance of selection and demographic processes for shaping geographical patterns of population structuring at individual SNP markers in herring. Comparing levels of genetic differentiation, as estimated with F_{st} , showed that differentiation among all population samples was approximately 30 times larger across outlier markers compared to across the 246 neutral markers. The 16 identified outlier markers exhibited highly divergent genetic profiles across population samples, with differences in allele frequencies being greatest among regional population groupings. This observation corresponds to expectations if outlier markers reflect divergent adaptations to local (regional) environments. Markers associated with functional genes involved in local adaptation can potentially be identified by correlation between allele frequencies and important ecological variables, or by extreme allele frequency differences between geographic regions. The results from this analysis showed that ten of the 16 outlier SNPs were correlated with one or more environmental parameter, of which salinity and temperature came out with high correlations for several of the outliers. These results point to that adaptation to local environments with respect to salinity and temperature and likely other hydrographic variables play a role for the elevated levels of population differentiation observed in outlier markers in comparison with neutral markers.

In **task 2.5**, we applied the results of tasks 2.1-2.4 to provide improved stock recruitment relationships and examine the consequences for indicators of sustainable exploitation. The intention



was to employ Management strategy evaluations (MSEs) to examine the implications of stock sub-structure, variable production of spawning products, and post-fertilisation processes. Two slightly different approaches were taken to address *the difference between reference points based on improved stock reproductive potential (SRP) indices and conventional reference points* (Deliverable 2.5.1). The first examined three stocks in the North Sea (namely herring, cod and plaice) and the second considered only North Sea plaice.

The first approach looked at MSY based reference points with the intention of evaluating the impact of uncertainty on their use within the management frameworks (contact Richard Nash, richard.nash@imr.no, for further detail). A major source of uncertainty which is rarely considered is model mis-specification, i.e. where reference points are based on non-biologically based estimates of spawning potential (spawning stock biomass is calculated assuming that egg production is proportional to mass-at-age and that maturity at age is constant). In addition, it is assumed that whilst processes such as recruitment and productivity vary there is no particular trend over time (i.e. stationarity). However, recent studies have shown that

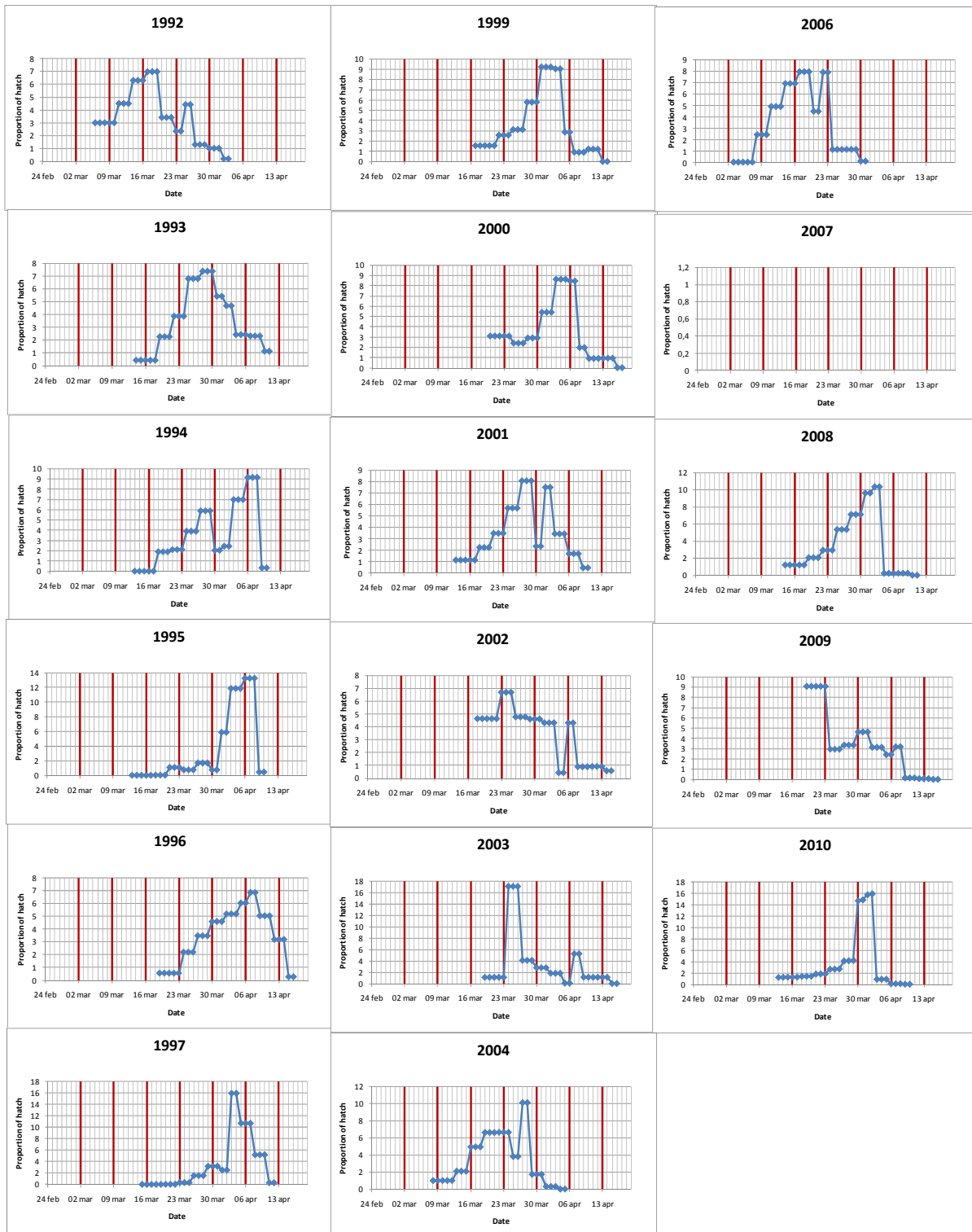


Fig. 3. Hatching curves for Norwegian Spring spawning herring based on survey data. maturity and egg production can vary over time. Also the plus group is assumed to be homogeneous in that all fish within the plus-group experience the same catchability and natural mortality and often in stock assessment advice, no growth is assumed. However, as fish stocks recover to levels associated with B_{MSY} the plus group will include fish from a wide range of ages and ignoring their dynamics may result in management frameworks failing to meet their targets. We compared current ICES reference points with ones calculated using stock recruitment relationships based on biological



