SCIENCE FOR SUSTAINABLE MARINE BIORESOURCES

A report for the Natural Environment Research Council (NERC), the Department of Environment, Fisheries and Rural Affairs (DEFRA) and the Scottish Executive for Environment and Rural Affairs (SEERAD)

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Executive Summary

The Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (DEFRA) and the Scottish Executive Environment and Rural Affairs Department (SEERAD) commissioned a study to explore the possibility for improvements in the science supporting current and future management needs in the area of Marine Bioresources*. The study was endorsed by English Nature (EN), Scottish Natural Heritage (SNH), Joint National Conservation Committee (JNCC), the National Federation of Fishermen's Organisation (NFFO) and the Department of Agriculture & Rural Development in Northern Ireland (DARDNI). These improvements are expected to broaden and integrate the science on which management is based by establishing multi-disciplinary research teams drawn from across diverse science sectors. It is recognised that this may require new organisational structures that cut across traditional sectoral, disciplinary and institutional boundaries. Significant changes in the funding relationships between governmental and non-governmental bodies are expected as a result. The ultimate objective is to achieve a culture change in the way partners engage in this science area. The study was conducted over two months in the period January to April 2005, and included visits to key institutions (Universities, NERC Centres, and fisheries laboratories), interviews with scientists and the analysis of submitted forms describing existing research projects.

The study confirmed a number of key issues that need to be addressed:

a) The appreciation that human exploitation of the seas and environmental change are together causing widespread ecosystem change at a pace that is challenging our ability to provide effective scientific advice. As a result, the sustainability of the marine ecosystem is in question.

b) The concern that the marine ecosystem science base in the UK is poorly integrated and highly fragmented. Division in the funding mechanisms, research priorities and research focus between research councils and government departments, and the lack of a clear national marine research strategy is contributing further to this fragmentation. As a result, the use of UK's marine ecosystem science is not maximised or pulled-through effectively to policy.

c) The realisation that changes in the EU Common Fisheries Policy (CFP), favouring a move towards longer-term forecasting more resilient to uncertainties, a progressive regionalisation of the advice, and a determined intention to apply ecosystem considerations in resource management, provides a window of opportunity to re-focus our research approach, long-term vision and science delivery.

The study concludes that a more strategic and holistic ecosystem-oriented research programme is required, integrating aspects from the natural, social and economic sciences. This programme would be conducted in partnership with conservation bodies and user communities to deliver effective ecosystem-based management solutions. This recognises that the necessary framework for understanding and protecting the structure and function of ecosystems has been lacking. This ambitious programme would need a new implementation platform that reflects the diversity of the scientific and stakeholder communities. It is suggested that this platform takes the name of the **Marine Ecosystem Research Partnership (MERP)**, with the following objective:

> "*to provide underpinning interdisciplinary knowledge of the functioning of UK's regional ecosystems to develop sustainable exploitation strategies for marine bioresources, compatible with conservation, and supportive of a diverse and profitable industry".*

The Marine Ecosystem Research Partnership (MERP) should be implemented as a virtual centre of excellence to demonstrate the long-term commitment of the partners to its objectives and goals. However, a central physical body for the Partnership is required to implement the science, to facilitate data access and mobility of resources, and to develop the communication and knowledge transfer tools required to carry the knowledge through to management applications.

A research programme for the first phase of the MERP is proposed, based on an analysis of the UK's strengths, weaknesses and gaps in this science area, and after broad community consultation. The programme is based on four research modules and one cross-cutting data, communication and knowledge-transfer module:

- Module 1 – Long-term patterns of marine ecosystem variability and change
- Module 2 – Comparative ecosystem functioning of UK's regional seas
- Module 3 – Spatial and temporal dynamics of key bio-resources and ecosystem units
- Module 4 – Governance, ecosystem co-management, and the development of innovative scientific advice
- Module 5 – Data Management, communication and knowledge-transfer

* 'Marine bioresources' is used here as a generic term to describe living resources potentially supplied by marine-based organisms (of all trophic levels) across the whole ecosystem, including humans. This definition excludes aquaculture, but includes non-food products

It is suggested that specific research activities be implemented on the basis of consortia bids that address not only scientific needs but also the structural and institutional issues mentioned above. In a second phase, MERP's research should focus on providing effective feedback to support and optimise existing monitoring strategies of the marine ecosystem, and on the delivery of ecosystem based management applications capable of reconciling both conservation and the needs of user communities.

