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International Council for the Exploration of the Sea

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Executive summary

In 2011, WGFE (Working Group on Fish Ecology, D. W. Kulka, Chair, meeting chaired by Ralf van Hal) met at the Johann Heinrich von Thünen-Institute, Institute of Sea Fisheries, Hamburg Germany, 3–7 October. Twelve participants from 7 different countries, 5 present in Hamburg and 7 by correspondence, addressed the Terms of Reference. As in previous years, the report is structured as a single chapter for each ToR. Below, the results of each of the 2011 ToR are summarized.

ToR a: This ToR has not been dealt with this year. However, WGFE sees a clear need for these types of models and like to see work on this topic continued. Therefore WGFE suggests this ToR in a similar form to the Working Group on Multispecies Assessment Methods (WGSAM) where the necessary expertise to develop and present these kinds of models is present.

ToR b: This ToR has a clear link with the work done in Europe on the 'Good Environmental Status' (GES) descriptors and its indicators. A huge amount of work has taken place in the latest year on these indicators for GES. Even at same time as the WFGE meeting took place a meeting in on the GES-indicators for GES-descriptor 3 took place in the ICES headquarter. Therefore, WGFE felt unfit to within a week extent the available work on indicators.

ToR c: Some methods are described that can be used for analysing survey data in a spatial context. Using three case studies the use of some of these methods is described. The first case study focuses on the effect of permanent closures on Georges Bank. The second case study analyses the effect of climate change on North Sea fish assemblages, while the third case study looks at threatened migratory species and specifically sturgeon in New York Bay.

ToR d: The work on this ToR in latest year has resulted in a paper: Exploring the abundance–occupancy relationships for the Georges Bank finfish and shellfish community from 1963 to 2006. Now further work has been performed on this during this meeting.

ToR e: A case study on the relationship between climate change and a regime shift in the South-Eastern Baltic Sea (Gdansk basin) has been done as an extension of the work done is WGIAB 2010. In general, the present state of abiotic and biotic components of the marine ecosystem of the Gdansk basin in the Baltic Sea in relation to their performance in the period 1976–1985 (up to the main regime shift) revealed that, despite some positive changes in environmental conditions for population growth of Eastern Baltic cod (high absolute values of salinity in the deep and bottom layers of deep-sea basins and high position isohaline 11‰), the modern period has characteristic differences.

ToR f: As part of the role of SIBAS, a Workshop on Marine Biodiversity (WKMARBIO) was convened in February 2011 to further ICES' engagement in biodiversity issues. This workshop defined 25 actions and several recommendations to implement the actions that ICES might take to make a more influential contribution to marine biodiversity science and advice. A recommendation generated to WGFE (and other EG's) was to review the outputs of the ICES SIBAS Workshop on 'Biodiversity indicators for assessment and management' (available February 2011) and report on a number of aspects. Overall, WGFE finds that the broad components that together describe 'fish biodiversity' are covered, in terms of the structure (age, length, trophic, functional, genetics), species composition and geographical range of fish assem-

blages, and the status and structure for species of particular interest. In order to progress on the development and adoption of specific indicators, WGFE would suggest that: A standardised approach for the identification and prioritisation of species of particular interest (for species of commercial, ecological, cultural and conservation importance) should be developed within the ICES community. There should be a consistent and coherent approach to developing metrics for those species for which there is a good knowledge of stock structure. For example, if ICES assesses any given fish species by stock units, then diversity metrics should be developed for comparable stock units, so as to avoid any potential mismatch between 'species-level' and 'stock-level' advice. There should be due caution with regards the development of metrics and indicators based on ratios. Indicator development should be at the appropriate geographical scale for both the assemblages and species of interest. Conducting analyses for national waters may, under certain circumstances, be uninformative or give a misleading status. For fish of commercial importance, there needs to be a consistent and coherent approach to advising on 'biodiversity' issues and metrics with stock assessment methods. Any 'biodiversity' metric developed for individual commercial fish stocks should augment and not contradict the stock assessment advice.

The ICES community has only part of the data that are required to assess and quantify the tradeoffs between fishing and the status of fish populations and communities. Information to provide metrics on the status of many fish stocks and some fish species of biodiversity interest, and the status of the wider fish assemblage are available for many parts of the ICES area. In contrast, data for the social and economic viewpoint may not be available, and such information is generally outside the expertise of WGFE.

In addition to the general approach discussed by SIBAS, it is also important to recognise that the European Commission has published examples of potential metrics to indicate on 'Good Environmental Status' (GES).

ToR g: This ToR was received on a very short notice, a couple of days before this meeting. It asks to use the Scientific Guidelines for Designing Marine Protected Area Networks in a Changing Climate developed by the NAMPAN-ICES Study Group on Designing Marine Protected Area Networks in a Changing Climate (SGMPAN). The intention of the guidelines is to be able to selected species, species groups or habitats that are most vulnerable to climate change, and think of possibilities to use MPA's to protect these species. WGFE mainly focussed on species and then in particular fish species or species relevant for fish. The first guideline focuses on species with an important role in the ecosystem, which is a difficult concept that can be interpreted differently. The perceived importance of the ecosystem role played by particular species, species assemblages or habitats depends crucially on the time scale at which the roles are examined. Like all management interventions, the planning of marine protected area networks requires a clear enunciation of objectives, which in turn require decisions on what ecological targets are desired. The list which WGFE create based on the first guideline are the well-known species, the time constrains limit further evaluation of possible candidates. This is similar with the lists created for the other guidelines. Guideline 3 on migration of species, does not really limit the list of candidate species as most fish species show some of the migrational behaviours discussed within the guideline. Selection will mainly be based on the fact if protection by MPAs is useful for the species rather than on the traits related to migration and the species dependence on currents affected by climate change. In the discussions on this ToR during the meeting, for most participants it seems very difficult or unlikely to design MPAs to protect the migration behavior of species in a changing climate.

ToR h: This is a long term ToR for WGFE which is used to present work done by some of the members on the effects of climate. It looks at Exploring species-level responses to recent warming in the northeast Atlantic. It is meant as an indication of the type of work that can be done during the meetings in coming years.

1 Opening of the meeting

The ICES Working Group on Fish Ecology (WGFE) convened its meeting in Hamburg at the Johann Heinrich von Thünen-Institute, Institute of Sea Fisheries. It started on 3 October and adjourned on 7 October 2011. The meeting was chaired by Ralf van Hal, The Netherlands, who was interim chair replacing the official chair Dave Kulka, Canada. The meeting was attended by 12 participants from 7 different countries. Seven of the participants contributed by correspondence, thus only 5 participants were actually present in Hamburg. A full participants list is found at Annex 1.

2 Adoption of the agenda

The agenda was considered and following requests phrased at the ICES Annual Science Conference in Gdansk, it was agreed to extend the list of ToRs with one: Using the Scientific Guidelines for Designing Marine Protected Area Networks in a Changing Climate developed by the NAMPAN-ICES Study Group on Designing Marine Protected Area Networks in a Changing Climate (SGMPAN). This has become ToR g, owing to which the long-term ToR now got letter h.

Owing to the low number of participants present in Hamburg, it was agreed to focus initially on three ToRs that were considered to have the highest priority, ToR f, g and c and delay the remaining ToRs to later in the week, or to the 2012 meeting. The draft agenda is found at Annex 2.

3 Introduction

3.1 Terms of Reference

The **Working Group on Fish Ecology** (WGFE), chaired by Dave Kulka, Canada, will meet in Hamburg, Germany, 3–7 October 2011 to:

a) Present new results on modelling the interacting effects of climate and fisheries on productivity and community structure, including spatial aspects;

b) Review and evaluate metrics to characterize, monitor and detect changes in the structure, function and productivity of fish communities;

c) Develop, explore and apply spatial methods for comparing and summarizing fish and fish community distributions in relation to environment and habitat;

d) Examine abundance/distribution relationships within species, and groups of species in different ecosystems in relation to habitat, environment and in relation to anthropogenic impacts;

e) Evaluate fluctuations within fish communities:

   i. What constitutes regime shifts in fish communities? Can mechanisms be identified detected?

   ii. State changes - Cycles vs. regime shifts

   iii. Are anthropogenically induced changes alterable?

f) Review, report on and develop the outputs of the ICES SIBAS Workshop on 'Biodiversity indicators for assessment and management'*;

*Review the outputs of the ICES SIBAS Workshop on 'Biodiversity indicators for assessment and management' (available February 2011) and, based on the indicators that have been proposed and the reporting processes they are intended to support, report on:

- The strengths and weaknesses of the proposed indicators for fishes and fish communities;
- Recommended modifications to the indicators;
- The process that would be used for data acquisition, analysis and reporting of the indicators;
- The tradeoffs between fishing and the status of fish populations and communities that need to be considered when setting targets for biodiversity indicators;
- The information, data and tools that are available to assess and quantify these tradeoffs;
- How the indicators, targets and tradeoffs might be presented as advice;
- The additional data, information and science needs to quantify tradeoffs.

g) Using the Scientific Guidelines for Designing Marine Protected Area Networks in a Changing Climate developed by the NAMPAN-ICES Study Group on Designing Marine Protected Area Networks in a Changing Climate (SGMPAN), species, habitat, and ecosystem specialists in ICES expert groups are asked to assess ecosystem components to identify which species and habitats appear most vulnerable to climate change and what areas appear to be most in need of protection.

Long-term Terms of Reference

h) Examine climate change processes and predictions of impacts.

WGFE will report by 14 November 2011 (via SSGEF) for the attention of SCICOM.

4 Modelling effect of climate and fisheries on fish productivity and community structure

a) Present new results on modelling the interacting effects of climate and fisheries on productivity and community structure, including spatial aspects

4.1 Introduction

Theoretical modelling studies have been carried out for studying effects of fishing and human pressures on marine fish communities. For example FishSUMS, a length-structured multispecies fish community model, was developed for modelling past and future trends in the Large Fish Indicator (LFI) in the North Sea (ICES 2009). Similarly, the Size-Based model (SIBmo) of the North Sea fish community was used to explore trade-offs between fisheries (single-species MSY) and conservation (Large Fish Indicator) objectives for the North Sea and to examine how fish community state indicators respond to changes in fishing pressure (ICES 2009). The inclusion of spatial aspects, preferably small scale spatial aspects consistent with biological and physical structures, enables the use of these models to explore trade-offs in a spatial context and to evaluate the effect of spatial management measures on the community indicators (ICES, 2010).

Questions on modelling the interacting effects of climate and human pressures in a spatial context on the early life stages as well as on the adults are phrased in the guidelines for Designing Marine Protected Area Networks in a Changing Climate that will be discussed in Chapter 10 and the potential use of it is considered as well in Chapter 6 on the use of spatial methods. Many of the targets set in with the European Habitat directive (Natura2000 network of protected areas) and the MSFD implies the need of taking into account multiple pressures on the ecosystem in a spatial context, for which these types of models could be used.

WGFE clearly sees the need for these models as has been discussed in recent reports (ICES, 2009, 2010). However to be able to present new results on modelling, experts in modelling food web interactions in relation to human pressures and climate change were not present at this years' workshop. Considering the members list and responses to meeting invitations in recent years, it seems unlikely that this expertise will be present at meetings in the near future.

Owing to this, WGFE decided not to consider ToR a) during this years' meeting and there are some doubts about continuing work on this ToR in the future. However, the ToRs for the WGFE 2012 meeting have already been approved by SCICOM including ToR a). A final decision on the ToR will thus be postponed to next years' meeting and will depend on expert participation during that meeting along with discussions with other working groups, e.g. WGSAM or WKE2E that could take over the task.

As there is clear need for these types of models, WGFE would like to see work on this topic continued. Therefore WGFE suggests this ToR in a similar form to the Working Group on Multispecies Assessment Methods (WGSAM), the necessary expertise to develop and present these kinds of models is present. It would closely fit one of their long term aspirations to include spatial structure into the models to evaluate spatial management. WGFE could work with WGSAM by considering the fish related processes and mechanisms to improve the models and by reviewing and interpreting the modelling results within in the relevant contexts. This has been communicated with one of the chairs of WGSAM, and considered a reasonable option, which could already be discussed at WGSAMs upcoming meeting.

5 Metrics for characterising changes in the structure, function and productivity of fish communities

b) Review and evaluate metrics to characterise, monitor and detect changes in the structure, function and productivity of fish communities

5.1 Background

Fishing has a number of direct effects on marine ecosystems because it is responsible for increasing the mortality of target and non-target (by-catch) species and disturbing marine habitats (Jennings and Kaiser, 1998).

Pauly*et al.* (2000) support that capture fisheries modify a number of factors such as abundance, spawning potential and possibly, population parameters of the target and non-target species. They modify the structure of age and size, the sex ratio, genetics and species composition of the target resources, as well as of their associated and dependent species. Fishing generates by-catch, discards and high grading, the latter being a practice that is popular in areas under TAC management (Garcia *et al.*, 2003; Rijnsdorp *et al.*, 2007). Productivity and community changes can be used as an indicator of the state of an ecosystem. Metrics have proven having the ability to do that, as the use of indicators is well established for describing changes in structure, function and productivity of fish communities.

An indicator provides a measure for a particular criterion in relation to a particular component or multiple components. The concept of indicators has been borrowed from environmental management, using pollution indicators, bio-indicators and indicator species. The assessment of state provided by an indicator allows inferences to be made on the state of a wider set of components, and/or the prevailing environmental conditions. Indicators are highly dependent on long data series.

ICES is actively involved in utilising ecosystem indicators through several study and working groups (e.g. WGBIODIV, SGERAAS, BEWG, SGIMT, WGSPEC, WGSE, …). The European Marine Strategy Framework Directive (MSFD), part of the EU's Integrated Maritime Policy (IMP) relies on such indicators. The Marine Strategy Framework Directive (2008/56/EC) (MSFD) requires that the European Commission should lay down criteria and methodological standards to allow consistency in approach in evaluating the extent to which Good Environmental Status (GES) is being achieved. The process of agreeing on these indicators and standards at the European level is ongoing. This process will be followed by specification of GES at the regional and national levels, conducting initial assessments, and continuing current monitoring activities (ICES Advice, 2010). Scope of the directive is to protect more efficiently the marine environment across Europe (ICES, 2010). At the core of MSFD is the concept of Good Environmental Status (GES) and the establishment of clear environmental targets and monitoring programs. Regarding MSFD and the concept of GES, ICES has established groups of independent experts as well as workshops. The workshop on MSFD (WKMSFD) has been producing technical and scientific reports to support the EU Member States (MS) in the implementation of the MSFD.

This ToR has a strong link with the European MSFD descriptors 1 and 3 on biodiversity and sustainable exploitation of commercial fisheries respectively. WKMSFD is currently undertaking this work and because of that there is some overlapping on the work of WKMSFD and WGFE regarding the ecosystem indicators.

5.2 Use of size-based indicators for Ecosystem Approach to Fisheries Management (EAFM)

For management of fisheries stock, indicators are often used based on reference points that indicate the need for management actions. Size-based community and ecosystem metrics have been proposed as indicators to support the Ecosystem Approach to Fisheries Management (EAFM) (Jennings and Dulvy, 2005). Size of organisms is a key-factor to ecological processes and changes in size distributions may happen due to many causes. Body size is one of the most important of these biological parameters because it is responsible for structure and function of molecular, cellular and individual characteristics up to shaping ecological and evolutionary dynamics (Calder 1984). Retrospectively, it has been noted that truncation in age and size structure was concomitant with the collapse of Newfoundland's Northern cod (Hutchings and Myers 1994) and a number of other species (Longhurst 2002; Trippel 1995; Gislason and Rice 1998; Bianchi *et al.* 2000; Rogers and Ellis 2000). While climate and other natural sources cannot be ruled out in explaining demographic shifts, fishing mortality has been estimated at 400% that of natural mortality (Mertz and Myers 1998) and biases towards removal of larger individuals (Limburg 2008) closer to population centres (Limburg *et al.* 2008).

Size-based indicators (SBI) can be calculated with relatively regular species-size-abundance data, available from surveys of monitoring programs. A list with the definitions of size-based indicators, objectives, and reference directions of change under fishing pressure, was made available by Shin *et al.* (2005).

WGFE 2010 was asked to describe and follow possible changes in the productivity and community, utilizing metrics that could be calculated with regular survey data. A new size-structure metric (size diversity) for fish communities was evaluated using simulated community data, calculated for survey data from various regions and compared to LFI. The North Sea had the lowest size diversity of all communities, in particular in recent years, with an overall decreasing time trend. The highest diversity indicating the most even size spectrum was found for the Eastern Corsica shelf and the Eastern English Channel. Species diversity was higher than size diversity in most communities.

During WGFE 2010, the large fish indicator (LFI) in the North Sea was compared to other metrics for the same area. Catch fisheries are size-selective, targeting large fish which are more vulnerable. Such actions modify the size structure and functioning of fish assemblages (Shin *et al.*, 2005). Calculations were based on survey data from the EU's Data Collection Framework (DCF) of seven European fish communities. An issue with such data, although they can be relatively easily accessible, is that they are almost completely derived by fishing gears that are both species- and size-selective, such as the European trawlers. This is restricting the composition of data in terms of species and size, the latter being recognized as a key feature in marine ecological processes (WGFE, 2010).

5.3 Future recommendations

The results of WGFE 2010 were limited due to lack of experts, which is the case also for WGFE 2011 reviewing the metrics. As a step forward for the next years, it had been suggested that reference levels would be set for additional areas, taking into account the uniqueness of fish communities and environmental conditions in each area.

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6 Spatial methods for comparing and summarising fish and fish community distributions in relation to environment and habitat

c) Develop, explore and apply spatial methods for comparing and summarizing fish and fish community distributions in relation to environment and habitat

6.1 Spatial methods applied to survey data to infer physical structure and process

6.1.1 Rational

As ecosystem based management becomes the focus of managers it will be important that assessment and management of ocean resources include zoning as a critical element (Pikitch *et al.* 2004; Halpern *et al.* 2008) and maintenance of biodiversity as an important goal (Levin and Lubchenco 2008, Palumbi *et al.* 2008, Slocombe 1998). Ecologically-based approaches require managing collections of species within (sub)components of the ecosystem (Tolimieri and Levin 2006) that achieves a geographically-based endpoint (Murawski 2007), and where zonation is along ecological gradients, as opposed to political ones (U.S. Commission on Ocean Policy 2004). Further, anticipated climate impacts complicate planning due to likely community shifts that will change local species composition.

