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Report of the Working Group on Small Pelagic Fishes, their Ecosystems and Climate Impact (WGSPEC)

21 January 2010

Cadiz, Spain

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CIEM Conseil International pour l'Exploration de la Mer

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Executive summary

Small pelagic fishes comprise about one third of the world's annual catch and play an important role in most coastal and shelf sea ecosystems in the ICES area. They are very sensitive to climate variability and serve as early indicators for ecosystem changes. The ICES Working Group on Small Pelagic Fishes, their Ecosystems and Climate Impact (WGSPEC) has a high priority because the impact of climate variability on small pelagic fishes and their ecosystems has been largely ignored at ICES, as ICES had put its focus on climate studies of larger predatory fish (cod) and more northern ecosystems. During its half day meeting, the WG discussed relevant subjects for future workshops and theme sessions, as requested by the ToRs. It recommends to organize over the next year three workshops in relation to climate impact on small pelagics and their ecosystems: 1) Workshop on Basin-wide Impact of Atlantic Multidecadal Oscillation, AMO (WKAMO); 2) ICES/PICES Workshop on Reaction of Northern Hemisphere Ecosystems to the Climate Events in the Late 1980s: a Comparison; 3) ICES/PICES Workshop on Climate-driven World-wide fluctuations in Small Pelagic Fish: Reviewing Growth Physiology, Revealing Mechanisms and Unifying Current Theories. This WG is an ideal vehicle to continue and strengthen collaboration with PICES which has been successfully started some years ago in the field of small pelagics and climate by joint workshops and theme sessions. Also, the new interest of ICES in strengthening collaboration with the regional Mediterranean Science Commission (CIESM) is reflected in WGSPEC, as there are various Mediterranean initiatives studying climate impact on small pelagics.

Opening of the meeting

The ICES Working Group on Small Pelagic Fishes, their Ecosystems and Climate Impact (WGSPEC) met for the first time at the Instituto Español de Oceanografía in Cádiz, Spain, in the afternoon of 21 January 2010, back to back with a meeting of the EU Project FACTS (Forage Fish Interactions). The meeting was opened by the chairman Jürgen Alheit, Germany.

1 Introduction

1.1 Background

Small pelagic fishes comprise about one third of the world's annual catch and play an important role in most coastal and shelf sea ecosystems in the ICES area. They are short-lived and feed directly on plankton. Therefore, they are very sensitive to climate variability and serve as early indicators for ecosystem changes. They have usually a prominent position as predators and prey in ecosystems. All this makes them ideal targets for climate studies. Their sensitivity to climate impact particularly evidenced by spectacular population crashes and rises demonstrates clearly the need to consider climate impacts in fisheries management.

This Working Group has a high priority because the impact of climate variability on small pelagic fishes and their ecosystems has been largely ignored at ICES, as ICES had put its focus on climate studies of larger predatory fish (cod) and more northern ecosystems. Impact of climate variability on small pelagics such as herring, sardine, anchovy, sprat and capelin within the NE Atlantic from the Mediterranean in the south to Arctic waters in the north has been demonstrated in a large number of publications, but never been analyzed in a coherent manner comprising all the different ecosystems in this region. WGSPEC attempts to close this gap.

The formation of this new Working Group is a support action for the new Science Strategic Initiative for Climate Change (SSICC) of ICES.

This Working Group is an ideal vehicle to continue and strengthen collaboration with PICES which has been successfully started some years ago in the field of small pelagics and climate by joint workshops and theme sessions. Also, the new interest of ICES in strengthening collaboration with the regional Mediterranean Science Commission (CIESM) is reflected in WGSPEC as there are various Mediterranean initiatives studying climate impact on small pelagics.

1.2 Terms of Reference

a) Prepare a workshop to analyze the impact of climate on ecosystems in which small pelagic fishes such as herring, sardine, anchovy, sprat and capelin play an important role;

b) Suggest relevant joint theme sessions and workshops for ICES and PICES which are also relevant to ICES assessment working groups on pelagic fish;

c) Report by 15 March on potential contributions to the high priority topics of ICES Science Plan by completing the document named "SSGEF_workplan.doc" on the SharePoint site. Consider your current expertise and rank the contributions by High, Low or Medium importance;

d) Prepare contributions for the 2010 SSGEF session during the ASC on the topic areas of the Science Plan which cover: Individual, population and community level

growth, feeding and reproduction; The quality of habitats and the threats to them; Indicators of ecosystem health.