Finally, it is recognised that the common European ownership of many marine resources requires the integration of MERP's research with activities of other European partners. Principles for achieving this integration are briefly introduced.

In conclusion, a number of recent UK-commissioned reports (PMSU 2004, RSE 2004, RCEP 2005), policy changes (CFP 2003), and international agreements, have provided a unified vision of the challenges facing the UK with regards to the conservation and sustainable use of the marine ecosystem. A window of opportunity is offered to respond to these challenges with inclusive scientific vision, but further delay will eventually limit the ability of science to make a difference.

1. Introduction

The Natural Environment Research Council (NERC), the Department for Environment, Food and Rural Affairs (DEFRA), the Scottish Executive Environment and Rural Affairs Department (SEERAD) are seeking to establish a joint venture to tackle critical issues in the area of sustainable exploitation of marine bioresources. The overall thrust expects to:

- integrate the knowledge of fisheries assessment and management, fisheries ecology, marine ecosystems, oceanography, biology and economics held by UK academic, research council and government research organisations
- develop multi-disciplinary research teams drawn from across the UK science sectors, working together under an organisational structure which cuts across traditional sectoral and institutional boundaries, to deliver the best science and management advice that the UK can provide
- achieve a culture change, involving both an opening up of multi-disciplinary access and engagement in this area of marine science, and a significant change in the funding relationships between governmental and non-governmental science.

The first step towards this end was a brainstorming workshop held at the SEERAD-FRS laboratory in Aberdeen on 24-25 May 2004. At this workshop some provisional key science priorities were identified:

- Linking ecosystem variability, fisheries and socio-economics
- Synthesis of knowledge through modelling
- Underpinning of UK marine monitoring programmes

The workshop was followed by a community meeting held at Murrayfield Stadium, Edinburgh on 2 September 2004, with the aim of identifying a number of potential scientific foci as well as the nature of such a venture.

To follow on the momentum created, and to crystallise the ideas put forward in these meetings a scoping study was commissioned to identify new areas of underpinning science and possible ways of implementation/ partnerships required to achieve a step-change improvement in the sustainable ecosystem-based management of marine bioresources. This scoping study was to include visits to key organisations and stakeholders, and an open call for inputs/views. The study was endorsed by English Nature (EN), Scottish Natural Heritage (SNH), Joint National Conservation Committee (JNCC), the National Federation of Fishermen's Organisation (NFFO) and the Department of Agriculture & Rural Development in Northern Ireland (DARDNI). The terms of reference of the study are available in Appendix 1 *[separate document]*.

2. Why a new research activity on "Sustainable Marine Bioresources"?

It is widely acknowledged that a combination of environmental change and human activities are contributing to worldwide changes in marine ecosystems. The pace of these changes is challenging our ability to provide innovative, adaptive scientific advice, and as a result the sustainable and profitable use of the marine ecosystem services is in question.

In addition, the credibility of scientific advice has been challenged. Scientists affiliated to government laboratories are not perceived as independent by all stakeholders; Regularly, their advice is criticised as outdated or incomplete, because it depends on unreliable catch data, because it does not reflect the immediate state of the stocks (the advice process has substantial lags between the most recent data incorporated in the analysis and the implementation of the advice) and because it has no mechanism to incorporate perceived useful knowledge (e.g. changes in distribution or spawning areas as observed by fishers). More often than not though, the lack of credibility for scientific advice reflects poor understanding of scientific methods by the fishing industry as a result of poor communication. Building understanding of and confidence in scientific advice is a significant driver behind the scoping study, and should go hand in hand with improvements in data collection, appropriate treatment of scientific uncertainty and a substantial enlargement of the context of stock assessments. In return this should lead to better access to data and more accurate reporting, thus promoting scientific confidence.

Credibility loss in marine bioresources science is not exclusive to UK. Recognising this fact, the current President of ICES recently recommended a three-pronged approach: separating scientific institutions from management bodies, promoting collaborative research with the fishing industry, and providing transparent quality assurance of scientific advice in a three-pronged approach to address this issue (Sissenwine & Mace 2003).

Governance issues make the management of European fisheries resources extremely complex, and for this reason scientific advice should be robust, historically consistent and therefore justifiably conservative. The other side of the coin though is that EU fisheries management is criticised for “over-simplifying the problem” by relying on single species modelling that assumes that future catches can be forecasted, and that species interactions and ecosystem dynamics can be overlooked. Critics point out that biological uncertainties are not addressed adequately, and that the advice is geared towards providing optimal solutions instead of a set of flexible policy options and associated consequences. There is considerable support to move EU fisheries management beyond short-term forecasts by providing broader advice that takes account of ecosystem dynamics and policy options. This move would be consistent with the European Commission’s desire to move towards a system of advice less sensitive to error, such as one based on harvest control rules (e.g. European Commission 2004, ICES 2005a).