6.1.2 Background

Incorporation of species - habitat relationships is well established in the formulation of European, Canadian and USA policy. The European Union Marine Strategy Framework Directive - Good Environmental Status Criteria, Descriptor 1 states "The assessment of species also requires an integrated understanding of the distribution, extent and condition of their habitats to make sure that there is a sufficiently large habitat to maintain its population, taking into consideration any threat of deterioration or loss of such habitats". The Canadian Species At Risk Act (SARA) requires assessment and protection of critical habitat for species at risk, similar to the Endangered Species Act (ESA) in the United States. The Federal Fisheries Act provides Fisheries and Oceans Canada with authority for the conservation and protection of fish and fish habitat essential to sustaining commercial, recreational and Aboriginal fisheries. Federal fisheries in the USA are subject to the Magnuson-Stevens Fishery Conservation Management Act which requires that all fisheries management plans identify Essential Fish Habitat (EFH) and minimized to the extent practicable the adverse effects of fishing on EFH. Federal regulations define EFH as "those waters and substrate necessary to fish for spawning, breeding, feeding, or growth to maturity", and adverse effects as those which are "more than minimal and not temporary".

Policy directives that require measures for protecting habitats imply an understanding of fish and fish community distributions in relation to environment and habitat factors. However, these relationships are often poorly understood and approaches generally rely on assessing proxies (e.g. loss of seabed vertical structure) or indicators (e.g. decreases in biodiversity) to identify where to enact spatial management measures (e.g. MPAs). Delimiting MPAs to protect such habitats requires mapping and spatial analyses which often use Geographical Information Systems and spatial statistical methods. Examples are provided to demonstrate applications of mapping and spatial methods presently emanating from the above directives to protect fish habitats.

6.1.3 Analysis options

6.1.4 Biodiversity metrics

Species richness, one of the proxies or measures of biodiversity, is an example of an ecosystem emergent property that can be measured and perhaps used in the development of decision criteria in fisheries management (Link 2002). Fish species richness, the number of unique fish species per tow, can be estimated from survey data and observed commercial otter-trawl trips. There are a variety of biodiversity metrics available including, but not limited to, species richness and evenness. Once values are determined, they can be interpolated across space to determine regions of high biodiversity, and any temporal changes assessed.

6.1.5 Principal Component Analysis

There has been substantial effort to classify areas of the ocean, based on characteristics that consider spatial structure of biodiversity in support of geographically-based management. Ordination techniques demonstrate persistent biological structure along environmental discontinuities on the Northwest Atlantic continental shelf using trawl survey data (Overholtz and Tyler 1985; Gabriel 1992; Mahon *et al.* 1998). While the broad assemblage designations of Mahon *et al.* (1998) and others have been generally supported (Jørgensen *et al.* 2005), one valid critique of these techniques is the subjectivity with which cutoffs in eigenvalues and eigenvectors were made (Souissi *et al.* 2001).

There has been a progression from a heuristic to probability-based methods to identify true patterns in datasets over the past few decades (Fields *et al.* 1982). Bootstrapped and standard principal component analysis (PCABTSP and PCA, respectively) were employed to address this deficiency in the analysis of multivariable ecological datasets (Jackson 1993; Jackson 1995; Pillar 1999). Despite allowing axis reversal amongst bootstrap runs (Mehlman *et al.* 1995), PCABTSP-based techniques have been shown, using both simulated and real data, to outperform other methods in determining the number of nontrivial principal components (Jackson 1993, 1995; Pillar 1999) and eigenvector loadings (Peres-Neto *et al.* 2003).

PCABTSP provides a methodology for determining the cutoff (stopping rule) and determining relationships amongst species using a probability-based method. PCA has a significant advantage in that each new variable (principal component) is uncorrelated with others and can be statistically tested against physical variables. This is particularly helpful in dealing with multiple scales within datasets and the multiple, interacting influences of physical variables in determining species' distributions, and allows species to belong to multiple species groups. However, it is important to recognize that while contribution to multiple assemblages does allow for some of the non-linear interactions in ecological systems to be accounted for, the linear nature of each principal component does mean that complex non-linear processes will not.

Analysis of NMFS trawl survey data follows procedure outlined by Jordaan *et al.* (2010) for analyzing PCABTSP and a "normal" PCA with three steps:

1) Evaluate PCABTSP eigenvalues and establish stopping rules using 95% confidence intervals to divide PCs between those that provide a meaningful dissection of the data and those which are considered trivial components (Jackson 1993). Only relevant PCs are included in further analyses.

2) Using the relevant PCs, species eigenvector 95% confidence intervals are compared to one another, and to a score of 0. This allows a determination of both which species are correlated in abundance (i.e.: form assemblages) and which (groups of) species are driving the patterns for PCs (significantly different from 0).

3) Relate relevant PC scores at each site to spatial data and map spatial biodiversity indices. An inverse distance weighting (IDW), or other interpolation technique, can then be used to established assemblage areas.

6.1.6 Multidimensional scaling/ANOSIM

Field *et al.* (1982) suggested that patterns in species should be examined prior to determining important physical factors, which precludes the use of some analyses such as canonical correlation analysis. Current ecological classification has widely adopted non-parametric ranking of similarities in order to create a matrix that can identify geographically-related divisions in assemblages and species that contribute to patterns (Field *et al.* 1982). Heavy computing loads were identified as a limitation in classification analysis and stopping rules (Field 1969; Field *et al.* 1982) Fortunately this is a factor that no longer exists. However, this method has a long history in ecology and continues to be the most widely used technique. The Bray-Curtis measure of similarity and non-metric multi-dimensional scaling ordination can accommodate robustness and flexibility, but sacrifice information by using rank data (Field *et al.* 1982). In contrast, the PCABTSP sacrifices flexibility and robustness to gain a more quantitative edge.

Ranked matrices of similarities among samples can be constructed using the Bray-Curtis similarity measure. Then ordination by non-metric multidimensional scaling (MDS) (Kruskal& Wish 1978, Clarke & Green 1988) can be used to detail patterns. Formal significance tests for differences between groups can be performed using the ANOSIM permutation test (Clarke & Green 1988, Clarke 1993).

6.1.7 Unsupervised Bayesian clustering to determine sub-assemblage structure

Determining sub-assemblage structure can be a valuable method for investigating the distributions of fish in relation to habitat and/or the environment. Further, by time-slicing long-term datasets it is possible to incorporate a dynamic element to the analysis to look at change through time in sub assemblage structure, or the movement of sub-assemblages in space, perhaps in relation to changing environmental conditions.

A recent study used unsupervised Bayesian clustering to look at patterns of sub-assemblage structure through time in the northeast Atlantic demersal fish assemblage in response to recent warming (Simpson *et al.* 2011). This method was used in preference to k-means clustering, since it is unsupervised and so is not prescriptive about the number of clusters that should be found (see example in section 6.3).

6.1.8 Relationship to physical data

There is a rich history of analyses that relate structure to physical variables and a variety of these will be tested (see Anselin 1995, Anselin 1996. Anselin *et al.* 2006, Boots 2002, Fotheringham *et al.* 2002, Ord and Getis 1995, Ord and Getis 2001). These can include simple correlations, further PCAs, boosted regression trees, geographically weighted regression, tests for local spatial autocorrelation, Moran scatterplots and tools such as Getis-OrdGi hot spot analysis available using ESRI® ArcMap™ ArcToolbox™ spatial analysis software.

6.2 Case study I – Georges Bank closures

Permanent closures in the Georges Bank/Gulf of Maine region (Figure 1) are currently used to reduce fishing effort of groundfish and destruction of essential habitat. It was determined that complex habitat, particularly gravel, on Georges Bank was essential for juvenile Atlantic cod, (*Gadusmorhua*) and four permanent habitat closed areas were developed using information on fish distribution and sediment data from Poppe *et al.* (1989) (NMFS, 2003). A detailed fine-scaled sediment analysis by Harris and Stokesbury (2010) indicated that this stated objective was not achieved, and the intended habitat that were to be protected only account for between 0.9% to 38% of each of the current closed areas. A gap between the location of closed area and intended protected habitat exists (Harris and Stokesbury 2010). The reason for the gap was a paucity of sediment data, generally speaking, at the time of the closed area development.

We will focus the discussion on permanent closures. Although closed area 1 (CA1, Figure 1) existed in various forms prior to 1994, the NMFS implemented closure year round through emergency action to reduce mortality on groundfish stocks, which had experienced dramatic declines through the 1980s and early 1990s. The remaining area and Essential Fish Habitat (EFH) closures (CA1, CA2, NLCA) were enacted in 2004 to minimize impacts of the groundfish fishery on EFH. There has existed a groundfish survey in the region since 1963, thus if the survey could be used to delineate locations of EFH, or multi-species assemblages that managers are seeking protection for, this data could have been useful in closed area design. Further, while there is expanding data coverage for sediment data, trawl data (either fisheries dependent or independent) is often more widely available.

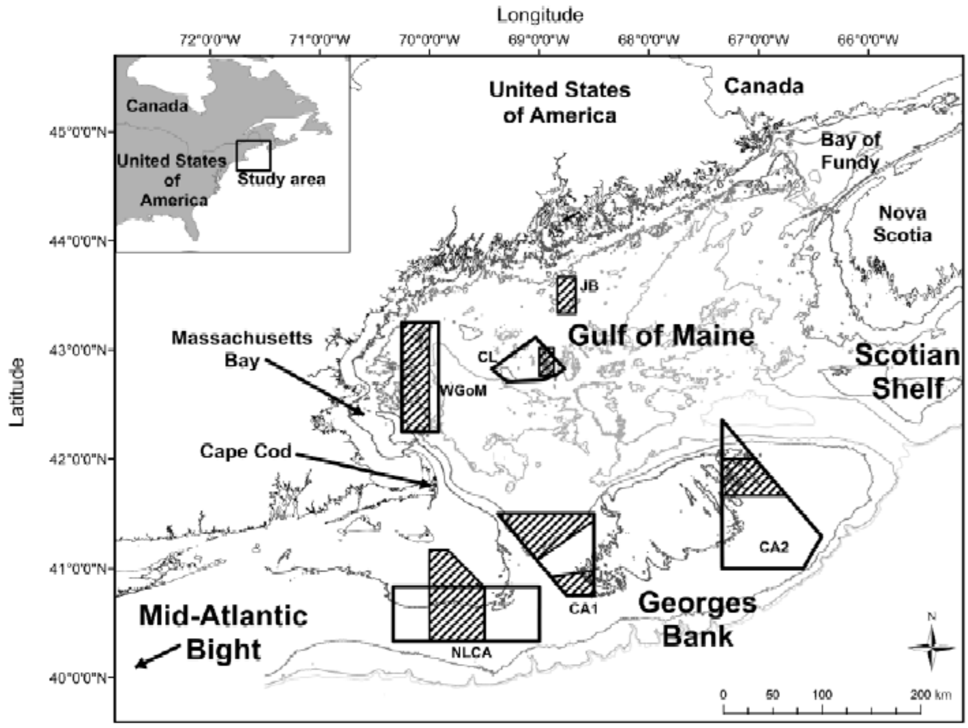

Figure 1. Closed areas in the Gulf of Maine and Georges Bank region. Closed areas are represented by polygons and EFH closures by hatched polygons. NLCA = Nantucket lightship, CA1 and CA2 = closed area 1 and 2, WGoM = western Gulf of Maine, CL = Cashes Ledge, JB = Jeffery's Bank.

The primary dataset to be used in this work is a subset of the National Marine Fisheries Survey (NMFS) fall trawl survey. Conducted primarily by the research vessels Albatross IV and Delaware II, the NMFS survey used a Yankee 36 bottom trawl with a 1.27 cm mesh liner, towed for 30 min at 3.79 knots and sampling was conducted during the day and night (Sosebee and Cadrin, 2006). A total of 300–400 trawls were executed each season from the Gulf of Maine (GOM) to just south of Cape Hatteras, NC. The NMFS fall survey began sampling in 1963 and primarily sampled the waters of Southern New England and the Gulf of Maine before being expanded to include inshore stations in 1973. The resolution of the NMFS survey is one station per 872 km^2 each year.

There are 3 distinct time periods when the NMFS trawl survey was prosecuted, with a gradual shift from a later to earlier mean survey date (Figure 2). Many species are migratory, and this causes problems in analysis. Thus, only years with a mean survey date of 290 (or 17 October), were used in the primary analysis. That primary analysis suggested that the multivariate analyses identify locations of cobble habitat, using interpolated PCA scores (Jordaan *et al.* In Prep; Figure 3). The species groups matched other analyses, providing some measure of robustness (Gabriel 1992; Mahon *et al.* 1998; Jordaan *et al.* 2010). Thus, it appears that multivariate-based indicators of species assemblages can distinguish (EFH) habitat for certain species using survey data, and because multiple assemblages are identified can also be used in biodiversity conservation.

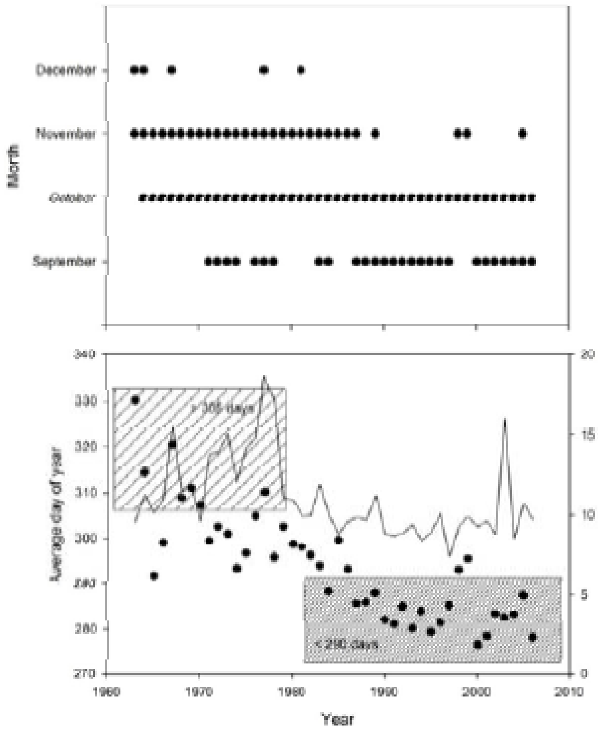

Figure 2. Changes in the mean survey date observed in the NMFS fall bottom trawl survey. Primary analysis was restricted to survey years with a mean survey date less than day 290.

Other analyses completed in the Gulf of Maine suggest scale-dependent organization of species assemblages from tidepool assemblages that structure along vertical (position relative to tide height) and horizontal (wave exposure, estuarine) conditions (Jordaan *et al.* 2011). The intertidal zone follows much the same pattern (Jordaan 2010). Further, isolated habitat types can only be colonized by species that have adapted sufficient dispersal ability and required physiological and physical characteristics (Jordaan 2010).

Future analyses will reduce the spatial extent of the NMFS dataset to cover the area of sediment data analysed by Harris and Stokesbury (2010).

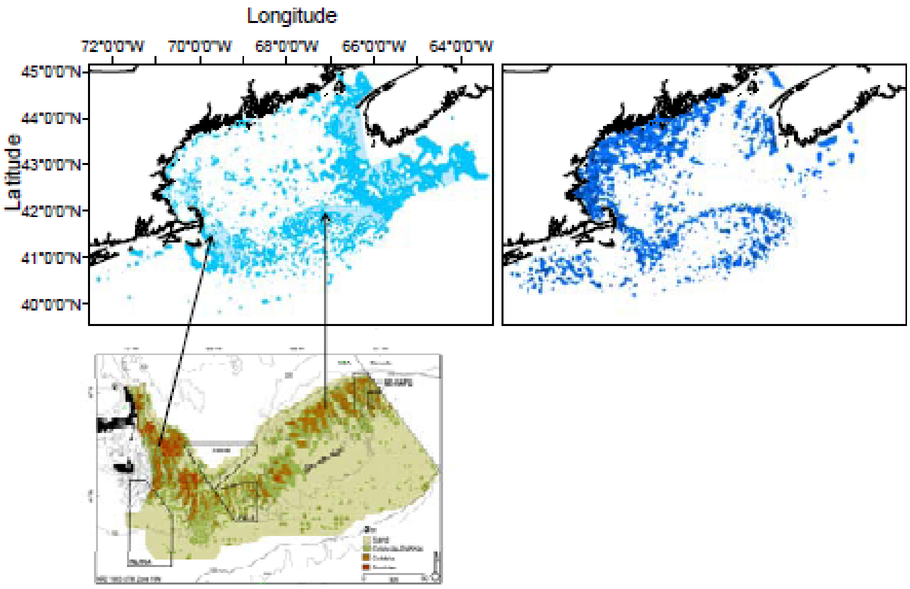

Figure 3. Correspondence between multivariate descriptors of species assemblages determined from trawl (top 2 panels; Jordaan *et al.* In Prep) and sediment (bottom panel; Harris and Stokesbury 2010) data. Trawl data displays only species assemblages with contribution of Atlantic cod, the target species for closed area 1 (CA1-N, CA1-S). Preliminary results suggest strong associations between species assemblages and sediment characteristics that could be used in closed area design.

6.3 Case Study II – North Sea assemblages and climate change

Unsupervised Bayesian clustering was used to analyse a compilation of 11 different long-term monitoring datasets from fisheries agencies. For each year and 172 1x1° lat-long cells, determine the presence or absence (P-A) of each of 177 northeast Atlantic species. Presence-Absence was used as it is a measure that is robust to differences in gear/season/agency between different surveys. This matrix was then condensed to a 5-year time slice P-A matrix.

Using the Institut Jacques Monod AutoClass portal (http://ytat2.ijm.univ-paris-diderot.fr/) this matrix can be uploaded and cluster ID for each cell and time slice is determined. It is important to have all the timeslices in the same matrix so that a cluster ID given to time slice X is the same cluster ID given to timeslice Y if the characteristics are similar.

By this method, it was found that the data were best separated into 12 sub-assemblages (Figure 4). The distribution of these clusters was spatially coherent, and by looking at sub-assemblage distributions in different time slices, a general pattern of geographic stability in the assemblage (at least in terms of P-A) was seen. The exceptions were the Irish Sea/Channel, and northwest North Sea, where one cluster gradually replaced another, very probably as a result of warming.

If data were all from a single survey, abundance could be analysed directly rather than deferring to P-A, which would give a more powerful analysis within a single dataset.