1.3 Participants

The meeting was attended by 13 scientists representing 8 countries (Annex 1).

2 Presentations and Discussions

Jürgen Alheit gave a presentation on impact of climate on small pelagic fish and their environments which is summarized as follows:

Small pelagic fishes such as sardine, anchovy, herring and others represent about 20–25 % of the total annual world fisheries catch. They are widespread and occur in all oceans. They support important fisheries all over the world and the economies of many countries depend on those fisheries. They do respond dramatically and quickly to changes in ocean climate. Most are highly mobile; have short, plankton-based food chains and some even feed directly on phytoplankton. They are short-lived (3–7 years), highly fecund and some can spawn all year-round. These biological characteristics make them highly sensitive to environmental forcing and extremely variable in their abundance. Thousandfold changes in abundance over a few decades are characteristic for small pelagics and well-known examples include the Japanese sardine, sardines in the California Current, anchovies in the Humboldt Current, sardines in the Benguela Current or herring in European waters. Their drastic stock fluctuations often caused dramatic consequences for fishing communities, entire regions and even whole countries. Their dynamics have important economic consequences as well as ecological ones. They are the forage for larger fish, seabirds and marine mammals. The collapse of small pelagic fish populations is often accompanied by sharp declines in marine bird and mammal populations that depend on them for food. Major changes in abundance of small pelagic fishes may be accompanied by marked changes in ecosystem structure. The great plasticity in the growth, survival and other life-history characteristics of small pelagic fishes is the key to their dynamics and makes them ideal targets for testing the impact of climate variability on marine ecosystems and fish populations (Alheit *et al*. 2009).

North Atlantic marine ecosystems are exposed to the forcing of several climatic phenomena, such as the North Atlantic Oscillation (NAO), the Atlantic Multidecadal Oscillation (AMO) and global warming. The interdependence between these different climate indicators and their individual as well as their combined impact on marine ecosystems are extremely poorly understood. At present, a fascinating natural climate experiment involving small pelagic schooling fish with pelagic eggs such as sardines, sardinellas, anchovies and sprats, is going on in waters surrounding Europe, which has been largely ignored, in spite of its acute and future commercial importance for the European fishing industry. Numerous observations by European fishery scientists over the last 20 years demonstrate clearly that small pelagic fish populations in all shelf seas surrounding Europe from the North African upwelling and the Black Sea in the south up to the Baltic Sea and southern Norwegian coasts are shifting their distributional borders to the North with concomitant dramatic changes in abundance and recruitment. Spectacular examples are the invasion of the North Sea by anchovies and sardines since the 1990s which have established spawning populations in this northern shelf sea and the penetration of the western Baltic Sea by anchovies. Another example is the drastic increase of the Baltic sprat stock which was initiated in the late 1980s.

All these pronounced changes in distribution and abundance of small pelagics seem to be associated with recurrent climatic events or periods, oscillations, rather than with global warming. The late 1980s, when the Baltic sprat exploded and, similarly, sudden changes on other trophic levels in the central Baltic were recorded, were characterized by a sudden increase of the NAO index, a climatic signal which also was reflected in the dynamics of other European shelf sea ecosystems and even in northern and central European freshwater lakes. Anchovies and sardines started around the mid-1990s to extend their northern distribution limits into the entire North Sea, several years after the increase of the NAO index. Apparently, they had been spawning there already in the 1940s and 1950s, but disappeared again in the 1960s. Interestingly, from about 1930–1960 and again since the mid-1990s, the AMO, which represents North Atlantic water temperature, has been in a positive phase. Consequently, invasion of anchovies and sardines into North Sea and Baltic seems to be associated with the dynamics of the AMO. Sprat, seemingly a species better adapted to cold water situations than anchovies and sardines does not move out of the Baltic sea in spite of warmer temperatures. Rather, it appears to protract its spawning period into colder seasons of the year. Under extreme conditions as in winter 2002-03, when the summer and fall intrusions of warm North Sea water resulted in rather high temperatures from November to January in the Bornholm Basin, sprat even spawned in winter time, a phenomenon never been observed before.