data and incorporating the full age structure for North Sea cod, herring and plaice. The study showed that reference points calculated by conventional methods can seriously over-estimate the level of fishing mortality associated with MSY and under-estimate MSY. During this work it became apparent that the fitting of any stock-recruitment relationship was dependent on the underlying assumptions concerning the behaviour of the stock at low stock sizes. This in turn led to uncertainty concerning the reference points. We then examined the effect of various assumptions e.g. natural mortality rate, growth rate etc. on the perception of the value of the reference points. This resulted in a manuscript highlighting the use of elasticity analysis for evaluating the causes of uncertainty and important factors in reference points (contact Richard Nash, richard.nash@imr.no, for further detail).

The second approach examined the consequences for North Sea cod, in terms of estimation of stock status, of using the above described simplifying assumptions on reproductive biology. SSB, currently used as a proxy for SRP, was compared to a more complex metric, the total egg production (TEP). TEP was computed based on the historical time series of abundance at age, output of the stock assessment model, and also used as a basis to compute SSB. Then, as for SSB, the abundances at age were multiplied by the maturity ogive, to estimate the number of adult fish at age. While the number of mature fish is multiplied by their weight at age to compute the SSB, the TEP uses the fecundity at age (contact Thomas Brunel, thomas.brunel@wur.nl, for further detail). Larger fish have a high reproductive output per unit of weight that smaller ones, which is a first departure from the assumptions made when using SSB, and the effective individual reproductive output is therefore very dependent on the age of a female. Based on reference points derived from TEP, it is possible to look at the historical perception of the stock (position of the SRP compared to the reference points through time). Both SSB and TEP give the perception of a stock having its historical high level in the late 1960s-early 1970s and declining throughout the late 1970s until present time (contact Thomas Brunel, thomas.brunel@wur.nl, for further detail). The stock is estimated to have gone below SRP_{pa} in the early 1980s and below SRP_{lim} in the late 1990s for both SSB and TEP. However, the perception of the stock is different for earlier period, with TEP being much more dynamic than SSB, and reaching levels corresponding to MSY around 1970, while SSB was estimated to reach a maximum at 78% of B_{msy} at that time. The study showed that in the case of North Sea cod, reference points values are dependent on the measure of SRP chosen. The difference seems, however, to be mainly coming from the maternal effect on egg survival, much more than the allometric fecundity relationship and the main discrepancy between SSB and TEP is observed at large stock size.

To describe *the outcome of management strategy evaluations examining the effect of population sub-structure, variability reproductive potential and environmental variability upon exploitation of fish stocks* (Deliverable 2.5.2), two cases were analysed, North Sea cod and North Sea sole, a stock which has cryptic sub-population structure.

The results on North Sea cod (contact Thomas Brunel, thomas.brunel@wur.nl, for further detail) were used to investigate the implications for management of using maturity ogives assumed constant (while being time varying in reality) and of using SSB as a measure of SRP (while in reality recruitment is related to TEP), in a simplified management strategy evaluation framework. Managing the stock based on SSB was more precautionary: the stock spent a lesser proportion of the simulation time at levels below the precautionary reference points, and never went below the limit reference point. This was not the case when TEP was used for management. There was no cost in terms of yield, with a slightly higher annual yield than when TEP was used, and a slightly smaller interannual yield variability.



MSE modelling fully confirmed the well-known theoretical predictions about the effects of sub-stock structure on stock dynamics under management aiming at MSY (contact Axel Rossberg, axel.rossberg@cefas.co.uk, for further details). Noteworthy were the relatively long time scales over which the less productive stock declined, despite substantial differences in steepness between the two stocks. Therefore, while Larkin (1977) is likely to be right “that fishing has eliminated some substocks”, recovery might still be possible for others. Achieving this requires active research to identify independent, depleted stock units, and the development of management strategies that support their recovery. Even when productivity of stock components is not sufficiently different to lead to collapses, better understanding of stock structure would still almost certainly allow adjustments of management strategies with both positive economic and ecological outcomes.

An unexpected result of this study was that relatively few historical SR data points were required for an MSY management procedure that dynamically adapts the underlying F_{msy} estimate. This suggests that along these lines management might indeed be able to track changes in stock dynamics resulting from environmental change. A question arising that deserves further attention is whether a similar management regime that is applied to several interacting stocks but disregards these interactions will also eventually reach a stable state, and whether this stable state can reasonably be interpreted as a realization of multispecies MSY.

The stock and recruitment relationship was examined for Norwegian Spring Spawning herring and is reported in Ndjuala et al. (2010). The SSB, SSN and TEP were all used as a predictor of recruitment. The use of measures other than SSB did not significantly improve the prediction of recruitment or provide a better model. There was a suggestion that there could be some influence on the survival through to recruitment due to stock structure (proportion of repeat spawners in the stock). In addition, other studies on this stock have suggested a predatory influence on the larvae from e.g., the fjordic saithe stock which in turn highlights the point that factors beyond the spawning stock or egg production have a significant effect on the numbers of recruits. Thus it was not possible to construct a better model of recruitment than that currently used i.e. SSB versus recruitment. In addition to the attempt to improve herring stock and recruitment relationships, two further possible recruitment relationships we examined for the Barents Sea multispecies modelling. Neither resulted in an improved model. The first attempt was to examine the impact of including, or excluding temperature in cod recruitment. A previously observed relationship between temperature at the Kola section and cod recruitment the following year has recently broken down. The work concluded that such issues were an irreducible and unquantifiable uncertainty in the recruitment, and hence in the multi-species model as a whole. This is discussed further under WP 5.