Many UK institutions currently undertake relevant research in the area of Marine Bioresources, but most of them do not participate in the advisory process conducted through ICES working groups. This is primarily because there is no funding available to invite non-governmental scientists to attend ICES working groups. On the other hand, government scientists are not eligible for many research council and academic funding mechanisms, thus limiting their involvement in R+D projects. These constraints do not encourage cross-fertilization between academic and applied research communities, effectively limiting the ability to develop and apply innovative science. Division of funding mechanisms and priorities between Research Councils and Government Departments, and changes in the funding of science in support of the Common Fisheries Policy by Brussels are a barrier to collaboration, which if removed, could provide a substantial enhanced science base to support marine resource management. The lack of a coordinated, strategic vision and direction across this diverse research base means that non-government science is often poorly focused and of low utility to policy makers while government science is dominated by short-term pressures (reactive science) that inhibit strategic science. The development of strategic research objectives across academic and government Institutions would ensure that fisheries science and advice is accessible, diverse and understood outside a small inner circle.

A strong integrated and interactive science base would address some of these shortfalls, while at the same time would increase the UK’s influence while providing the EU with robust evidence to support policy areas that the UK wishes to develop. The urgency in addressing the reality expressed above has been recently brought about by a number of scientific, policy and structural drivers, summarised as follows:

2.1 Scientific Drivers

2.1.1 Climate change – Climate change has already been identified as the biggest threat to the planet by the UK Chief Scientific Advisor. It is likely to cause significant changes in the physical, biochemical and biological functioning of the oceans, and its consequences are already obvious. Annual sea surface temperatures around the UK coastline have warmed by 0.5°C in the period 1871- 2000. Winter bottom temperatures at all North Sea fishing grounds show a 1.5°C warming since the 1970s (DEFRA 2005). Such changes have already been identified as causing many changes in distribution, diversity (Beaugrand *et al.*2002), and phenology (Edwards & Richardson 2004) of marine plankton, plus fish and other nekton (Hawkins *et al.* 2003). The UKCIP02 climate change scenario report (Hulme *et al*. 2002) suggests that a continued rise in the temperature of UK’s coastal waters is expected, with the shallowest seas such as in the southern North Sea and English Channel warming the most (between 2-4ºC up to the year 2080, AFMEC 2005) whilst those off northwest Scotland expecting to warm the least. Ocean warming will have a direct as well as indirect impact on the marine environment. More responsive and adaptive research will be required, linking monitoring and ecosystem modelling efforts with climate-dependent model parameterisation.

2.1.2 Overfishing –The proportion of commercial fish populations in the area covered by the International Council for the Exploration of the Sea (ICES) that is inside 'safe biological limits' has declined from 26% to 16% between 1996 and 2001 (RCEP 2004). In the UK these declines have particularly affected the whitefish sector (cod, haddock, sole and plaice), which are under intense biological and fishing pressure (PMSU 2004). Fishing pressure is particularly intense on large fish. This selective exploitation is known to have caused impacts in ecosystem structure and functioning (Hall 1999, see below), biodiversity loss, and fish stock volatility. There are indications that exploited populations may be losing genetic diversity, which is believed to affect the stock's capacity to adapt to climate change as well as to local conditions. Other indirect effects of, for example, stock volatility, are that it increases the dependence of marine populations on a favourable environment, because of a reduction in the population age structure and a reliance on new recruits to sustain them. While most experts agree that governance, rather than science, is the weakest link in the management chain (Cochrane 2004, Mace 2004), our research base needs to adapt to help manage resources successfully balancing exploitation and conservation needs, rather than react to excessive ecosystem use.