Assuming that global warming will continue, dynamics of small pelagics will have profound consequences for fisheries and their management in North and Baltic Seas. Sardines and, particularly anchovies, will increase their population abundances, maybe locally up to commercial sizes. Sprat will spawn earlier in the season and its population size will depend on the match/mismatch situation with its food sources. In any case, drastic changes in the dynamics of small pelagics will occur with concomitant problems for fisheries management. As has been observed in the Baltic and other ecosystems, small pelagics are usually good indicators of changes of entire ecosystems. Needless to say that the changes described above for anchovies, sardines and sprat were paralled by similarly dramatic changes in abundance, distribution and phenology of key plankton populations. Consequently, if fisheries management wishes to mitigate these future scenarios, it has to act in the ecosystem context.

Future research on small pelagics in the Baltic has to focus, in addition to routine fisheries monitoring of sprat and anchovy, on reproductive and feeding biology. It has to be verified whether anchovy is successfully reproducing in the Baltic and whether sprat is successfully shifting its spawning period. Such investigations require studies on key species of the entire ecosystem, particularly of the pelagial. Small pelagics although having similar feeding modes of biting and filtering usually have different prey spectra determined by size-selective filtering mechanisms which are even thought to be responsible for alternating abundances or regime shifts. An invading small pelagic fish species can settle successfully only when plankton of the right size is available. Consequently, small pelagics are often indicators of changes in the composition of phyto- and zooplankton communities. Indeed, numerous recent publications have demonstrated dramatic changes in phenology, abundance, distribution and composition of plankton communities in North and Baltic Seas during the last 20 years, often in response to climate forcing. For successful reproduction, fish need, *inter alia*, food of the right size at the right time. Under changing climatic conditions, this might be a problem when the fish and their respective food enter a mis-match situation. Consequently, a successful shift of the spawning period might indicate a profound change in the timing of life cycles of key plankton organisms.

These few examples demonstrate that:

- changes of the dynamics of small pelagic fish populations can indicate profound changes in entire ecosystems, such as regime shifts;
- consequently, small pelagics are an excellent indicator for profound ecosystem changes;
- careful monitoring of dynamics of small pelagics is an indispensable tool of successful ecosystem and fisheries management;
- successful monitoring of small pelagics should be carried out in the ecosystem context.

3 Term of Reference A

a) Prepare a workshop to analyze the impact of climate on ecosystems in which small pelagic fishes such as herring, sardine, anchovy, sprat and capelin play an important role.

3.1 Workshop on Anchovy, Sardine and Climate Variability in the North Sea and Adjacent Areas (WKANSARNS)

Since the mid-1990s, anchovies and sardines have occurred in highly increased numbers in North Sea, Baltic Sea and Irish Sea, sometimes in almost fishable quantities. It has been assumed that this happened in association with climate variability as expressed for example by the NAO and the AMO. The main objective of the workshop is to reveal the mechanism for expansion in the spatial distribution of anchovies and sardines. Current hypotheses are that the observed increase in the species presence in the North Sea result from movements from southern populations or from pulses of North Sea relict populations that already had their life cycles in the North Sea (ICES 2007).

This workshop was already accepted by the SCICOM Steering Group on Ecosystems Function Resolutions in 2009, before WGSPEC was formed. It will be chaired by Mark Dickey-Collas, Pierre Petitgas, and Jürgen Alheit and will meet in Nantes, France, 6–9 July 2010 (Annex 2).

WGSPEC has endorsed this workshop and will assist in preparing and organizing it.