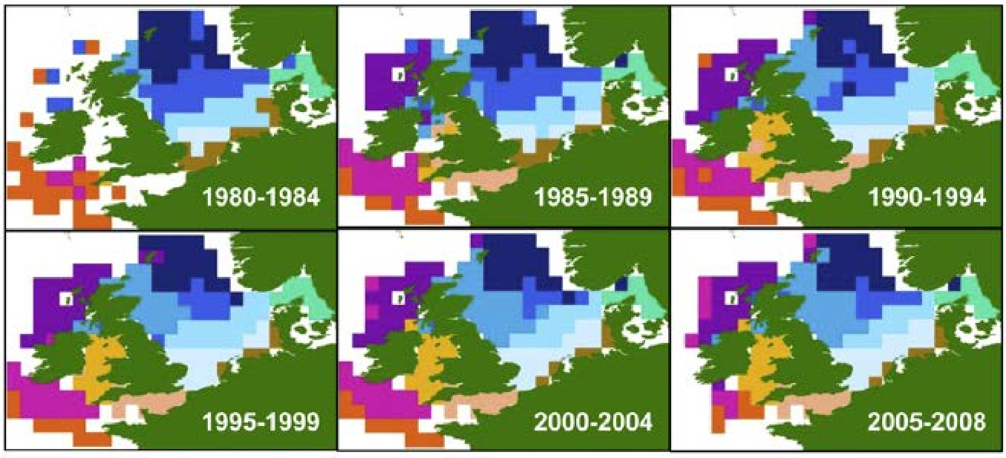

Figure 4. Twelve biogeographic clusters (the different colours), identified by Bayesian analysis of presence-absence data, that maintained similar distributions over six 5-year periods. White cells indicate locations with insufficient fish-abundance data.

Simpson *et al.* (2011) then used PCA to determine the effects of recent warming on the northeast Atlantic fish assemblage. The same 11 surveys were used, and for each of the 172 1x1° lat-long cells, the mean abundance of 177 species was determined from each survey. Each survey was analysed separately as abundance estimates are affected by differences in gear/season/agency. For each cell-survey, the data were log-transformed and then a Principal Component Analysis used to determine the major axis of variation (major trend in beta-diversity) as described by the scores for the first principal component (PC1). Generally, this method captured ~34% (range 20–74%) of the variation in the data in the first component.

It was then possible to look at the strength of association of each PC1 series with environmental factors. The potential drivers that were investigated included Sea-Surface and Sea-Bottom Temperatures (SST & SBT), which were tested using annual as well as winter and summer means, ad tested with a 1, 2, and 3-year time lag. Also tested was the trend in multispecies fishing mortality (as estimated by ICES WGs) for different regions. By randomising the same data and determining the likely association that could be expected by chance, and subtracting this (as an R2 value) from that of the non-randomised data, it was possible to determine the "percentage variation above chance in assemblage composition through time associated with environmental change". Since it is the strength of association, this measure is directly comparable between different surveys, and can be averaged for cells where there were overlapping surveys (Figure 5).

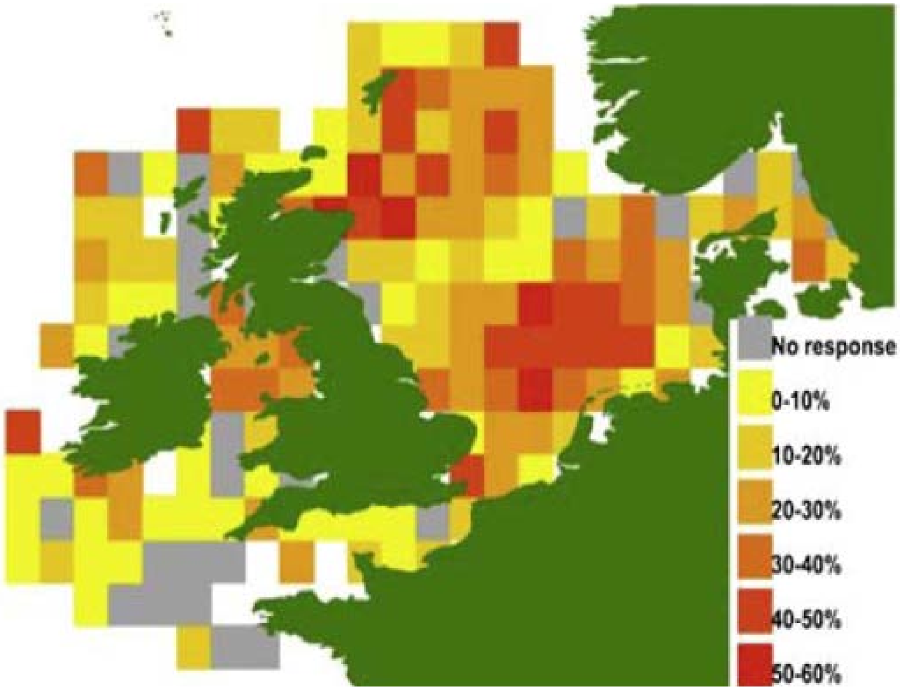

Figure 5. Eighty-two percent of cells with a positive assemblage response to warming (percentage variation above random in beta-diversity trend explained by temperature).

This method is robust to differences in surveys, allowing macroecological change to be assessed at spatial scales greater than individual surveys.

6.4 Case study III - Incorporating concerns for threatened migratory species

Protected area allocation such as the designation of Vulnerable Marine Ecosystems is often undertaken because species are identified as vulnerable in some way (eg. species of concern), typically in response to sharp declines in abundance or that the species undertakes a critical life history function within the designated area. Thus, single species needs can dictate policy and it will be important to account for biodiversity in these cases. One such example is the Atlantic sturgeon (*Acipenseroxyrinchus*), a long-lived, anadromous fish with a historic range from Hamilton Inlet on the coast of Labrador to the Saint Johns River in Florida (Smith and Clugston, 1997). A major commercial fishery once existed throughout its historic range with peak estimated US landings of 3.3 million kg in 1890 (Smith and Clugston, 1997). Unable to support intensive fishing, Atlantic sturgeon populations collapsed throughout the eastern seaboard by 1901 (Secor *et al.*, 2002). During the late 1900s, there was a brief re-emergence of the Atlantic sturgeon fishery in New York and New Jersey (Kahnle *et al.*, 2007) with peak landings of 125 000 kg in the late 1980s (Waldman *et al.*, 1996; Bain *et al.*, 2000). In 1990 the Atlantic States Marine Fisheries Commission (ASMFC) developed a fishery management plan for the conservation and restoration of Atlantic sturgeon, which aimed to restore population levels that supported harvests at 10% of the historical peak landings (ASMFC, 1990). With a continued decline in the population, a 1998 ASMFC amendment instituted a 40 year moratorium necessary to protect 20 year-classes of females (ASMFC, 1998). Currently, Atlantic sturgeon are to be listed under the United States Endangered Species Act.

Recent work has demonstrated that sturgeon aggregate in the area around the mouth of the Hudson River in May and October each year (Dunton *et al.* 2010; Unpub. Dat). During these aggregations, there is contribution from multiple rivers along the eastern US coast, suggesting significant mixing of the multiple genetic populations during migrations (Dunton *et al.* Accepted). Widely distributed spawning stocks can therefore be exposed to heavy fishing activity and habitat degradation in relatively small areas, illustrating the need for spatial management. Thus, heavy inshore trawling in the New York Bight(NYB) is a potential source of incidental bycatch mortality for fish spawned in rivers from the Hudson River to as far south as the Savannah River. This need is highlighted by a recent analysis indicating that three of the five distinct population Segments (DPS) areas (New York Bight, Chesapeake, and Carolina) have a greater than 50% chance of becoming endangered within the next 20 years, while the Gulf Maine and South Atlantic are under a moderate risk (<50% chance) of becoming endangered (Patrick and Damon-Randall 2007). Dunton *et al.* (2010) recommend spatial closures to protect the aggregation areas.

A current project has been developed to recommend area closures to protect sturgeon aggregation areas. A direct relationship among fishing intensity, decline in diversity, and loss of secondary production has been demonstrated (Hinz *et al.* 2008). Area-based restrictions displace fishing intensity to locations outside any protected area, potentially placing habitats and species not considered in planning at risk of overexploitation (Hilborn 2003, Murawski *et al.* 2005, Hiddink *et al.* 2006) and the biodiversity of that area at risk. For example, shifted fishing effort becomes concentrated along protected area boundaries (Murawski *et al.* 2005, Kellner *et al.* 2007). Thus, before enacting any protection for sturgeon aggregations, potential impacts on areas potentially outside protection must be considered.

6.4.1 New York trawl survey – data

The New York (NY) trawl survey consisted of two surveys for (1) young-of-the-year bluefish and (2) sub-adult Atlantic sturgeon. The sampling area encompassed the waters inshore of a depth of 30 m with the practical inshore limit of 8–10 m from Montauk Point to the entrance of NY Harbor (Figure 6). The survey utilized a depth-stratified sampling design with strata based on the depth intervals 0–10 m, 10–20 m, and 20–30 m. Tows were randomly selected using a random number generator and conducted for an duration of 20 min at a tow speed of 3–3.5 knots during daylight hours. The net was a three to one two-seam trawl (headrope 25 m, footrope 30.5 m) with forward netting comprised of 12 cm stretch mesh tapering down to the rear netting of 8 cm stretched mesh lined with a 6.0 mm mesh liner within the codend.

The bluefish survey was initially restricted to the 10 and 20 m depth stratum where 10 tows per depth strata were completed for a total of 20 tows per cruise. Sampling took place from June to October in 2005 and August to September in 2006. The survey was confined to the 10 m depth strata in September, October, and November of 2007 with 25, 24, and 27 tows completed, respectively. The Atlantic sturgeon survey a total of 10 cruises were completed from October 2005-June 2007 with 30 tows per cruise distributed within the 10, 20, and 30 m depth stratums. Sampling months included October, November, January, April, May, and June. A total of 10 tows were completed for each depth. In June 2007, 36 tows were confined to the 10 m depth stratum.

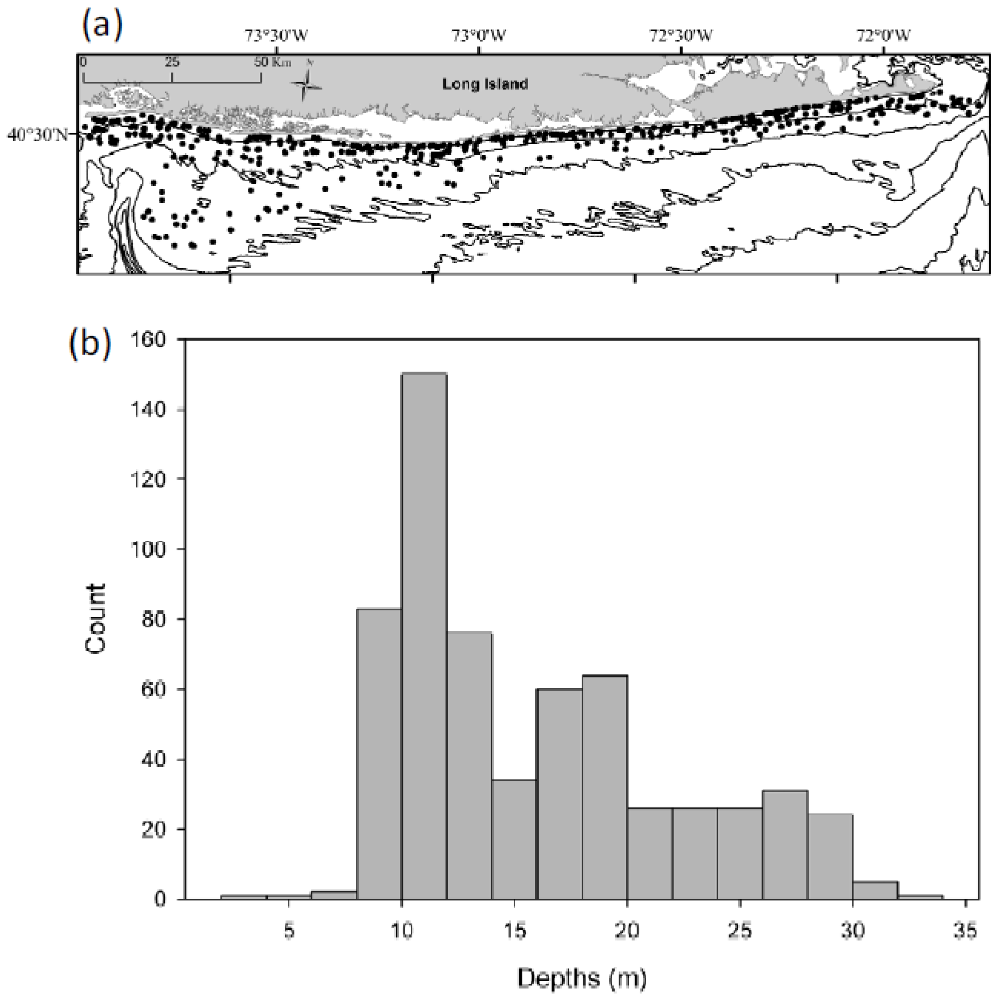

Figure 6. Spatial (a) and depth-related (b) effort in trawl survey.

6.4.2 NY trawl survey – results

Species prevalence and average per tow (Figure 7), cutoff established at present in 10% of tows with average of at least 1 per tow. The following species were therefore removed from the PCA: American lobster, American sand lance, Atlantic croaker, Atlantic silverside, Atlantic sturgeon, Blue runner, Dwarf goatfish, Haddock, Inshore lizardfish, Lined seahorse, Northern pipefish, Ocean pout, Oyster toadfish, Sea scallop, Shortfin squid, Silver anchovy, Spot, Striped anchovy, Striped burrfish, Striped cusk eel, Tautog, Unclassified shrimp, Yellowtail flounder.

PCA results indicate that first 4 PCS have largest changes in eigenvalues, thus the first 4 are considered good for further interpretation, account for 36.6% of variation in species (Figure 8).

The survey was run 9 times annually, which allows an analysis of the temporal aspects of the species assemblages. Unlike analyses of other nearshore systems (e.g. Jordaan *et al.* 2010), surveys within Long Island waters did not produce significant spatial segregation of communities and instead species assemblages structured along the temporal scale (Figure 9).

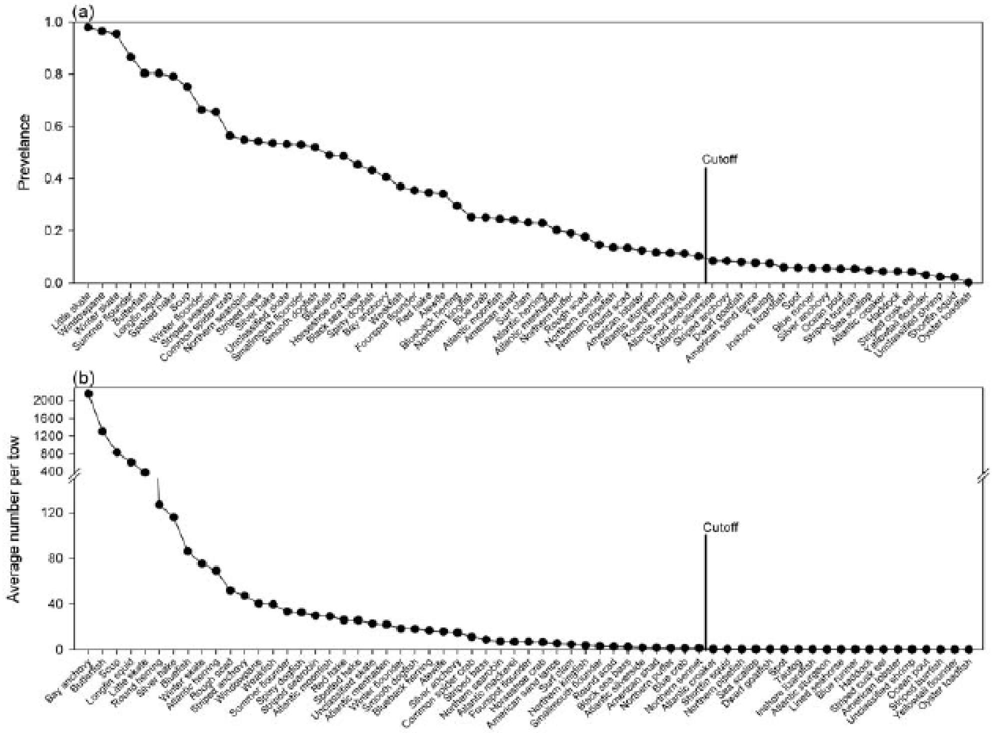

Figure 7. Prevalence (a) and average number of individuals per tow (b) effort in NY trawl survey.

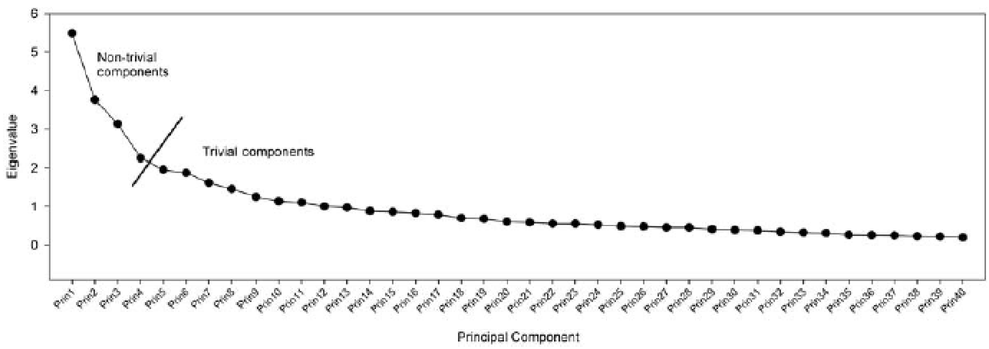

Figure 8. Screen plot of PCA eigenvalues demarking the non-trivial and trivial components.

