Executive summary:

Removal of a forage fish has consequences for both predators and prey of forage fish. As everything is connected, every management action has a price which goes beyond the apparent, direct effect on the target species. The fishery on forage fish can therefore not be seen in isolation, as the immediate gain in profit from the fishery has to be discounted by the lowered potential for production of large piscivorous fish. Management actions on other species also influences forage fish, i.e. conservation efforts on marine mammals or sea birds have direct consequences for the predation pressure on forage fish.

The objective of the FACTS project has been to provide insight and quantitative advice on the ecosystem wide consequences of management actions directly or indirectly related to forage fish.

The two overarching questions were:

1. What are the consequences of forage fish fisheries on

(a) predator growth and abundance,

(b) economic output of fisheries on piscivorous species, and

(c) ecosystem stability and the risk for regime shifts?

2. What are the consequences of changes in predator populations on forage fish populations and fisheries?

The methods have a combination of ecosystem models, of process studies aimed at feeding into the models, of economical models, and of data-analysis of existing data sources. The project covers four ecosystems in detail; Norwegian-Barents Sea, Baltic Sea, North Sea and Bay of Biscay.

FACTS has brought together leading European fisheries and university institutes working on creating the tools for ecosystem based management. The active involvement of the institutes in the current management has provided a means for the results of the project to feed into management. The project furthermore included a network component which has ensured a wider dissemination of methods and results within the marine scientific community.

FACTS has compiled process knowledge on climate drivers and trophodynamic interactions of forage fish with prey, other forage fish and their predators. The tasks were designed to compile data sets and process knowledge required to disentangle various drivers (climate and trophodynamic relationships) impacting forage fish populations. Hence, we provided quantitative estimates of the relationships between changes in forage fish species and their prey, their competitors, and their predators. These were applied in the course of the project to deliver assessments of the role of these species within European marine ecosystems.

FACTS has parameterised and utilized a suite of models to yield quantitative estimates of ecosystem responses to perturbations from human activities and environmental change. The work was conducted in two phases. In the first phase, a suite of models was improved by incorporating process knowledge on climate drivers and trophodynamic interactions into model parameterizations. In the second phase, simulations that utilize different 'perturbations' were employed within these models to estimate the role of forage fish in ecosystem stability as influenced by differences in biodiversity among the four FACTS Case Study regions.

Adding economics to the quantitative ecosystem response models, FACTS has analysed different public policies to find alternatives that add to the economic welfare of society. The objective has been to quantify costs and benefits in economic terms of perturbations directly or indirectly on forage fish populations.

Based on the field data, data analyses and ecosystem modelling, FACTS provided both system-specific and generic advice relevant for the development of ecosystem-based management in European waters. The FACTS project has used two routes of information flow that produced such advice. On the one hand, advice was directly transferred based on the increased process knowledge on trophodynamic interactions, simulations of ecosystem-level responses, and cost-benefit tradeoffs of forage fisheries. These results have assisted in answering immanent ecosystem management questions, including multi-species interactions' impact on single-species yield, sensitivities of predators to changes in forage fish, ecosystem stability and integration of economics.

To supplement this approach another route was chosen, by identifying and recommending

i) tools that are available but not yet applied,

ii) short-term improvements to these tools, and

iii) long-term research needs that must be met in order to advance European ecosystem-oriented management.

Project Context and Objectives:

FACTS will develop and disseminate advice on the consequences of various forage fish harvest strategies to the ecosystem including their economic implications. FACTS research focuses on seven forage fish species (anchovy, herring, capelin, Norway pout, sardine, sandeel and sprat) that are a major natural resource to the European community and represent key elements in the functioning of marine ecosystems. FACTS will eliminate critical gaps in knowledge that currently exist concerning the impact of variations in forage fish populations (due to various drivers such as climate and fishing) on the trophodynamic structure and function of different European marine ecosystems.

To accomplish this goal, FACTS will answer the following questions:

1.What are the major short- and long-term drivers of changes in commercially and ecologically important forage fish populations within European waters?

2.What are the biological and economic consequences of changes in forage fish populations in terms of their prey, their competitors and their predators?

3.What are the biological and economic consequences of changes in predator populations on forage fish populations and their fisheries?

4.What is the role of forage fish species in maintaining biodiversity and ecosystem stability?

FACTS partners have long-standing expertise in marine ecosystem trophodynamics, are the main researchers examining the role of forage fish species within European waters and routinely apply quantitative models of marine food web interactions. Furthermore, the FACTS partners have at hand the extensive data series necessary to realistically conduct such complex ecological analyses. Thus, the FACTS consortium is uniquely equipped to answer these key questions.

FACTS research is conducted within four regional Case Studies (Baltic Sea, Barents Sea, Bay of Biscay, and North Sea) to provide gradients in biodiversity and climatic impact. These gradients enable cross-ecosystem comparisons of biodiversity and stability in relation to variations in forage fish populations. A fifth, modelling Case Study provides a necessary second route to cross-ecosystem comparison by examining the generic principles governing interactions between forage fish population dynamics and ecosystem responses.

Moving beyond extensive process knowledge, FACTS will develop new operational models that estimate the biological and economic tradeoffs associated with various exploitation strategies of forage fish stocks in major European fisheries. Moreover, as the main providers of advice on forage fish in the North Atlantic, FACTS partners are also able to translate these model outputs into urgently needed advice on how best to move beyond the single-species approach of current fishery assessments and adopt ecosystem-oriented management. The FACTS project is thus addressing major research objectives set forth by the revised Common Fisheries Policy, the Marine Strategy Directive (2008/56/EC) and EU Marine and Maritime Research Strategy.

The Science and Technology (S&T) objectives of the FACTS project have been:

1.To quantify the trophic interactions between forage fish and the prey and predators, establish levels of competition between forage fish species within each case study region, and assess the impact of climate change on FACTS forage fish within European waters.

2.To quantify ecosystem responses to perturbations from human activities especially fisheries impact and environmental change.

3.To provide cost-benefit analyses and cost-effectiveness analyses of perturbations on forage fish populations, either through fishing or from predators (sea birds and marine mammals).

4.To develop case study specific and generic advice for ecosystem-based fisheries management of forage fish populations in European Seas.

In the objective description for theme 2 'Food, agriculture and fisheries, and biotechnology' (European Commission C(2008)4598 of 28 August 2008) in the work programme several social, environmental and economic challenges are listed. The FACTS project refers to the following:

Challenge FACTS

growing demand for safer, healthier, higher-quality food coupled with the sustainable use and production of renewable bio-resources

FACTS will produce tools to assess the sustainability of resource use from a multiannual (medium and long term) and ecosystem perspective.

Threats to the sustainability and security of agriculture, aquaculture and fisheries

FACTS will include cascading threats to sustainability, for example the effects of fisheries on small pelagic fish for large demersal fish, and FACTS will analyse sustainability from an economical point of view.

Increasing demand for food production to take into account animal welfare and rural and coastal contexts

FACTS will, beyond fisheries management, assess the consequences of fisheries on small pelagic fish for bird- and marine mammals populations

Specifically, the call text for topic KBBE-2009-1-2-14 states that

'The objective of the project is to establish the role of foraging fish , particularly with regards to ecosystem stability, which is relatively unknown and to establish the costs and benefits of maintaining high levels of foraging fish in an ecosystem.'

This objective has been the basis for formulating the FACTS project. Specifically, FACTS aims at developing operational definitions of 'ecosystem stability' and 'cost and benefits' in an ecosystem management context, based on explicit knowledge of key processes in major European fisheries ecosystems.

The expected impact as stated in the call is 'to support the integration of the ecosystem approach in the Common Fisheries Policy. It will improve knowledge on the role of foraging fish (fish which are low in the trophic chain) in the ecosystem and their economic values for the fisheries sector. '

A pre-requisite for the integration of the ecosystem approach in the CFP (Common Fisheries Policy) is the availability of quantitative models that mimic the impact of fisheries on the ecosystem, i.e. not only on the target species, but also on their predators, their prey, and other trophic levels (trophic cascades). The FACTS consortium is capable of this effort, both in terms of modelling competence and biological knowledge. Furthermore, the EU is committed to the contents of the Johannesburg World Summit on Sustainable Development Plan of Implementation, including targets to restore depleted fish stocks by 2015. To this end, FACTS will also substantially improve the understanding of the impact of forage fish stocks, their predators and prey as part of the ecosystem.

The project call on forage fish is coordinated with Theme 6 of FP7 ('Environment (including climate change) '). In this respect, FACTS considers climate change as a driver of changes in commercially and ecologically important forage fish populations within European waters. For this reason, FACTS is bridging the gap between advancing our knowledge on the interactions between the climate and ecosystems on the one hand, and advancing ecosystem management on the other.

When assessing the economic values of forage fish for the fisheries sector, indirect effects have to be accounted for as is the case for the ecological assessment. For example forage fish exploitation can induce changes in the value of fisheries for demersal species. The FACTS project aims at analysing these economic issues in detail in a dedicated work-package that will be tightly linked to the biological modelling.

The Common Fisheries Policy (CFP) has three main objectives (according to the Commissions communication on the reform of the CFP from 2002):

-responsible and sustainable fisheries and aquaculture activities that contribute to healthy marine ecosystems

-an economically viable and competitive fisheries industry which will benefit the consumer

-a fair standard of living for those who depend on fishing activities

The FACTS project interprets these objectives as dependent on each other. However, despite the obvious need for fisheries management that accounts for the ecosystem as a whole, such management has not yet been implemented. This might be due to the lack of quantitative models that both mimic ecosystem effects of fishing and are applicable for management purposes. Another probable problem is that traditional fisheries reference points such as minimum acceptable spawning stock biomass or maximum sustainable yield have not yet been defined in an ecosystem context. Applying the maximum sustainable yield to a given species will often render it impossible to get the maximum sustainable yield for its predators or prey.

There exists, hence, a substantial need for improvement. This is foreseen in the Marine Strategy Framework directive: In view of the dynamic nature of marine ecosystems and their natural variability, and given that the pressures and impacts on them may vary with the evolvement of different patterns of human activity and the impact of climate change, it is essential to recognise that the determination of good environmental status may have to be adapted over time (taken from Directive 2008/56/EC (Marine Strategy Framework Directive)). The Marine Strategy Framework Directive constitutes the vital environmental component of the Union's future maritime policy, designed to achieve the full economic potential of oceans and seas in harmony with the marine environment. To his end, FACTS will develop the decision tools to assess the consequences at an ecosystem level of a given set of harvesting priorities, including their economic implications.

Furthermore, we will make these decision tools available where they are needed: in the ICES and STECF working groups that delivering the basics for the recommendation of harvesting strategies to the Commission. This can be done because key participants in the FACTS project are active members of these working groups.

The FACTS project has the potential to bring ecosystem-orientated management in the European water a significant step ahead, by contributing to following aspects of the CFP:

CFP elements FACTS contributions

Industrial fishing

Impact of industrial fishing (mostly forage fish) on eco-systems

Incorporating environmental concerns into fisheries management

Impact of forage fish populations and their fisheries on ecosystem stability and resilience

Improvement of scientific advice for fisheries management

Implementation of FACTS in ICES (International Council for the Exploration of the Seas) and STECF assessment working groups

Socio-economic consequences of multi-annual fisheries strategies

Linkage of ecosystem and economic models of fisheries impact on ecosystems

Project Results:

Main Science and Technology (S&T) results (25)

Climatic drivers (T1.1)

Within each system, long-term time series analyses revealed significant correlations between either direct (temperature, winds) and/or indirect (prey field / trophodynamic) effects of climate on forage fish productivity (or distribution).

For FACTS case study regions and target species, these can be briefly summarized as:

i. Bay of Biscay: Application of machine learning techniques predicted years of low, medium and high recruitment related to mean North Atlantic sea surface temperature and meridional momentum fluxes across offshore banks for sardine (Sardina pilchardus) and the first PCA component of de-trended climate indices, upwelling index and wind strength and direction in European anchovy (Engraulis encrasicolus).

ii. Barents Sea: Warming shifts the distribution of capelin (Mallotus villosus) northward likely due the direct effect of the species' relatively narrow range in temperatures (2 to 7) required for spawning and via changes in larval drift. Spring spawning herring have stronger year classes during warmer years due to changes in spawning and hatch times, drift regions and temperatures, and the magnitude of predation losses.

iii. Baltic Sea: Warming and decreased salinity have had positive effects on both sprat (Sprattus sprattus) and herring (Clupea harengus) via both direct (thermal tolerance in sprat) and/or indirect (increase in preferred prey species in both species) processes. An important, indirect effect is the reduction of cod recruitment due to climate-driven changes in hydrography.

iv. North Sea: Warming temperatures have markedly increased the productivity of anchovy (that appear to be relict populations that have persisted at low levels in the region) as well as improved conditions for life cycle closure of sardine in southern regions (e.g., German Bight) since the mid 1990s. Physiological foraging and growth models for larval herring and sprat suggested that the former has lower prey requirements at the same temperature but that sprat (spawning April - June) was predicted to be insensitive to differences in temperatures observed in the 1990s. Larval survival during the winter was predicted to constrain the adaptability of autumn spawning herring facing warming conditions.