3.2 Workshop on Basin-wide Impact of Atlantic Multidecadal Oscillation, AMO (WKAMO)

Recently observed changes in latitudinal distribution of marine organisms (plankton, benthos, fish) on both sides of the North Atlantic seem to be associated with the dynamics of the AMO and are very similar to observations from the high AMO phase during 1930–1960 and in the late 19th century. This is very obvious for small pelagic fish populations such as sardine, anchovy and herring (see for example Alheit *et al*. 2007), but also for demersal fish such as cod (Drinkwater 2006). Consequently, it seems very likely that the dynamics of marine populations in the North Atlantic are influenced by multidecadal climatic variability. Neither is it known what the origin of the AMO is, nor is the extent of its impact on marine ecosystems understood. In addition, the association of AMO and NAO and their joint impacts are far from clear.

Because of the importance of the AMO for small pelagic fish, a workshop is proposed with these terms of references: 1) Compare and analyze the different hypotheses for the origin of the AMO; 2) Compare and analyze the recent observations of the impact of the AMO on distributional shifts of marine populations on both sides of the North

Atlantic; 3) Compile historical observations of AMO impact during the two known previous high AMO phases; 4) Analyze whether the AMO can be predicted (and, consequently, latitudinal shifts of marine populations). Participants should be recruited from the fields of climatology, physical oceanography, plankton, benthos and fisheries oceanography, biology and assessment.

The workshop will be chaired by Jürgen Alheit (Germany) and Janet Nye (USA) and be organized in summer 2011 in Boston or Providence (USA).

4 Term of Reference B

b) Suggest relevant joint theme sessions and workshops for ICES and PICES which are also relevant to ICES assessment working groups on pelagic fish.

4.1 ICES/PICES Workshop on Reaction of Northern Hemisphere Ecosystems to the Climate Events in the Late 1980s: a Comparison

Regime shifts have been observed during the late 1980s in several northern hemisphere marine ecosystems in the Atlantic and the Pacific such as Baltic Sea, North Sea, Mediterranean, Oyashio-Kuroshio System and the Japan/East Sea which all have important small pelagic resources. A respective multi-authored manuscript has been drafted by an earlier joint ICES/PICES workshop describing the associated climatic teleconnection patterns between these ecosystems which are widely separated from each other. This earlier descriptive exercise will be extended now in a quantitative way. Long-term time series of physical, chemical and biological variables from these regional ecosystems will be compared and analyzed by a team of experts from PICES and ICES countries using multivariate statistics. These studies will yield further insight into how ecosystems change state, as, for example the rates and magnitudes of change are not the same for the different systems reflecting regional specific differences in the forcing factors. In any one geographical ecosystem the expression of changes resulting from climatic forcing may take on different patterns reflecting the detailed mechanisms and local processes that are influential within the constraints of the larger scale forcing. However, there is growing evidence that although climate forcing appears to be a significant trigger for many regime shifts, those ecosystems subject to high levels of human activity such as fishing pressures appear to be at greater risk to this phenomena (ICES 2009).

The workshop will be chaired by Jürgen Alheit, Germany, and NN, PICES, and organized in Koblenz, Germany, in spring 2011. Participation of scientists from the Mediterranean is encouraged.

4.2 ICES/PICES Workshop on Climate-driven World-wide fluctuations in Small Pelagic Fish: Reviewing Growth Physiology, Revealing Mechanisms and Unifying Current Theories

An ICES/PICES workshop on advancing our understanding of the growth energetics of various small pelagic fish species. The workshop would focus on gaining a mechanistic (physiologically-based) understanding of historical and current climate-driven fluctuations in small pelagic stocks by thoroughly reviewing literature on: 1) preferred prey species, rates of feeding; 2) metabolic requirements for growth and 3) environmental regulation of reproduction. Emphasis will be given on inter-specific and intra-specific (among life stage) comparisons of engraulid and clupeid species inhabitating all parts of the world's oceans. A second goal is to identify environmental changes leading to individual - and population-level growth limitation. During the 5

day workshop, participants will make direct comparison of laboratory and field data revealing how climate-driven changes in abiotic and biotic factors regulate growth and survival of egg, larval, post-larval, juvenile and adult life stages. Modelers (IBM, DEB) and biologists will be invited. At least one high impact journal article is planned from the workshop.