2.1.3 Changes in ecosystem functioning – Climate change and fishing pressures are both impacting the functioning of our seas. These changes are not necessarily linear or geographically consistent though, because of inherent differences in the functioning of the UK's regional seas. For example, the Celtic Sea currently requires twice as much secondary production than the North Sea to support pound for pound in landed fish, yet we do not know whether this reflects natural differences in the functioning of the systems or an indication of differential external impacts. As North Sea fisheries are focussed on lower trophic levels in the marine food web than in the Celtic Seas (industrial fisheries for planktivores in the North Sea *versus* piscivores in the Celtic Seas), the latter hypothesis seems worryingly possible. Trophic analysis suggests that the trophic level of the North Sea has decreased over the last two decades (Jennings *et al.* 2002), partially as a result of total fish biomass declines, suggesting a reduction in the complexity of the marine ecosystem, with potential consequences for ecosystem resilience. Many other examples of differential changes in the functioning of marine ecosystems have been observed in UK waters, from climate-induced changes in the biomass and seasonality of phytoplankton blooms (Reid *et al.* 1998) to fishery-driven changes in seabird abundance as a result of fishing discards (Votier *et al.* 2004). Clearly, a more adaptive, holistic and innovative science, capable of addressing both climate and anthropogenic impacts at ecosystem level is required.

2.1.4 Need for integrated natural and socio-economic research – Resource managers do not manage the marine ecosystem, but rather the use of ecosystem resources by humans. Therefore, the role of people in the successful management of these resources cannot be overemphasised. However, scientific advice for the purpose of fisheries management is almost entirely void of social and economic components (partially because this research sector is poorly developed in fisheries), creating distrust in and conflict with user communities. The need to build trust between politicians, scientists and the fishing industry through multi-disciplinary research that incorporates the concerns, aspirations and knowledge of the user communities is not as recognised as it should be. There are several reasons for this mistrust, including poor understanding of the process leading to the scientific advice, but the principal cause is the exclusion of the fishing industry from the process. Scientific advice is often criticised for been outdated and for using unreliable (misreported) fishing statistics, even though the science cannot be blamed for the lags between the scientific assessment and the implementation of management decisions, nor can it be responsible for the poor reporting of those criticising the advice. There is little doubt, however, that the continuous deterioration in the quality of fisheries data, which is required in the stock assessment process, is compromising the accuracy of the scientific advice, funnelling a spiral of further distrust and potential conflict. This state of affairs can only be addressed through the development of co-management tools involving all stakeholders with adequate buy-in. Cross-disciplinary research in support of co-management arrangements must focus especially on the impacts of management decisions on the stocks themselves, on the ecosystem, on the fishing communities and on the fishing industry, taken into account adaptation and vulnerability issues in both the natural and socio-economic domains. The reformed CFP makes specific reference to the potential of spatially-explicit management to improve sustain-ability. It would be crucial to develop science that takes into account, at the proper scales, not only the dynamics of the resources, but also of the communities making use of them, in a more innovative, holistic, spatially-explicit and adaptive manner.

2.2 Policy Drivers

UK, European and international policy has evolved steadily and substantially from the implementation of the 1992 United Nations Law of the Sea. Many of these policy changes have not been reflected in our research priorities, in the way we conduct research or on the structures needed to deliver advice. These policy changes, however, provide useful guidelines for future scientific implementation:

2.2.1 The Convention on Biological Diversity – The 5th ordinary meeting of the Conference of the Parties (CoP V, Nairobi 2000) agreed (Decision 6) to " endorse the description of the ecosystem approach …, call upon Parties …/… to apply, as appropriate, the ecosystem approach…/…, and invited Parties…/… to identify case-studies and implement pilot projects …/…and strengthen regional, national and local capacities on the ecosystem approach;

2.2.2 The 2001 UN Food and Agriculture Organization (FAO) Reykjavik Declaration – The 47 country signatories of this Declaration (UK included) reached agreement to “.../...individually and collectively work on incorporating ecosystem considerations into management”. For this purpose the signatories agreed to “identify and describe the structure, components and functioning of relevant marine ecosystems, diet composition and food webs, species interactions and predator-prey relationships, the role of habitat and the biological, physical and oceanographic factors affecting ecosystem resilience”.

2.2.3 The 2002 Johannesburg World Summit for Sustainable Development – The WSSD agreed to target the developing of a coherent network of marine protected areas by 2012 and to restore depleted fish stocks to maximum sustainable yields by 2015.

2.2.4 The reformed European Common Fisheries Policy (2003)– This expresses the need to “…regionalise the management of CFP through the establishment of seven Regional Advisory Councils”. In addition the new CFP has adopted a stronger commitment to the protection of the marine environment as a fundamental objective, and the progressive implementation of an ecosystem-based approach to management.