Climate-driven Regime Shifts: Climate-induced changes in the hydrography in the Baltic, North Seas recently caused an ecosystem regime shifts with changes at all trophic levels. The climate-driven mechanisms are more conspicuous in the Baltic and Barents Seas compared to the North Sea due to differences in the complexity of the food webs. In the Baltic, reduced salinity and warmer temperatures since the early 1990's favoured the expansion of Acartia spp and reduced the population of Pseudocalanus acuspes which increased the reproductive success of both sprat and herring. Recruitment environment relationships in some herring stocks predicted positive effect of temperature. Warming is positively correlated with herring recruitment but the mechanism is thought to be indirect via increased prey abundance and feeding success and survival of early life stages. Sprat are thought to benefit both directly (thermal tolerance) and indirectly (prey field) from warming. Interactions are apparent between Baltic herring and sprat. Large stock sizes of the latter are correlated with reduced adult condition in the former, an intrinsic factor also significantly correlated with herring recruitment success. Both herring and sprat have benefited from decreased predation pressure from cod. The complex changes in interaction strength among food web components are more difficult to disentangle in the North Sea where a higher number of species with different biogeographic affinities (e.g. Lusitanian vs. boreal) interact.

Regional Processes Differ within Systems: Research on forage fishes in both the Baltic Sea (herring) and Barents Sea (capelin) highlight the importance of performing spatially-explicit analyses of climate impacts within marine systems; the strength of climate-driven changes in key processes vary spatially. In the Barents Sea, the strength of the increase and/or differences in zooplankton biomass in years of warmer temperature are not consistent across the system with more northern areas experiencing the largest differences due to hydrographic changes (and domination by Arctic versus Atlantic water masses / zooplankton communities). In the Baltic Sea, analyses of 5 herring stocks indicated regional differences with three of the five showing positive relationships between recruitment and temperature. In that case, salinity differences among the systems and the timing of herring spawning also likely contributed to differences. A second important factor is that the strength of climate-driven changes may depend upon stock size via density dependent regulation of zooplankton resources, the strength of which will also depend upon regional characteristics. Finally, differences between the southern and northern North Sea areas are apparent in terms of zooplankton community structure and water mass characteristics that will affect forage fish species composition and productivity.

Prey (T1.2)

Baltic Sea: The diets of all life stages (larvae, juveniles and adults) of sprat and herring have been well documented. These studies were reviewed with emphasis on the reliance of sprat and herring on calanoid copepods such as Pseudocalanus sp., Temora longicornis s and Acartia spp. Diet studies in combination with food consumption estimates from bioenergetics-based modelling and gastric evacuation studies support the assertion that both species can exhibit top-down control on zooplankton. Due to their high abundance, age-0 juveniles appear to be particularly important regulators of the zooplankton community. Predator consumption rates along with differences in feeding strategies (particulate versus filter feeding) and optimal temperatures (e.g., between 18 to 20°C for sprat) are highlighted. These basic, diet studies agree well with estimates of trophic position from food web modelling utilizing ECOPATH. In that model (parameterized for mid-1970's food web, suggest that both species mainly occupy the third and fourth trophic levels. Trophic transfer efficiency was estimated to be 12% with the bulk of energy flow coming directly from phytoplankton as opposed to being detritus-based.

North Sea: Diet and trophodynamic analyses in the North Sea indicate a more diverse role for forage fish species. This report includes new diets studies performed on sandeel, anchovy and sardine, and includes a review of previous work on sprat, herring and mackerel. Besides a reliance on a greater diversity of zooplankton, these diets studies shed light on an important difference in the trophodynamic role of forage fishes. As opposed to the Baltic Sea, where a lack of predator-prey overlap largely excludes fish eggs and larvae, 'traditional' North Sea forage fishes such as mackerel, herring may intensively feed upon fish early life stages. In the newly re-established clupeids (anchovy and sardine), anchovy is a particularly opportunistic feeder that often preys upon fish eggs and larvae. For example, 60% of anchovy stomachs collected from this species in the German Bight contained fish larvae (most likely sprat). The intensity of feeding upon eggs and larvae varies seasonally and spatially, indicating the importance of understanding forage fish movements and predator-prey overlap.

Trophic controls on the productivity of forage fish in the North Sea were explored using bioenergetics-based models for sandeel and via PCA and Sequental Regime Shift Detection Method (STARS) that included herring, sandeel, and Norway pout. In both analyses, forage fish recruitment patterns were related to patterns in North Sea zooplankton time series. For sandeel, recruitment failure of the 2002 year class coincided with three factors: 1) high biomass of age-1 sandeel, 2) high abundance of relatively small (Paracalanus and Pseudocalanus) copepods, and 3) low concentrations of larger copepods (Calanus ssp.). The PCA and STARS analysis of phytoplankton, zooplankton, forage fish, and top predators suggested alternative periods of bottom-up and top-down control. Important transitions occurred in early 1970s and the late 1980's. In the latter phase (1989 to 2000), the productivity of piscivores was positively correlated with the productivity of forage fishes, suggesting bottom-up control of top predators. The time period of the latter change coincides with the regime shift documented for the North Sea.

Competition (T1.3)

An in situ process study on the respective role and quantitative impact of predation and hydrographic conditions on sprat and cod egg mortality in the Bornholm Basin, Baltic Sea, revealed that the intra- and interannual importance of both mortality factors changed after the large-scale environmental variation caused by the inflow of North Sea waters in early 2003.

Two approaches have been used to evaluate competition between Baltic herring and sprat. First, using an extensive database of stomach contents the feeding niche overlap between both planktivores has been evaluated. Second using an international database on hydroacoustic measurements of the two fish species, temporal changes in clupeid condition have been modelled in relation to biotic and abiotic conditions. The results show that the restructuring of the Baltic ecosystem, characterized by a drop in the predator cod and an outburst of the sprat stock (ICES 2009), was clearly accompanied by drastic changes in the condition of sprat and herring in the whole Baltic Proper. Furthermore it could be shown that during the past 30 years, density dependence, mediated by the large spatial and temporal variations in sprat stock size, has been the main regulator of the temporal changes of both sprat and herring condition.

Anchovy (Engraulis encrasicolus) increased its abundance and distribution in the North Sea during the mid-1990s and may consume similar zooplankton and/or compete with other occupants of the North Sea like herring (Clupea harengus) and sprat (Sprattus sprattus). The diet of anchovy, herring and sprat of comparable sizes sampled close in time and space were compared to understand how the three species utilize the zooplankton resource and establish whether their diets overlap or not. Anchovy was found to be a more generalist species consuming a higher abundance and mass of food. Herring was more specialized with few prey items making up most of the stomach contents. Sprat was intermediate. The dietary overlap between anchovy and sprat was highest, followed by herring and sprat before anchovy and herring. We conclude that on a background of changing plankton species, anchovy is likely to have a good chance of finding enough food and we don't consider that trophic interference by anchovy is likely to be involved in the decrease in herring recruitment.

Two different approaches are being utilized to assess the potential niche overlap of anchovy, sprat and herring in the North Sea. The first summarizes all available information on diets of the three species in the North Sea based upon gut content analysis of juvenile and adult life stages collected at fronts, well mixed and stratified waters (primarily in the German Bight, southern North Sea, an important nursery ground for forage fishes). That analysis quantifies potential overlaps (as mentioned in 1.3.2.1). The second method estimates realized overlaps by examining both prey niche as well as spatial overlap of sprat, anchovy and herring.

The second method utilizes two main approaches:

1) optimal foraging sub-routines implemented within individual-based models for each of the three species, and

2) field data on juvenile and adult distributions – particularly during spring and summer.

Although anchovy exhibits more diet flexibility and omnivory than either sprat or herring, the three species often consume the same prey sizes / species. The degree of spatial overlap will be critical for the strength of competitive interactions. Physiological differences leads to different life history scheduling of these species in the North Sea which minimizes competition during the early larval phase but not during late-juvenile phases (particularly for sprat and anchovy).

Distribution and food overlap of sprat and sardine larvae were investigated during late spring 2003 on two transects covering the full range of environmental conditions in the German Bight. Larvae co-occurred on all stations investigated. The results on food overlap confirmed that sprat and sardine larvae share a wide range of prey types. Competition for food is possible and gut fullness and feeding success were similar in both species. However, direct competition seemed to be partly avoided by different preferences in ambient conditions.

The importance of large bivalve molluscs (red) as a prey item for plaice, dab and haddock has declined dramatically since the early 20th Century, whereas sandeels (yellow) have increased in importance, as have polychaete worms (green) to plaice and crabs (orange) to haddock. The importance of sandeels has also increased in whiting and grey gurnard stomachs (not shown), and these changes reflect real changes that are known to have occurred in the availability of certain prey items over the 100 year period.

Long-term changes in the relative importance of forage fish species in the North Sea have been revealed by comparing recently digitised diet data for predatory fishes between the early 1900s, 1950s, and early 2000s. There was very limited evidence, in particular, of sandeels being eaten in the 1900s (when hard-shelled molluscs were still abundant in predator diet), but sandeels became increasingly important in the 1950s and are now hugely important especially for whiting. Meanwhile the relative importance of herring has decreased.

The diet of anchovy (Engraulis encrasicolus) in the North and Baltic Seas was studied using stomach analysis on samples from four sampling events in different areas. Zooplanktivory was confirmed; the most frequent prey items (in over 40% of stomachs) were copepods, malacostracan larvae and fish larvae. In the Baltic Sea, Paracalanus spp. and Pseudocalanus spp. were important in relative terms; in the German Bight, Temora spp. dominated the stomach contents. Relative abundances of prey items varied with area more than absolute abundance or presence absence of items. Moreover, the level of resolution of prey categories influenced which prey categories were considered to be most important in driving variability in stomach content. Anchovy diet is broad across the seasons, years and areas sampled, suggesting that it is not a specialist feeder in the North Sea. The similarity of diet between anchovy and other clupeids, as well as anchovy consumption of larval fish, makes the new increased anchovy population a potential intraguild predator of commercial species like herring.

In addition to the analysis of the analysis of intraguild predation between anchovy and herring in the North Sea the issue has been analysed at two other level: 1) generic relevance and 2) anchovy - sardine in the Bay of Biscay. For the first case a paper is in press in Marine Biology, whereas a second paper is in preparation.

The role of intraguild predation in the population dynamics of small pelagic fish. In this paper we argue that understanding marine ecosystem functioning requires a thorough appreciation of the role of intraguild predation to system dynamics. The theoretical predictions of intraguild predation models might explain some of the community features observed in marine ecosystems such as low diversity in upwelling and productive systems and species alternation in response to moderate external forcing. Finally, we argue that an ecosystem approach to fisheries requires that the size-structure of fish populations should be taken into account and that it is extremely important to account for the predators of early stages (eggs and larvae) to gain a thorough understanding of the key interactions between species.

The ingestion of anchovy eggs by sardines and the potential impact on anchovy eggs mortality has been estimated using sardine stomach contents and the overlap between sardines and anchovies. It has been estimated that sardines ingest anchovy egg at a median rate of 1190 anchovy eggs d-1 kg-1 of sardine. This implies that 26 % of the egg anchovy egg production is consumed by sardines and that 40 % of the anchovy egg mortality can be attributed to sardines.

Species-specific physiological-based maps of habitats supporting the survival of non-feeding stages (embryos / eggs and yolks sac larvae) are being developed based upon optimal and sub-optimal temperatures (optimal and pejus temperatures) of the four species. The width of thermal windows is broadest in herring (3 to 20°C), followed by sprat (5 to 17°C), sardine (6 to 19°C) and anchovy (16 to 27°C). Sardine displays the lowest tolerance to brackish salinity, reducing it's habitat to offshore, full marine areas. In contrast, sprat is found in slightly lower salinity areas of the German Bight (river plume fronts) while anchovy life cycle closure requires more coastal, shallow water areas (Wadden Sea, etc.) with reduced salinity and warmer temperatures. Early larvae feeding requirements (starvation thresholds) are being examined using physiological-based IBMs. Maps of later life stages are also being produced utilizing GAM analyses of field distributions and fine-scale maps of modelled temperature and salinity.