A second possible improvement that was examined was in capelin recruitment. It has been suggested that juvenile herring in the Barents Sea and migrating to North Atlantic may be significant predators on capelin larvae, to the extent that the biomass of herring could control the strength of the capelin recruitment. However there is no relationship between the modelled capelin recruitment and either the total mass of juvenile herring in the Barents Sea or the herring old enough to migrate. Consequently including this relationship did not appreciably improve the model. It may be herring are one important driver of capelin recruitment success, however if so the relationship is not a simple one. It is possible that there are detailed factors of timing or migration routes that influence the overall predation mortality suffered by the capelin larvae, or that herring predation can have an impact when combined with other mortality sources. For example jellyfish have also been a significant and highly variable predator on larval fish in the Barents Sea over the time period (Eriksen et al 2012). At present there is insufficient data to parameterize these combined effects of predation pressure on capelin recruitment



The conclusion is that recruitment is a complex process, and attempting to find single drivers which show consistent relationships with recruitment is often going to be a futile exercise. And, as demonstrated with the temperature linkage, even when such drivers are identified, their influence can vary or cease without warning. All results on improving stock recruitment relationships were reviewed at a workshop in February 2011 (contact Anna Rindorf, ar@aqua.dtu.dk, for further details). At the workshop, it was apparent that there were no cases where using more sophisticated measures of stock productivity outcompeted the simple SSB measure as a predictor of recruitment. Further, there were no consistent long term correlations with climatic conditions which could be used to predict more reliable estimates of recruitment. As a result, the planned *integration of improved recruitment models in the multispecies models* (Deliverable 2.5.3) was not performed.

In the absence of improved process-based models of recruitment, recruitment was included in the multispecies model by combining SSB-recruit relationships for the average recruitment with “year factors” of deviations to tune the annual historical recruitment to that which best matches the historical data (Howell and Bogstad 2010). This gives realistic historical recruitment, with the correct intra- and inter-specific correlations, although such an approach limits the predictive accuracy of the models. However, the transient nature of possible environmental drivers of recruitment variation (Howell et al. 2013) means that attempts to use any currently available recruitment models in a predictive capacity have associated irreducible and unquantifiable uncertainties.

During the work to *implement realistic recruitment variability* in the North Sea SMS, the Commission signalled that they would consider the effect of multispecies MSY reference points only in the Baltic Sea and not look further at the North Sea until after the successful implementation in the Baltic Sea. At this point, continuing work in the North Sea would have meant that the project would not have an influence on management until long after the final report. Work was therefore continued on this task in the Baltic Sea SMS. A key issue in the Baltic Sea is the lack of precautionary reference points for any of the stocks. As simulations progressed, it became clear that the estimated F_{MSY} values often appeared not to be precautionary in the definition used by ICES, though they gave stable long term average yields. To avoid providing advice which was not precautionary, it was attempted to estimate reference points for all species from stock recruitment curves. Relationships could be fitted for both cod and herring without using additional information. However, for sprat recruitment continued to increase with stock size making it impossible to estimate the points on the relationship required for the estimation of reference points. When recruitment success was made temperature dependent, this pattern changed and it was possible to estimate a Ricker curve and associated reference points (WKMULTBAL 2012).

In **task 2.6**, it was intended to utilise the improved stock-recruitment relationships in the improved multispecies prediction models. As described above, this could not be implemented in the planned case studies. However, during the work on the Baltic Sea, it was decided to use a temperature dependent stock recruitment relationship for sprat in this area, and this work is reported below. A further purpose of the task was to fit Schaeffer models to all the multispecies models with the intention of providing a simple model suitable for use in the economics modelling in WP4. In addition, this would provide a tool to compare and contrast the dynamics of multispecies models.

A temperature dependent stock recruitment model of Baltic Sea sprat was used for predictions of multispecies Maximum Sustainable Yield in the Baltic during WKMULTBAL 2012 (Deliverable 2.6.1). The possibility to allow the long term average temperature to follow the predicted long term average increase was considered, but it was decided instead to follow the ICES guidelines stating



that all MSY predictions should be under the assumption of maintaining the current external conditions. Presenting future stochasticity was a particular problem, as simply using historic stochasticity is not likely to produce an unbiased estimate. Instead, it was chosen to focus on the average and assume that average temperature was unchanged. This was considered the preferable solution under the circumstances, however, this method will provide estimates of future recruitment variation which are too low and hence will underestimate the probability of falling below limit reference points such as B_{lim} . This highlights the necessity to have predictions not only of average conditions but also of variation in these conditions in order to use climatically influenced stock-recruitment relationships in stochastic models to evaluate the degree to which different management measures can be considered precautionary.

During the initial phase of DEFINEIT, an American sister project emerged in the US and Canada (CAMEO stock production modeling workshops (spmw) 1 and 2). The aim of this project was to use production models to compare ecosystems in the North Atlantic and on the west coast of the US/Canada. Comparisons were made both within species (i.e. comparing cod or codlike species in all areas), within guilds (i.e. comparing demersal piscivores in all areas), and of total fish biomass. In order to avoid duplicating investigations, DEFINEIT initiated a cooperation with the CAMEO project and exchanged data for ecosystems not previously covered in the CAMEO project (The North Sea and Baltic Sea) (Deliverable 2.6.2). Further, the efforts in DEFINEIT were refocused to analyse some of the methodological issues with production models such as the bias incurred by using deterministic methods to estimate parameters and the effect of autocorrelation in parameters. The results showed that the parameters are generally poorly determined if the assumption of perfect knowledge and absence of stochasticity are relaxed, casting serious doubts on the reliability of results of deterministic models. A simplified version of the stochastic model was used to estimate the production model for the North Sea needed in WP4 (contact Anders Nielsen, an@aqu.dtu.dk, for further details). No corrections were made for different regimes or climatic effects as climatic indicators generally performed poorly in the CAMEO exercise when applied uncritically across species.

WP 3: Bycatch, discards and environmental impacts

Task 3.1 was removed from the project during the budget negotiations, but to assure consistency with the proposal text, the numbering of the remaining tasks has been kept in the original format.