The workshop will be chaired by Myron Peck, Germany, representing ICES, NN representing PICES and Carl van der Lingen, South Africa, representing southern hemisphere participation.

4.3 ICES/PICES Theme Session on Climate variability: Responses and Comparison of Northern Hemisphere Marine Ecosystems

This theme session has been accepted by SCICOM for the 2010 ASC in Nantes, France, (Annex 3). WGSPEC endorses this session and WGSPEC members will actively participate.

4.4 PICES/ICES Topic Session Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting

This topic session has been accepted by PICES for the 2010 Annual PICES Meeting in Portland, USA, (Annex 4). WGSPEC endorses this session and WGSPEC members will actively participate.

5 Term of Reference C

c) Report by 15 March on potential contributions to the high priority topics of ICES Science Plan by completing the document named "SSGEF_workplan.doc" on the SharePoint site. Consider your current expertise and rank the contributions by High, Low or Medium importance.

See Annex 5.

6 Term of Reference D

d) Prepare contributions for the 2010 SSGEF session during the ASC on the topic areas of the Science Plan which cover: Individual, population and community level growth, feeding and reproduction; The quality of habitats and the threats to them; Indicators of ecosystem health.

Postponed until ASC 2011.

7 Recommendations and Future Plans

7.1 Recommendations

WGSPEC recommends to organize:

- Workshop on Basin-wide Impact of Atlantic Multidecadal Oscillation, AMO (WKAMO)
- ICES/PICES Workshop on Reaction of Northern Hemisphere Ecosystems to the Climate. Events in the Late 1980s: a Comparison
- ICES/PICES Workshop on Climate-driven World-wide fluctuations in Small Pelagic Fish: Reviewing Growth Physiology, Revealing Mechanisms and Unifying Current Theories

- PICES/ICES Topic Session Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting

7.2 Future Plans

WGSPEC will continue its work by correspondence and during the workshops recommended for the next 12 months. Details of the next working group meeting will be discussed during the WKANSARNS in Nantes in July 2010.

8 References

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Drinkwater, K.F. 2006. The regime shift of the 1920s and 1930s in the North Atlantic. Prog. Oceanogr. 68: 134–151.

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Annex 1: List of Participants

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Annex 2: Terms of Reference for WKANSARNS

2009/2/SSGRSP04 The **Workshop on Anchovy, Sardine and Climate Variability in the North Sea and Adjacent Areas** (WKANSARNS), chaired by Mark Dickey-Collas*, The Netherlands; Pierre Petitgas*, France; and Jürgen Alheit*, Germany, will meet in Nantes, France, 6–9 July 2010 to:

a) Synthesise and test the potential hypotheses for the multi-decadal fluctuations of anchovy and sardine abundance in the North Sea and adjacent areas;

b) Produce a working paper to be submitted for publication on the current understanding of the causes of the fluctuations of abundance relating to the hypotheses raised in a);

c) Recommend areas which required further investigation and highlight the gaps in our knowledge of the dynamics of anchovy and sardine in the North Sea for the purpose of stimulating and advising further research.

WKANSARNS will report by 15 August 2010 (via SSGRSP) for the attention of SCICOM.

Priority	The workshop is considered timely as it will bring together the various projects on small pelagics in the North Sea which have been ongoing. This is seen as a medium priority.
Scientific justification	The workshop fits into the first two thematic areas of the ICES Science plan in that it improves our understanding of the functioning of the North Sea ecosystem and also the interactions of humans with the ecosystem. There are many ongoing projects investigating the dynamics of North Sea anchovy and sardine, but these are as yet not feeding through into the ICES knowledge base. The purpose of this workshop is to aid these investigations by allow a cross fertilisation of ideas between researchers and to produce a working paper (aimed to be published in the peer reviewed literature) on the current state of our understanding of the dynamics of anchovy and sardine in the North Sea and the highlight challenges still remaining. The results will feed into the ICES position paper on climate change being prepared by the SGCC.
Resource requirements	No specific resource requirements beyond the need for members to prepare for and participate in the meeting.
Participants	These would include climatologists, oceanographers, ecologists, ecophysiologists, stock assessment scientists, ecosystem modellers.
Secretariat facilities	SharePoint site, secretarial support for the report.
Financial	None from ICES other than the report.
Linkages to advisory committees	An obvious very close link with the ICES Climate Change steering committee and the PICES FUTURE Scientific Steering Committee.
Linkages to other committees or groups	This area of research has many links to both ACOM and SCICOM expert groups.
Linkages to other organizations	ICES and PICES will seek widened participation for this group including contact with relevant academic and intergovernmental.