The diet of the dominant pelagic fish in the Bay of Biscay has been investigated in order to evaluate the diet overlap between different species. Stomachs of anchovy, sardine, Atlantic and Mediterranean horse mackerel, Atlantic mackerel, Atlantic-Chub mackerel and sprat have been collected and analyzed under the microscope. Different factors affecting the diet composition were analyzed in order to define the best methodology to define the diet overlap of different predators. Then the overlap was analyzed in terms of diet dissimilarity.

Empirical evidence on anchovy cannibalism and predation of the main small pelagic fish species on anchovy eggs and larvae sharing the same niche in the Bay of Biscay was provided. In addition, the global impact that egg predation could have on anchovy egg survival rate is estimated as well as the effect of the cannibalism by the anchovy itself.

Spatio-temporal variations of carbon and nitrogen stable isotopes ratios in various taxa representative of the open marine ecosystem food web of the Bay of Biscay have been determined. Emphasis was put on potential differences between neritic/coastal vs. oceanic/deep-sea organisms and benthic vs. pelagic organisms.

δ13C and δ15N values decreased considerably from inshore to offshore organisms (fish and other taxa). As such, δ15N values are not only an indicator of the trophic position, but of the feeding area also. High variability of signatures in small individuals was detected, more particularly in small individuals of sardine and anchovy (strong overlap of isotopic niches).

There was a better segregation of species when looking at large individuals, but variability of isotopic signatures remained high in large anchovies. Furthermore, for both size classes, individuals of sprat presented less variable values and higher δ15N values in average than sardine and anchovy, suggesting a more specialised diet and more coastal feeding area for sprat throughout ontogenesis.

Based on the survey series PelGas in spring (2000 - 2011) and stomach content data, the potential for anchovy egg predation by anchovy (cannibalism) and sardine (intraguilde competition) was evaluated. Anchovy egg predation by sardine seems more important than cannibalism by anchovy. The spatial extension of spawning anchovy together with the overlap between the distributions of sardine and anchovy eggs seems to correlate to recruitment. Sardine distribution could have changed, resulting in an increased overlap with anchovy over the series.

T1.4 Predators (T1.4)

A number of manuscripts produced within FACTS, focusing more specifically on predator–prey links between forage fish and predatory fishes, seabirds and marine mammals, with emphasis on quantifying removals by predators. These predator-prey relationships were studied in the 4 case study areas of FACTS: the Barents, Baltic and North Seas, and the Bay of Biscay.

In the Baltic Sea, the population of grey seal (Halichoerus grypus) has been increasing from historical low levels in the 1970s. Within FACTS, the diet of grey seal was investigated from stomach and intestine samples over the period 2001 to 2007 and the removals of clupeid fish (herring and sprat) and other fish species were estimated (per seal sex and age groups, geographical location and month). Herring was the most common species in the diet of grey seal (found in 73% of the individuals), and represented the main food item (80% of diet). The second species, sprat, was much less important (present in 21% of the individuals sampled and representing 6% diet). The importance of predation on sprat was small (annual removals corresponding to less than 1% of the SSB). In the Gulf of Bothnia (ICES SDs 30-31), the estimated removals of herring by seal predation were also negligible (less than 1% of SSB). In the central Baltic Sea (ICES SDs 25 - 29 + 32), removals of herring by seal predation represented an increasing proportion of the SSB (from 4% to 10% over the years 2000 to 2010) and since 2004, has corresponded to as much as one third of the commercial catch (in weight) since 2004.

Data on harp seal (Pagophilus groenlandicus) diet composition in the Barents Sea was available for the period 1990-2006. Diet composition changed under contrasting capelin abundance regimes. Within FACTS a multi-species functional response model was fitted on this historical diet data to represent harp seal consumption rates on capelin, herring polar cod, cod, haddock krill and amphipods. However, the fit of the model (ability to reproduce the observed diet, given the historical abundance of the prey species) was low, mainly because of data limitations. It was then decided not to use directly this model in GADGET (the multi-species model used in FACTS for the Barents Sea).

In the Bay of Biscay, the top predators considered were predatory fish (sea bass and tuna) and dolphins. Within FACTS, the diet of European sea bass (Dicentrarchus labrax) on the continental shelf of the Bay of Biscay has been investigated using stomach content and isotopic analyses. European sea bass appeared to feed mainly on four forage fish species (mackerel, horse mackerel, anchovy and sardine by order of importance). While generally described as an opportunistic fish, this study indicates that European sea bass actively select these species (they are more abundant in stomachs than expected from their abundance in the sampled location respectively to other prey species). The spatial and temporal variation of anchovy predation by albacore (Thunnus alalunga) and bluefin (Thunnus thynnus) tuna in the Bay of Biscay was also studied. The study showed a preference of albacore tuna for anchovy when present in its feeding area. Anchovy is a major prey for juvenile Bluefin. For both species, predation on anchovy has a marked seasonality. Predation has intensified after the recovery of anchovy in the recent years (2009-2010) compared to earlier years when the stock had collapsed (2004-2007), principally owning to an expansion of anchovy spatial distribution in autumn, increasing its exposure to predation. The effect of fish abundance variations on the diet composition of common dolphin (Delphinus delphis) in Galician waters was studied focusing on three species, sardine, blue whiting and hake juveniles. A sigmoid functional response was identify for sardine, with predation increasing with abundance when abundance is low, but a saturation occurring rapidly even at low sardine stock size. The relationship of juvenile hake was almost linear. The amount of removals for commercial fish by the most common cetacean species were also quantified, based on each species energy requirement, population size, and diet. The results suggested that, at the scale of Atlantic coast of the Iberian peninsula, the two main dolphin species (common and stripped dolphin) together consume annually 3.85kt, 7.7 kt and 13.8 kt of horse mackerel, sardine and blue whiting respectively. The estimated consumption for sardine represents 3 to 6% of the natural mortality of sardine.

The profitability of forage fish (energy content) for top predators in the Bay of Biscay was also investigated, as it is also an important parameter for multispecies models. Analyses were carried out to determine the chemical composition of 78 different species potentially (given their size range) part of the diet of Bay of Biscay top predators. The results showed large variations in energy content (mainly related to the proportion of fat) among forage species. The main forage fish species of the Bay of Biscay were classified as high quality species (greater than 6kj per gram) but still with some differences among species, with sardine and mackerel having the highest energy content (8.7kj/g and 7.9 kj/g) and anchovy and horse mackerel the lowest (5.8 kj/g and 6 kj/g).

The diet of the main marine mammal species of the North Sea (harp, harbour and grey seals, harbour porpoise and Minke whale) has been characterised within FACTS, based on prey otoliths found either in gastrointestinal tract contents (cetacean species) or in faeces (pinnepeds). Diet estimates, and (when the resolution of the data allowed it) spatially disaggregated diet estimates were provided for inclusion in the North Sea multi-species model. The contribution of forage fish to the diet of marine mammal varied among species. For Minke whale (only few samples) sandeel was the dominant species, and some herring and mackerel were also found. Harbour porpoise had a highly variable diet, predominantly composed of small cod and whiting, and to a lesser extent, sandeel and gobies, but could also be occasionally dominated by flatfish or herring. The diet seal species was mainly composed of sandeel and occasionally sprat (for harbour seal) and gadoids (harbour and grey seals).The consumption of forage fish by whiting, the main piscivorous series in the North Sea, was also studied within FACTS, based on the ICES stomach content data base. The analysis revealed important spatial and inter-annual variations in the diet of whiting.

Multispecific functional response models for predation of common guillemot (Uria aalge), and harp seal on forage fish and other fish species were fitted within FACTS. For common guillemot, data on chick provisioning and on abundance of two main prey (sandeel and sprat) on a major North Sea colony were available for the period 1992-2005. The model was able to reproduce historical changes in consumption in agreement with changes in prey abundance (including sandeel decline). The study also indicated that energy intake of chicks was more sensitive to sprat abundance than sandeel abundance. It also appeared that guillemots are able to adjust their foraging behaviour (i.e. selection of prey) depending on the abundance of the different prey species in order to ensure a constant energy intake to the chicks. In the case of harp seal, a functional response for the consumption rate of 10 fish prey species was fitted. The model predicts that consumption of any given prey is likely to be influenced by the availability of alternative prey, and sandeel abundance appears to have a particularly strong effect. In years (such as 2003) when North Sea sandeel stocks are at low levels, it might be expected that there will be indirect impacts on other prey via seal predation and probably also as a result of other predators such as seabirds which are likely to change their diet in response to sandeel shortages.

The distribution of harbour porpoise was also studied. At the scale of the entire North Sea, the distribution estimated by visual counts during scientific surveys appeared to be mostly driven by geographical factors (depth, distance to the coast). The distribution of prey species had little (for whiting the main prey of harbour porpoise) to no (for herring and sandeel) influence on porpoise distribution. The distribution and density were also estimated at finer scale in the Dutch waters by mean of aerial surveys. The total abundance of porpoise in 2010 was estimated to be 660 thousand individuals (1.33 ind/km^2), and the distribution showed marked seasonal variations.

Finally the impact of changes in abundance of the main prey species on top predators in the North Sea was studied. For harbour porpoise, a distributional shift occurred between 1994 and 2005 which might be linked to the decline of the whiting stock, more pronounced in the north than in the south. There was also evidence to suggest that porpoises in the North Sea, and especially in northern areas, may have been experiencing nutritional challenges in recent years with reduced rates of fecundity and survival, and starvation. Evidence from diet studies also suggested a general broadening of harbour porpoise diets, perhaps indicating that difficulties with food supply may be causing a move away from preferred prey to a more diverse range of species. For grey seal, results suggest an association between condition and prey abundance in seals that breed on the Isle of May. Female mass measured immediately after giving birth is positively associated with sandeel abundance in the local area. Further, fecundity one year is related to female mass at the end of the breeding season in the previous year. Taken together, these suggest a link between forage prey abundance and life history. A positive relationship between seal mass and sandeel abundance is consistent with other evidence of the strong preference of seals for this prey. There was also evidence for a negative relationship between seal mass and the abundance of flatfish and gadoids (either due to a lower energetic value of these species as prey or due to competition for other prey such as sandeel with these species). In the case of whiting, the link between consumption of forage fish and whiting biology (condition, reproductive output) at the individual level could not be investigated, since the data used (ICES data set) contained pooled samples.

T2.1 Parameterization and improvements of models (T2.1)

The Barents Sea can be broadly characterized as being divided into two regions; a north-eastern, Arctic water dominated area, and a south-western, Atlantic waters dominated area. The north-eastern area is relatively close to the ice edge, with cold waters and dominated by cold water adapted species. Forage fish are predominantly polar cod and feeding capelin, with relatively few predators. The south-eastern region has warmer waters, with a more diverse assemblage of fish including young Norwegian Spring Spawning herring. The main predator species (including cod) are predominantly in the south-western region, with only a small fraction of the populations feeding in the north-eastern area.

It should be noted, however, that the division between these two regions is not geographically fixed, but rather can vary seasonally and between years. In addition the area of open sea in the north-eastern area will vary according to the extent of the sea ice. Nor is the distinction between conditions and species quite as clear cut as outlined above. Finally, a reduction in ice-cover in recent years has led to a greater proportion of the cod stock entering the north-eastern are. However the split does represent a useful 'broad-brush' description of the Barents Sea ecosystem.

Within the FACTS project we are investigating the utility and feasibility of extending the spatial structure in the multi-species Gadget model to include this split. The model currently contains a single Barents Sea area, in addition to a cod spawning area in the Lofotens, and mature herring and whale overwintering areas in the Atlantic. The Gadget framework allows for multiple areas; however these need not have their spatial location explicitly defined. We are therefore basing the 'spatial' split of the Barents Sea into two areas on ecosystem considerations, and not accounting for seasonal or annual variations in the actual positioning of the border between the two areas. In order to accomplish this split the non-modelled 'other foods' need to be defined separately for each predator in each of the different regions. An improved time series of other food is currently in development for the model as a whole, and will be used to provide the 'other food' in the two regions.

The inclusion of this spatial structure will be of use in improving the modelling of predation, especially on the capelin. It will also allow for explicit modelling of energy transport from the northern to the southern Barents Sea in the annual capelin spawning migration. The fact that behaviour of fish in relation to the north-east/south-west split in the Barents Sea is evolving in response to climate change provides a second motivation for including this in the model. We will then be better able to model such changes as they occur, and will have the possibility to conduct modelling experiments to investigate the possible effects of different future climate and ecosystem scenarios.