2.2.5 The European Union “Habitats Directive” (2004) - The aim of this Directive is to contribute towards ensuring bio-diversity through the conservation of natural habitats and of wild fauna and flora in the European territory of the Member States to which the Treaty applies, through a coherent European ecological network of special areas of conservation (Natura 2000).

2.3 Structural Drivers

Finally, a number of recent UK commissioned reports and Institutional statements identify structural issues that need to be considered:

2.3.1 The Department of Food and Rural Affairs (DEFRA) strategy entitled “Safeguarding our seas” (DEFRA 2002), which highlights the need for an ecosystem approach to marine stewardship.

2.3.2 The Science & innovation investment framework 2004 – 2014 (DTI 2004) noted that “Research Councils’ programmes [should be] more strongly influenced by and [science] delivered in partnership with end users of research”, to contribute to greater responsiveness of the publicly-funded research base to the needs of the economy and public services.

2.3.3 The Prime Minister’s Strategy Unit report (PMSU2004) calls for Research Councils, universities and government agencies to pool their scientific expertise to deliver the knowledge and understanding needed to progress the objectives and practice of ecosystem-based fisheries management. The report also highlights the importance of innovative and integrated research to widen the scientific scope of fishery management. This conclusion was endorsed by the Inter-Agency Committee for Marine Science and Technology (IACMST), recognising that fisheries science has diverged from other related sciences, like oceanography and community ecology, in maintaining a focus on single-species descriptions.

2.3.4 The RCEP Report (RCEP2004) recommended changes in the emphasis of research away from management of fish populations towards a wider focus on the marine environment. In order to deliver responsible governance scientific advice needs to be relevant, responsive, respected and right, but it must also provide a better means of dealing with the uncertainties associated with ecosystem complexities.

2.3.5 The DEFRA Integrated Assessment of the State of UK Seas “Charting Progress” (DEFRA 2005) which recommends the development and publication of indicators of ecosystem state, in conjunction with OSPAR and EU works programme. This report also recommends the creation of a partnership to provide a national lead in the management and stewardship of marine data and information (MDIP).

2.3.6 The **FAO** has recognised that the implementation of the Ecosystem Approach to Fisheries (EAF) would require a change of present science and management infrastructures (S Garcia;in ICES 2004b), with particular attention to the following scientific areas:

- Better understanding of ecosystem functioning, variability and change
- Better uncertainty and risk assessment and management
- Improved forecasting capacity
- Identification of key indicators
- Provision for assessment of policy and management options
- Integration of socio-economic sciences
- Broader and effective communication with society

- Area based, possibly with nested structures.
- Goals and choices must be scoped with stakeholder involvement (including fishermen) from an early stage
- Cross-sectoral advice to governments, Institutes and stakeholders, possibly through new platforms, such as RACs.

in pursuit of the following EAF objectives (FAO 2003):

- Maintain ecosystem integrity
- Consider species interactions
- Minimize fisheries impact
- Broaden stakeholders participation
- Promote sectoral integration.

There is general support of the view that changing the institutions and processes by which fisheries management is applied, as part of the implementation of the EAF, will have immediate payoffs in improving fisheries sustainability (Botsford *et al.* 1997). While filling scientific gaps is needed, the real challenge may be in crafting new local and regional institutions to deliver policy-relevant science and adequate governance.

3. State of the research in the UK

Having identified the problems, and outlined scientific, policy and structural issues to be addressed, it is important to assess the ability and readiness of the research base to provide the required paradigm shift. As part of the scoping study members of the research, policy, conservation and end-user communities were consulted to identify strengths, gaps and opportunities with regards to scientific expertise in the UK in this area of science. The consultation process was based on the following:

a. Attendees to the Aberdeen and Murrayfield meetings were approached by e-mail and invited to contribute “scoping forms” to describe existing (or completed in the last 2 years) research activities (Fig 1). They were encouraged to circulate this invitation further, but otherwise no attempt was made to actively engage institutions to submit scoping forms. This should be taken into account in interpreting the results. Scientists were asked to fill one form per research project, and were encouraged to send as many forms as necessary (see Appendix 2 *SEPARATE DOCUMENT*).

b. The sponsoring organisations of the scoping study were consulted to draft a list of organisations/ individuals that should be approached for direct consultation (Table 1). However, not all relevant institutions could be visited due to logistical difficulties and time constraints. Over one hundred individuals were consulted. In these visits individuals were encouraged to introduce their research, provide their own view of the state of the research on Marine Bioresources (including Institutional issues), promote support for

Figure 1. ***Distribution of the 191 scoping forms received by research institution (see Appendix 2 for further details*** *SEPARATE DOCUMENT****).***