Annex 3: Joint ICES/PICES Theme Session

Session S

Joint ICES/PICES Theme Session on "Climate variability: responses and comparison of northern hemisphere marine ecosystems"

Chairs: Jürgen Alheit (Germany), Harald Loeng (Norway), Ann Hollowed, PICES, (USA) and Suam Kim , PICES, (Republic of Korea)

The climate of northern regions is changing and marine ecosystems are heavily impacted by climate variability. Relevant questions related to external forcing functions that link global and regional climate processes to the physical oceanography are *inter-alia*:

- how does the climate vary and what changes do we see in the physical conditions
- how does variability in the physical aspects of the marine systems affect ecosystem structure and processes?
- how can we integrate across spatial and temporal scales to permit forecasting
- how changes in climate may affect the productivity and sustainability of the marine ecosystems?

Climate impact studies have been made within single ecosystems or between different systems of the same region. However, comparisons between ecosystems of different regions or even of different ocean basins are rare. Such comparisons are vital in order to better understand responses of ecosystems to climate forcing, particularly with a view to large-scale climate forcing and teleconnection patterns.

The Theme Sessions invite contributions which compare the development in physical and biological oceanography in different regions of the north. Comparisons of climate variability impact between Atlantic and Pacific ecosystems are particularly welcomed.

Annex 4: FIS/POC/BIO Topic Session

S8: FIS/POC/BIO Topic Session (26 October, 1 day)
Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting
Co-sponsored by ICES

Co-Convenors:
Jürgen Alheit (Germany), Suam Kim (Korea), Harald Loeng (Norway), James Overland (U.S.A.) and Yasunori Sakurai (Japan)

Invited Speakers:
Shin-ichi Ito (Tohoku National Fisheries Research Institute, FRA, Japan)
Franz Mueter (School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, USA)
Hans-Otto Pörtner (Alfred Wegener Institute, Germany)
Kazuaki Tadokoro (Tohoku National Fisheries Research Institute, FRA, Japan)

Understanding the role of natural variability, occurring over a variety of temporal and spatial scales is essential for effective management of marine ecosystems in the wake of predicted global change. Evidence suggests that climate variability can trigger regime shifts in marine ecosystems. Regime shifts are characterized by a reorganization of marine communities, species dominance, and tropho-dynamic relationships. Often, synchronous shifts occur in aquatic ecosystems that are separated by thousands of kilometres. This finding suggests that atmospheric teleconnections are mediating regional system changes. We postulate that comparative studies of ecosystems that have experienced regime shifts will provide insights into the expected responses of marine organisms to climate change. Papers are invited that go beyond simple pattern matching. The primary focus will be on understanding shifts in the pelagic realm, including phytoplankton, zooplankton, small pelagic fishes, gadids, and squids. Preference will be given to research that provides evidence of the functional responses and relationships that underlie regime shifts, and to statistical or modelling studies that successfully simulate observed shifts.