The Baltic Sea comprises a heterogeneous oceanographic environment largely influencing the spatial and temporal distribution of cod, herring and sprat (Sprattus sprattus), the three dominant fish species in the area. Despite local differences in stock abundance, structure and reproductive success, the stocks are traditionally managed as geographically homogeneous units, thus disregarding any local effects on regional dynamics and persistence of the stocks. Using a spatially disaggregated statistical food-web model FACTS used a metacommunity perspective on source-sink dynamics and management of Baltic Sea fish stocks. Fitted to area specific time-series of multiple abiotic and biotic variables our analysis showed regional patterns of dispersal and migration, dependent on local species interactions (competition and predation), commercial fishing and climate effects on recruitment and survival. The results provide valuable insight concerning metacommunity structuring and source-sink dynamics of marine fish populations; an important knowledge-base for implementing sustainable (spatial) management tools under the ecosystem approach to marine and fisheries management.

In 2007 the so called 4M-package, conducting the MSVPA (multi-species virtual population analysis) has been replaced by SMS. SMS is a stochastic multispecies model describing stock dynamics of interacting stocks linked together by predation. It operates on annual or seasonal time steps. The model consists of sub-models of survival, fishing mortality, predation mortality, survey catchability and stock-recruitment. SMS uses maximum likelihood to estimate parameters and the total likelihood function consists of four terms related to observations of international catch at age, survey CPUE, stomach contents observation, and a stock-recruitment (penalty) function. Specifically for the Baltic Sea, the advantage of SMS is that the food selection sub-model is able to account for the observed changes in herring and sprat weight at age, which co-occurred with the increase of sprat abundance during the 1990s. As a first step to implement the FACTS work in the relevant Baltic assessment working group (ICES WGBFAS), the transition from 4M to SMS was documented and SMS derived predation mortality rates for herring and sprat were made available to WGBFAS. The work has been conducted in close collaboration the ICES working group on multisp4ecies stock assessment methods (WGSAM).

The northwards relocation of sprat and herring biomass to northern areas of the Baltic Sea has removed large fractions of herring and sprat biomass away from predatory cod, and has possibly decoupled cod eggs from predation pressure of clupeids and cod larvae from competition with sprat. For this reason, an extended model with area-dependent predation mortality for cod, herring and sprat has been developed. ICES Sub-division based values for predation mortalities of herring and sprat were derived in the hindcast SMS by accounting for the distributions of cod, herring and sprat when estimating the prey-specific consumption rates of cod. This implementation needs cod stomach content data by ICES sub-division. These data have already been compiled. However, as well as in the other SMS hindcast runs, the material might be outdated, because the sample are from the period 1979 to 1993, and no later samples are include in the cod stomach content database. The results show primarily that the model now is applicable for the simulations and forecasts planned in the FACTS project. However, since the results depend heavily on the spatial distributions of cod, herring and sprat, these distributions have to be further evaluated and discussed. This work will be done during the next months in ICES and STECF working groups, which are relying on the FACTS results to be implemented in future Baltic multispecies management plans.

The dependence of Baltic cod growth on herring and sprat abundances has been estimated using a simple statistical model and is ready to be used in SMS forecasts. Analyses indicated that temporal and spatial variability in weight at age of cod is mainly caused by variability in weight at age of the youngest fish considered in the analysis, i.e. age-group 3, while differences between growth rates of older fish have shown to be limited, both in a temporal and in a spatial comparison. In addition to the work outlined in the description of work, FACTS will also implement density-dependence in herring and sprat growth.

The work conducted in FACTS was closely coordinated with STECF and ICES in order to integrate the FACTS results in the currently developed multispecies management plan for the Baltic.

The North Sea case multispecies model deliverables included the inclusion of predator-prey overlap and density dependent consumption levels followed by investigations of food dependent growth. However, in the FACTS workshop in January 2011, two issues were pointed out which required attention in order to obtain the project goals for the North Sea. One was the incomplete representation of forage fish (sprat, sardine and anchovy not included) and the other was the lack of marine mammals in the model.

Three forage fish examined in FACTS were not included in the North Sea SMS model: sprat, anchovy and sardine. The latter two have recently become increasingly abundant. However, the SMS model builds on historic data of food composition, and in the period covered by stomach samples (1981-1991) these two species were much less abundant. Hence, the preference of the predators for these preys could not be determined from the available data. Furthermore, no estimates of the biomass of these species in the North Sea over time are available. Therefore, it was not possible to examine these species as prey in the model.

In contrast to this, sprat has been present in the North Sea throughout the modelled time period, and in addition to diet composition including sprat, catch series of sprat exists. Previously, sprat has been modelled in multispecies models and hence the data exists to include this species as prey directly. In addition to the requirement of data, it is also a requirement that either a reliable population model can be built or a reliable series describing the development in biomass over time can be constructed. For sprat, the Herring Assessment Working Group (HAWG) had decided not to produce an assessment as the available data series were considered inconsistent and hence could not be used as basis for an analytical assessment. To include sprat in the SMS model, it was necessary first to examine the consistency of the available data and to get the approval of HAWG for modelling this species. The consistency was investigated in a study that was subsequently presented to HAWG. The study showed good consistency of the time series in IBTS and Acoustic surveys, and it was decided together with HAWG to proceed with including sprat in the SMS again. With sprat in the model, it was decided in modelling terms to consider anchovy and sprat as 'sprat-like'. This would allow model predictions of increased biomass of these species to be modelled through increasing recruitment success of sprat.

The lack of marine mammals in the model was addressed by first performing a preliminary analysis showing the likely effect of each of 4 marine mammal species. This study was presented at the ICES ASC and showed that both grey seals and harbour porpoises were likely to be very significant predators on particularly adult cod. Of these, only grey seals were originally planned to be included as predators in the North Sea SMS. However, as harbour porpoises seemed to be an even more important predator, it was decided to collect data on population size, consumption and diet composition to allow the inclusion of this species in SMS.

The FACTS modelling work in the North Sea culminated in a new North Sea key run presented at WGSAM in October 2011. This key run includes sprat, grey seal and harbour porpoise and is based on an updated time series of 10 seabird species. It shows that the two marine mammals now impose a natural mortality on 2 and 3-year old cod which is large enough to offset the decrease in total mortality obtained through restrictions on the fishery, clearly an important finding. Further, sprat is found to have remained virtually constant over the past 20 years.

With the inclusion of the harbour porpoise and sprat, significant work had to be done to obtain and include the necessary data and background knowledge. During this time, it was not possible also to secure time series of distributions of these species, grey seals and seabirds. Therefore, it was not possible to produce a key run which included the newly included area-based predation mortalities. This work will be completed over the next 3 months when distribution data from all species is available. This order of events was chosen as new studies have shown the total population of predators can be of far greater importance than their diet distribution (ICES session on top predators).

The way to include food dependent growth was discussed in detail in the project. Previous studies have failed to find large effects of food abundance on growth in length of cod though condition is affected by local abundance of energy rich prey. Until it is clearer from process studies of the link between food abundance and growth in FACTS if and how food dependent growth should be included, the effort on this has been postponed. Density-dependent consumption levels will be incorporated in the North Sea back to back with the changes made in the Baltic Sea. However, focus in the near future will be on growth in the Baltic Sea where previous studies have shown a clear relationship between growth and food abundance.

Fish generally grow several orders of magnitude between the larval and adult stage. Many ecological properties of organisms are related to body size, and hence small fish often have very different ecological roles than large conspecifics. This also implies that omnivory, the feeding on more than one trophic level by individuals of the same species, is a common phenomenon in fish. Intraguild predation is omnivory in its simplest form, where two species compete for the same resource, but one of the species can also eat its competitor. In models, persistence of both species in such a configuration is difficult to obtain. In marine fish communities however, it is observed routinely. One way in which persistence of omnivorous species can be established is by incorporating it as an ontogenetic diet shift, where small individuals of both species compete, and large individuals of one can feed on the small individuals of the others species. FACTS showed in the North Sea case study that this mechanism can not only lead to persistence of a single omnivorous species, but also to persistence of multiple omnivorous species. This is possible given that the adults have sufficiently different diets.

The Bay of Biscay has long been subjected to intense direct and indirect human activities that lead to the excessive degradation and sometimes overexploitation of natural resources. Fisheries management is gradually moving away from single-species assessments to more holistic, multi-species approaches that better respond to the reality of ecosystem processes. Quantitative modelling methods such as Ecopath with Ecosim can be useful tools for planning, implementing and evaluating ecosystem-based fisheries management strategies. The aim of FACTS in this case study was therefore to model the energy fluxes within the food web of this highly pressured ecosystem and to extract practical information required in the diagnosis of ecosystem state/health. A well-described model comprising 30 living and two non-living compartments was successfully constructed with data of local origin, for the Bay of Biscay continental shelf. The same level of aggregation was applied to primary producers, mid-trophic-levels and top-predators boxes. The model was even more general as it encompassed the entire continuum of marine habitats, from benthic to pelagic domains. Output values for most ecosystem attributes indicated a relatively mature and stable ecosystem, with a large proportion of its energy flow originating from detritus. Ecological network analysis also provided evidence that bottom-up processes play a significant role in the population dynamics of upper-trophic-levels and in the global structuring of this marine ecosystem. Finally, a novel metric based on ecosystem production depicted an ecosystem not far from being overexploited. This finding being not entirely consistent over indicators, further analyses based on dynamic simulations are required.

In the Generic case study, development of a general 'size-spectrum' food-web model has been finished. The model is based on the assumption that big fish eat smaller fish. Growth is food-dependent and determined by a standard bio-energetic budget. Mortality is determined from the consumption of prey by predators. Model parameterization is based on general size-based scaling of search rate, maximum consumption, standard metabolism, and background mortality. Species in the model is characterized by their asymptotic size, and forage fish are the species with an asymptotic size less than 100 g. The model is to be applied to make general impact assessment of size-based fishing.

The direct and indirect effects of changes in environment, fishing and top predators (T2.2)

All the multispecies Fmsy values for Eastern Baltic cod, Central Baltic herring and Baltic sprat are higher than the single species values. Particularly for cod and sprat higher Fs give very similar yields on the long term and will give lower SSBs and in some cases risks of stock decline to the 'lower biomass' reference points (that is a first suggestion for a lower SSB to avoid impaired recruitment). Model results indicate that although higher Fs on Eastern Baltic cod give little increase in cod yield, a higher cod F gives higher yields from Baltic sprat and Central Baltic herring. As current modelling for Fmsy does not include any structural uncertainty, risks of stock decline and impaired cod recruitment will be higher than those estimated. The presence of year-year constraints in change in cod TAC increases the variability in stock size and the increases are greater in a multi-species system (for detailed results, please cf. STECF 2012; in this report only the main results will be presented). The present distribution pattern, with a limited distribution range for cod (concentrated in the southern area) and basin wide distribution for herring and sprat (but mainly concentrated in the northern areas, at least in some seasons), implies that an increase in F on cod, not necessarily will result in increasing Baltic wide clupeid stock sizes. Conversely a decrease in F on cod will not necessarily result in a decrease of the Baltic clupeid stock size if it will not be accompanied by a cod expansion to northern areas. However, cod cannibalism will be higher and limited growth of cod due to food deprivation will become a bigger problem.

On the other hand, a reduction of clupeid F in Sub-division 25 will likely improve growth and condition of cod as well as reduce cannibalism. An increase in clupeid F in northern areas

(SDs 27-32) will likely not have a negative effect on cod, since this will not affect the stock component distributed in southern areas (SD 25-26). Further, a higher F on clupeids in northern areas would likely reduce density dependence and improve the growth and condition of clupeid stocks (ICES 2012b). Higher Fmsy proxies for herring and sprat are also obtained when density dependent growth is assumed for the two species, as the stocks compensate by a higher growth at lower stock densities due to either higher fishing mortalities or predation.

The Gadget model has been used to investigate possible different scenarios for the herring fishery in the Barents Sea; the impact of herring abundance on capelin recruitment, and the importance of uncertainties in our knowledge of whale migration on ecosystem dynamics. Results from the modelling 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.

There has been a certain amount of interest recently in 'non selective' fishing. FACTS therefore used the Gadget multispecies model for the Barents Sea to examine the possible effects of such a fishing regime on the forage fish and predators in the Barents Sea. This analysis indicates that a flat selectivity fishery may be able to preserve the stock biomasses, but only at fishing levels which severely reduce the profitability of the existing, sustainable, fisheries in the Barents and Norwegian Seas. Such fishing would also make management tailored to the needs of specific species more difficult. It is difficult to see how stakeholder agreement could be obtained for such a regime. Reduced predation from harp seals would benefit capelin, giving significantly larger stock sizes during the capelin booms, thus providing more food to predators during this period. Reduced predation from minke whales gives little impact on the capelin, since they also prey on adult cod, and the reduction in predation pressure from the whales is almost balanced by the increased pressure from the higher cod stock. Herring are slightly affected, but the juveniles only remain in the Barents Sea until the age of three before migrating to the North Atlantic, and there is thus little time for predation in the Barents Sea to have an impact on the herring stock.