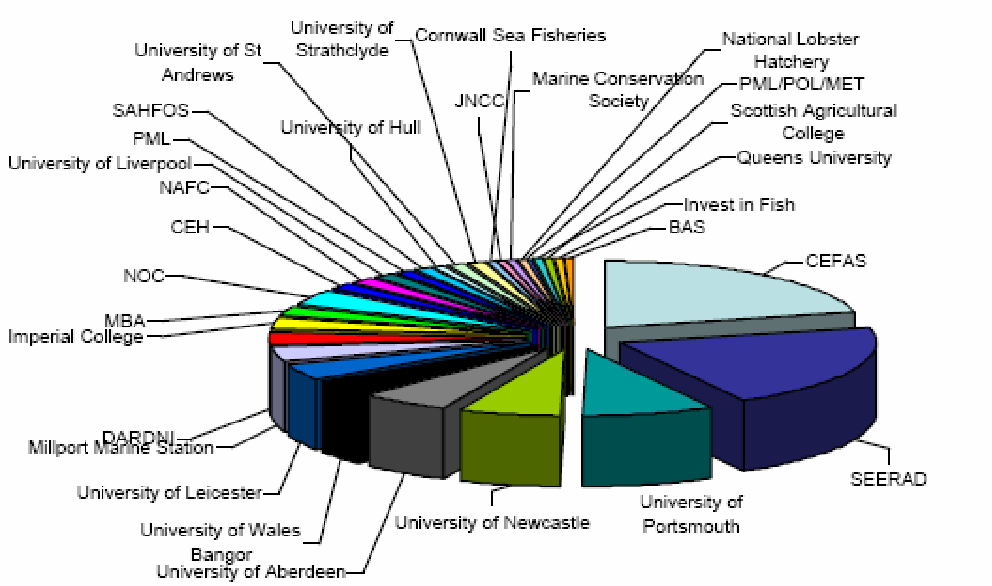


Table 1. ***List of institutions and individuals consulted during the scoping study, through personal visits, e-mail exchanges or telephonic consultation (excluding correspondence related to the submission of scoping forms. See Appendix 2*** *SEPARATE DOCUMENT* ***).***

VISITS

British Oceanographic Data Centre (BODC) – Roy Lowry, Juan Brown
CEFAS – Mike Armstrong, Ewen Bell, Chris Darby, Georgi Daskalov, Clive Fox, Trevor Hutton, Simon Jennings, Andrew Kenny, Steve Malcolm, Julian Metcalfe, Jose de Oliveira, Andy Payne, Ted Potter.
CEH Banchory – Sarah Wanless, Morten Frederiksen, Francis Daunt, Mike Harris
DARDNI – Richard Briggs, Richard Gowen, Matt Service
DEFRA Fisheries Science Unit – John Lock, Michelle Verrecchia
DEFRA Policy Division – Colin Penny, Anthony Hines, Ed Dyson
DEFRA Marine and Waterways Division – John Roberts, Beth Greenaway, Paul Leonard
European Commission DG Fish – Jacques Fuchs, Ernesto Peñas, Miriam Garcia Ferrer, Armando Astudillo
Glasgow University – Bob Furness
Joint Nature Conservation Committee – Mark Tasker, Ian Mitchell, Tom Blasdale, Lee Hastie
Marine Biological Association of the UK – Stephen Hawkins, David Sims, Matt Frost
MET Office – Mike Bell, John Siddorn, Rosa Barciela
National Federation of Fishermen's Organisation – Doug Beveridge
NERC SMRU – Ian Boyd, John Harwood
North Sea Commission – Tony Hawkins
Plymouth Marine Laboratory – Icarus Allen, Jerry Blackford, Mel Austen
Proudman Oceanographic Laboratory – Roger Proctor, John Huthnance
SAHFOS – Chris Reid, Anthony Richardson, Martin Edwards
Scottish Fishermen Federation – Fiona Gowland
Scottish National Heritage – David Donnan, Dominic Counsell
SEERAD FRS – Robin Cook, Bill Turrell, Mike Heath, Nick Bailey
Strathclyde University – Bill Gurney, Doug Speirs, Eddie McKenzie, Jessica Andrews
Univ College London – Sophie des Clers
Univ of Newcastle – Christopher Frid, Nicholas Polunin, Selina Stead
Univ of Plymouth – Lawrence Mee
Univ of Portsmouth (CEMARE) – Sean Pascoe, Premachandra Wattage, Aaron Hatcher, Pierre Failler, Trond Bjorndal
Univ of Wales Bangor – Michel Kaiser, Gary Carvalho
Univ of Aberdeen – Tara Marshall, Graham Pierce, Monty Priede, Paul Thompson, Beth Scott, Martin Solan
Univ of St Andrews – Steve Buckland, John Harwood, Chris Lynam