Annex 5: Contribution of WGSPEC to the Science Plan

ICES Science Plan High Priority Research Topic 1 : Understanding Ecosystem Functioning

11 Climate change processes and predictions of impacts

- 111 ICES niche: ecosystem responses to selected physical oceanographic scenarios
- 112 Define responses at the individual and population level to changes
- 113 Changes in distributional patterns at the species and community levels
- 114 Prediction of responses to selected climate change future scenarios (IPCC)
- 115 Responses based on physical-biological interactions and using long-term ICES data

	111	112	113	114	115
WGSPEC	H	H	H	H	H

12 Biodiversity and the health of marine ecosystems

- 121 Biodiversity and scale in ecosystems: genetic, population, species, community levels
- 122 Relate biodiversity to resilience and plasticity of ecosystems
- 123 Define indicators of ecosystem health: attributes of ecosystems, conditions of change, external pressures
- 124 Comparative analyses to study of resilience of shelf seas exploited ecosystems

	121	122	123	124
WGSPEC	L	M	L	M

13 The role of coastal zone habitat in population dynamics of exploited species

- 131 Coastal zone: essential nursery grounds and home of invertebrates, critical to mariculture. These habitats are threatened by human activities.
- 132 Focus on processes linking habitat to spatial patterns at the population and community levels.
- 133 Ecosystem-based marine spatial planning
- 134 Sustaining ecosystem goods and services

	131	132	133	134
WGSPEC	L	L	L	L

14 Fish life history information in support of EAM

- 141 Relate population variability, vulnerability, viability to external and ecosystem drivers.
- 142 Make use of spatial contexts and in particular operational oceanographic products
- 143 Monitor the status of populations and ecosystems with indicators
- 144 Predict population distributions, connectivities, and recruitment
- 145 Relate growth, reproduction, and feeding to the quality of habitats
- 146 Increase knowledge on fish physiology and behaviour, and their genetic basis
- 147 Processes underlying connectivity between populations: larval transport, fish movements

	141	142	143	144	145	146	147
WGSPEC	H	L	L	H	M	M	L

15 Sensitive ecosystems (deep-sea, seamounts, arctic) and data-poor species

- 151 Map habitats for conservation and management: develop habitat classification systems and mapping tools
- 152 Basic studies on the biology and ecology of these species and ecosystems in relation to water circulation, productivity, and climate change
- 153 Vulnerability to fishing: unfished deep-sea habitats, long-lived slow growing species
- 154 Rare species: genuinely rare, apparently rare to sampling
- 155 New species that are as yet unknown to science in these special environments

	151	152	153	154	155
WGSPEC	L	L	L	L	L

16 Integration of surveys and observational technologies into operational ecosystem surveys

- 161 Develop an ecosystem monitoring programme with: existing time-series, emerging survey methodologies, enhanced coordination (plankton nets, acoustics, optics, trawling) and a network of fixed stations.
- 162 Aim of providing indicators in support of advisory needs of integrated management and ecosystem status reporting

	161	162
WGSPEC	L	L

17 Role of top predators (mammals, birds, and large pelagics) in marine ecosystems

- 171 Role in the functioning of marine ecosystems: "top-down" controlled systems
- 172 Anthropogenic impact: removal of larger fish and increase top predators
- 173 Comparative analyses of ecosystem dynamics in response to changes in abundance and relative composition of top predators

	171	172	173
WGSPEC	L	L	L

ICES Science Plan High Priority Research Topic 2 : Understanding of Interactions of Human Activities with Ecosystems

21 Impacts of fishing on marine ecosystems

- 211. Understand the impacts of fishing on all components of the ecosystem.
- 212. Gather information on biota of all types (landings, discards at sea, subject to increased mortality through unobserved interaction with fishing gear) and on habitat.
- 213. Focus on technical challenges associated with collecting and interpreting the data required to assess fishing impacts
- 214. Modify, develop, and implement fishing gears designed to minimize fishing impacts.
- 215. Strategies to reduce the costs of fishing.

	211	212	213	214	215
WGSPEC	M	L	L	L	L

22 Carrying capacity and ecosystem interactions associated with mariculture

- 221. Define carrying capacity for cultured species within diverse coastal environments where there is an increasing competition for space.
- 222. Mitigation of the impacts of aquaculture through the development of multi-trophic aquaculture systems (e.g. kelp, salmon and mussel).
- 223. Interactions between wild and "farmed" species, contaminants associated with disease control and feeds, and escapement impacts.