In **Task 3.2**, a range of bycaught populations at risk were identified by analysing their sensitivity and susceptibility to specific fisheries. For the majority of fish stocks sensitivity to fishing mortality is determined largely by their ability to compensate reductions in stock size by increases in per capita recruitment, and for many commercially exploited fish stocks one of the stated management objectives is therefore to maintain spawning stock biomass and egg production above the level where recruitment to the adult stock would decline. For by-catch species this level cannot be determined directly due to insufficient data. Instead a relevant safe maximum level of spawning stock reduction from the unexploited state is inferred from analysis of stock and recruitment information for comparable target species. This estimate is then compared to spawning stock biomass per recruit estimates for the by-catch species at various levels of fishing, where spawning stock biomass per recruit is calculated from information about growth, recruitment and mortality. By considering the reduction in spawning stock per recruit from the unexploited level at different levels of fishing the relative sensitivity of different by-catch species to fisheries generated mortality can be inferred from their life history. Methods to estimate spawning stock per recruit, including understanding the impact of natural mortality, were explored (contact Henrik Gislason,



hg@aqua.dtu.dk, for further details). Various risk-based approaches were also considered for data-poor, multi-species scenarios, including Productivity Susceptibility Analysis (PSA). This semi-quantitative approach was applied to 46 species of North Sea fish and 15 elasmobranchs, caught in two demersal mixed fisheries (otter trawl and set net), in order to define biological sensitivity and fisheries susceptibility of these species (Deliverable 3.2.1). The three most vulnerable species across the two métiers were all Selachii sharks (porbeagle shark, spurdog and tope). This was followed by 11 further elasmobranchs (8 batoids) and 3 teleosts (Norway redfish, wolffish and cod) in the top 25% most vulnerable species (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail).

The *distributions of the top 16 sensitive species* (Deliverable 3.2.2) (common to both fleets) were mapped using IBTS survey data from 2002-2011, aggregated across the Quarter 1 and 3 surveys. Similarly standardised fishing effort data across all fleets and countries operating in the North Sea were mapped using aggregated effort data. In this way, the overlapping distributions allowed relative catch and fishing pressure exerted on these sensitive species to be quantified and presented (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail).

Additional work was conducted on mammals and sea birds (contact Simon Northridge, simon.northridge@st-andrews.ac.uk, for further detail). The population sizes and estimates of sustainable take limits for the most numerous species of seabird and marine mammal have been collated for the North Sea. All available bycatch rate data have been compiled to provide a quantitative overview of the vulnerability of each species to each gear type for which observer data are available. Certain species and gear combinations occur much more frequently than others. Specifically harbour porpoises, seals and guillemots are frequently recorded in static nets, while longline fisheries have relatively high rates of bycatch for fulmars and kittiwakes. The data collated are not necessarily representative of all North Sea fisheries, and sampling biases are noted. Nevertheless, when the observed bycatch rates are compared with a crude index of overall fishing effort for static nets, it is possible to see which species are most likely and least likely to be subject to unsustainable levels of annual removal.

Using distribution data from a long term sightings database, together with STECF data on the spatial distribution of fishing effort within the North Sea, it has also been possible to explore the susceptibility of several species to bycatch in specific gear types. A method of calculating and displaying risk of bycatch is developed, and 25 maps of species distribution (summer and winter for bird species) are presented as guides to where further monitoring and / or mitigation measures might best be focused (contact Simon Northridge, simon.northridge@st-andrews.ac.uk, for further detail).

Effort limits necessary to assure sustainable populations of non-target species (Deliverable 3.2.2) were difficult to estimate for various reasons including problems with the landings data (e.g. short time series, some reported landings data not being species specific) and there being no clearly defined reference points for some non-target species. However, through a series of approximations and assumptions, it was possible to estimate the partial fishing mortality imposed by different fleets and from this the reductions in effort needed to hit the conservation reference point of F0.1 (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail). The results of the analysis were passed to WP 4.

Size based models were investigated both to *explore their use identify appropriate indicators for management of sensitive fish species* (Deliverable 3.3.1) and to *illustrate the trade off between the effects of fishing on non-target fish species, yield etc.* (Deliverable 3.4.2). Community level indicators, such as the large fish index, are not found to be particularly useful at managing sensitive species on their own (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail). This is because community indicators are based on aggregated biomass and abundance measures across the community and consequently changes in the status of individual species are not detected. Although the community indicators suggest that the community is healthy when spurdog is not overexploited, and unhealthy when spurdog is overexploited, there is no guarantee that this will always be the case.



This result is likely to be because the fishing scenario explored increases fishing pressure across the North Sea as a whole. Given the relatively small biomass of spurdog it is possible that an alternative fishing strategy may strongly deplete the spurdog population without the resulting change in biomass being apparent in the community level indicators.

The model was also used to explore and illustrate the trade-offs between the economic benefits of fishing and the sustainability of target and non-target species using a risk based approach. Revenue and Net Present Value (NPV) are calculated as the economic benefits and the probabilities of species being over-exploited are calculated as the sustainability indicators. By comparing the two, the trade-offs of alternative fishing strategies can be evaluated in terms of expected revenue and NPV against the probabilities of over-exploiting one or more species. It is then up to the manager to make an informed decision based on this information (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail).

The evaluation of a range of fisheries and metiers against Marine Stewardship Council (MSC) criteria (Deliverable 3.4.1) was concerned with exploring how non-retained bycatch and sensitive species are considered by the MSC assessment process. The project participants did not have experience of carrying out assessments of fisheries using the MSC methodology. The work therefore focused on existing assessments and examined how non-retained bycatch and sensitive species affect the outcome, including proposed management options to minimise the impact of the fishery, rather than attempt to carry out new assessments of previously unassessed fisheries. This included using the sensitive elasmobranchs defined in the risk based framework, used by the MSC for assessments in cases where data are limited (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail). The work also explored a new tool that has been developed at Imperial College that uses a modification to the MSC assessment process to include uncertainty.

WP 4: Economic and socioeconomic indicators

The overall aim of WP4 was to develop resource indicators that combine economic, social and biological indicators. The traditionally used indicator of economic activity is the operating economy of the fishing fleet (landing value, profit, employment). However, such indicators neither relate directly to the benefit for the whole society nor are they necessarily sustainable. Therefore, relevant indicators for the economic return in fishing must be based on a sustainable socio-economic measure. Sustainable socio-economic return does, however, only state the present return to society of the existence of a fishery, not the economic potential of the fishery. To this aim, the Maximum Economic Yield must be determined and the socio-economic return associated with a move to the MSY and simultaneous minimisation of fishing fleet determined. To allow fisheries to conform to dynamic MSY levels, adaptive management must be planned within agreed governance structures and the rules for governance must be robust and simple to interpret. In terms of economic indicators it is furthermore important to take a stochastic approach, since variance and uncertainty are critical issues in relation to the economic performance of natural resource systems, when risk plays a significant part. Note that **Task 4.1.1** was removed from the project during budget negotiations.