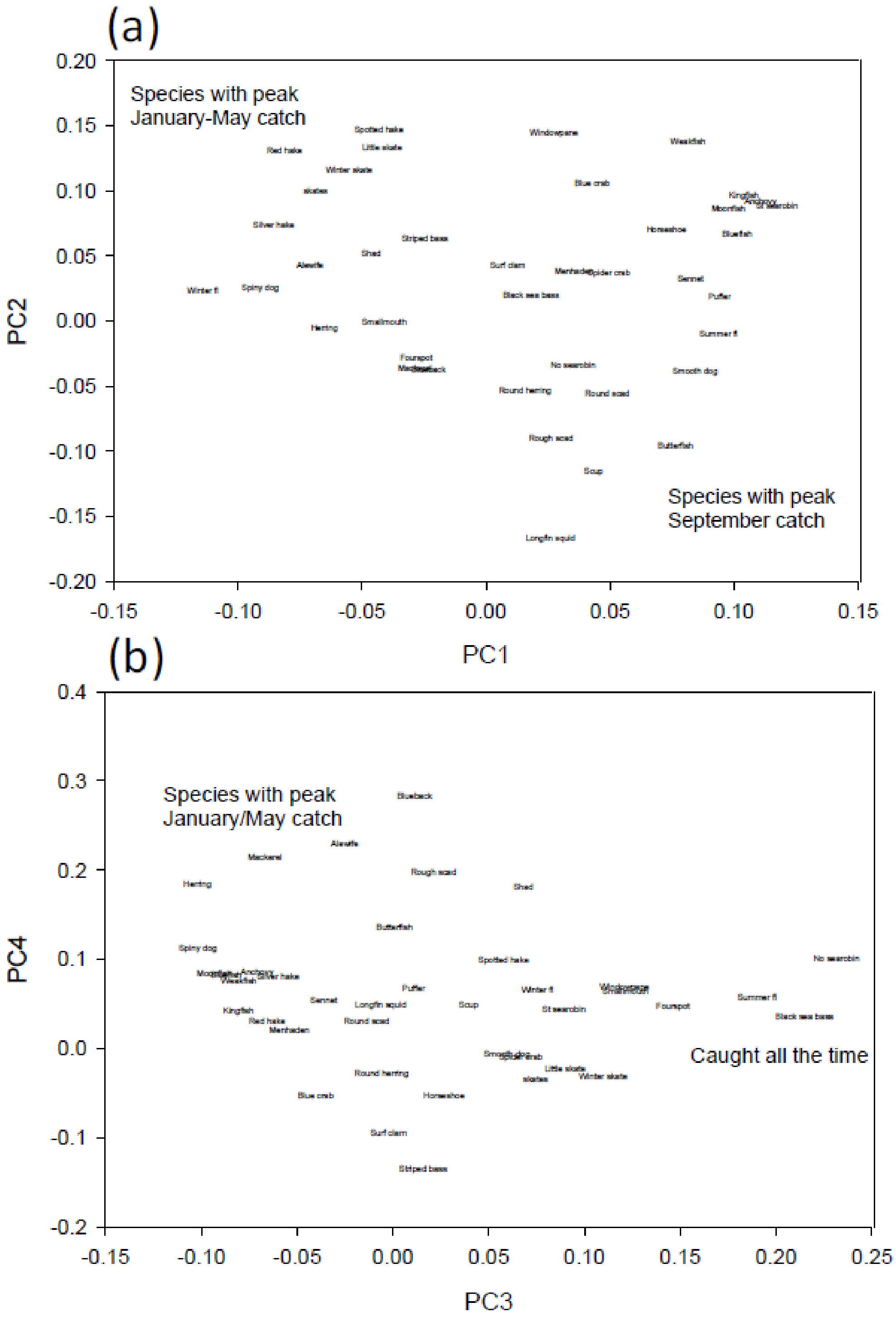

Figure 9. PC1 vs. PC2 (a) and PC3 vs. PC4 (b) from multivariate analysis of NY trawl.

6.4.3 Temporal aspects to biodiversity

There was no statistically identifiable spatial structuring in the NY trawl survey data, unless a single species such as sturgeon was focused on. The results instead demonstrated that nearshore waters of long Island, NY, are the site of an ever shifting set of species. This results in a particularly dynamic ecosystem in a structural sense. Further, many species share the space at varying life stages as is the case with bluefish and other migratory species where first young individuals enter the region followed by adults or that have different reproductive schedules such that length distributions are not equivalent among species.

Models often assume a fixed area or assign imports and exports of nutrients and energy in order to simplify. The suite of species chosen in any model can contain species that are highly mobile. In this study, almost every species moved out of the survey area over some time of the year. Some species were more ephemeral members of the community, while others were more sedentary. When determine or assigning “keystone” or key ecosystem players, one should be careful that the appropriate ratio of inputs and outputs are applied. For example, winter flounder may be captured in a bi-annual survey in the region, but spend much of the remained of the year in inshore areas spawning or offshore in summer feeding grounds.

Surveys were also conceived largely to sample a few key economically valuable species, and thus species that were not traditional targets of past fisheries but have found their way into targeted present-day exploitation may be substantially misrepresented in survey catches.

Not all species were included in the PCA analysis, and this is part of the problem. If a species is found in higher numbers some years (or in more places like the sturgeon) but not frequently enough to make some cutoff in species for further analysis, then it will be considered “not important”. While species not sampled at a high enough rate within this spatio-temporal scale to base conservation zoning upon were left out of the analysis. The reality is that sturgeon are, for example, a coastwide species that aggregates. Thus management may have to consider multiple scales, despite the fact that it will never be sampled adequately in a stratified design, unless sub-surveys upon sub-surveys are undertaken. In a dynamic setting like the Long Island coast, where sturgeon have a major staging area, and almost all species move through with seasonal patterns, and the forage community changes on monthly time scales, a number of species and management scenarios that use ocean zoning/ area-based management techniques will have to be considered.

6.4.4 Temporal aspects to biodiversity

Biodiversity has often been treated as a static variable, for example in the identification of biodiversity hotspots that deserve protection. However, some regions experience substantial species turnover. The waters off Long Island, NY, experience dramatic changes in temperature over the year with tropical species such as the invasive red lionfish (*Pteroisvolitans*) occurring over the summer months and inshore spawning of the winter flounder (*Pseudopleuronectesamericanus*) during the winter. This difference can be observed from sea surface temperature maps, equating to around a 20˚C change in temperature from summer to winter (Figure 10).

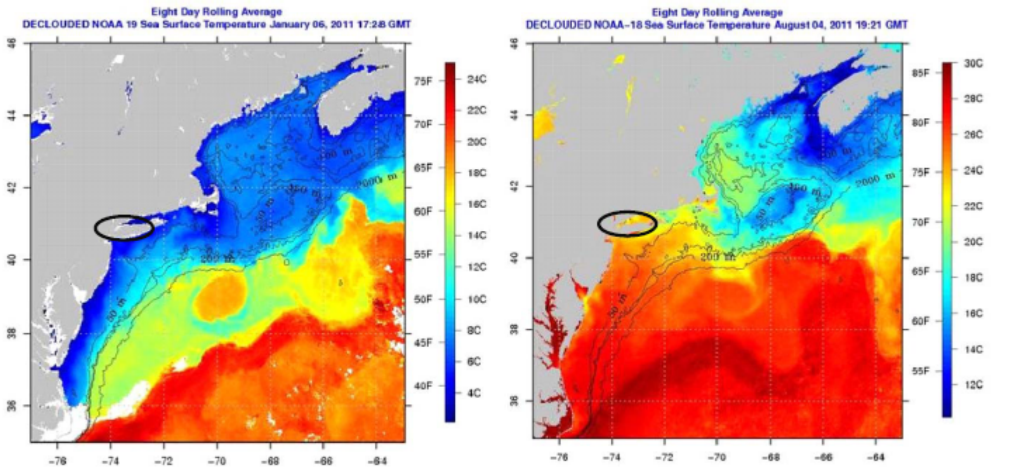

Figure 10. De-clouded 8-day average sea surface temps of northeastern United States. Long Island is circled. Images from: Rutgers University Institute of Marine and Coastal Sciences Coastal Ocean Observation Lab, at http://marine.rutgers.edu/mrs/sat_data/?product=sst&nothumbs=0

6.5 Can temporal aspects be integrated?

Averaging rates (consumption, movements, etc.) based on 1 or 2 surveys per year will likely vastly misrepresent the real dynamics. Thus, we expect that predator-prey and other ecological functions reflect patterns in species' assemblages and managing at small scales will be particularly challenging.

The principal axes in such analysis can lie across either spatial and/or temporal variation, and the effect of scale will be important in determining which. However, it will be critical to account for each. It appears, from the analysis that a number of other species of concern (alewife, winter flounder) enter into the region during the potential closure period, and ensuring that are-based protection will not impact these populations will be critical to success within an ecosystem perspective.

6.6 Recommendation

Perform data analyses using multiple techniques to elucidate differences in conclusions and outcomes that could benefit or misinform managers. Key findings should address model choice and related outputs, usefulness to managers, interactions among species, and test assumptions including the use of multiple years and species cutoff choice.

6.7 References

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7 Abundance/ distribution relationships within species, and groups of species in different ecosystems in relation to habitat, environment and in relation to anthropogenic impacts

d) Examine abundance/distribution relationships within species, and groups of species in different ecosystems in relation to habitat, environment and in relation to anthropogenic impacts

7.1 Background

The work done in previous years on this ToR at WGFE was successfully submitted to the Ecological Applications and published in 2011. The abstract of that paper is shown in the following section. Unfortunately, this year no work could be done on this ToR, but WGFE wishes to continue this work in the near future.

7.2 Exploring the abundance–occupancy relationships for the Georges Bank finfish and shellfish community from 1963 to 2006

Abundance–occupancy (A–O) patterns were explored temporally and spatially for the Georges Bank finfish and shellfish community to evaluate long-term trends in the assemblage structure and to identify anthropogenic and environmental drivers impacting the ecosystem. Analyses were conducted for 32 species representing the assemblage from 1963 to 2006 using data from the National Marine Fisheries Service's annual autumn bottom trawl survey. For individual species, occupancy was considered the proportion of stations with at least one individual present, and abundance was estimated as the mean annual number of fish captured per station. Intraspecific relationships were estimated to provide information on utilization of space by a species. Multispecies interspecific relationships over all species for each year were fitted to estimate assemblage structural changes over the time series. Results indicated that the slopes and strengths of interspecific A–O relationships significantly declined over the duration of the time series, and this decline was significantly related to groundfish landings. However, the rate of decline was not constant, and a breakpoint analysis of interspecific slopes indicated that 1973 was a period of “state” change. More importantly a jackknife-after-bootstrap analysis indicated that the early 1970s followed by the 1990s were periods of higher than average probability of significant break points. While it is difficult to determine causation, the results suggest that long-term impacts such as habitat fragmentation may be influencing the species assemblage structure in the Georges Bank ecosystem. Further, we used slopes from the intraspecific A–O relationships to derive a measure of a species' potential risk of hyperstability, where catch rates remain high as the population declines. Combining this measure of the risk of hyperstability with resilience to exploitation provided a means to rank species risk of decline due to both demographics and the interaction of the behaviours of the species and fishing fleets (Frisk *et al.* 2011).

7.3 Literature

Michael G. Frisk, Daniel E. Duplisea and Verena M. Trenkel (2011) Exploring the abundance–occupancy relationships for the Georges Bank finfish and shellfish community from 1963 to 2006. Ecological Applications 21:1, 227-240.

8 Fluctuations within fish communities

e) Evaluate fluctuations within fish communities:

i. What constitutes regime shifts in fish communities? Can mechanisms be identified detected?

ii. State changes - Cycles vs. regime shifts

iii. Are anthropogenically induced changes alterable?

8.1 Background

This ToR has been created mainly to facilitate discussions on the theoretical concepts regarding fluctuations within fish communities and if possible could be supported by data analyses done during the meeting. It was introduced as a ToR at the WGFE meeting in 2009, during which the whole group of members present enthusiastically participated within the discussions regarding this subject. The low attendance and the pressure of finishing other prioritized ToRs by this small number of members, has limited the opportunities to have similar discussions as in 2009. However WGFE still plans to have these discussions and potentially analyses coming from these discussions in the near future.

8.2 Case Study: Climate change, abiotic conditions and the stocks of the main commercial fish species of the south-eastern Baltic Sea in recent decades.

In recent decades there have been significant changes in the Baltic Sea ecosystem. The main change in the late 1980s, being regarded a shift in the fish community, from a community dominated by cod, to a system dominated by sprat (Mollmann C. *et al.* 2009, MacKenzie B.R. *et al.* 2000). The main reasons for the transition to a new state of the Baltic, along with anthropogenic influence (fishing, eutrophication, etc.) were the major changes generator mode factors determining the temperature, salinity, and oxygen regimes in the different layers of the sea and consequently the conditions of spawning, feeding and nutrition of the main commercial fish species (MacKenzie B.R. *et al.* 2000, Zezera A.S. *et al.*, 2011).

In this case study based on an integrated ecosystem analysis (IEA) of abiotic (according to long-term observations Helcom (ICES) and AtlantNIRO in the Gdansk Basin)and biotic (spawning biomass of cod, herring and sprat, the number of recruitment according to AtlantNIRO and ICES data) components provides characteristics of long-term changes and the current state of the South-Eastern Baltic ecosystem. In total 23 variables were analyzed: 13 - abiotic, 7 - biotic and 3 - human (fishery).We considered the following time periods: 1974–2010 - abiotic parameters and the main commercial fish stock size as stock units, 1992–2010 - abiotic parameters and the main commercial fish stock size in ICES sub-division 26.

The analysis was performed according to Practical guidelines for performing Integrated Ecosystem Analyses (WGIAB2011). In the analysis used the program R and its packages for statistical computing and software STARS.

Analysis of the status of abiotic variables of the Baltic Sea and an assessment of their long-term changes made based on long-term observations on the international oceanographic monitoring station in the Gdansk Basin in South-Eastern Baltic (P-1). In this case we used survey data performed AtlantNIRO, ICES database (http://www.ices.dk). In addition, the climate index was calculated as the sum of the normalized anomalies of annual average air temperatures, water in the 0–100 m layer and the area of the Baltic Sea ice-free during its maximum development. Calculation of the anomalies was carried out with respect to the average for the period 1961–1990.

Characteristics of biotic state variables (the value of stock and the recruitment number of major commercial fish species) is carried out according to international autumn acoustic surveys (BIAS) and winter bottom international trawl (BITS) surveys (conducted in the Baltic by AtlantNIRO and institutions in other countries. The time series of the variables used for the IEA presented in the table, the results of the IEA - Figures 11–14.

Integrated analyses

For period 1974–2010 the first principal component explained 36% of the variance. Time trajectory indicates that the system moved to another state with a transition period of 1988–1990. The most important abiotic variables of PC1 were the increase in climate index, temperature over the layers, desalination, and oxygen deficiency in the depth layers. The other variables important according to PC1 were the increase in sprat SSB and decrease in cod and herring SSB, relevant against the background of increasing commercial exploitation on these species.

For period 1992–2010 only in the Gdansk basin the first principal component explained 29% of the variance. Time trajectory indicates that the system move from one to another state with a transition period of 1998–1999 and some in 2007. The most important in abiotic variables of PC1 were the increase in temperature and salinity in the depth layers, desalination in upper layers and oxygen deficiency in the depth layers, in other variables – increase of cod SSB, decrease of sprat SSB, and stabilization of herring SSB at low level; increase sprat, decrease cod and herring fishing mortalities.

Table 1. Time-series used for integrated ecosystem analysis (IEA) in the South-East Baltic Sea.

№	Variables	Abbreviation	Unit	Years	References
1	ClimateIndex	Climate Index	-	1974 (1992)–2010	AtlantNIRO, ICES
2	The water temperature in the layer 0–10 m in May	T_0–10_m	°C	1974 (1992)–2010	
3	The water temperature in the layer 40–60 m in May	T_40–60_m	°C	1974 (1992) –2010	
4	The water temperature in the layer 80–100 m in May	T_80–100_m	°C	1974 (1992) –2010	
5	The water temperature in the layer 0–10 m in August	T_0–10_a	°C	1974 (1992) –2010	
6	The water temperature in the layer 40–60 m in August	T_40–60_a	°C	1974 (1992) –2010	
7	The water temperature in the layer 80–100 m in	T_80–100_a	°C	1974 (1992) –2010	

	August				
8	Water salinity in the layer 0–10 m in May	S_0–10_m	psu	1974 (1992)–2010	
9	Water salinity in the layer 80–100 m in May	S_80–100_m	psu	1974 (1992)–2010	
10	Water salinity in the layer 0–10 m in August	S_0–10_a	psu	1974 (1992)–2010	
11	Water salinity in the layer 80–100 m in August	S_80–100_a	psu	1974 (1992)–2010	
12	The depth of isohalsine 11 ‰, the average May and August	H11‰	m	1974 (1992)–2010	
13	The oxygen content in the layer 80–100 m (the average May and August)	O2_80–100m	ml/l	1974 (1992)–2010	
14	Sprat recruitment (Age 1 - 1 year)	age 0_sprat	mill.sp.	1974 (1992)–2010	AtlantNIRO, BAD1, WGBFAS 2011
15	Sprat Spawning stock Biomass	SSB_sprat	thous.t		
16	Herring recruitment (Age 1 - 1 year)	age 0_herring	thous.sp.		
17	Herring Spawning stock Biomass	SSB_herring	tonnes		
18	Average weight of herring in ICES SD 26	w_herring	kg		
19	Cod recruitment (Age 2 - 2 years)	age 0_Cod	Thousands - 25-32 SDICES 26 SDICES Indicesforage 2		AtlantNIRO, DATRAS, WGBFAS 2011
20	CodSpawningstockBiomass	SSB_Cod	Tonnes - 25-32 SDICES 26 SDICES Indicesforage 3–10		
21	Sprat fishing mortality (Fbar 3–5)	F_sprat			AtlantNIRO, WGBFAS 2011
22	Herring fishing mortality (Fbar 3–6)	F_herring			
23	Cod fishing mortality (Fbar4–7)	F_Cod			

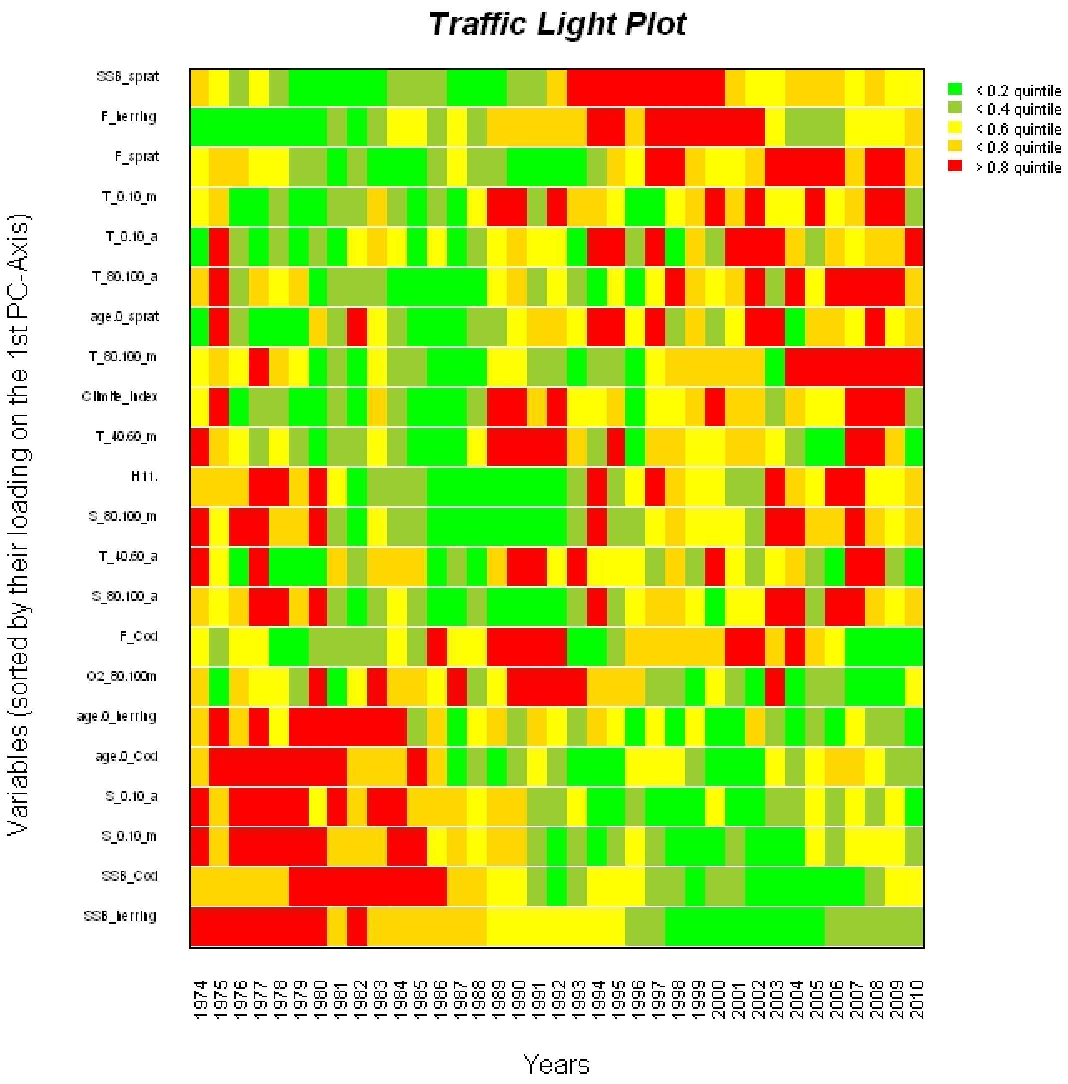

Figure 11. Traffic-light plot of the temporal development of the South-East Baltic (Gdansk basin) and fish stocks time-series 1974–2010. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table 1.