CORRESPONDENCE/ TELEPHONIC/ VIDEO-CONFERENCE

CEFAS – Carl O'Brien, John Pinnegar
Council for Wales (CCW) – Clare Eno
DFO Canada – Jake Rice (ICES WG Regional Ecosystem Descriptions)
English Nature – Helen Beadman, Daniel Suddaby
FAO – Kevern Cochrane
Imperial College – Murdoch McAllister
North Atlantic Fisheries College – Ian Napier
NOAA National Marine Fisheries Service – Pat Livingston
Royal Commission on Environmental Pollution – Jonny Wentworth
SAMS – Graham Shimmield
UK Cabinet Strategy Unit – Robert Gould
Univ of East Anglia - Edward Allison
Univ Marine Biological Station Millport – Rupert Ormond

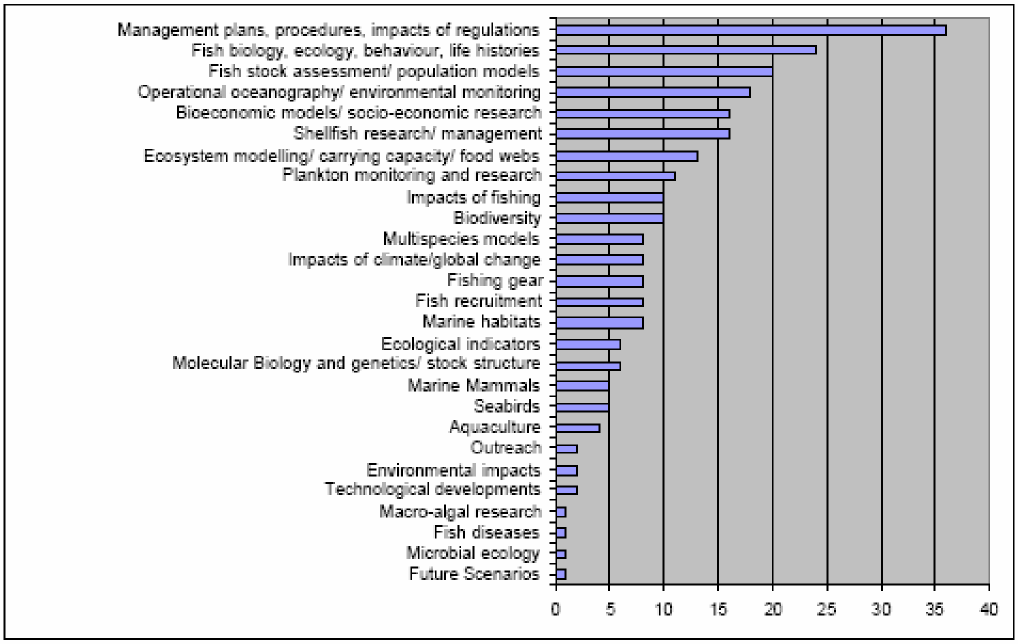
specific areas of research, and contribute views to implementation arrangements for a new activity in this area. Most interviewees contributed scoping forms to back up the conversations.

A total of 191 Scoping forms were received as a result of the call. Although they do not reflect the entirety of the research effort on Marine Bioresources, they provide good indications of strengths and weakness, both scientifically and institutionally. They also highlight the commitment of the community to the spirit of this initiative. Figure 1 presents the results by research Institution, and Table 2 breaks down the forms into research areas. From the forms received and the consultations undertaken, the following overall conclusions were reached:

1. CEFAS and SEERAD are by far the strongest players in this research area. Both institutions (as well as DARDNI) would need to be full partners in any successful UK-wide new research initiative on Marine Bioresources.

2. In addition, a large number of UK institutions contribute to this science area to variable extent. Their contribution complements, and occasionally duplicates, work conducted at the research laboratories. However, some of these institutions appear close to critical mass, and are likely to lose further competitiveness unless their expertise is harnessed better (see below). This provides clear evidence of the fragmented nature of the research base alluded to in the introductory section.