In **task 4.1**, the annual user value was identified for the demersal fishery in the North sea, in the status quo reference year 2007 and in Maximum Economic Yield (MEY). Landing value, profit and employment were identified for the demersal North Sea fishery in status quo and in MEY, together with stock levels of the most important demersal species (Deliverable 4.1.2). This has been done using two different stock production models, one including species interactions (predation), based on the response surface model developed in DEFINEIT and one not including species interaction, estimated using ICES historical data for the demersal species in the North Sea. These production models have been built into a bioeconomic model assessing the economically optimal



exploration of the North Sea demersal fishery, reached through optimisation of the total fleet profit given variation of the fleet efforts. As such the model determines the MEY for the North Sea demersal fishery, given assumptions about species interactions and the possibility for reallocation of capacity within the demersal fleet.

The resulting output from the model has been used to discuss how much can be gained relative to status quo, both biologically (stock size) and economically (possible increase in profitability of the fleet) if the fishery reaches MEY (contact Ayoe Hoff, ah@foi.ku.dk, for further detail). By including species interaction in the forecast model, the possible increase in profitability decreases relative to the predictions not including species interaction. It is concluded that assessment models not including species interactions probably overestimate both the economic outcomes of the fishery and the possible gain in stock levels when moving towards MEY. The models were extended with a module modelling the bycatch fishing mortality of demersal elasmobranchs in the North Sea, using data produced in DEFINEIT. MEY was then evaluated given the constraint that the elasmobranch fishing mortalities should stay below sustainable limits (Deliverable 4.1.3). It is shown that given the constraint the possible profitability of the fishery in MEY is reduced considerably compared to the case with no limits on elasmobranch bycatch; when species interactions are included the MEY profitability of the fishery does not differ much from status quo (contact Ayoe Hoff, ah@foi.ku.dk, for further detail).

The results offer valuable information for long term management assessment: MEY in itself is an indicator of how a fishery can be exploited in a biological as well as economically optimal sustainable way, recognizing that fisheries management has a significant impact on human behaviour as well as on ecosystem development and must as such be based on solutions that take into account the behaviour and economic interests of humans, as well as resource preservation. Adding species interaction to the model makes the final MEY estimates more realistic from a biological point of view, compared to more simple models without species interaction. Finally adding limits to elasmobranch bycatch provides valuable information of the possible costs and benefits of limiting the fishery to keep elasmobranch at sustainable levels.

In **task 4.2** the project identified the *potential context of economic indicators in a responsive management system* (Deliverable 4.2.1). Economic data is vital for the utilisation of holistic approaches to fisheries management as bio-economic models are needed that combine ecosystem approaches with an economic assessment of the ecosystem services. The development of bio-economic models helps policy makers to evaluate the economic and biological performance of different fisheries management strategies at the same time. However, economic data are often incorporated in models developed with a biological focus, without a clear understanding of the issues with the data, adequate time series, or an assessment of the assumptions made in collecting or collating these data. This has significant impacts on the output of the models and their ability to assess the economic value of different management strategies. Recent study has estimated the value and cost of commercial fisheries to evaluate alternative management strategies in the Baltic Sea using a bio-economic model. This study found that economic data for all fleets fishing in the Baltic Sea were not available, so assumptions were necessary to incorporate economic data in fisheries assessments (e.g. using Danish economic data as a proxy to estimate fixed and variable costs for other Baltic fleets). A similar evaluation of the economic data for fleets fishing in the North Sea is required to understand how economic data can best be included alongside ecosystem parameters in bio-economic models. Hence, in DFEINEIT we assessed the availability and reliability of economic fisheries-related data for the North Sea, and described the potential impacts of these factors on the



development of bio-economic models (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail).

Economic data for countries that border the North Sea were evaluated between 2002 and 2009. The number and temporal resolution of economic measures recorded, and comparability over spatial and temporal scales were assessed for each country. The main fleet segments in the North Sea were identified based on previous studies and economic data were combined into a single database. The majority of economic measures were recorded at a national level, apart from effort, landing weight and value that are recorded at a regional level. Hence, assumptions must be made to adjust or scale economic performance data for use in bio-economic models of the North Sea. The key assumption needed is that fleet economic parameters can be estimated using average values of economic measures for the main fleet segments over the relevant period. French data for the main fleet segments in the North Sea was excluded from this analysis due to omission of non-variable costs before 2007, caveats associated with economic profit estimates in 2009, and uncertainties in the approach used to estimate capital value. This analysis showed that significant assumptions are required to integrate economic input for the main fleet segments into the bio-economic models for the North Sea. The implications of these findings for the development of bio-economic models were discussed and recommendations were made for changes to economic data collection that could improve bio-economic modelling and support more effective and holistic approaches to fisheries management.

In **task 4.3** the project *identified a range of possible economic indicators relevant to responsive management systems* (Deliverable 4.3.1) at various scales in a review of the economic indicators currently in use in marine capture fisheries (contact Polina Levontin, polina.levontin02@imperial.ac.uk, for further detail). The results are presented in the form of an annotated list within a summary table.

In **task 4.4**, DEFINEIT *demonstrated the effects of using such economic indicators within practical responsive management systems* (Deliverable 4.4.1). Simulation models were developed for case example fisheries from other WPs, in which economic indicators can be sampled and used in rules for responsive management to demonstrate the likely impact on outcomes. Stochastic simulations give a range of outcomes, demonstrating the degree of uncertainty associated with these indicators. The impacts have been demonstrated on different temporal, spatial and sectoral scales. Performance of management options or indicators was evaluated in terms of modelled output and through stakeholder consultation on performance criteria. The work on task 4.4 is split into three: stakeholder based evaluations, stochastic model simulation of NPV as an indicator in a context of a multi-species fishery; and an ecosystem model simulation to show how practical size-based management led to increases of profitability in Norwegian Spring Spawning (NSS) herring.