In addition reduced seal predation on the capelin gives significantly more food for cod during capelin booms, thus reducing cannibalism and increasing cod recruitment. However during capelin collapses the reduced predation is not sufficient to appreciably mitigate the collapse, and thus cod cannibalism gives a higher mortality on young cod than might otherwise occur.

The EcoPath with EcoSim (EwE) model of the North Sea foodweb revealed that fishing sandeels had the highest impact compared to fishing on other low-trophic level species (herring, sprat, mackerel, krill). The trophic level itself of the forage fish species was not so important with regards to the ecosystem impacts of its fishery; rather, this was mainly influenced by its abundance levels (compared to the biomass of the species eating it), and by its connectivity (total number of other species that have trophic links with the forage fish species). However, presence of groups with trophic niches similar to the exploited species can dampen the ecosystem effects of depleting the target species.

When a fishery targeting forage fish species co-occurs with a fishery targeting larger sized predator species the yield of the two fisheries becomes linked. A generic, size- and trait based marine community model has been used to investigate these interactions in terms of the impacts on the size structure of the fish community, growth and recruitment of fish, and yield from the fisheries, and to identify management trade-offs among the different fisheries.

The role of forage fish on ecosystem stability and biodiversity (T2.3)

Bay of Biscay: OSMOSE (Object-oriented Simulator of Marine ecOSystems Exploitation) is a multispecies and Individual-based model (IBM) which focuses on fish species. We have implemented the model to the ecosystem of the Bay of Biscay in order to investigate trophic interactions between different species. This model assumes opportunistic predation based on spatial co-occurrence and size adequacy between a predator and its prey (size-based opportunistic predation). It is therefore a suitable tool to explore processes such as competition, intraguild predation or cannibalism. Variability in fishing pressure is used to test the sensitivity of the system to changes in external forcing.

Generic: The size-spectrum model developed in 2.1 has been optimized and implemented as a web application (see http://spectrum.stockassessment.org online). The model quantifies how management actions targeted on one group of species propagates to the rest of the community.

The website has open access, and it is possible for anyone to analyse the impact of fishing on the whole ecosystem based on three different fleets:

(i) an 'industrial' fleet targeting fish with an asymptotic size less than 100 g;

(ii) a pelagic fleet targeting small pelagics with an asymptotic size in the range 100 g to 4 kg;

(iii) a demersal fleet targeting fish with an asymptotic size larger than 4 kg.

We have initiated work on a systematic characterization of the ecosystem response to fishing on forage fish with the 'industrial' fishing fleet.

The role of forage fish on ecosystem stability and biodiversity (T2.3)

For the Baltic Sea, an Ecopath with Ecosim Baltic Proper food–web model was developed to simulate and better understand trophic interactions and their flows. The model enables the quantification of the flows through the food-web from primary producers to top predators including fisheries over time. The model is able to explain 51% of the variation in biomass of multiple trophic levels and to simulate the regime shift from a cod dominated to a sprat dominated system. Using a spatially disaggregated statistical food-web model, we applied a metacommunity perspective on source-sink dynamics and examples of management alternatives for Baltic Sea fish stocks. Fitted to area specific time-series of multiple abiotic and biotic variables our analysis showed clear regional patterns of inter-population exchange between all species and areas, dependent on local species interactions (density dependence, competition and predation), commercial fishing and climate effects (e.g., temperature, salinity and oxygen) on recruitment and survival.

In the Bay of Biscay, a mass-balanced model (Ecopath) representing energy fluxes within the food web was fitted to diet and abundance data for a large range of species, and integrated the removals from the fisheries and the incidental by-catch of cetacean. The model was first used to describe the overall structure and functioning of the ecosystem, and based on a number of ecological metrics, to give a diagnostic on the state / health of the ecosystem. The Bay of Biscay was classified as a mature and stable ecosystem (a large proportion of its energy flow originating from detritus). Bottom-up processes were found to play a significant role in this ecosystem, both for the population dynamics of upper trophic levels and for the global structuring of the ecosystem. A novel metric based on ecosystem production depicted an ecosystem not far from being overexploited (the removals by fishing exploitation reducing the energy available for upper ecosystem levels, thus reducing the secondary production). Based on this ecosystem model, a trophic level based model was derived, and used to simulate the state of the ecosystem corresponding to different levels of fishing effort and targeting different trophic levels. The results were analysed with a special interest on the consequences on cetaceans. Within the toothed cetacean community, bottlenose dolphins appeared the most sensitive to resource depletion by fishing. Common dolphins and harbour porpoises were found to be mostly impacted by their incidental captures in fishing gears.

A generic simplified community model representing the main functional groups (eg planktivorous pelagic fish, demersal piscivorous fish…) of the ecosystem was developed to provide qualitative indications of direction of changes at equilibrium to be expected from a permanent increase or decrease in i) environmental productivity (resulting in higher plankton standing stocks) or ii) the size of the fishing fleet targeting the different functional groups. This modelling exercise aimed more specifically at investigating the role of species compensation (resulting from within-group competition) in preventing the propagation of fishing and/or environmental perturbations along the predatory links. This approach was applied to the Georges Bank, Bay of Biscay and North Sea fish communities, which were subject to different fishing regimes, and underwent environmental changes over the last decades. All three communities changed substantially. Compensation did not prevent impacts from propagating through the food web; rather, multiple pressures did. Within functional groups, species or groups of species reacted differently to common pressures, resulting in species replacement, or compensation, which contributed to maintain functional diversity.

The effect of the same perturbations (changes in the primary production and fisheries) were investigated in the more quantitative framework provided by the Ecopath model developed for the Bay of Biscay. Robust conclusions (i.e. validated by both qualitative and quantitative models) regarding the effect of pelagic fishery were not on its targeted stocks but on the opposite (demersal) branch of the food web, the same pattern applied to the demersal fishery. The generic importance of intraguild predation (i.e. competing species eating each other) for ecosystem stability has also been investigated. An article reviewed the role intraguild predation among pelagic species in mediating the influence of external pressures, such as fishing or environmental variations, on marine communities. In the case of anchovies and sardines, where one species feeds on the early life stages of the other, intraguild predation is a mechanism to be taken into account in the interpretation of the alternation between species. A theoretical modelling study also investigated the link between the coexistence of multiple intraguild predators in a system and their degree of omnivory. The results show in that persistence of multiple intraguild predators is possible if predators exhibit life-history omnivory (e.g. feeding of prey of different trophic levels at their different life stages) and differ in adult diets. Coexistence is possible because community dynamics force one life history omnivore to act as a predator and the other to act as a consumer.

Economics into ecosystem models (T3.1)

Bay of Biscay: A bioeconomic model has been developed for the Basque purse seiner fleet which catches a range of pelagic fish. Since Basque purse seiner fleet shares the resources of the Bay of Biscay, others fleets have to be included in the model. Given that, the model besides being multistock, is a multifleet model. The compromise between data and objective resulted in the selection of five species and two principal fleets. Other fleets are included in the model but in more general terms. The temporal resolution of the model has been defined on the basis of the highest resolution possible that will allow us to model in a realistic way the behaviour of the fleets. Although fishermen take the fishing decision day by day, a daily resolution was not possible due to the lack of data, thus a monthly resolution was established.

The following functions have been defined: With respect to biomass dynamic population two possible functions has been considered; Biomass Dynamic Population Growth (Pella and Tomlinson Model) and Age Structured Population Growth function. In the economic side of the model, an effort model which simulates the short term behaviour of the sequential pelagic fleet has been created, two price models have been considered (fixed price and price dynamic which depends on the catches), production function is defined according to Cobb Douglas production function. We assume here that the catch in the middle of the season as in Pope's approximation. Costs functions have been also defined, separating fixed costs (are fixed along the period) and variable costs that depend on the effort allocated to each species and on the type of vessel. And finally a Capital function has been included (currently only 'Fixed Capital Function' has been is set and the 'Capital Dynamic' will be developed).

Combining all functions cited above, the model structure has been built. This model, named FLBEIA, has been developed in FLR. It is an R package developed to conduct Bio-Economic Impact Assessment under Management Strategy Evaluation framework. The package is built on top of existing FLR packages, which provides function to condition the simulations, to run them and to analyse the results.

The novelty of the current model lies in the fact that the biological side interacts with economic side with a monthly resolution and also lies in inclusion of covariables operating model that will allow us to include relationships between species. In that sense, the choice that makes each skipper of the target species will affect not only to this species, but also to those species that are related to the target species. For this reason fishermen behaviour or fishing pattern has been very well defined. To this end the involved fleets, especially Basque fleets, have been analysed in detail to find out what their fishing behaviour is month by month; when the target species are available for those fleets, how many days per month each fleet operates, when they change the fishing gear, etc. With this exhaustive analysis of the fleet a Sequential Fisheries Behaviour model which reproduces the Basque pelagic fleets' behaviour has been developed.

Baltic Sea: Traditional fisheries economic models have been criticized by biologists, especially if results are obtained applying simple biomass models. Biological stock assessment models, on the other hand, are more sophisticated with regard to biological content and include the population age structure but rarely take into account economic objectives. To overcome these shortcomings, we included a full age-structured population model based on the SMS in a bio-economic optimization problem.

North Sea: An external economic module to the SMS model has been constructed. This module takes the stock biomasses resulting from running the SMS model and evaluates the economic outcomes for the relevant fleets given these biomasses. The economic cost benefit module asks how the fleets fishing forage fish in the North Sea, and additionally the total Danish fishing fleet, will reallocate effort optimally when/if the fishing mortalities for forage fish are changed. By optimally is meant that the model optimizes the fleet profits by reallocating effort between fleets and species when faced with changing fishing patterns for forage fish. The cost benefit module added externally to the SMS model answers the question 'if the fishing patterns for forage fish are changed, what will be the optimal reallocation of fisheries among fleets and species for the fleets involved in the forage fish fisheries'. The module answers this question by maximizing the total fleet profit with respect to effort allocation in and between fishing fleets. Additionally the module asks what the tradeoffs will be for the total Danish fishing fleet of changing the forage fish fishery patterns.

Generic: The generic ecosystem model was revised and formulated to fit economic analysis. A side effect of this work was a significant improvement in the performance of the program in form of increased speed. Traditionally, there is a difference in how fishery is modeled from an economic production perspective and how fishery is modeled in biological models. FACTS succeeded in formulating the fishery in such a way so the two approaches can be joined.

Cost-benefit analyses (T3.2)

A bioeconomic model for a North Sea fishery has been coupled to recruitment parameters and species interactions matrices for the multi species Schaefer model estimated with the SMS model. The bioeconomic model includes detailed economic income and cost structure evaluation for each fleet segment in the Danish North sea fleet, and additionally the non-Danish fleet segments targeting forage fish in the North Sea has been added to the model, also including detailed income and cost structure. The model performs optimisations of the total net income of both the Danish fleet and the non-Danish forage fishery fleet, given the forage fish management scenarios, by reallocating effort between fleet segments. As such the model asks what will be the economically optimal fleet structure, given proposed management scenarios, and in this case what will be the costs and net income of the Danish North Sea fleet and the overall forage fishery fleet in the North sea. Two management scenarios have been investigated; increasing the forage fish fishing mortalities one by one to (or close to) the fishing mortality in maximum sustainable yield (FMSY) and decreasing (restricting) the forage fish fishing mortalities one by one to below half of the fishing mortality in status quo (2007).

As may be expected the overall picture is that the forage fishery fleet will profit, compared to status quo, from increased forage species fishing mortalities in the short run, but will lose income when the fishery for forage fish is reduced. The Danish fleet also gains income when the forage fish fishing mortalities are increased and loses income when the fishing mortality of the forage fish are increased respectively restricted. However, where the largest part of the increase in income is caused by the Danish forage fishery fleet when the forage fish fishing mortalities are set equal to (or close to) FMSY, the decreasing income when the forage fish fishing mortalities are restricted also comes from other Danish fleet segments not targeting forage fish. Thus the total Danish fleet will be affected negatively if it is decided to reduce the forage fish catches in the North Sea, and it must be assumed that other European fisheries will be affected in a similar manner. Thus if the aim is to increase the forage fish stocks in order to provide food for other fish and top predators preying on forage fish this may have far reaching economic consequences for the North Sea fishing fleet, and not only for the forage fishery fleet. To evaluate costs and benefits of changes in the management of Baltic sprat in interaction with the cod fishery and environmental uncertainty, we include a full age-structured population model in a bioeconomic optimization problem. The model is applied to a Baltic sprat fishery, and is explicitly formulated for a schooling fishery. We show that this model produces optimal steady states that may be higher or lower compared to the earlier and simpler delayed-recruitment formulation. Setting a first focus, the numerical specification is used to study the interaction of the forage schooling fishery with its main predator, the Baltic cod.