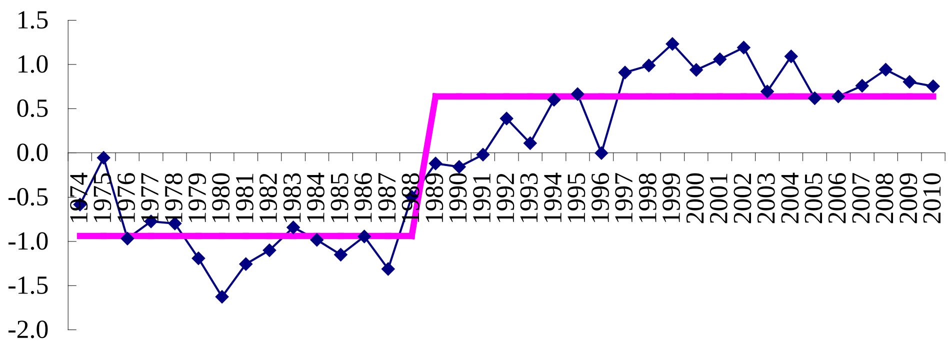

Figure 12. Results of STARS analysis on the first principal component based on all variables (Shifts in the mean for PC1, 1974–2010, Probability = 0.05, cutoff length = 20, Huber parameter =3).

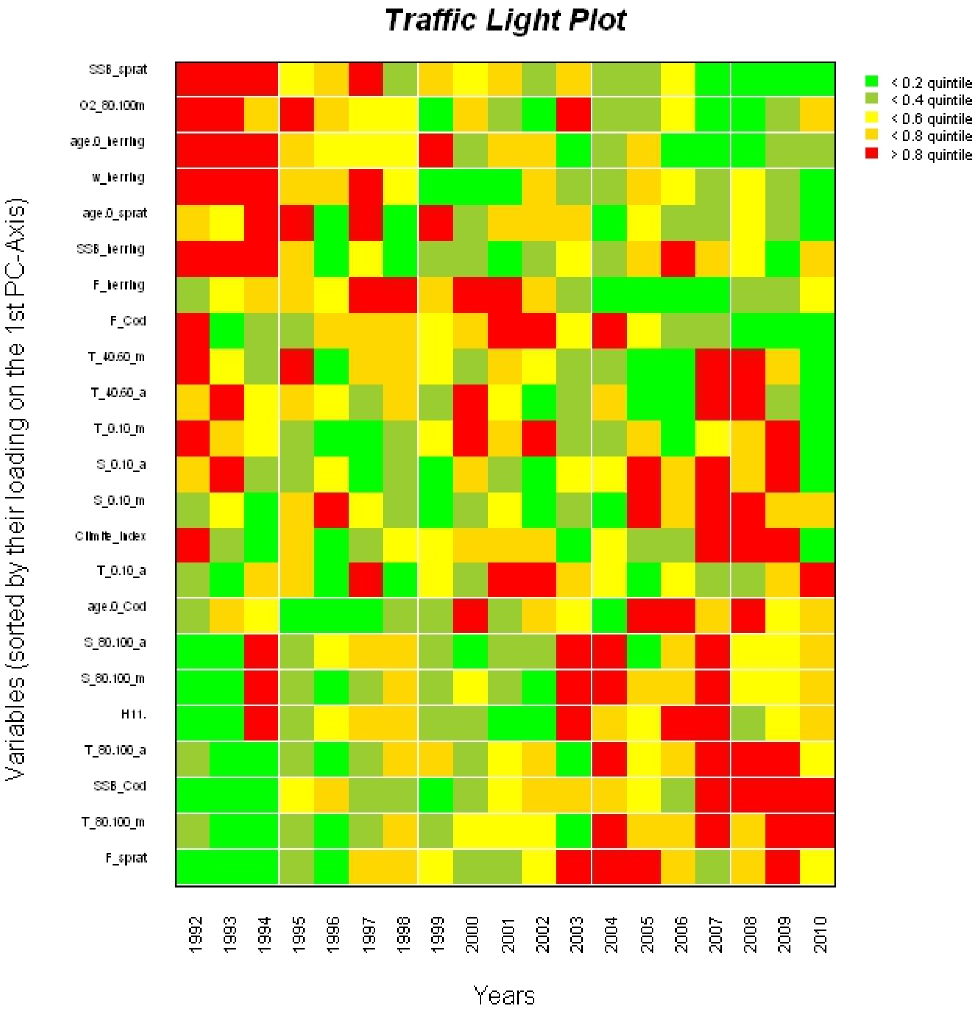

Figure 13. Traffic-light plot of the temporal development of the South-East Baltic (Gdansk basin) and fish stocks of ICES SD 26 time-series 1992–2010. Variables are transformed to quintiles, colour coded (green = low values; red = high values), and sorted in numerically descending order according to their loadings on the first principal component. Variable names are explained in Table 1.

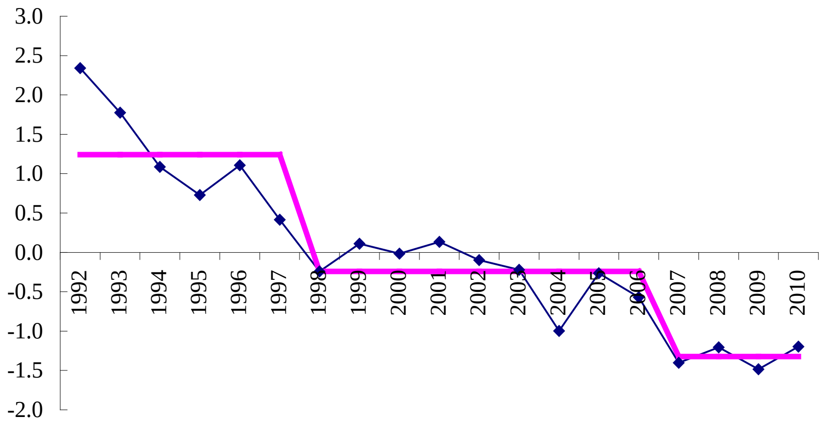

Figure 14. Results of STARS analysis on the first principal component based on all variables in ICES SD 26 (Shifts in the mean for PC1, 1992–2010, Probability = 0.05, cutoff length = 10, Huber parameter = 3).

Analysis of changes in abiotic conditions over the past 40 years has shown that the main causes of the incident of the regime shift was, on the one hand, the long period of freshening of the sea, caused a significant decrease in water exchange with the North Sea, on the other hand, higher water temperatures due to climate warming.

The negative trend in salinity in the deep layers of the sea was observed from early 80s to early 90s, with a minimum of absolute values in the Gdansk basin (8.6‰) in the bottom layer in 1990 (average for 1961–1990 – 11.0‰, an anomaly – -2.4‰). In 1993, noted the sign change of the trend and increase the salinity of deep waters. In the upper layer of the sea the desalination period has begun in the late 80s and continues to this day, the minimum salinity of surface water in the Gdansk basin (6.9‰) was recorded in 1999 (in average – 7.6‰, an anomaly – -0.7‰).

Southeast Baltic, as well as all the sea, is a region with a high rate of warming. So, the coefficient of linear trend (b,°C/10 years) in mean annual air temperature in Kaliningrad, which characterizes the rate of warming in the region for years 1976–2010 was +0.52°C/10 years. The most intense warming observed in the 1976–1990 (+1.19°C/10 years) with a peak in the winter season (+2.37°C/10 years). In the surface layer of the sea in the Gdansk basin the maximum rate of increase in water temperature was also observed in the period 1976–1990 (+1.68°C/10 years) with a peak in the spring (May) season (+2.55°C/10 years).

Average annual water temperature anomalies in the surface layer with an average 9.5°C were as follows: in 1981–1990 – +0.3°C, in 1991–2000 – +1.0°C, 2001–2010 – +1.6°C. In the bottom layer the warm period began in 1997 with an average 5.0°C, the anomalies for the periods 1981–1990 – -0.5°C, 1991–2000 – +0.2°C, and for 2001–2010 – +1.4°C. The maximum temperature anomalies throughout the water column (average 6.1°C) were characteristic of the last decade (+0.9°C).

Feature of the period 2001–2010 along with high heat reserve of the water column was to increase the salinity of deep and bottom waters to levels close to the level 70s – early 80s (an anomaly – +0.4‰). However, in the surface layer of the sea, in contrast to the 70-80s, remained negative anomalies of salinity (an anomaly – -0.4‰).

In the early 90s increased sprat stock (ICES SD 22–32) and in 1996/1997 it's peaked. Currently, there is a little above average long-term level. Baltic herring stock of the central Baltic (25–27, 28.2, 29 and 32 ICES SD) in this period decreased to a minimum in 2001, after a bit grown up and has now stabilized at low levels. The spawning stock of the Eastern Baltic cod (ICES SD 25–32) fell from the highest level observed in 1980–1984. To the minimum - in the early 90s.

The lowest level of spawning biomass observed in 2005. In the last five years the cod stock began to rise, but still remains below the average annual level (WGBFAS 2011).

Stock analysis of the main commercial fish species in 26 ICES sub-division (including Russian zone) in 1992–2010 showed that in 2005 there was reduction in the sprat recruitment number, and since 2007 in the size of its stock to the level of long-term average. The stock of herring decreased from 1996, increased slightly in 2005 and stabilized at a level below the average long-term. In the late 90s observed an increase in the proportion of small, slow-growing marine herring and decrease coastal rapidly growing large herring.

In contrast to sprat and herring, which size of its biomass as a stock unit, and in sub-division 26 has a whole changed similarly, the state of the stock of Eastern Baltic cod in the sub-division 26 had its own peculiarities. Thus, despite the decline of the Eastern Baltic stock in 2005 to its lowest historical level, in south-eastern Baltic Sea

(Gdansk Basin, especially in Russian zone), on the contrary, since 2000s, some increase in size of the cod stock observed, with a pronounced positive "jump" in 2008 which was reflected in more pronounced growth of biomass in 2009, 2010 and was a consequence of abundant generations 2005, 2006. Therefore, in SD 26, along with high commercial exploitation of sprat, one of the reasons why the size of its stock decrease to the level of long-term average was increase of the cod biomass and strengthening its role as a predator in the last 2 years.

In general, the present state of abiotic and biotic components of marine ecosystem of the Gdansk basin in the Baltic Sea in relation to their performance in the period 1976-1985 (up to the main regime shift) revealed that, despite some positive changes in environmental conditions for population growth of Eastern Baltic cod (high absolute values of salinity in the deep and bottom layers of deep-sea basins and high position isohaline 11‰), the modern period has characteristic differences. They are include a significant reduction in the frequency of strong advection of North Sea waters (even in comparison with the previous period of freshening of the sea in 1900–1940), less favourable oxygen regime of deep water, the maximum in the heat reserve of water masses in instrumental observations and the low level of salinity in the upper layer of the sea.

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9 Review of the outputs of the ICES SIBAS Workshop

9.1 Background

To ensure that ICES work remains current and correctly focussed in a changing policy environment, ICES has established a Strategic Initiative on Biodiversity Advice and Science (SIBAS). This initiative seeks to build on ICES existing capacity to further develop the profile, relevance, influence and use of biodiversity science and advice. As part of the role of SIBAS, a Workshop on Marine Biodiversity(WKMARBIO) was convened in February 2011 to further ICES' engagement in biodiversity issues (ICES 2011a).

WKMARBIO defined 25 actions and several recommendations to implement the actions that ICES might take to make a more influential contribution to marine biodiversity science and advice. Particular foci of the report were actions to improve accessibility and quality control of biodiversity data, the selection and application of a more comprehensive suite of indicators and reference points, the understanding of activity-pressure-state relationships, and the development of a strategic science programme that ensures ICES can influence and respond to future policy directions.

A recommendation generated by WKMARBIO to WGFE (and other EGs) was to:

f) "Review the outputs of the ICES SIBAS Workshop on 'Biodiversity indicators for assessment and management' (available February 2011) and, based on the indicators that have been proposed and the reporting processes they are intended to support, report on:

- The strengths and weaknesses of the proposed indicators for fishes and fish communities;
- Recommended modifications to the indicators;
- The process that would be used for data acquisition, analysis and reporting of the indicators;
- The tradeoffs between fishing and the status of fish populations and communities that need to be considered when setting targets for biodiversity indicators;
- The information, data and tools that are available to assess and quantify these tradeoffs;
- How the indicators, targets and tradeoffs might be presented as advice;
- The additional data, information and science needs to quantify tradeoffs."

The broad classes of indicators, as summarised by ICES (2011a), are given in Table 7.1. ICES (2011a) stated that "This table (Table 7.1 of this report) can be used as a starting point for ICES expert groups that focus on specific ecosystem components to report on (i) the strengths and weaknesses of these classes of indicators, (ii) to identify those that are most suited to supporting the policy drivers identified in Section 1 of this report, (iii) to recommend modifications to these indicators if appropriate, and (iv) to describe the process that would be used for data acquisition, analysis and reporting of the indicators"

Table 7.1. Classes of indicators that would be of short term or medium use to policy and management agencies (From ICES 2011a). The column headings were developed for convenience at the SIBAS workshop and are to be interpreted colloquially. In some cases the terms in the table and heading do not match more precise uses of the terms in formal ICES advice.

TYPE	CLASS	LEVEL / SCALE	SPECIFICATION / TYPE OF PROPERTY	RELEVANCE – TYPE OF USERS
State/structure	Diversity	Community	Structure	All
	Diversity	Community	Functional diversity	All
	Population	Species or stock	Size, Range, Composition	All
	Population	Protected, Endangered and Threatened species; Invasive species; Charismatic; Highly migratory; Bioengineers; Forage	Size, Range,Composition	All
	GeneticDiversity	Species (otherlevels in specificcases)	Structure	Fisheries Management,Conservation
	Habitat	Multiple scales	Size, Range, Composition	All
	Habitat	Multiple scales	Usage – population / community use of available habitat	Conservation & recovery;(All)
	Habitat	Multiple scales	Proportion of suitable conditions where habitat	Conservation & recovery,(All)

			is present	
	Habitat	Species/Community	Patchiness and connectivity	Conservation, Fisheries
State/Function	Strategic	Community/Ecosystem	Marine trophic index (MTI), other trophic indicators from models or community data	Conservation, biodiversity(reporting on state ofsystem - SOS)
	Strategic	Community/Ecosystem	Ratios of functionalgroups	Specific to pressure;Reporting SOS
	Strategic	Community/Ecosystem	Flow/length of foodchain, etc	Biodiversity & conservation;Reporting SOS
	Strategic	Community/Ecosystem (Population)	Resilience	Reporting on SOS. Indirectback to All
Pressure	Magnitude/extent ofactivity; trend	Multiple scales/Ecosystem	Inherently pressure-specific	Fishing, Shipping, Tourism,mining, oil extraction, etc. All
	Accumulatedeffects	Species/Community	Pollution,contamination	All
	Environmentalforcing	Community/Ecosystem	Physical and chemical variables; community abundance ofcharacteristic species / groups (southern, calcifiers)	All (accommodate but notmanageable)

In their report, WKMARBIO defined biodiversity in its broadest sense, as the variety, quantity and distribution of life, which is fundamental to the function and resilience of ecosystems and the goods and services that they provide. The examples they then provide of the interpretation for the concept of biodiversity in international agreements/policies such as the Convention on Biodiversity (CBD) and the Marine Strategy Framework Directive (MSFD), and the classes of indicators listed in Table 7.1, further confirm the breadth of their definition. Given the multifaceted definition of biodiversity, a suite of indicators is required to fully assess its status and evaluate pressure-response relationships.

9.2 The strengths and weaknesses of the proposed indicators for fish and fish communities

The ToR provided to the WGFE requests advice and comments on proposed indicators, whereas Table 7.1 only listed generic classes of indicators. In the absence of specific proposed indicators, the present response is therefore also to some extent generic. The WGFE is well placed, along with other ICES working groups, to provide advice on the appropriateness of more specific indicators in the future.