Uncertainty is inherent and universal in decision-making. In recent decades there have been steady strides towards a risk based management approach for fisheries. A first step towards acknowledging uncertainty is to identify, describe, and catalogue the sources of uncertainty that might have an impact on decision-making. DEFINEIT introduced a methodology based on a novel tools developed in Excel and used this to formalise the process of elicitation of uncertainties, from both experts and stakeholders, for Norwegian and Russian Herring in the Barents Sea (contact Adrian Leach, a.w.leach@imperial.ac.uk, for further detail). A spreadsheet-based questionnaire was designed to elicit stakeholder's views about the value of various economic and biological indicators. In the questionnaire stakeholders are required to assess the strength of an indicator in each of three dimensions: Availability; Descriptiveness and Predictability. Availability is defined as the economic efficiency of the indicator or, less formally, "how easy is it to get information". The Descriptiveness



dimension allows the user to score the sensitivity of that indicator to trends in the fishery. The final dimension, Predictability, is about the indicator's reliability for decision making, assessing confidence that management actions can be causally linked with changes in that indicator. So the three dimensions can be thought of, respectively as "Can we get it?", "Does it tell us anything?" and "Can we use it?" This rule-based matrix methodology enables uncertainty expressed by stakeholders in each dimension to propagate through to the Overall Indicator Score. This enables synthesised comparisons of indicators. Perceptions of uncertainty in fisheries often vary widely among scientists, industry and interest groups, and hence tools that can ensure inclusivity and that are able to represent differences of opinion are invaluable where decision-making depends on broad agreement and more generally, where effective management depends on commitment from stakeholders. An extension of the questionnaire tool, developed in DEFINEIT, has already been adopted by a new FP7 project (MYFISH) where it was used by more than 60 workshop participants to evaluate, record and summarise perceptions of 47 indicators. The participants came from a broad range of stakeholder groups (fishing associations, scientists, managers, processors, marketers and NGOs) and represented 5 geographical regions (Baltic Sea, North Sea, Mediterranean Sea, Western Waters and Widely Ranging Fish).

Testing economic indicators with simple models is an established practice in optimal control theory. A set of indicators were evaluated within a two species predator-prey model with known optimal solutions (contact Lars Ravn-Jensen, lrj@sam.sdu.dk, for further detail). The preliminary results suggest that indicators can be effective as a part of adaptive management system aiming for economic efficiency.

A stochastic simulation model was used to test some ideas regarding economic (and biological) indicators; the main purpose with regard to task 4 was to explore NPV indicator behaviour in a multi-species fishery context. For this purpose a model was used that represents dynamics of 12 commercial North Sea species, the model is based on the knowledge regarding size-base predation and species distribution and was mainly employed in WP3 to explore issues with sensitive, non-target species (contact Kieran Hyder, kieran.hyder@cefas.co.uk, for further detail). Recruitment depends on the primary production which is stochastic, as energy available in the form of primary production varies from year to year. To mimic regime shifts in the environment stochasticity affecting recruitment has auto-correlated structure. Fishing is modelled in a simplified form, there are two types of gear and the selectivity is species specific. We simulated the responses of the multi-species fishery to different exploitation levels over a period of 200 years. NPV indicator was calculated for a period of 20 years using 5% discount rate. In a multi-species fishery maximising NPV for individual species involves making different decisions for the overall fishery. In order to maximise the total NPV from the fishery fishing level slightly higher than current is needed. But maximising overall economic benefits comes at a trade-off: some of the stocks are likely to end up outside biological constraints, defined as B_{lim} as a result. Removal of larger fish, the predators, is seen to benefit prey species, and so some species will increase in biomass as a result of exploitation level that maximises NPV.

The ecosystem simulation model GADGET was used to demonstrate how practical size-based management could have led to observed increases of profitability in Norwegian Spring Spawning (NSS) herring (contact Daniel Howell, daniel.howell@imr.no, for further detail). The Norwegian Spring Spawning (NSS) provides a good historical example of international cooperation to ensure that that the fishery was conducted to maximize financial benefits rather than catch in tonnes. Although the fishery has historically targeted both adults and juveniles, the catch since 1986 has been restricted to adult fish, mostly caught within Norwegian waters. The herring are largest and fattest as they head to their Norwegian overwintering and spawning grounds, and are worth more per



kg as well as being relatively close to shore. This means that the most profitable place to catch them is in Norwegian waters. Additionally the long lived nature of the herring, combined with their sporadic recruitment makes fishing the adult fraction of the stock more stable than a juvenile fishery which only targeted ages 1-3. The successful fishery since 1986 has been managed using SSB to assign quota, but used a combination of minimum landing size, a ban on discards, and access to national waters to ensure that the quota is targeted to achieve the highest value catches with the minimum impact on the stock. A brief historical analysis of the change from adult and juvenile fisheries to one on adults only is combined with modelling analysis of the possible outcomes if such a change had not been achieved. Results indicate that even if the juvenile fishery had taken a relatively small portion of the overall catches it would still have had an appreciable negative effect on the stock size and hence the long term profitability of the fishery. Significant differences arose when attempting to maintain the value of the catch when switching from adult to juvenile target species, indicating that a “balanced harvest” strategy may not be economically optimum.

WP 5: Synthesis and dissemination

WP5 had two objectives: Firstly, to synthesise the results of WP1 to WP4 to ensure that the advice given to managers is consistent with an ecosystem approach to management under a changing climate rather than consistent with one aspect but inconsistent in all others and secondly to assure that the scientific community, managers, stakeholders and the general public are informed of the results of the project.

In **task 5.1**, the future stock dynamics and the subsequent limits to sustainable ecosystem exploitation and the area delivering maximum sustainable economic yield under selected climatic scenarios was the focus (Deliverable 5.1.1). Due to the lack of significant improvement of the stock recruitment relationship in task 2.6, completing task 5.1 would not be appropriate. Hence, with one exception, only predictions assuming historically observed recruitment success etc. were made. The one case in which the effect of climatic conditions on reference points was included was the estimated maximum sustainable yield of Baltic Sea sprat (WKMULTBAL 2012). The recruitment success of this stock was highly correlated to temperature and without including the effect of temperature, the stock recruitment relationship increased monotonically for all values of SSB. However, as accurate models of future climate variability were not available, predictions were made assuming constant temperatures equivalent to the most recent period.