We compute optimal management under three cod stock scenarios:

(a) a reference case, using the situation in 2008,

(b) a 'low cod' case using historically low predator abundance values, and

(c) a 'high cod' case using historically high predator stock estimates.

Given a linear objective function and an interest rate less than 9%, it is optimal to apply a pulse fishing strategy. The pulse fishing property disappears if interest rate exceeds 10% or if the objective function is nonlinear. The striking differences in optimal management under the three cod stock scenarios highlight the importance of species interaction. Addressing environmental uncertainty, we examined the effect of climate change induced temperature increase on the outcome of the ecological-economic model. For the case of Baltic sprat, we illustrated how to combine field observations of temperature increase and stock-recruitment modeling to estimate optimal management strategies in dependence of economic factors and climate change scenarios. Optimal management strategies, in our terminology, maximize a societal objective function that takes into account the benefits (i.e. the economic value of the yield) and the costs of fishing. We considered an explicitly dynamic framework, where present reductions in profit (which are necessary to rebuild the currently overfished stock) are pitted against higher future profits from fishing.

The effects of fishing and climate change on the stock were taken into account as dynamic constraints in the optimization. Economic optimal solutions depended upon variability in temperature-trajectories. Under climate change scenarios, mean optimal fishing mortality and related yields and profits increased. The amount of increase was limited by the general shape of the stock-recruitment model and the assumption of density-dependence. This highlights the need to better formulate environmentally-sensitive stock recruitment models. To evaluate costs and benefits of management options in a multi-species context, a new approach in defining management objectives, taking into account the multiple ecological, economic or social needs has to be taken. In recent time, the scientific community, as well as advice-giving organizations have broadened their scope and explore the potential for multispecies (or ecosystem) assessment as well as for coupling ecologic and economic considerations for integrated advice. We use the Baltic Sea as an illustrative case study to examine the effects of moving from a pure single-species advice to a multi-species advice, which is incorporating known species interactions. Including species interaction in an age structured, ecological-economic optimization model results in trade-offs between the three fisheries involved (cod, herring and sprat). These have to be communicated to stakeholders. In the Baltic, management aiming to achieve an economically efficient multi-species solution will result in winners (cod fishery) but also losers (sprat and herring fisheries). If quotas for the three species are not equally distributed among countries, compensation may be needed to find international acceptance for efficient management.

Using an ecological-economic multispecies model, we compute optimal harvesting scenarios in the absence of compensation. We imply varying objectives, how to distribute the benefits of fishery management for the cod, sprat and herring fisheries. We show that our modeling approach also offers the possibility to calculate the economic costs of including ecosystem constraints, e.g. minimum forage fish biomasses. Due to the strong predatory impact of cod on herring and sprat, such an approach might be especially valuable in the Baltic Sea. One of the main targeted species by the Basque purse seiner fleet is the Bay of Biscay anchovy, which historically has been highly valued by the market. However, the biomass of that species suffers high fluctuations along the time. Intraguild predation between small pelagic fish is well documented and it can be particularly strong between anchovies and sardines. Sardine, which coexists with the anchovy in the Bay of Biscay, has a lower commercial value than anchovy. Therefore, sardine could be not only a substitutive species when the anchovy biomass is under limit reference point, but also a tool to help anchovy biomass to be restored. In order to analyse how fishermen behaviour can impact on anchovy biomass levels when targeting more or less sardine, a multispecies and multi fleet bio-economic model has been built using the R package FLBEIA1. That model provides a flexible and generic tool to conduct Bio-Economic Impact Assessments of harvest control rule based management strategies under a Management Strategy Evaluation framework.

A range of simulations will run considering different fishing strategies and different levels of interaction between sardine and anchovy. Results will be analysed from the biological and the economic point of view. Several analyses were carried for French fishing fleet-ecosystem interactions: First, the mutual dynamics of fleets and stocks were analysed. For this a semi-qualitative approach based on qualitative models developed in WP2 was used to analyse the joint dynamics of fleets and stocks in the multispecies, multifleet fisheries. External drivers included vessel buyback, fuel price, and fish prices, as well as environmental fluctuations.

Resource status was measured by abundance and length metrics; fleet capacity was measured by total horse power, and economic metrics such as profitability and earnings were examined as well. A maximum likelihood approach was used to identify the combined metric trends with the largest support in the data. The approach was applied to the French Bay of Biscay fisheries in 2000-2007. Combined-metric time trends suggested that decreases in fleet capacity did not result in decreasing fishing impacts; trends in stocks and fish prices were not the major drivers of changes in fleets either. Rather, the vessel buyback program might have been the main factor determining fleet dynamics over that period. Second, economic cost modelling allowed to identify the major factors driving fishing costs in the French Bay of Biscay fisheries. It also provided fishing cost estimates for the whole French fleet. Third, the economic contribution of forage fish and their predators to French fleet income and costs structure was analysed and evaluated against the economic portfolio theory.

According to portfolio theory applied to fisheries management, economic risk is reduced by harvesting together in a portfolio stocks of species whose economic returns are negatively correlated and for which the portfolio return variance is smaller than the sum of stock specific return variances. Using a range of economic indicators these predictions were tested for the Bay of Biscay fishing fleets. The portfolio width of fleets ranged from 1-3 trophic groups corresponding to 4-19 species. Economic returns varied strongly and consistently in time between fleets; their interannual variability was independent of portfolio width. The ratio between fuel energy used for fishing and energy contained in landings varied from 0.4 for purse seines to 25 for mixed (pelagic and/or demersal) trawlers; the interannual variability of this ratio decreased with portfolio width. Finally, the ratio between the interannual variability in total sales revenues per fleet to the sum of species specific sales revenue variabilities was larger than 1 except for the fleet using hooks. Thus overall were was no evidence that the portfolio strategy used by most French fleets in the Bay of Biscay stabilized economic returns, though it does seem to stabilize energy return on fuel investment. In the generic case study, to investigate the trade of between, in a marine ecosystem, to fish at low trophic level or at high trophic a sizespectrum model is analyzed. The model is implemented with two fleets: Fleet R (reduction) targeting small species (maturing as small) and Fleet C (direct human consumption) targeting large species (maturing as large). The analyze show that the exploitation of the small species have a notable economic impact on the fishery of the large species, but not the other way around. The model indicates that there has to be a balance between harvesting the small species and the large species. The present management of the North See is, at present exploitation rate, not far from having the right balance, with a little to high ratio of small species. However the model's optimal point is at around half the present days harvest of the North See for both fleets.

Cost of conservation (T3.3)

For the Barents Sea, we fit a multi-species dynamic model to time-series population and diet data in the Barents Sea, and investigate the emergent effects of marine mammal predation on fisheries for cod, capelin and herring. Scenarios in which marine mammals are reduced in number are run, and the effects on fisheries under contrasting regimes of management are explored. We also investigate the consequences of these different fishing scenarios for the marine mammal populations.

Once the GADGET model had been fitted to the fish, fishery and marine mammal data, the following scenarios were investigated using simulations in order to explore the costs of marine mammal predation in this system. (a) The original model, fitted to time series fish survey and stomach data for the Barents Sea (the „base case‟ scenario) (b) All conditions remain as for the original model runs, but the abundance of harp seals was reduced by 25% in all years (c) All conditions remain as for the original model runs, but the proportion of the minke whale migrating into the Barents Sea each summer was reduced by 25% in all years.

Marine mammal predation is an important factor in the Barents Sea ecosystem, where the absolute levels of consumption may be considerable (for example harp seals may consume up to 13% of the total cod biomass in a given year). This suggests the potential for the seals to act as serious competitors with the fishery. Increased marine mammal populations inevitably result in increased net fish consumption, but their predation on cod, which is itself an important predator in the system, can also diminish cod predation pressure on fish at lower trophic levels and this effect may compensate for increases in marine mammal predation: this can be the case for example in the cod-capelin-minke whale interaction. Equally the impact of predation on forage fish can have indirect impacts on the cod, in addition to direct predation from marine mammals. The scenario experiments also suggest that marine mammals as generalist predators may play an important role in controlling and possibly stabilizing oscillatory dynamics in the system, particularly those involving cod.

To investigate the impacts of fisheries on marine mammal populations, we explored the consequences of changes in management for fish stocks and their dependent predators. The Gadget multispecies model was used to examine the possible effects of a non-size-selective fishing regime ('flat fishing') on the forage fish and predators in the Barents Sea. In scenario

(d) a forecast approach was adopted. We predicted the effects on fish stocks of a continuation of current fishing strategy for 2011-2020 and contrasted this with 'flat fishing' at a plausible level of F=0.2 for the same time period.

Under the 'flat fishing' scenario, the exploitation rate at 0.2 leads to a lower stock size for cod in 2020 than under the agreed HCR. Based on these predicted fish stocks, a GAM relating harp seal condition to prey abundance was used to predict the female seal blubber mass for the period 2011-2020.

Flat fishing is sometimes thought to be a poor management approach that tends to result in reduced catches and biomass in some stocks (e.g. cod) if pursued with no provision for adaptive management. One consequence in the Barents Sea system is a general reduction in the stock of juvenile herring and this is likely to have effects on the condition of marine mammals. Minke whales in the mid 1990's had lower body condition than in the beginning of the 1990's and it has been shown that minke whales in the Barents Sea are in better condition when either juvenile herring or capelin occurs in high numbers. There is then a risk of adverse effects on the whale population if herring stocks are particularly low due to over exploitation, because if capelin also becomes scarce, the whales may be unable adequately to compensate by exploiting other prey such as krill and gadoids. Changes in the adult herring biomass may also result in changes in minke whale migration behaviour, resulting in unpredictable shifts in predation pressure across the ecosystem.

However, based on the empirical model of harp seal condition and its relationship to prey abundance, adult female harp seal condition appears to improve under the 'flat fishing' regime. This appears rather counter-intuitive but we attribute the effect on the seals mainly to a reduction in competition for krill and amphipods - resources exploited by seals, capelin and cod. It is interesting to note by analogy that in the North Sea, grey seals have shown continued steady population growth during a period of considerable over-exploitation during which the abundance of larger predatory fish such as cod (which form part of grey seal diets) was substantially reduced. Grey seals were, it seems, able to find adequate nutrition despite the reduced abundance of some of their prey species.

The North Sea ecosystem has a rich mix of forage fish that including herring, sprat, sandeel, Norway pout, sardine and anchovy. The North Sea has large fisheries that target forage fish (sandeel, sprat, Norway pout and herring).

Maintenance of populations of top predators such as marine mammals, birds and large fish is key to ensuring marine biodiversity, an important aspect of Good Environmental Status and hence of successful ecosystem management. As we strive to restore and maintain Good Environmental Status under the Marine Strategy Framework Directive, consumption by natural predators is likely to increase substantially from what we have today. The North Sea is an area of great economic interest to fisheries, and large stocks of natural predators will remove prey from the system which may have substantial economic value. However, whether this will lead to conflict depends on the degree of competition between the fishery and the natural predators. In order to evaluate the importance of such competition, clearly it is crucial to know how much prey is available. However, conventional single species stock assessments are likely to underestimate stock size if natural predators play an important role in removing fish, especially for the smaller/younger cohorts, because mortality for those cohorts will be underestimated. This is a concern, especially where fisheries management relying on MSY is advocated. Even where multi-species models are used to model fish populations and to explore the potential consequences of management options, problems can potentially arise when important predators are left out of the model.

In a multi-species framework we can infer that stocks which are exploited by natural and human predators at rates at or close to their maximum production range are in danger of collapse. In this situation, fishermen and predators can have the ultimate effect of virtually destroying each other's food source. In addition to this risk, they are competing strongly for the limited resources because competing consumers reduce the amount of prey available in the short term. In contrast, stocks which are less exploited do not suffer risks of collapse and the degree of competition is likely to be much smaller. In particular, stocks (given they are not close to levels giving rise to maximum production) which are consumed in comparable amounts by a longer list of predators are likely to be rather insensitive to moderate changes in the consumption of individual predator species, e.g. a suite of competitors are not likely to be strongly affected by a 5% change in the abundance of a single predator, whereas 2 predators competing for a single resource might be sensitive to such changes in one another's populations.