FAO guidelines (1999) highlighted that indicators are not an end in themselves, but a tool to help make clear assessments of and comparisons between the ecological status of systems or management frameworks through time (FAO, 2004). There is a clear need for a suite of indicators that can be aggregated or interpreted in concert, rather than focussing on individual indicators. Developing a set of sustainability indicators will assist in assessing performance of policy and management and to stimulate actions to better pursue sustainability objectives (FAO, 2004). In this way, multiple criteria that are described in the MSFD could be supported, providing greatest levels of synergy between the descriptors and therefore most efficient use of the resources (FAO, 2003; Jennings and Dulvy, 2005; Rice and Rochet, 2005; Piet *et al.*, 2008).

Community level diversity

In terms of sampling fish, the broad scale, international fishery independent surveys coordinated under the auspices of the ICES IBTSWG and WGBEAM, or conducted nationally elsewhere (e.g., Canada, U.S.A., Iceland, etc.), can inform on the fish 'assemblage', which is subtly distinct from a pre-defined fish 'community'. Some specific fish communities are not or only poorly sampled by these (and other national) surveys (e.g., coastal and estuarine fish communities, large pelagic fish community, reef-associated fish communities, deep-water fish assemblages). As such, ICES may not be able to provide indicators for specific fish communities, but can provide metrics based on regional fish assemblages, as sampled by a particular gear at a particular time of the year.

Two attributes of the fish assemblage were suggested: structure (here presumed to refer to 'biodiversity metrics', such as species richness and evenness) and functional diversity. There is a considerable literature on species diversity metrics, and although existing data can be used to inform on the spatial patterns and temporal changes in diversity metrics, it is unclear as to how tightly linked such univariate metrics would be to specific human pressures.

In terms of 'functional' diversity, although many fish can be classified generally into functional groups (e.g. trophic or reproductive guilds), the functional role of a number species in the ecosystem is less well known. Furthermore, given ontogenetic changes in functional group affiliation, summarizing functional diversity for an assemblage is not straightforward.

Table 7.1 also suggested trophic indicators (including the marine trophic index) and ratios of functional groups. Developing indicators based on ratios can be problematic, as these may be strongly influenced, for example, by a particular strong year class. Metrics influenced by both a denominator and numerator can be problematic for both interpretation and management.

Metrics for species of particular interest

ICES (2011a) identified several types of species of particular interest, including protected, endangered and threatened species; invasive species; charismatic species; highly migratory species; bioengineers; and forage fish.

Although there is a clear role for developing indicators for particular species of concern, there are obvious issues with regards both species selection and data availability. A robust, method for prioritising species of concern, from which those where there are sufficient data can then be selected, is required, and ICES is well placed to undertake such a task.

It is possible to identify the fish species that correspond to some of these categories (e.g. legally protected species), but many lists of 'endangered and threatened species' are to some extent arbitrary, and a common approach to categorising the threat status of North Atlantic marine fish (e.g. the application of IUCN criteria) is still required to ensure consistency in the application and interpretation of the related indicators.

Invasive species are typically in coastal and estuarine environments, and with the exception of round goby *Neogobiusmelanostomus* in the Baltic Sea, there are few cases of invasive fish species in the marine environment of the ICES area. It is noted, however, that introduced fish species occur in other parts of the North Atlantic, such as lionfish *Pteroisvolitans* in the temperate and tropical nearshore waters of the NW Atlantic, and there are a wide range of Lessepsian fish migrants in the Mediterranean Sea, some of which have established breeding populations.

Focusing on 'charismatic' species does not seem to be a scientific approach, although if a species is viewed as important (for commercial, ecological and/or nature conservation reasons), and there are appropriate data to examine the species, then there are potential benefits for communications with the general public if the species is also viewed as 'charismatic'. Furthermore, the status of a charismatic species may provide a high profile indicator for other stocks.

Developing robust indicators for 'highly migratory species' is also appropriate, although (depending on the geographical extent of the migration route and the annual variability in migratory behaviour), data from the ICES area alone may be insufficient to fully understand the complexities of such species.

There is a clear ecological role of both forage fish and top predators in the marine environment, and although including such species in indicator development, it should be noted that catches of forage fish (e.g. small clupeids, sand eels, sand gobies etc.) can be highly variable in current surveys, and that many of the larger predatory fish are poorly sampled in existing surveys. This will affect metrics of stock size, area occupied and size composition.

Developing metrics that inform on the size distribution (and age structure where data permit), geographical range and relative abundance should be achievable for some species from existing data and surveys. This may also be achievable for some other species with slight modifications to existing surveys (as long as this doesn't compromise the integrity of the existing survey).

To the extent that mortality patterns in marine ecosystems are size-dependent, changes in the size composition of well sampled species may provide an indicator for changes in similarly-sized but less well sampled species. ICES WGFE and WGECO are well positioned to provide advice on the degree to which such inference is possible in particular circumstances.

Genetic diversity

There are at least two broad components of genetic diversity that can be monitored and assessed. The first is changes in the relative status of species, population or subpopulations that have been shown to be genetically separated. The second is changes in allele frequencies within species and populations.

Although there have been several studies on the genetic diversity of fish stocks/species, such programmes are not always internationally coordinated and often lack the resources for proper broad scale analysis. Consequently structure below the stock/population level is not known for most species, precluding the production of reliable indicators for those components of biodiversity.

Many indicators of change in stock/population allele frequencies require a regular and standardised approach to sample collection, processing and monitoring (e.g., Therkildsen *et al.* 2010)which is presently not typically undertaken. Whereas this could be done in the near future, especially with advances in genetic technology and ensuing decreases in sample processing costs, it presently is only realistically achievable for selected case-study species. On the other hand, quantitative ecological techniques such as probabilistic reaction norms (e.g., Heino *et al.* 2002; Olsen *et al.* 2004) and the modelling of otolith back-calculation growth data (e.g., Swain *et al.* 2007) have been used to infer fisheries-induced evolution in maturation and growth of fish stocks. These techniques therefore produce indicators of genetic change, but applications are limited to well-studied species.

9.3 Recommended modifications to the indicators

Overall, WGFE finds that the broad components that together describe 'fish biodiversity' are covered, in terms of the structure (age, length, trophic, functional, genetics), species composition and geographical range of fish assemblages, and the status and structure for species of particular interest. In order to progress on the development and adoption of specific indicators, WGFE would suggest that:

a) The term 'assemblage' is used instead of 'community' when referring to fish catches from trawl surveys;

b) A standardised approach for the identification and prioritisation of species of particular interest (for species of commercial, ecological, cultural and conservation importance) should be developed within the ICES community. Subsequently, those species deemed of higher priority should be appraised in terms of the degree of available data, and potential metrics tested for their utility as indicators;

c) There should be a consistent and coherent approach to developing metrics for those species for which there is a good knowledge of stock structure. For example, if ICES assesses any given fish species by stock units, then diversity metrics should be developed for comparable stock units, so as to avoid any potential mismatch between 'species-level' and 'stock-level' advice;

d) There should be due caution with regards the development of metrics and indicators based on ratios;

e) Indicator development should be at the appropriate geographical scale for both the assemblages and species of interest. Conducting analyses for national waters may, under certain circumstances, be uninformative or give a misleading status;

f) For fish of commercial importance, there needs to be a consistent and coherent approach to advising on 'biodiversity' issues and metrics with stock assessment methods. Any 'biodiversity' metric developed for individual commercial fish stocks should augment and not contradict the stock assessment advice.

9.4 The process that would be used for data acquisition, analysis and reporting of the indicators

Data acquisition

For many fish species and the wider fish assemblage, most regional data will come from internationally-coordinated (e.g. BIFS, WGBEAM, IBTSWG) or national fishery-independent trawl surveys. Associated experts and expert groups should ensure that data collection is appropriate for 'biodiversity monitoring'. These groups have manuals that should facilitate standardised catch sampling and length reporting, although consistent species identification remains an issue for certain taxa.

Quality assurance

Although not requested in the ToR, the WGFE reiterates the need for correct data checking and quality assurance of data prior to analyses. The trawl survey data available on, for example, DATRAS, still contains some errors (database input errors and more fundamental misidentifications), and if this valuable resource is to be used for the development of biodiversity indicators, sufficient resource needs to be allotted to improving the quality of these data.

Clear meta-data on the surveys must be available to potential users of the data and in the present context should include a description of the reliability of species identifications and a description of any changes in the survey design or implementation that may affect the various indicators. The EU directive INSPIRE highlights the need for standardized meta-data describing the database structure and general properties of geo-referenced data collected using public funds.

Analysis and reporting

Many 'biodiversity' metrics can be proposed, with ICES Expert Groups leading on exploratory analyses. Some of these metrics may be suitable for use as indicators, and ICES should lead on a coordinated approach to 'benchmarking' such indicators.

Analyses of data would best be undertaken by an ICES Working Group, and if international trawl survey data are to be used, this would require the participation of multiple Expert Groups. Hence, although WGFE would be well placed to conduct analyses of survey data for fish assemblages (and for certain species not examined by assessment working groups), such studies should be conducted with active participation of IBTSWG, WGBEAM, etc., as well as experts on other national surveys. In terms of commercial stocks, the relevant assessment group should be charged with undertaking the 'biodiversity' assessment, so as to ensure consistency in advice.

Reporting should be made for the appropriate geographical units, ranging from defined, biologically-meaningful fish assemblages to single-species (or stock where possible) units.

9.5 The tradeoffs between fishing and the status of fish populations and communities that need to be considered when setting targets for biodiversity indicators

The Marine Strategy Framework Directive (MSFD) considers that "The marine environment is a precious heritage that must be protected, preserved and, where practicable, restored with the ultimate aim of maintaining biodiversity and providing diverse and dynamic oceans and seas which are clean, healthy and productive" (European Commission 2008). Furthermore, the MSFD "should also support the strong position taken by the Community, in the context of the Convention on Biological Diversity, on halting biodiversity loss, ensuring the conservation and sustainable use of marine biodiversity…".

The MSFD should also "contribute to coherence between different policies and foster the integration of environmental concerns into other policies, such as the Common Fisheries Policy…", and the Common Fisheries Policy (CFP, including in the future reform) "should take into account the environmental impacts of fishing and the objectives of (the MSFD)".

Hence, there will be a need to balance fishing opportunities with 'biodiversity indicators' for both fish and other elements of the marine ecosystem that may be affected by fishing activities, and the MSFD also states that there needs to be "due consideration of social and economic concerns in the setting of targets".

The trade-off between fishing and the status of fish populations and assemblages is a political question. The role of ICES science groups is to highlight the scientific issues, in terms of data collection, analysis and description of status, and to analyse and comment on possible risks associated with different management options. It is the role for other fora (e.g. ACOM and STECF) to advise on realistic targets and the trade-offs between nature conservation and commercial fishing.

Furthermore, the impact of fisheries on any given species of biodiversity interest may be highly variable, as it based on several factors, including the:

a) biological vulnerability of the species to over-exploitation given particular levels of fishing (e.g., fishing mortality relative to natural mortality and other components of population productivity);
b) susceptibility of the species to capture in various fisheries;
c) probability that the species can survive capture and discarding;
d) options for mitigation (e.g. gear modification and/or or changes to fishing practises) that can reduce discard mortality;
e) cumulative effects of other sources of adverse anthropogenic impact;
f) potential indirect effect on species, via alterations in the food web and habitat structure.

9.6 The information, data and tools that are available to assess and quantify these tradeoffs, and the additional data, information and science needs to quantify tradeoffs

The ICES community has only part of the data that are required.

Information to provide metrics on the status of many fish stocks and some fish species of biodiversity interest, and the status of the wider fish assemblage are available for many parts of the ICES area from trawl surveys, though there are some data gaps (see Section 2.7 of ICES 2010 for a summary).

In contrast, data for the social and economic viewpoint may not be available, and such information is generally outside the expertise of WGFE.

The adverse effect of anthropogenic activities other than fishing on marine fish biodiversity has generally not been well studied nor has the cumulative and synergistic effect of different activities.

9.7 How the indicators, targets and tradeoffs might be presented as advice

WGFE is a science group, and consider this to be a question better placed to groups with an advisory role such as WGECO and ACOM. WGFE can provide scientific input into the development and testing of biodiversity metrics for fish, and their utility as potential indicators. The agreement of realistic targets, and balancing these requirements with the management of human activities is an issue for ACOM.

9.8 Potential indicators for the Marine Strategy Framework Directive

In addition to the general approach to indicator development discussed by SIBAS, it is also important to recognise that the European Commission has published examples of potential metrics to indicate on 'Good Environmental Status' (GES) (European Commission 2010). The advantages and disadvantages of some of these suggested metrics have been discussed in various ICES Expert Groups (e.g. see Section 3 of ICES 2011b; Section 11 of ICES 2011c).

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10 Using the Scientific Guidelines for Designing Marine Protected Area Networks in a Changing Climate developed by the NAMPAN-ICES Study Group on Designing Marine Protected Area Networks in a Changing Climate (SGMPAN)

g) Using the Scientific Guidelines for Designing Marine Protected Area Networks in a Changing Climate developed by the NAMPAN-ICES Study

Group on Designing Marine Protected Area Networks in a Changing Climate (SGMPAN), species, habitat, and ecosystem specialists in ICES expert groups are asked to assess ecosystem components to identify which species and habitats appear most vulnerable to climate change and what areas appear to be most in need of protection.

10.1 Introduction

SGMPAN developed during their workshop in August of 2011 "Scientific Guidelines for Designing Marine Protected Area Networks in a Changing Climate" (Brock *et al.*, 2011). The report proceeds on the expectation that climate change affects populations, habitats, and ecosystems differently, depending on their underlying characteristics (ICES, 2011).

"Resilience" is defined as a key concept, describing the ability of an ecosystem to recover from disturbances, or to be resistant against disturbances. The guidelines are based upon the original definition in Holling (1973): 'the magnitude of the disturbance that a system can absorb without fundamentally changing.'

WGFE is asked to "identify which species and habitats appear most vulnerable to climate change" and to "identify areas that appear to be most in need of protection".

Pörtner and Peck (2010) provided a comprehensive review of the current understanding of mechanisms in the impact of climate change on marine ecosystems and fish. SGMPAN (August 2011) lists properties at the level of populations, habitats or the entire system that enhance the resilience of marine ecosystems (Brock *et al.*, 2011).

Table 1 from Brock *et al.* (2011): A list of some properties which enhance resilience of marine systems.

Populations	Habitats	Ecosystems
Connectivity	Heterogeneity	Connectivity (spatial fluxes, trophic connections, mobile link species)
Dependence on critical habitats	Spatial arrangement and composition	Abundance and size structure of upper trophic levels
Sensitivity to environmental conditions	Foundation species	Community size structure of plankton
Flexibility in migration routes	Ecosystem engineers	Phenological matches
Population size and age structure	Level of disturbance	Species richness
Geographic distribution	Bathymetery, topography and rugosity	Functional redundancy (taxonomic diversity)
Number of population subunits or metapopulations	Habitats supporting critical life stages	Response diversity
Phenology	Biogeographic transition zones	Community evenness
		Beta-diversity

10.2 Sensitivity of species or habitats to climate change

Species most vulnerable to climate change

SGMPAN (Brock *et al.*, 2011) listed a number of properties, which enhance the resilience of marine ecosystems to climate change (Table 1). Vice versa, it could be deducted that similar factors as those mentioned in the first column of the table, also determine the vulnerability of individual species, where they could be synthesized in relation to the following properties:

Abundance:

- Population sizes

Population dynamics:

- Population age structure

Spatial distribution:

- Geographical distribution; number of population subunits or meta-populations
- Dependence on critical habitat
- Flexibility of migration routes

Timing of occurrence:

- Phenology

Species' sensitivity to climate change

With respect to exiting knowledge about species' sensitivity to climate change, WGFE finds these questions worth pursuing:

1) How has individual species' sensitivity been detected/ determined?

2) Have mechanisms been identified that lead to sensitivity?

3) Do other stressors apart from climate change enhance sensitivity?

In principle, several approaches could be thought of that may be applied in order to detect sensitivity to climate change. The most obvious are (a) time series analyses of survey data and (b) investigations of the response of a species or habitat to temperature changes, increased acidification, or single events of (climate-related) disturbance. The latter could be sudden rises in temperature or e.g. abrupt changes in turbidity, current intensity or flow patterns with storm events. Under (b), analyses of individual species' sensitivity to parameters like temperature or current strength could in principle be investigated in the field through statistical methods (correlation), or as process studies in the laboratory, supported with process modelling, e.g. through IBM models (Hinrichsen *et al.*, 2011; Peck and Hufnagl, in press).

Apart from the *a priori* sensitivity of an individual species or life stage of fish, other factors may additionally influence the sensitivity. Evidence exists that fishing decreases the stability of fish population dynamics in a way that they become more susceptible to disturbance, and it appears justified to presume that this also refers to disturbance by climate change (e.g. Hsieh *et al.*, 2008).

Anderson *et al.* (2008) analyzed data from the 50-year time series of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) and investigated different hypothesis to explain the overall observation that fished populations can fluctuate more than unharvested stocks. They found some, but limited evidence for the hypothesis that "truncated" fish populations, in which fisheries induced decreased average body size and age, would track environmental fluctuations directly. Strong evidence was in contrast obtained for the presumption that age-truncated or juvenescent fished populations have increasingly unstable population dynamics because of changing demographic parameters such as intrinsic growth rates.

Perry *et al.* (2010) investigated the sensitivity of marine systems to climate and fishing. They claim that, rather than considering the effects of climate and fishing separately, fisheries management should rather take the combined effects and interacts between the two into account. The mechanism by which fishing could make fish more sensitive to climate change would be the mentioned alteration of age and size structures, but also the removal of certain groups from the gene pool, and a shift in dominance of life history traits.

Planque *et al.* (2010) also state that in probably most case, effects resulting from fisheries and from climate change will act in combination, and that rather than separating them, or looking at them in isolation, interactions should be considered. The authors state that exploitation increases sensitivity to climate change and that "overall (and despite the specificities of local situations) reduction in marine diversity at the individual, population and ecosystem levels will likely lead to a reduction in the resilience and an increase in the response of populations and ecosystems to future climate variability and change." Planque *et al.* (2010) conclude that under similar climate forcing, populations of long-lived species with fisheries-induced truncated age structures would be more prone to collapse (and the collapse will likely be attributed to environmental causes). They claim that the critical situation of the North Sea cod is a good example of this phenomenon. For one, strong fishing pressure over a long time would have decreased the size of the spawning stock and narrowed its age structure. At the same time, recruitment success of North Sea cod is negatively correlated with sea temperature (Planque and Frédou, 1999; O'Brien *et al.*, 2000).