	221	222	223	224	225
WGSPEC	L	L	L	L	L

23 Influence of development of renewable energy resources (e.g. wind, hydropower, tidal and waves) on marine habitat and biota

- 231 Impacts on ecosystem structure and function: structural habitat features, influence on ocean circulation and mixing
- 232 Evaluate risk of potential impacts, identify mitigation options
- 233 Coordinate multi-disciplinary research to augment existing knowledge base

	231	232	233
WGSPEC	L	L	L

24 Population and community level impacts of contaminants, eutrophication, and habitat changes in the coastal zone

- 241 Understanding the impacts of contaminants at the individual, population and community levels.
- 242 Estimating the cumulative impacts of contaminants, eutrophication, and changes in habitat substrate.
- 243 Synthesize knowledge on the impacts of diverse land-based and marine activities
- 244 Characterize the status of regional coastal zone ecosystems and causal relationships
- 245 Synthesize ecological understanding, identify gaps in knowledge and monitoring needs, based on the rich data sets for the coastal zone

	241	242	243	244	245
WGSPEC	L	L	L	L	L

25 Introduced and invasive species, their impacts on ecosystems and interactions with climate change processes

- 251 Processes that facilitate intentional and accidental introductions of species in the North Atlantic and their drivers (e.g., role of climate change).
- 252 Impact on the distribution and abundance of native biota through niche displacement, ecosystem structure (e.g. biodiversity) and function (e.g. food chain processes).
- 253 Risk assessment modelling for evaluation of management options
- 254 Support the development of regulatory frameworks and implementation of management measures through member countries and IMO, OSPAR, and HELCOM.

	251	252	253	254
WGSPEC	L	H	M	L

ICES Science Plan High Priority Research Topic 3 : Development of Options for Sustainable Use of Ecosystems

31 Marine living resource management tools

- 311 Development of indicator-based evaluations of species and habitats at different spatial scales, with reference points.
- 312 Exploration of management options under the "ecosystem approach"
- 313 Address issues associated with integrated management and conservation objectives.
- 314 Operating needs of the EAM: spatial extent of management areas, strategies to meet conservation objectives and report on ecosystem characteristics.

	311	312	313	314
WGSPEC	L	M	M	L

32 Operational modelling combining oceanography, ecosystem and population processes

- 321 Facilitate the availability and dissemination of long-term data
- 322 Give a reliable description of the actual marine conditions including physical and ecosystem variables, using analyses, forecasts, and model-based products
- 323 Evaluate the accuracy of the predictions as well as limits to forecasting.
- 324 Operational models to support the specific needs for the advisory process.
- 325 Forecasting of trends in recruitment as a function of oceanographic variables
- 326 Prediction of spatial pattern in populations and community properties due to changes in the environment.
- 327 Operational models to predict the development and spreading of harmful algal blooms, and environmental effects in the event of oil spills in the sea.

	321	322	323	324	325	326	327
WGSPEC	M	M	M	L	L	M	L

33 Marine spatial planning, effectiveness of management practices (e.g. MPAs), and its role in the conservation of biodiversity

- 331 Develop and evaluate integrated management procedures of the multiple uses of the oceans, in particular spatial planning tools.
- 332 Predict benthic habitat spatial patterns based on a combination of geomorphological and oceanographic properties.

- 333 Utility of MPAs (with a range of sizes and spatial patterns) for diverse conservation objectives under Integrated Management.
- 334 Sensitivity of benthic habitats to disturbance and reference points on the limits to disturbance for a range of anthropogenic impacts.
- 335 Evaluate GIS methods with respect to the specific needs of marine spatial planning.

	331	332	333	334	335
WGSPEC	L	L	L	L	L

34 Contributions to socio-economic understanding of ecosystem goods and services, and forecasting of the impact of human activities

- 341 Behavioural responses/strategies of the users of ocean ecosystems.
- 342 Social and economic motivations of ocean industries
- 343 How ecosystem goods and services are turned into socio-economic values
- 344 Forecast the impact of human activities and evaluate mitigation options
- 345 Assessment of the resilience properties of marine ecosystems
- 346 Role of biodiversity at the species and genetic levels in ecosystem functioning.

	341	342	343	344	345	346
WGSPEC	L	L	L	L	L	L