We first estimated the amount and value removed of prey fish by fish predators, seabirds, marine mammals and fisheries (together termed predators in the North Sea) from 1963 to the present. Considerable uncertainties arise in the estimation of these consumption rates due to a number of factors including:- uncertainties in estimating diet and consumption based on scat or stomach samples; 'noisy' diet data with substantial variability between individuals; and uncertainties in the estimation of predator population structure and size.

Results of a new SMS North Sea key run were presented at WGSAM in October 2011. This key run included sprat, grey seal and harbour porpoise and was based on an updated time series of 10 seabird species. It shows that the two marine mammals now impose a natural mortality on 2 and 3-year old cod which is large enough to offset the decrease in total mortality obtained through restrictions on the fishery, clearly an important finding.

Prey stocks which are exploited at rates at or close to their maximum production range are obviously in danger of collapse and hence predators can have the ultimate effect of virtually destroying each other's food source. In addition to this risk, they are competing to a large degree for resources. In contrast, stocks which are less exploited do not suffer risks of collapse and the degree of competition is likely to be much smaller. In particular, stocks which are consumed in comparable amounts by a longer list of predators are likely to be rather insensitive to reasonable changes in the consumption of individual predators. Hence, the predators are not likely to be affected by changes in the abundance of a single predator. The stocks of Norway pout, sandeel and herring would fall in this category as they are all preyed on by numerous predators and, at least recently, at levels of removals substantially below their maximum production. In contrast, species such as cod, whiting and haddock are preyed on by fewer predators and their removals are closer to their production. Hence, for these stocks, there can potentially be substantial competitive effects between predators.

Integrating process and generic knowledge (T4.1)

Due to their tight coupling to the dynamics of lower trophic levels and their high rates of reproduction and growth, forage fish are excellent bio-indicators of climate change worldwide and are extremely important to food web dynamics and fisheries catches and food security world-wide. The trophodynamic and commercial role of forage fishes highlights that a variety of pressures interact to affect forage fish species. These pressures include changes in 1) bottom-up processes due to climate-driven changes in physical-biological coupling within lower trophic level examined in FACTS 1.1, as well as 2) top-down processes due to both climate and fisheries impacts on the distribution and abundance of competitors (intraguild) and predators of forage fishes.

FACTS produced six manuscripts that compare various aspects of forage fish among different systems. Manuscript 1 reveals differences in the ecophysiology and habitat requirements among five different species of forage fishes, highlighting stage-specific differences in habitat requirements in all species. Differences in diets and thermal physiology help explain differences in life history strategy and the 'boom and bust' dynamics frequently observed within and among marine ecosystems. The focus of this manuscript is to examine how climate-driven (bottom-up) factors may affect species in European and Japanese waters. This, reductionist approach of examining the potential strength of one pressure (climate) on populations, then allows additional, interacting pressures (such as fisheries exploitation) to be examined. A clear message from this study is the lack of biological knowledge on many key species, which is surprising given the complexity of biophysical, individual-based models being developed to examine various populations. Manuscripts 2, 3 and 4 examine the structure of marine food webs and the trophodynamic role of forage fish within different systems. Manuscript 2 utilizes ecopath models established for different European ecosystems to examine how energy is tranfered through the food web.

The strength of coupling between zooplankton and forage fish and the dominant trophodynamic process (top-down versus bottom-up) displayed a clear latitudinal gradient (with top-down processes stronger at higher latitudes). Within Manuscript 3, simple foodweb models of Georges Bank, Bay of Biscay, and North Sea are constructed to examine different pressures (internal food web dynamics and external forcing through fishing). These areas have been subject to different fishing regimes and have undergone environmental changes over the last decades. All three communities changed substantially but differences in food web structure and the action of antagonistic pressures help explain changes in functional groups, particularly changes in forage fishes. Manuscript 4 examines how fishing pressure on forage fish potentially influencecs foodweb structure and productivity. Modelling results suggest that fishing forage fish at levels that are half of their maximum sustainable yield (MSY) is likely necessary to avoid consequences to ecosystem productivity. Five regions were compared in MS 5, including three eastern boundary currents, as well as SE Australia, and the North Sea. Finally, Manuscripts 5 and 6 utilize a size- and trait-based marine community model to investigate the interactions between fisheries on forage and larger (forage fish predator) fishes in terms of their impacts on the size structure of the fish community, growth and recruitment of fish, and yield from the fisheries. This generic, size-based tool is based on standard metabolic relations at the individual level and uses asymptotic size as a trait.

The theory predicts fundamental differences between vital rates and response to fishing between small and large species cautions against using fishing mortality leading to maximum yield per recruit as a reference point. The results imply that even though small species have a higher capacity for recovery than large species their resilience towards fishing is lower than expected from metabolic scaling rules. Given the unique role that forage fish play within marine ecosystems, both generic (sizebased) and more complex food web models (parameterized for specific systems) offer advantages and disadvantages to resolving how various pressures affect forage fishes. The complex dynamics of forage fishes is best examined using a comination of approaches including complex, parameter-rich models designed to include various bottom-up and topdown processes, more generic, functional group models that eliminate some redundant complexity allowing various pressures (climate, fishing) to be examined and generic (sizebased) approaches built on first principles. Although generic approaches highlight commonalities among food web processes, comparisons across systems using more complex models suggest that the relative strength and impact of different pressures depends upon the biological and physical complexity of the ecosystem and the ecology of resident (forage fish) species.

System-specific recommendations (T4.2)

(i) Baltic Sea

The predominant forage fishes are sprat and herring and the commercially most relevant predatory fish species is Baltic cod.

Q1 Does the strength of the impact of forage fish on the Baltic Sea food web differ between sub-systems and how do such regional differences influence advice on ecosystem-based management? - Baltic cod feed primarily on sprat and to a lesser extent on herring (and if these are scarce, cannibalise on juvenile cod); in turn, herring and sprat feed on cod eggs. Previously, spatial overlap between these three species was extensive implying tight trophic links, but this has changed and currently, most herring and sprat are outside of the predatory reach of cod (too far north). This implies wide regional differences in trophic links.

Q2 How important are density-dependent feedback loops between forage fish, their prey and predators and how do these influence ecosystem stability? - The currently limited spatial overlap between sprat/herring and cod implies limited density-dependent feedback loops between these forage fish and predator species, unless cod expand into more northerly areas and overlap with herring and sprat becomes substantial. If cod have limited spatial overlap with key prey forage fish, higher local cod densities will imply higher cannibalism.

Q3 What are the economic costs and benefits (for fisheries and other ecosystem services) of changes in the management of Baltic Sea forage fish, taking into account interactions with top predators (cod and seals) and climate induced ecosystem changes? - The cod fishery is the economically most important fishery in the Baltic. Under strong predator-prey coupling, economically optimal multispecies management would lead to a large cod stock, a medium-sized herring stock, but a very low sprat stock. Increases in sprat target SSB, e.g. in order to avoid recruitment impairment or to take ecosystem considerations into account, would have to be paid in terms of forgone profits from the cod fishery. Under current spatial de-coupling, the shadow price of fishing sprat in the south-western part (the area where overlap with the cod stock exists) might be high, as growth and reproduction of cod is negatively impacted by food shortage. Quantification is, however, currently not possible. Anticipated climate change will increase sprat stock productivity owing to higher recruitment success. Related higher potential exploitation rates are enforced due to lower productivity in the cod stock, resulting in lower predation mortality.

(ii) Barents Sea

The forage fishes of highest commercial importance are capelin (exploited within the Barents Sea) and Norwegian spring-spawning herring (residing in the Barents Sea as juveniles, but not exploited until fish have left and migrated into the Norwegian Sea); the third forage fish, polar cod, mainly occurs very far north and is not exploited at any great scale.

Q1 Is the difference in the strength of the bottom-up effects between the capelin collapses due to differences in the amount of other fish prey available to the predators? - This hypothesis was supported by analysis of combined survey-haul and acoustics data sources on abundance dynamics of capelin, cod, and the potential alternative prey species for cod; as well as cod stomach contents data. These revealed that during the 1980s capelin collapse, alternative cod prey species were scarce, cod cannibalism was high, and condition poor; the cod stock declined. During two later capelin collapses (mid-1990s and mid-2000s) alternative prey species were available, and impacts on the cod stock were mild.

Q2 Why was there good recruitment of capelin in the Barents Sea in some years even though there was a large amount of herring was present? - From the 1970s to early 2000s close negative relationships between capelin and herring abundance in the Barents Sea were documented (unexpected as herring prey on juvenile capelin), but the relationship appears to have broken down. This remains not fully understood but may be attributable to local differences in spatial distribution and/or management of capelin fishing pressure in association with cod dynamics.

Q3 Why do herring leave the Barents Sea as 3-year-olds in some years, while in other years, most stay until age 4-5? - Differences in the age at migration likely relate to significant between-year-class differences in juvenile herring growth rates, which are both density- and temperature-dependent. Year-classes can moreover be different in the proportions that as juveniles reside in the Barents Sea (where growth tends to be slow), more southerly Norwegian fjords (fast growth), or the Norwegian Sea itself (variable juvenile growth rates).

(iii) Bay of Biscay

The predominant forage fishes are sardine, anchovy and sprat, which show various trophic interactions including food competition and intraguild predation. Horse-mackerel and mackerel also occur in large numbers. Hake is a very important predatory fish that preys on these forage fishes.

Q1 Is increasing fishing pressure on sardines and sprat likely to help restore the anchovy? - These species interact through diet overlap (food competition) and intraguild predation. On the basis of a Mixed Trophic Impact analysis of the levels of food competition, it is most likely that increasing fishing pressure on sardine and sprat will not to help restore the anchovy population in the Bay of Biscay. This differed, however, from the result derived from analysing intraguild predation between these species. Sardine prey extensively on anchovy eggs in the entire area, and sprat do so in the Gironde area. Hence if increased fishing pressure on anchovy or sprat leads to reduced spatial overlap with anchovy and hence less egg predation, a positive effect on anchovy stock abundance may be expected.

Q2 Does forage fish overfishing modify the stability of the Bay of Biscay ecosystem? - Different ecosystem model types and structures were tested to examine stability of the Bay of Bay ecosystem, and the following management recommendations for small pelagics were derived based on conclusions that were consistent across model structures and types (i) a rise (decline) in primary productivity will drive an increase (decrease) in small pelagic fish abundance; (ii) an increase in piscivorous demersal fish abundance (hake) will create a high risk of decline in small pelagic fish abundance. Simultaneous single-pressure management measures might conflict. The fisheries for hake, anchovy and sardine need to be considered together.

Q3 What is the most cost effective way to increase the profitability of the pelagic fishery with limited effects on the ecosystem as a whole? - Recently the French forage fish fishery consisted primarily of pelagic trawlers and purse seiners. The profits of the French purse seine fleet were negative during 2004-2006 when the anchovy fishery was closed, but the fishery quickly recovered thereafter on its own even before the reopening of the fishery in 2010. The French pelagic trawl fleet remained highly profitable in all years despite the closure. Given the success of this fleet it is hard to conceive how the profits could be much further improved through additional management intervention. Anchovy discards were very low (less than 1% by value). Thus landing the discarded anchovy would not have improved the profits of the French pelagic fleet, and a discard ban is therefore unlikely to improve the profitability of the pelagic fishery.

(iv) North Sea

The North Sea has a broad portfolio of forage fish species: herring is primarily targeted by human consumption fisheries; sandeel, sprat and Norway pout are targeted by extensive industrial fisheries; and anchovy and sardine only occur at low biomass levels and are only exploited by very small-scale (but increasing) fisheries.

Q1 What are the costs and benefits of maintaining small-mesh fisheries on herring, sprat, sandeel and Norway pout in the North Sea - FACTS scientists created a bioeconomic cost-benefit model consisting of an economic module for the North Sea forage fishing fleet, added to a multispecies model. This suggested that relative to a 2007 'status quo', the North Sea forage fishing fleet gained (higher net income) when F for forage fish species was increased to near or equal to FMSY. In modelling scenarios where F values for forage fish species were limited below ½F2007, the total North Sea FF fleet obtained a lower contribution margin and lower net income relative to the 2007 'status quo'.

Q2 How would reductions in herring, sprat, sandeel and Norway pout populations impact seabirds, marine mammals, and predatory fish? - Seabirds are most dependent on forage fish and vulnerable to forage fish reductions, owing to specialised diet needs (high proportion of forage fish ind diet) and distributional constraints (seabird foraging is limited to vicinity of colonies, especially during the breeding season). They are followed by marine mammals, and predatory fish are considered less vulnerable to local forage fish depletions owing to greater flexibility to switch between prey species. Amongst different forage fish species, sandeel is crucial prey to the greatest diversity of top predators (especially shag, great skua, Sandwich tern, puffin, guillemot, kittiwake, minke whale, harbour and grey seal).