Habitats most vulnerable and sensitive to climate change

A large class of habitats that is potentially vulnerable and/or sensitive to climate change is those of biogenic origin. These include structures such as coral assemblages (defined broadly to also include organisms such as sea pens, order Pennatulacea), sponge beds or reefs, beds of emergent plants such as eelgrass or kelp, and densely packed beds of bivalve-mollusks. The traits of those habitats that confer vulnerability and/or sensitivity are best reviewed by respective experts, not WGFE, though the considerations listed above for species are certainly pertinent.

Physical habitat structures that may be affected by climate change include oceanographic features such as fronts, upwelling zones, seasonal sea ice and predominant current patterns. Changes in small and large scale ocean circulation due directly to climate change, and indirectly via enhanced freshwater input due to glacial melting, will affect the nature and location of particular habitats. Where the intersections of geological (e.g., substrate), bathymetric and oceanographic conditions create an important habitat for fish, subtle changes in the latter can alter their use and utility. Understanding sensitivity to climate change in this context also requires expertise that is outside that available in WGFE, specifically in physical oceanographic modelling.

10.3 Guidelines for Designing Marine Protected Area Networks in a Changing Climate

Four high level objectives which the SGMPAN considered to be critical to conferring resilience in the face of climate change are presented as guidelines in (Brock *et al.*, 2011). These are considered in turn with respect to fish and fish habitats.

Guideline 1: Protect species and habitats with crucial ecosystem roles, or those of special conservation concern

Step 1: Identify species and habitats with crucial ecosystem roles or those of special conservation concern.

Step 2: Identify the traits of those species/habitats identified in Step 1 for vulnerability to projected climate change impacts.

> Step 3: Determine whether the traits vulnerable to climate change impacts (Step 2) can be mitigated by or adapted through MPAs or MPA networks.
>
> Step 4: If the traits identified in Step 2 can be mitigated by MPAs or MPA networks, specialists should estimate the timescale over which their subject is expected to respond to climate change and hence trigger a reevaluation of the MPA boundaries.

Steps 3 and 4 relate to the designation and design of MPAs and are not considered here.

In order to apply the guidelines, a clear definition of the overall goal of the network of MPAs is prerequisite. Accordingly, the term “crucial” needs to be defined with respect to this objective to follow. It has to be clarified, whether e.g. maximum biodiversity is the primary goal, or maximum support of certain functional groups, or protection of specific (threatened or declining) species, or maximum yield in the fisheries of desired species.

The perceived importance of the ecosystem role played by particular species, species assemblages or habitats depends crucially on the time scale at which the roles are examined. For example, on a broader scale, ecosystem components that might be considered crucial likely differed prior to and following the advents of widespread whale hunting and industrial fishing. For the Northwest Atlantic, the role of cod (*Gadusmorhua*) has changed in the long term, under the influence of both, fishing and climate (Rose, 2004). Likewise, on a finer temporal scale, the ecological role (and inferred importance) of cod in many NW Atlantic ecosystems has likely changed in as little as the past two to four decades (Link *et al.*, 2009). Like all management interventions, the planning of marine protected area networks requires a clear enunciation of objectives, which in turn require decisions on what ecological targets are desired. In some cases this may involve attempting to preserve the current structure of ecosystems and the goods and services they provide. In other cases it may be to attempt to restore ecosystems to a past state considered particularly productive or otherwise attractive to society. The Scientific Guidelines for Designing Marine Protected Areas in a Changing Climate (henceforth, The Guidelines) are not prescriptive regarding objectives other than conferring increased resilience to climate change. In the absence of the broader nature of marine protected area (MPA) objectives, it is not possible to identify species and habitats that are most vulnerable to climate change and therefore in need of protection in anything but a very general manner. Furthermore, the task of identifying species and habitats most vulnerable to climate change, and in turn identifying priority areas in need of protection, is one that requires a much more detailed analysis than can be provided by the WGFE in an annual workshop. While some species and habitat types are identified here, the aim was mainly to discuss their properties in the context of a prioritization exercise.

There are two broad, yet overlapping, manners in which climate change can be considered in MPA planning. First, MPAs can be planned to achieve various management objectives related to biodiversity, in the context of climate change. Under this scenario climate change is considered as an external factor that can potentially modulate the achievement of stated objectives. Second, MPAs can be planned with the expressed goal of enhancing the resilience of species and habitats that are particularly vulnerable to climate change; buffering against climate is thus a primary goal. The Guidelines do not explicitly make this distinction, though their nature suggests that they aim mainly to advise on this latter MPA planning impetus. The following recommendations from the WGFE were therefore formulated assuming that this was the intention of the Guidelines.

Guideline 2: Protect potential carbon sinks

Step 1: Identify habitats and species that function as potential carbon sinks.

Step 2: Describe the carbon flux system and identify carbon sources that feed the sinks identified in Step 1.

Step 3: Determine whether the carbon flux system is vulnerable to climate change impacts and whether it can be mitigated by MPAs or MPA networks.

Step 4: If the impacts on the system identified in Step 3 can be mitigated by MPAs or MPA networks, topical specialists should estimate the trends and timescale over which the system is expected to respond to climate change.

WGFE considers guideline 2 out of its realm as the working group presumes that fish are not of direct importance as carbon sinks in the world's oceans. In an overall carbon budget, lower trophic levels, which contain orders of magnitude more carbon, would appear to be of interest, here. Thus, WGFE presumes that oceanic carbon flux through fish does not need to be considered in the context of climate change and planning of MPAs. In specific situations on a local or regional level, where fish may potentially be of higher importance, detailed modelling would be needed to quantify their role.

Guideline 3: Protect ecological linkages and connectivity pathways for a wide range of species

Step 1: Identify potential ecological linkages and physical drivers such as prevailing currents.

Step 2: Build and apply dynamic models of adult movement and migration to test hypothesized connectivity among areas, including potential source-sink regions and migratory patterns.

Step 3: Build and apply dynamic models of larval transport to estimate connectivity between regions and identify sources and sinks.

Step 4: Determine whether the critical linkages and pathways identified above are vulnerable to climate change impacts and can be mitigated by MPAs or MPA networks.

Step 5: If the linkages and pathways identified above can be mitigated by MPAs or MPA networks, specialists should estimate the timescale and distances over which the linkages and pathways are expected to respond to climate change and hence trigger a re-evaluation of the MPA boundaries, or design the MPA or MPA network to be robust to these changes.

The criteria within this guideline relating to physical and ecological linkages do not contain a selection of links or pathways. As in guideline 1 only "crucial" species have to be considered, here in this guideline as a start all linkages and pathways have to be considered.

The step 1 of guideline 3, especially the population connectivity section can be used to create a list of fish species that needs to be considered within the context of climate change effects on the design of marine protected areas for these species. This list of species would be the starting point for steps 2 to 5. These Steps most likely reduce the list made under step 1. The ToR as given to WGFE seems to request the list that could be created based on step 1, as it is unrealistic to expect that this group could follow step 2 to 5 for all species defined in step 1 within the time frame of this meeting or in the near future.

Even focusing only on step 1 from this guideline during this meeting will result in an incomplete list of species, which is most likely to contain the obvious candidates. Knowing this, WGFE however will consider the selection criteria described in step 1 and will use them to select fish species and tighten the criteria where needed for fish.

Step 1 contains two overarching mechanisms for selection, population connectivity and food web connectivity. For the later aspect WGFE sees close links with guideline 1 and expects large overlap with the species already there. In case species or areas are important for food web connectivity it is likely that they were already selected on the basis of having a critical role within the ecosystem. Fish species that in the opinion of WGFE need to be considered here, other than the top predators mentioned within the guidelines document, are those that create short energy pathways within the food web. The fish species that consume primary production and are consumed by the top predators, being a highly effective way of transferring energy trough the food web. A species that classifies on this aspect is the menhaden (*Brevoortiatyrannus*) (Rogers and Van Den Avyle, 1989). Potentially many other forage fish need to be considered due to this reasons, but as stated already are likely listed already by guideline 1 having a crucial role within the ecosystem.

The first aspect considered within step 1, population connectivity, could result in a very long list of fish species to be considered in steps 2 to 5. Many fish species have passively drifting life stages or display clear (seasonal) migration behaviour and are as such susceptible to climate change effects. There is no clear guideline to discriminate between the species based on this measure. The duration and distance of drift are mentioned which potentially could be used to rank the species for their susceptibility to climate change, in order to prioritize species for which step 2 to 5 are performed. However it is not directly said that distance and duration by itself define the susceptibility. In many cases the environmental conditions in and the size of the potential settlement area are of more importance. As are other aspects as timing in relation to the match-mismatch theory which are unlikely to be influenced by spatial closures. Furthermore, is not very clear how MPA's would function in relation to passively drifting eggs and larvae. It seems intuitive more useful to make the settlement areas an MPA, as these seem easier to be defined. However, in some cases it might be possible to keep drift pathways free from potential obstructions like wind farms or larger human constructions (e.g. airports in sea or other forms of land reclamation) that could alter the important currents. For this current pathways could be considered for protections, however it might be possible using the models in step 3 to protect future pathways needed in a changing climate.

For the larger migratory fish it is likely that MPAs will have to move with a changing climate, and then still there is only a change of those species occurring in the areas. As long as no permanent obstructions are created between the crucial areas for large migratory fish species, it is likely that they will find their way from one area to the next. This might lead to a loss in energy and reproductive capacity, as they have to spent more energy to arrive in these areas if their regular pathways change owing to a changing climate. In order to create MPA's in a changing climate for these species, it is a necessity to understand why they use specific areas and if these features can be protected by installing MPA's rather than trying to model their migratory behaviour as is suggested in step 2. If the features of a specific area do not occur anywhere else it is unlikely that the species will find its way when climate change prevents it from reaching this crucial area. In case these features occur elsewhere, in at the moment unused areas these areas might become available under a changing climate. These areas seem to be preferred areas for MPAs under a changing climate. However only for a very limited number, if any, of species it is known why they migrate to specific areas. For example, a very well-studied species as plaice (*Pleuronectessplatessa*) is known to migrate seasonally from feeding areas to spawning areas in the North Sea. It is known which areas are used by it, however it is still pretty much unclear which features actually determine these areas (Loots *et al.* 2010) and if these features occur elsewhere as well and might be used by the species in a similar manner.

A species which WGFE considers to be particularly relevant to consider for a network of MPAs is one that requires protection in several locations, because the life stages or subpopulations are connected through ecological or physical linkages.

Guideline 4: Protect the full range of biodiversity present in the target biogeographic area

Step 1: Identify patterns of biodiversity in the target marine biogeographic area

Step 2: Assess the stressors and threats to those areas identified in Step 1 with respect to vulnerability to projected climate change impacts

Step 3: Determine whether the traits vulnerable to climate change impacts (Step 2) can be mitigated by MPAs or MPA networks

Step 4: Assuming MPAs or MPA networks can mitigate the traits identified in Step 3, topical specialists should predict the space/timescale over which their subject is expected to respond to climate change and hence trigger a re-evaluation of the MPA boundaries

WGFE did not consider this guideline 4, because it cannot be answered with respect to fish alone, but rather requires including analyses of the full range of marine species.

10.4 Application of the guidelines (Examples)

Guideline 1 – Step 1: Identify species and habitats with crucial ecosystem roles or those of special conservation concern

WGFE focused on few examples to identify species, which do at the same time take crucial roles within the respective ecosystem, and have also been reported to be sensitive to climate change. The resulting list of species below is accompanied by references to the species' sensitivity to climate change. This list of identified species has in part been taken from (Brock *et al.*, 2011), is here extended, but is far from representing a full list or even a comprehensive overview of the groups of species that would need to be taken into consideration. Associated references have also not yet been completed with a full, systematic literature search. WGFE suggest using this list as a starting point for a comprehensive overview that could be pursued over the coming years, and invites contributions to it from outside the working group.

Species

ZOOPLANKTON

Key zooplankton as prey species for early life stages of a number of commercially important fish species.

- Copepod *Calanus finmarchicus*; Documentation of sensitivity to climate – North Sea, North Atlantic incl. Barents Sea and Norwegian Sea: References in (ICES, 2011); (Hays *et al.*; Heath *et al.*, 1999; McGinty *et al.*, 2011; Ellingsen *et al.*, 2008).
- Copepod *Pseudocalanus spp.;* Documentation of sensitivity to climate: (Stegert *et al.*, 2010) – Baltic Sea
- Krill, euphausiid *Meganyctiphanes norvegica;* References to crucial role within ecosystem: (ICES, 2011 and references therein, p. 95). Documentation of sensitivity to climate: (Saundes *et al.*, 1997; Zhukova *et al.*, 2009; Tarling, 2010).
- Krill, *Euphausia superba*; crucial role on Southern Ocean: multiple references on Antarctic food chains, involving krill as the key zooplankton element.

FORAGE FISH

Key forage fish species for commercially important predatory fish, seabirds, or marine mammals

- Herring (*Clupea harengus*): Documentation of sensitivity to climate – Northwest Atlantic: (Melvin *et al.*, 2009)
- Sand eel (*Ammodytidae*): Sensitivity to climate change in the North Sea has been documented for sand eel(Arnott and Ruxton, 2002): "A negative relationship was detected between sand eel recruitment and the winter index of the North Atlantic Oscillation." Recruitment was negatively correlated with sea temperature during the egg/larval stages. Recruitment was positively correlated with feeding conditions during those stages, particularly the abundance of *Calanus*as prey (The species of *Calanus* has not been specified in this publication). In a study by van Deurs *et al.* (2009), survival of larval sand eel in the North Sea was positively correlated to the abundance of *C. finmarchicus*, but not *C. helgolandicus* during the month of February. [However, NAO_{DJFM} was not found to covary with CPR measures of *C. finmarchicus*, but only with *C. helgolandicus* and overall *Calanus* spp. abundance. – Could be a question of time scale; it has several time been observed that correlations with NOA index are depending on time span considered.]
- Capelin (*Mallotus villosus*): Prey for whales, seabirds and fish, especially cod. Distribution of capelin has been found to be very much dependent on climatic conditions (Rose, 2005). (Anderson and Piatt, 1999): Gulf of Alaska, forage fish capelin declined in the late 1970s in parallel with climate change. Narayanan *et al.* (1995) found that capelin changed their distribution repeatedly on the continental shelf off Newfoundland and Labrador in response to climatic variability between 1980 and 1992. Documentation of sensitivity to climate - Northern North Atlantic: (Narayanan *et al.*, 1995; Rose, 2005; Vilhjálmsson, 2002)

- Horse mackerel (*Trachurus trachurus*) - (Pipe and Walker, 1987; Reid *et al.*, 2001;Beare *et al.*, 2004; Peck *et al.*, 2009)

PREDATORY FISH

- Cod (*Gadus morhua*) – Cod is considered here as a predator of commercial importance. In the North Sea at the present situation, however, its previously crucial role in the ecosystem may be debated. Documentation of sensitivity to climate – Barents Sea: (Kjesbu *et al.*, 2010);– North Sea, Irish Sea, Baltic Sea: (Cheung *et al.*, 2009; Daewel *et al.*, 2008; Daewel *et al.*, 2011; Kjesbu *et al.*, 2010; Brander and Mohn, 2004).
- Hake (*Merluccius merluccius*). Documentation of sensitivity to climate change (e.g., Stenseth *et al.*, 2002). – Mediterranean: Conclusion from time series analyses of hake population development and climate indices that synergistic effects exist between fishing impact and climate (Hidalgo *et al.*, 2011).

Habitats

The Guidelines define habitat as "Those parts of the environment that together make a place for organisms to survive and prosper … and include physical, chemical, and biological components. Physical structure is often the most visible aspect of a habitat and is therefore the basis for most habitat classifications. However, physical structure alone is not sufficient to provide a functional habitat for an organism. Habitats can be dysfunctional, even though the basic physical structure is present, if aspects such as food webs or primary production have been altered. In addition, environmental properties such as temperature, salinity, and nutrient (food) availability greatly influence the use of these areas."

Following from this definition, the properties of habitats to consider when prioritizing them with respect to vulnerability to climate change are discussed primarily from the position of physical structures. In this respect, biogenic habitats and physical habitats that may be affected directly by climate change are primarily considered. The conjunction of physical structure with other environmental properties is certainly a crucial aspect of habitat functionality, but one which requires a much more detailed analysis, that is beyond what the WGFE can deliver this year. Rather than provide a list of habitats that would necessarily be incomplete, a discussion of the factors to consider in identifying habitats with a crucial ecosystem role is presented.

Two factors need to be considered, which in combination form the criteria for the selection of habitats that should receive the highest attention in terms of protection measures:

1) Key functionality; critical habitat

Some habitats are critical locations for the prosperity of individual species or life stages of species. As an example for seabirds, "Northern Gannets breed at only six colonies in North America, three of which are located within the Gulf of St. Lawrence (EC CWS, Waterbird Colony Database). These birds winter in the Gulf of Mexico." (Brock *et al.*, 2011). Obviously, such a strong limitation to very few breeding place would need to be considered in an overall evaluation of environmental impacts on this species.

2) Vulnerability

Some habitats may be particularly vulnerable to factors other than climate change. However, it should be taken into account whether possible negative impacts on such habitats could be enhanced due cumulative impacts of climate change and other sources of disturbance:

- Physically fragile and thus vulnerable habitats, e.g. coral reefs; long-lived deep-water corals;
- Habitats with vulnerability due to slow recovery from impacts, slow growth rates, e.g. long-lived deep-water corals.

Step 1: Identify species and habitats with crucial ecosystem roles or those of special conservation concern.

Existing criteria for the determination and designation of ecologically and biologically significant marine areas provide an excellent basis for identifying habitats with a crucial ecosystem role or of special conservation concern. Borrowing from the criteria developed in Canada, there are three main dimensions along which the ecological significance of habitats could be defined: *uniqueness*, *aggregation* and *consequences to the fitness* of the organisms that benefit from the habitats (DFO, 2004). Under this framework, classification of habitats occurs along a continuum of 'significance' that is necessarily relative. Elevated scoring along any one dimension, or intermediate scoring along two or three dimensions may be sufficient to consider a habitat as significant and possibly crucial.

The *uniqueness* property ranks broadly occurring habitats at one extreme, to habitats whose characteristics are unique, rare, distinct, and for which alternatives do not exist, at the other. Defined in this manner, uniqueness is also scale-dependent, with increasing importance with increasing spatial scale (e.g., the Great Barrier Reef is particularly unique at the global scale).