In **task 5.2**, it was planned to compare the parameters of the different Schaeffer models to investigate whether general properties of the dynamics of interacting fish stocks can be derived (Deliverable 5.2.1). This idea had simultaneously occurred in a sister project funded under CAMEO in the US. To avoid duplicating their work with a smaller dataset, DEFINEIT cooperated with the CAMEO workshop and increased their database with data from the Baltic and North Sea. This database was used for a string of comparative analysis presented under session O at the ICES annual Science Conference in 2011 (Link et al 2011 among others). General rules of thumb were difficult to derive, even with respect to productivity. During the estimation, it became apparent that deterministic models often provided biased parameter estimates. Hence, estimates from deterministic models could not be used in the project without fear of introducing bias. It was therefore decided to develop a full statistical multispecies production model, a task which has never before been attempted, presumably due to the difficulty in separating and estimating several types of error (Polachek et al. 1993). The model succeeded in estimating parameters and these parameters were



used in WP4. It was not used for system comparison as this task had already been performed by the CAMEO workshops.

In **task 5.3**, the communication of project results was in focus. The communication targeted both the scientific community, managers, stakeholders and the general public. A public web page was constructed in the beginning of the project and was regularly updated with documents produced under the project (www.defineit.dk) (Deliverable 5.3.4). The project coordinator and the WP leaders of WP3 and WP4 participated in the MARIFISH Workshop on the use of Indicators in Fisheries Management in 2010 (Deliverable 5.3.3), and received useful comments and advice on how to obtain the greatest possible impact on management. Among the recommendations was clearer description to the funding agencies of the advisory groups in which results of the project have been used directly to improve management recommendations. A newsletter was therefore constructed in month 24 of the project and posted on the web site and send directly to the national funding agencies. This newsletter has been updated with the dissemination events for 2011 and 2012 (Appendix A)(Deliverable 4.3.2). In 2011, a dialogue meeting on MSY in fisheries was held in Lyngby, with a total participation of more than 50 stakeholders from the industry and Danish Ministry for Food and Agriculture (contact Anna Rindorf, ar@aqua.dtu.dk, for further details) (Deliverable 5.3.3). In addition to this, a joint meeting was planned between the DEFINEIT project, the FP7 project GAP2 and the North Sea, Northwestern Waters and Baltic Sea RACs. However, as the NSRAC was unable to obtain funding for their part of the expenses, the meeting was cancelled by them. Within the project, several scientific articles have been published and more are in preparation (Appendix A)(Deliverable 5.3.1).

WP 6: Management

The objective of WP6 is to ensure that appropriate levels of communications are maintained among partners in order to achieve expected levels of scientific outputs, to report to the Marifish call secretariat via the contracted reports and, lastly, to ensure that project objectives are achieved on time and within the costs estimated.

In **task 6.1**, communication within the project is ensured. The project meetings were initiated with the kick-off meeting in Copenhagen (Deliverable 6.1.1), followed by a midterm meeting in Athens in November 2010 and a final project meeting in November 2012 (contact Anna Rindorf, ar@aqua.dtu.dk, for further details) (Deliverable 6.1.3). An internal project wiki was constructed at the start of the project and was used for exchange of documents etc (contact Anna Rindorf, ar@aqua.dtu.dk, for further details) (Deliverable 6.1.2).

In **task 6.2**, communication with the Marifish Call Committee is the focus. This includes day to day communication as well as the delivery of midterm- and final reports (Deliverables 6.2.1 and 6.2.2). Under this task, the midterm and final report has been produced and communication has taken place during both the granting procedure and the planning of the MARIFISH Workshop on the use of Indicators in Fisheries Management in 2010.

In **task 6.3**, the project co-ordinator and the work package leaders worked together to ensure the management of the project. In the initial phase of the project, a consortium agreement was signed by all partners (contact Anna Rindorf, ar@aqua.dtu.dk, for further details) (Deliverable 6.3.1). In month 23 of the project, it became clear that HCMR could not fulfil their obligations due to lack of national funding. This matter was discussed by the remaining project participants at the subsequent project meeting (contact Anna Rindorf, ar@aqua.dtu.dk, for further details) and a letter formulated to



the Marifish secretariat to inform about the resulting changes to the project (contact Anna Rindorf, ar@aqua.dtu.dk, for further details).



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- WKPELA 2012. Report of the Benchmark Workshop on Pelagic Stocks (WKPELA 2012). ICES CM 2012/ACOM:47



Appendix A. Management impact, stakeholder involvement and publications 2010-2012



MANAGEMENT IMPACT AND STAKEHOLDER INVOLVEMENT

Presentations and discussions of project results in 2010

- Presentation by [Daniel Howell](#) at the [ICES Working Group on Multispecies Assessment Methods 2010](#) on the temporal development in the amount of alternative food available to cod in the Barents Sea
- Presentation by [Daniel Howell](#) at the [ICES Working Group on Multispecies Assessment Methods 2010](#) on the Barents Sea model of species interactions affecting fish stocks.
- Presentation by [Daniel Howell](#) at the [ICES/Marifish joint Workshop on End to end models 2010](#) on proposed end-to-end models of fish stocks.
- Improved understanding of key processes contributed to the background knowledge in the [ICES Arctic Fisheries Working Group 2010](#) through the participation of [Bjarte Bogstad](#)
- Presentation of the DEFINEIT Barents Sea model by [Daniel Howell](#) to Statoil as part of an end-to-end (“ecosystem”) model to be used as a decision support tool in risk analysis for the oil industry.
- Presentation by [Anna Rindorf](#) at ‘[Fiskeripolitisk Årsmøde](#)’ 2010 on the likely consequences of MSY management on the fishery
- Presentation by [Anna Rindorf](#) at the [ICES Annual Science conference 2010](#) on the density dependence of mortality induced by predatory fish.
- Presentation by [Anna Rindorf](#) at the [ICES Working Group on Multispecies Assessment Methods 2010](#) on the importance of the saturation level of predatory fish and the spatial overlap of predators and prey to prey fish mortality.
- Presentation by [Mark Payne](#) at the [ICES Herring Assessment Working Group 2010](#) on the temporal development in SSB of different spawning components.
- Presentation by [Sophy McCully](#) at the [ICES Annual Science conference 2010](#) of the manuscript by McCully, S. R., de Oliveira J., Dobby, H., Beggs, S. and Ellis, J. R. (2010). The utility of fisheries-independent trawl surveys for evaluating spatial and temporal trends in the relative abundance of North-east Atlantic spurdog *Squalus acanthias*. ICES CM 2010/E:11.