Q3 Should forage fish populations be managed as a core component of the ecosystem and what is their role in ecosystem stability and dynamics? - Motivations for managing forage fish populations as a core ecosystem component rather than in isolation as single species, include the multitude of links highlighted in the FACTS project: with climatic variability, plankton dynamics, many species of predatory fish, seabirds and marine mammals, as well as the various trophic linkages between the different forage fish species or different life stages. Foodweb models suggest that reducing fishing mortality on forage fish may not necessarily lead to larger stocks of piscivorous fish, especially if their early life-stages compete with forage fish for zooplankton resources. In complex systems such as the North Sea, changes in the impact of fisheries on forage fish may have potentially complex (and perhaps unanticipated) consequences on other commercially and/or ecologically important species.

Model responses to different management scenarios (T4.3)

Within this deliverable, we evaluated the different ecosystem modelling approaches with respect to their ability to realistically reflect the ecosystem dynamics in response to different management scenarios of forage fish and hence their usefulness as operational tools for ecosystem-based fisheries assessment and management activities. This work includes comparing the different modelling approaches applied in FACTS with respect to their ability to capture dynamical properties as influenced by differences in trophodynamic complexity (e.g., biodiversity and the strength of trophic coupling). The work also involves identifying key metrics (model outputs) that can be used as endpoints for weighing potential management options.

The results of this exercise are given in the bulletin list below. Each bulletin point corresponds, according to the nature of the deliverable, to an already published manuscript or a manuscript in press:

1.In five well-studied ecosystems, we found that fishing these species at conventional maximum sustainable yield (MSY) levels can have large impacts on other parts of the ecosystem, particularly when they constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web. Halving exploitation rates would result in much lower impacts on marine ecosystems while still achieving 80% of MSY.

2.We demonstrated how the biological ensemble modelling approach makes it possible to evaluate the relative importance of different sources of uncertainty in future species responses, as well as to seek scientific conclusions and sustainable management solutions robust to uncertainty of food-web processes in the face of climate change.

3.Qualitative modelling provided robust conclusions regarding the effects of pelagic fisheries on the bentho-demersal food chain and the effects of demersal fisheries on the pelagic food chain.

4.We proposed a typology of methods and approaches that are currently used, or could possibly be used for making large-scale ecosystem comparisons.

5.We combined life-history invariants, metabolic scaling and size-spectrum theory to develop a general size- and trait-based theory for demography and recruitment of exploited fish stocks. Larger species have a higher egg production per recruit than small species. This means that density dependence is stronger for large than for small species and has the consequence that fisheries reference points that incorporate recruitment do not obey metabolic scaling rules. Even though small species have a higher productivity than large species their resilience towards fishing is lower than expected from metabolic scaling rules.

Future Research Needs (T4.4)

During the FACTS project and the FACTS symposium, following 10 points of major research needs in forage fish ecology and management have been identified:

1) Do all populations / stocks share the same (perhaps unique) ability to rebound from extremely low stock sizes? Can our exploitation patterns / intensity affect this trait - putting ecosystem structure and function at risk? Various harvest strategies need to be tested including estimations of risk which account for the unique properties of forage fish.

2) As the productivity of forage fish is dependent on life cycle closure, what habitats and their connections are keys to the survival and reproduction of exploited stocks?

3) Can indicators based upon aggregate measures across the ecosystem be appropriate for management at the local or sub-regional levels? What is the appropriate spatial scale of aggregation needed to effectively manage forage fish stocks in an ecosystem context?

4) There is a need to investigate different regulation systems and associated incentives applied to fisheries on forage fish within the context of the ecosystem approach.

5) Better empirical data streams have to be developed to detect indirect effects of forage fish fisheries on predators, ideally in an adaptive management framework. For example, up to date stomach contents data are desperately needed. This issue includes also the need for data assimilation methods suitable for different types of data and models.

6) There is a need for testing the robustness of management via biomass set asides or exploitation rates, including spatial issues. Furthermore, how to include those in bio-economic models? Compensation? Payment for ecosystem services?

7) There is a need to include the market implications of changes in forage fish stocks (e.g. value chain analyses). Evaluate the role of green fisheries and conservation pressures.

8) We need to develop tools to simultaneously explore all management strategies within GES. Especially, there is a need to investigate whether the current governance structures can handle the trade-offs in the ecosystem?

9) We need to investigate if ecosystem and economic risk can be reduced by by management of the portfolio (guilds) of stocks in an ecosystem approach.

10) We need to develop a suite of modelling tools that include not only complex (end-to-end), but models of intermediate complexity that are more tractable and practical.

Potential Impact:

Potential impact and main dissemination activities

The project has addressed the work programme topic FP7-KBBE-2009-1-2-14 'Sustainable use of seas and oceans: importance of foraging fish in the ecosystem' under area 2.1.2 'Increased sustainability of all production systems (agriculture, forestry, fisheries and aquaculture); plant health and crop protection', activity 2.1 'Sustainable production and management of biological resources from land, forest and aquatic environments' of Cooperation Programme Theme 2 'Food, Agriculture and Fisheries, and Biotechnology', call: FP7-KBBE-2009-3. As requested in the work programme, the project has assessed the importance of forage fish in European ecosystems and economy. This assessment can be used to weigh the cost and benefits of different levels of exploitation of the forage fish resources and hence provide a basis for decision makers to integrate forage fish dynamics and their exploitation into the ecosystem approach of the CFP. This has brought ecosystem orientated management in the European waters a significant step ahead.

The project has done so by:

-Providing knowledge basis for policy: The project has provided important knowledge tools for the Common Fisheries Policy, the Marine Strategy Framework Directive (adopted in June 2008) and future EU policies related to ecosystem based management of fisheries. It has enhanced the competencies of key scientific personnel involved with international scientific advice thus reinforcing the implementation of ecosystem based management principles.

-Significantly advancing the knowledge of forage fish population dynamics in European waters: By compiling existing, long-term data on the abundance of various forage fish species and their prey and filling gaps in existing knowledge with new analyses of gut contents and stable isotopes of forage fish, the project has quantified the trophic interactions between forage fish and their prey and further investigate the competition among forage fish species. Changes in potential habitat characteristics and the prey requirements have been quantified using physiological-based habitat modelling to determine likely areas of distribution.

-Estimating the consequences of forage fish population size and structure on top predators: The project has used multispecies models to investigate the effect of forage fish exploitation on the diet and food intake and, through bioenergetic models, the effect on reproductive potential of top predators. This has enabled to identify the ecological requirements and the economic costs for fisheries on forage fish and their predators of sustaining or reaching a specific reproductive potential of top predators along.

-Estimating economic effects of forage fish exploitation using integrated economic analysis of ecosystem models: The project has estimated the economic effects of forage fish exploitation through a model describing economic gain of fishing while using ecosystem models to describe the abundance of both forage fish and interactions with other components of the ecosystem. Integration of a model of species interactions and a model of market price of landings and costs of the fishery is unique and has provided an estimate of economic consequences which takes account of species interactions in contrast to traditional bio-economic single species models.

-Estimating the effect of forage fish exploitation on biodiversity and ecosystem stability: By quantifying the interconnections between forage fish and community level metrics, the project has estimated the relationship between changes in forage fish abundance and biodiversity and ecosystem stability. This will allow assessing the effect of future exploitation plans on these ecosystem characteristics and hence will allow the benefit of exploitation by fisheries to be weighed against the risk of ecosystem instability and regime shifts and declining biodiversity.

-Delivering general rules for forage fish management in an ecosystem orientated management: By analysing several ecosystems as well as generic models, the project has provided the basis for deriving general rules applicable to forage fish fisheries in European waters. This type of general knowledge required internationally coordinated investigations of forage fish dynamics in a range of different ecosystems rather than local studies. The general rules will be particularly valuable in areas where the population dynamics of forage fish are less well known or where the knowledge of the effects of forage fish abundance on top predator dynamics is limited.

The project has provided benefits for scientists, scientific advisors, policy makers, and stakeholders such as fishermen, NGO's and the European public:

-Scientists have benefited from establishing a scientific network of associated partners connecting forage fish research throughout Europe: Not only has knowledge been built up within the institutes participating in the project and disseminated to the scientific community, but a network connecting forage fish research throughout Europe has been formed through the collaboration with associated partners.

-Scientific advisors have benefited from making the quantitative knowledge available where it is needed: The key participants in the FACTS project are active members of a range of ICES working groups. The results produced in the FACTS project have therefore been introduced directly in the ICES working groups and contribute to the scientific advice given by ICES concerning the effects of exploitation of forage fish on a range of different economic and ecosystem levels.

-Policy makers have benefited from the tools and concepts developed in FACTS: The critical transition from a fisheries management system that in its theoretical roots is based on the dynamics of single exploited fish populations ignoring ecosystem effects.

-Stakeholders, such as fishermen, NGOs and the public have benefited from operationalising the ecosystem management: more effective and user-friendly management programmes that are better tailored to specific ecosystem related questions, e.g. the costs of conservation, have integrateed the dialogue between the different users of the European marine ecosystems and in the end enable a more effective use of European marine resources, while maintaining them in a healthy status.

The EU is committed to the contents of the Johannesburg World Summit on Sustainable Development Plan of Implementation, including targets to restore depleted fish stocks by 2015. To this end, FACTS has advanced the state of the art in development and application of strategic medium- to long-term fisheries management plans and their ecosystem effects. The project has contributed directly to the successful implementation of the CFP and the Marine Strategic Framework Directive with respect to ecosystem management.

The project has strengthened the European cooperation in this area of marine resource management, by creating a forum on forage fish, their ecological role and economic importance considering different harvesting strategies and climate change. The cross fertilisation of expertise across Europe has put Europe internationally in the fore front of fisheries and marine science related to forage fish being of fundamental importance for integration of the ecosystem approach into fisheries management and the success of the CFP.

The consortium has undertaken the following actions for using and disseminating knowledge to all Member States during the lifetime of the project and afterwards:

-Establishment of the project website during the first six months of the project, under the project's acronym with an extensive public section pen to all Member States.

-Publications in scientific popular press

-Publications in scientific journals

-Publications in daily/weekly press, specialized magazines and practitioner journals

-Issuing of press releases to local, national or international press at suitable occasions

-Organization of media events such as press releases, conferences, workshops, information days, for example on the occasion of a project meeting, as well as ensuring access to such events via webcasts.

-Production and dissemination of information dedicated to appropriate media, e.g. a printed brochure, and newsletters

-Participation at conferences, such as the ICES Annual Science conference.

The dissemination to advisory committees has been through direct person mediated knowledge transfer as scientists participating in the FACTS projects are members of several ICES advisory working groups including ACOM, WGSAM, WGFE, HAWG, WGMME, WGIAB and ICES Advice Drafting Groups as well as STECF subgroups. This has ensured that results are introduced in scientific advice with the shortest possible delay as FACTS scientists will bring working documents and presentation to the upcoming working group meetings.

The consortium has acknowledged that a pan-European approach to the operationalisation of the ecosystem management would be desirable, and attempts to come closer to this necessary broadness by building a network of associated partner institutes. Furthermore, similar initiatives are undertaken in the Northwest Atlantic. In order to guarantee an optimal flow of ideas and methods, the Consortium decided to include also a Canadian institute as associated partner.

Communication and exchange of information among Consortium- and associated partners will be:

-Intensive face-to-face communication through the regular meeting and workshops. The FACTS project foresees funding of the travel expenses for additional partners.

-Direct communication of all project partners through electronic mail as and when necessary.

-Through the partners' website (extranet) operational within the first six months, under the projects acronym, for distribution and management of project documents that will be made available in electronic format to the Consortium and associated partners only.

Internal project workshops have allowed the different participants to have a general view on the progress on the project. The organisation of the workshops and project meetings in the different participating countries has allowed the project partners:

-To better understand the specific national needs and barriers with respect to ecosystem management in specific regions against European and global background

-To estimate under what conditions the results of the project can be transferred into management actions with a view to assessing the probability and time line of introducing an ecosystem orientated management in that region.

In connection to its concluding symposium, the FACTS consortium has invite research scientists, managers, policy-makers and other stakeholders to present and discuss recent status and strategies for managing forage fish in an ecosystem context. Biological, ecological, modelling as well as socio-economic and management aspects have been covered. This symposium was planned in close collaboration with ICES via the Policy Committee and the European Commission in order to optimally advance our knowledge on forage fish interactions. The symposium has served as a forum to exchange ideas and views across disciplines and between scientists, fishing industries, NGOs, and managers.

List of Websites:

http://www.facts-project.eu