Habitats considered to not contribute significantly to the *aggregation* property include those that do not support a substantial portion of given fish populations of interest or for which there are many alternatives for those populations. At the upper end, a habitat would be considered as important for the *aggregation* property if most individuals of a species or a life-stage utilized the habitat for some part the year or if the habitat is utilized by a high number or diversity of species.

All habitats contribute to the fitness of the organisms that utilize them, by affecting directly or indirectly the rates of reproduction and mortality. However some habitats have more significant *fitness consequences* than others. Habitats in which crucial life history processes are carried out (e.g., spawning beds, nursery areas, refugia from predation) and whose availability could potentially cause a bottleneck for one or more populations would be considered as significant for their fitness. In cases where these populations represent a designable unit considered at high risk of extinction, the *fitness consequences* of potential habitat loss are all the more significant.

Examples of potentially ecologically significant habitats for marine fish include biogenic structures such as coral assemblages (define broadly to also include organisms such as sea pens, order *Pennatulacea*), sponge beds or reefs, beds of emergent plants such as eelgrass or kelp, and densely packed beds of bivalve-mollusks. They may also include physical structures such as particular substrate granulometry, alone or in conjunction with other important physical characteristics such as temperature, salinity and dissolved oxygen.

The ecological and biological significance of eelgrass (*Zostera marina* L.) has recently been assessed in Canada using criteria very akin to those above (DFO, 2009), providing an example of the type of evaluation that could be undertaken to assess the significance of a species or habitat. Eelgrass is a common, highly productive perennial aquatic plant that can form extensive intertidal and subtidal beds in estuaries and coastal areas in many parts of the north Atlantic, and at the basin scale specific beds would generally not be considered unique. However its function as a habitat structure for fish does score highly on the criteria for aggregation and for the fitness consequences for some populations. Structurally, eelgrass provides cover from predation, reduces local current regimes, and increases productivity of prey by augmenting local habitat complexity and surface area. There are no known eelgrass obligate fish species although the northern pipefish (*Syngnathus fuscus* Storer) is commonly associated with eelgrass habitat in maritime Canada during some phases of its life cycle. Eelgrass habitat has been shown to support higher densities and greater diversity of fishes in comparison to adjacent unvegetated habitats. Furthermore, eelgrass can serve as important spawning and nursery habitat. Some species of fish (e.g. Atlantic cod in northeast Newfoundland) preferentially settle in eelgrass beds while others actively migrate into the habitat post-settlement.

Guideline 1 – Step 2: Identify the traits of those species/habitats identified in Step 1 for vulnerability to projected climate change impacts

Species traits

- Copepod (*Calanus finmarchicus)*:

  Body size; lipid content; timing of high abundance; Abundance and timing of occurrence are important for larval and juvenile fish.

  During the last decades in the North Sea, the portion within the total *Calanus* abundance and timing of occurrence have shifted between the two species *C. finmarchicus* and *C. helgolandicus*; this has been accounted to climate change (Beaugrand, 2003).

  <u>Relevant traits:</u> Abundance; timing of highest abundance; lipid content.

- Krill (*Meganyctiphanes norvegica*)

  Climatic conditions influence maturation cycle of *Meganyctiphanesnorvegica* through ovarian development (Cuzin-Roudy and Buchholz, 1999).

- Krill (*Euphausia superba*)

  Climate change in the Southern Ocean apparently affects the reproductive grounds of krill, and consequently its recruitment, by reducing the area of sea ice formed near the Antarctic Peninsula, which causednoticeable changes in the food web (Loeb *et al.*, 1997; Walther *et al.*, 2002). Stenothermal nature of certain metabolic rates (Buchholz and Saborowski, 2000).

- Herring

  Decadal periodicity of atmospheric conditions were described to govern the alternating herring and sardine periods: Periods of the Norwegian spring-spawning herring and sardines in the English Channel coincided with inverse climatological/ hydrographic situations (Alheit and Hagen, 1997).

Corten (2002) and Planque *et al.* (2010) described the "conservatism" in migration patterns, which leads herring to maintain traditional routes, even under changed environmental conditions, and with possible negative impacts of a changed climate. Planque *et al.* (2010) presented a combined consideration of fishing and climate effects acting simultaneously.

- Sand eel

  Relevant traits: Environment – sea temperature; NAO index during months Dec-Mar; sand eel (species of interest) – larval survival; *C. finmarchicus* (prey) – abundance during larval phase of sand eel

- Capelin

  Relevant traits: Abundance; timing of highest abundance; growth rates. Temperature-dependency of larval growth rates: (Frank and Leggett, 1982).

- Horse mackerel (*Trachurus trachurus)*

  Relevant traits: temperature-dependent rates of egg development and hatching (Pipe and Walker, 1987)

- Cod (*Gadus morhua*)

  Relevant traits: Growth rates, abundance, Predation pressure

Habitats traits or characteristics

Biogenic structures are potentially most vulnerable to climate change impacts. The traits of those habitats that confer vulnerability are best reviewed by respective experts, not the WGFE. Generally, the types of characteristics that induce vulnerability in fish will also be those that make biogenic structures vulnerable, e.g., species with narrow environmental tolerances such as stenotherms, slow growth/late maturity, low dispersal ability, etc.

With respect to climate change and associated elevated and increasing atmospheric CO_2 concentrations, corals may be considered among the most potentially fragile biogenic fish habitats. The bleaching of corals due to water temperature swings to elevated levels is a well-known example wherein a substantial portion of the world's corals have been lost in recent decades. Corals, as calcifying organisms will also be susceptible to ocean acidification resulting from high and increasing CO_2 emissions. Many species of corals are long-lived, slow growing, and therefore will have a particularly low recovery rate.

Vulnerable fish habitats will also include those that are constituted by a convergence of oceanographic, geological and bathymetric characteristics. Though climate change will have a relatively small effect on the latter two characteristics, changes in local water temperature and chemistry (e.g., salinity, acidity, dissolved oxygen concentration) that result directly or indirectly from climate change and/or increased atmospheric CO_2 concentrations, are likely to affect the use and utility of existing habitats. In this manner, the location of areas where a particular convergence of habitat characteristics occurs is likely to change, as is their availability.

10.5 Conclusions from the application of the guidelines

Two different possible approaches (a) MPAs needed for which crucial species and habitats; MPAs to achieve various management objectives in the context of changing climate, (b) MPAs with the principal goal of buffering against climate change effects. - Here considered (b).

Brock *et al.* – page 6 "Here we present Guidelines that consider the ability of marine protected areas and networks to mitigate and adapt in the face of current and future climate change effects."

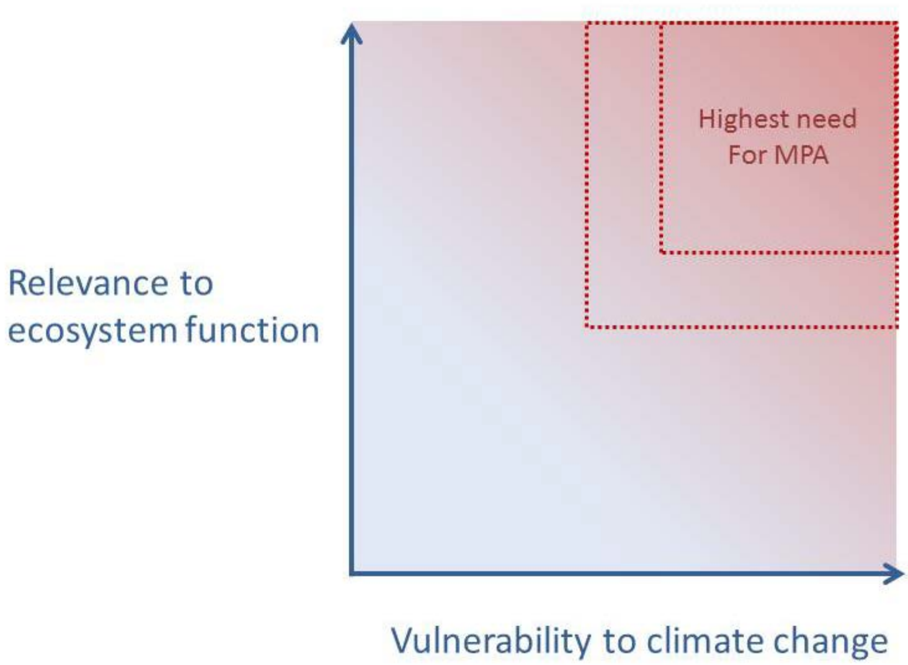

Figure 15. Generic, applies to species and habitats.

Areas most in need of protection

A network of Marine Protected Areas needs to be established with clearly defined objectives to allow for successful planning on the one hand, and for evaluation of its success on the other. The ICES Study Group on Designing Marine Protected Area Networks in a Changing Climate, SGMPAN (ICES, 2011) has considered options under the primary objective of "maintenance and enhancement of ecosystem resilience and resistance in the face of climate change".

An identification of areas most in need of protection, which follows the logic of these guidelines, would need all steps to be taken, based on the species and habitats which are considered crucial. Consequently, WGFE can at this stage not identify these areas.

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11 Climate change processes and predictions of impacts

h) Examine climate change processes and predictions of impacts

11.1 Exploring species-level responses to recent warming in the northeast Atlantic

Simpson *et al.* (2011) looked at the changes in abundance of species in the northeast Atlantic demersal fish assemblage in relation to warming That study used a Eularian (grid-based) approach, analysing trends in each of 172 1x1°lat-long cells to derive indices of change for a species across 11 different surveys. This method was used to directly compare data from surveys with contrasting gears and sampling seasons. For each cell-survey the trend in log-abundance for each species with the trends in temperature was compared. Sea-Surface and Sea-Bottom Temperatures (SST & SBT), were tested using annual as well as winter and summer means, and tested with a 1, 2, and 3-year time lag.

Having determined the strength of association (index of response to warming) for each cell, it was possible to calculate a mean index for a species throughout the region. For the 50 most abundant species, which made up >99% of the total fish, 27 species showed a positive response in abundance to warming (more fish in warmer years) and 9 showed a negative trend (Figure 16).

The index of response in relation to the characteristics of each species was examined to test whether it is possible to make predictions about the likely response of a species to climate change. There was a clear relationship between biogeographic affinity (Figure 17A), temperature preferences (Figure 17B), and a relationship between body size and response (small body size species more likely to respond positive to warming than large body size species).

Species likely to fare well in the northeast Atlantic with continued warming are smaller species of fish, with a southerly biogeographic affinity (Lusitanian), and a preference for warmer waters. These species include red mullet, red and grey gurnard, hake and John dory. In contrast, species likely to be increasingly challenged (such that they decline or move northwards towards more polar regions) are large body species with a northerly biogeographic affinity (boreal) and a preference for colder waters. These species include haddock, whiting, Norway pout and ling.

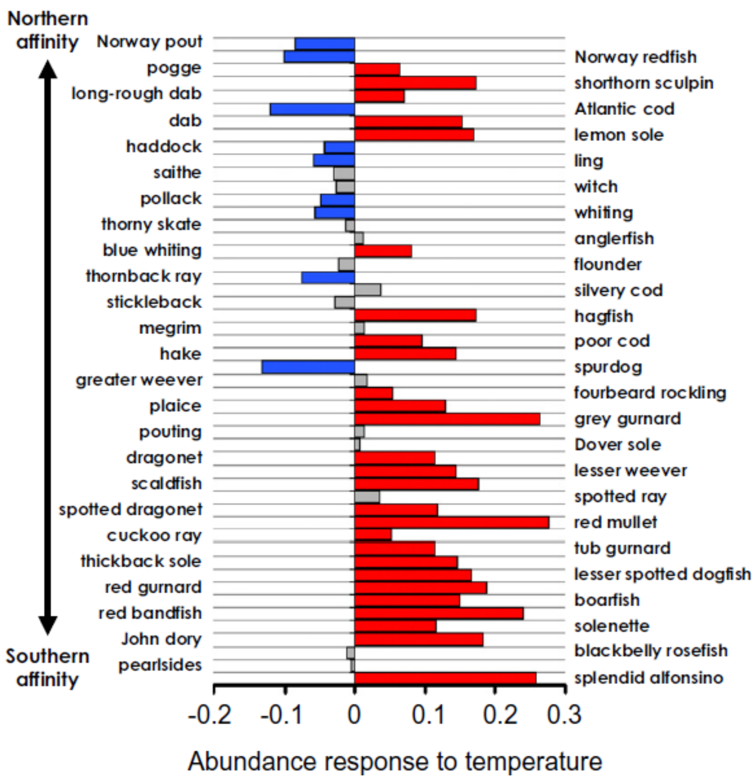

Figure 16. Species Abundance Responses to Warming. Mean species-level relationships between abundance and temperature for the 50 most common species in 172 1x1°cells. Red indicates an increase in abundance in warm years, blue indicates a decline, and gray indicates no significant response.

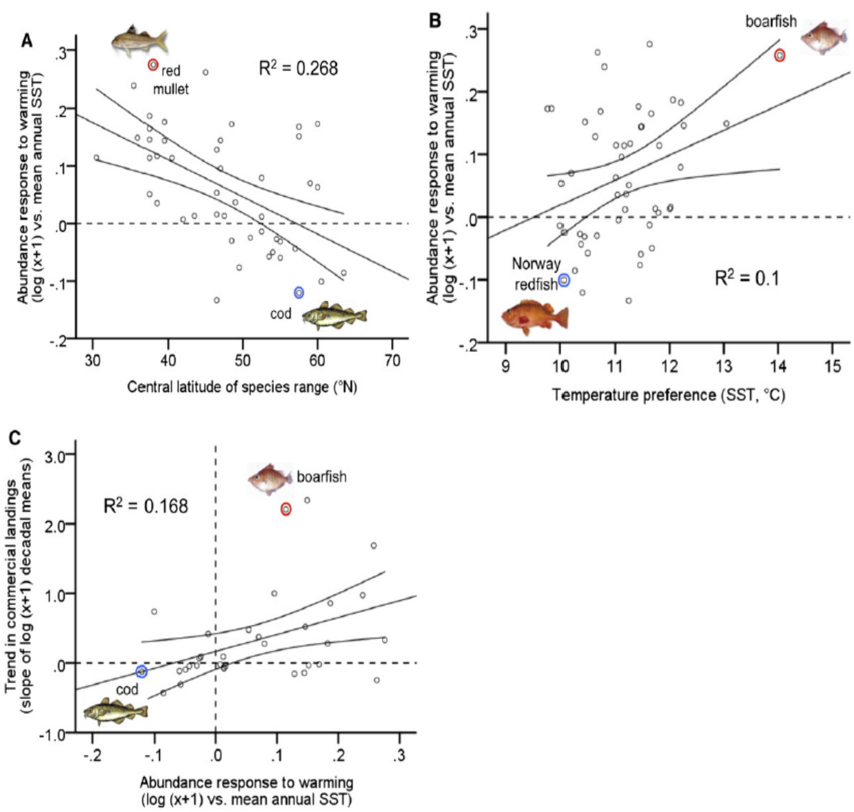

Figure 17. Species Responses to Warming and Impact on Fisheries. (A and B) Abundance response of species to temperature for the 50 most common species in relation to species characteristics: mean latitude of occurrence (A) and preferred temperature (B). (C) Increase in commercial landings of species with positive abundance responses to warming and decline in landings of species with negative responses.

11.2 References

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Annex 2: Agenda

MONDAY 03-OCT

9:30 Opening of the meeting

Adoption of extend list of ToRs and Agenda. Agreement on prioritising ToR f,g and c.

13:00 Lunch

14:00 Reconvene

16:30 Plenary on ToR g: discussion on the outline and the work prepared prior to the meeting.

18:30 Adjourn

TUESDAY 04-OCT

9:00 Start of the meeting: considering the section submitted by the participants working by correspondence.

12:30 Lunch

13:00 Reconvene

13:45 Plenary discussion on ToR f and ToR a

16:00 Discussion on the role of WGFE and possibilities to improve attendance

18:00 Adjourn

WEDNESDAY 05-OCT

9:00 Start

12:30 Lunch

13:00 Reconvene

16:30 Plenary on ToR g and c

19:30 Adjourn

THURSDAY 06-OCT

9:00 Start

9:30 Plenary on Tor F, F is finalized

12:30 Lunch

13:00 Reconvene

15:50 Plenary on ToR c and g

18:30 Discussion on WGFE issues, new chair, next meeting

19:30 Adjourn

FRIDAY 07-OCT

9:00 Start

9:30

12:30 Lunch

13:00 Reconvene

15:00 Plenary on ToR a, b, g, h

17:00 Adjourn

Annex 3: WGFE draft terms of reference for the next meeting

The **Working Group on Fishing Ecology** (WGFE), chaired by Ralf van Hal, The Netherlands, will meet in Copenhagen, Denmark, DATE 2012 [TBC] to:

a) To review and report on existing indicators of biodiversity that are linked to predictable changes in ecosystem function and/or to develop, assess and report on the feasibility and performance of such indicators.

b) To identify and report on functional characteristics that could lead to species being defined as 'keystone'.

All other ToRs will be submitted before the end of this year, as these are still under discussion.

Annex 4: Recommendations

The following Recommendations have been generated by the work of WGFE in 2011. They will be used, along with the Science Plan to guide the formulation of ToRs and work topics within the ToRs for the group. They can also be used more generally, at the discretion of ICES to formulate future directions.

Recommendation	Adressed to
1. ToR a: Present new results on modelling the interacting effects of climate and fisheries on productivity and community structure, including spatial aspects. We recommend that WGSAM takes over this ToR and by doing so takes over these types of modelling.	WGSAM
2. ToR a: WGFE is happy to assist WGSAM with the work on this ToR, any data handeling or reviewing and interpreting of the model results could be done within our group.	WGSAM
3. ToR g: To come up with an extensive list of species and areas as requested for this ToR is not an easy task, that according to WGFE can be done in a week while other ToRs have to be dealt with as well. Therefore we recommend that this ToR on itself should be dealt by in a separate workshop. WGFE could review the outcomes of this workshop.	SGMPAN
4. If there is a ToR proposed by SGMPAN for next year, WGFE proposes that a few members from SGMPAN attend the meeting of WGFE to pitch in and ensure they receive the products they are hoping for.	SGMPAN
5. WGFE struggle with attendance, and it is believed that this partially is caused by unclearity on the role of the WG. WGFE would like to get input on how its role within the ICES community is seen by other Expert groups as well as by SCICOM.	Other Expert Groups: WGECO SCICOM
6. WGFE recommends Ralf van Hal (IMARES, the Netherlands) as the next chair of WGFE for the next three meeting cycle (2012–2014).	