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MANAGEMENT IMPACT AND STAKEHOLDER INVOLVEMENT

Presentations and discussions of project results in 2011

- Presentation by [Daniel Howell](#) at the [ESSAS/PICES Open Science meeting, Seattle 2011](#) on the unquantifiable uncertainty in projecting stock response to climate change: Example from North East Arctic cod".
- Presentation by [Daniel Howell](#) at the [Norwegian-Russian symposium, Svalbard 2011](#) on the unquantifiable uncertainty in projecting stock response to climate change: Example from North East Arctic cod".
- Presentation by [Daniel Howell](#) at the [ICES Working Group on Multispecies Assessment Methods 2011](#) on timeseries of prey species abundance in the Barents Sea.
- Presentation by [Anna Rindorf](#) at a [dialogue meeting between scientists and stakeholders in the Danish fishery](#) on the definition of F_{MSY} and the effect of species interaction on F_{MSY} .
- Presentation by [Anna Rindorf](#) at the [ICES Annual Science conference 2011](#) on the effect of marine mammals on natural mortality of commercial fish in the North Sea.
- Presentation by [Anna Rindorf](#) at the [ICES Working Group on Multispecies Assessment Methods 2011](#) on the diet composition and population development of marine mammals and seabirds and on the effect of these predators on natural mortality
- Presentation by [Mark Payne](#) at the [ICES Herring Assessment Working Group 2011](#).
- Working document by [Anna Rindorf and Mark Payne](#) for the [ICES Herring Assessment Working Group 2011](#) describing the use of IBTS indices as indicators of sprat abundance.



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MANAGEMENT IMPACT AND STAKEHOLDER INVOLVEMENT

Presentations and discussions of project results in 2012

- Presentation by [Anna Rindorf](#) at the [ICES WGCHAIRS 2012](#) on the effect of marine mammals on natural mortality of commercial fish in the North Sea.
- Presentation by [Anna Rindorf](#) at the [ICES Herring Assessment Working Group 2012](#) on the presentation of an explorative assessment for sprat
- Presentation by [Morten Vinther](#) at the [ICES Workshop on Multispecies/Ecosystem Advice for the Baltic Fish Stocks 2012](#) on the consequences of species interactions for F_{MSY} , the modelling of spatially explicit predation and the effect of spatial overlap between predators and prey on the historic perception of natural mortality.
- Presentation by [Anna Rindorf](#) at the [EU-Norway Seminar on Long Term Management Plans 14-16 May 2012, Svalbard](#) on the effect of species interaction on F_{MSY} .
- Presentation by [Mark Payne](#) at the [ICES Herring Assessment Working Group 2012](#) on the temporal development in SSB of different spawning components.
- Presentation by [Mark Payne](#) at the [ICES Benchmark Workshop on Pelagic Stocks 2012](#)
- Working document for [ICCAT](#) by [McCully, S. R., Scott, F., Ellis, J. R., and Pilling, G. M.](#) (2012): Productivity and Susceptibility Analysis: Application and Suitability for Data Poor Assessment of UK Elasmobranchs. ICCAT/SCRS/2012/079.
- Working Document by [McCully, S. R., Scott, F., Ellis, J. R., and Pilling, G. M.](#) for the [ICES Working Group for Elasmobranch Fishes 2012](#) on the productivity and Susceptibility Analysis for Data Poor Assessment of Elasmobranchs in the Celtic and North Seas.



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Publications

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Planned publications

- Heath, M. R., Preedy, K. F., Culling, M. A., Crozier, W. C., Fox, C. J., Gurney, W. S. C., Hutchinson, W. F., Nielsen, E. E., O'Sullivan, M., Righton, D. A., Speirs, D. C., Taylor, M. I., Wright, P. J., Carvalho, G.R. 2012. Genetic diversity in fish populations is threatened by harvesting patterns.
- Hemmer-Hansen, J., Therkildsen, N. O., Meldrup, D., Nielsen, E. E. 2012. Evidence for selection on life-history trait candidate genes in natural populations of Atlantic cod (*Gadus morhua*).
- Payne, M.R., Ross, S.D., Clausen, L.W., Munk, P., Mosegaard, H and Nash, R.D.M. 2012. Recruitment decline in North Sea herring is accompanied by reduced larval growth rates. Planned submission to Marine Ecology Progress Series summer 2012.
- Payne, M. R. 2012. Reconciling field and laboratory observations of the vertical migrations of herring larvae: why don't they agree? Planned submission to Marine Ecology Progress Series summer 2012
- Payne, M. R. 2012. A forward-in-time inversion approach to the analysis of Ichthyoplankton surveys. Planned submission to Fisheries Oceanography summer 2012
- Smout, S., Rindorf, A., Vinther, M., Hoff, A., Frost, H., Northridge, S. and Phil Hammond, P. 2012. Consumption of fish by top predators in the North Sea.
- Blanchard, J. L., Andersen, K. H., Scott, F., Hintzen, N., Piet, G., Jennings, S. 2012. Trade-offs between biodiversity and food security objectives for the North Sea elucidated from fish community dynamics.
- Howell, D., Filin, A. A., Bogstad, B., and Stiansen, J.E. 2012. Unquantifiable uncertainty in projecting stock response to climate change: Example from NEA cod. J. Marine Science. Submitted, accepted with revisions.
- Kell, L., Nash, R., Dickey-Collas, M. and Mosquera, I. 2012. Including Biology in Biological Reference Points?: An evaluation based on North Sea cod, herring and plaice. Submitted to ICES Journal of Marine Science.