Table 2. ***Classification of scoping forms by science categories. Note that some projects may contribute to several categories.***



3. Collaborations between academic centres and fisheries research laboratories are evident and successful. However, links are informal and based on personal contacts. No formal platforms of collaboration exist, with the result that the capacity of the community is not maximised. In fact, partnerships between UK fisheries laboratories and their European counterparts are stronger than between UK academic and fisheries laboratories.

4. UK institutions have expertise in a wide range of topics in the area of Marine Bioresources research, in particular stock assessment/ management and fish biology (although with substantial gaps in, for example, physical-biological interactions, population processes such as recruitment, food web interactions and spatially-explicit modelling). Ecosystem understanding is fragmented, and modelling approaches to this end are largely academic and are generally not carried through to management applications.

5. Several UK institutions conduct research in support of the Ecosystem Approach to Management, mostly through European Union projects under Framework 6 and specific DEFRA funding. The research is often conducted in close cooperation with European fisheries laboratories. However, it is not adequately framed as part of a comprehensive scientific strategy or programme of research that would maximise the impact of their outputs and engage the scientific community as a whole.

6. In general academic institutions and Fisheries laboratories have a limited understanding of each other's strengths, research activities, delivery pressures and potential to meet each other's research needs. Institutions generally prefer to focus on work that "we can do ourselves" rather that seek out assistance and collaboration to tackle new issues. However, individuals are more flexible and willing to collaborate. Although in principle open to competition, the funding base for applied and academic marine science, both nationally and at European level, is effectively separated, entrenching these Institutional divisions. For example, progressive changes in the European Commission research funding in support of the Common Fisheries Policy have favoured government laboratories because Universities have been reluctant to invest in policy driven science as a result of RAE pressures. Considerable intellectual synergy between academia and fisheries laboratories could be achieved through a concerted effort to coordinate funding opportunities from research councils and government departments in this area of science.

7. There is concern that applied scientists are driven away from academic institutions, because of the emphasis placed on high impact publications in the HEI Research Assessment Exercises (RAE). Penalties on applied research are driving quantitative scientists towards more academic problems or to other countries where applied research is better valued. As a result, the ability of UK HEIs to train future generations of applied marine ecosystem scientists is in question.

8. Academic institutions have little appreciation of the pressures placed on scientists from fisheries laboratories with respect to ICES working group's demands and the need to respond to and advise government (often at very short notice). A 'sharing of the burden' through MERP would be cost effective and would allow space and time for fisheries laboratories to develop collaborative innovative research.

9. Data access remains one of the most significant stumbling blocks in fostering better collaborative science. This refers to issues of data availability, access and knowledge. Surprisingly, this is not only a problem in terms of Academic institutions accessing fisheries laboratories data (and viceversa), but also between fisheries laboratories across UK national borders.

Further analysis of the scoping forms and visits would not be appropriate. However, the information collected is sufficient to propose some basic principles for a new research activity which could address gaps in knowledge and build on inter-disciplinary strengths and needs.

4. Principles behind a new research activity

If marine resource management is to take into account ecosystem considerations, its supportive science needs to be developed to support this style of management. A more strategic and coordinated ecosystem-oriented research is required so as to build sufficient knowledge of ecosystem functioning, and to assess spatial and temporal change. Research should be policy-led to assist in the development of regulations, and should be multidisciplinary to include assessments of social and economic issues. A fully integrated and system-wide research programme may be the first useful step towards an effective ecosystem-based management of UK seas.

The previous section of this report has shown that the UK has a technically expert, but fragmented research base, which impacts on its ability to compete effectively nationally and at European level. What is required is an overarching effort to bring the players together in a collaborative manner, rather than promoting further competition and disintegration.

It is suggested that this collaboration should take the form of a new partnership for additional scientific delivery, here named the **Marine Ecosystem Research Partnership (MERP**, Fig 2**)**. The implementation of a research programme for the partnership is discussed later in this report. This partnership would require a common research strategy in order to rally the community in the same direction. In developing this common strategy the following preliminary aim is proposed:

> ***The aim of the Marine Ecosystem Research Partnership is to provide underpinning inter-disciplinary knowledge of the functioning of UK's regional ecosystems in order to develop sustainable exploitation strategies for marine bioresources, compatible with conservation, and supportive of a diverse and profitable industry***

More specific objectives include:

- To expand existing mono-specific modelling/ management approaches to achieve a more ecosystem process-oriented modelling approach
- To identify ecologically critical processes and consider their spatial and temporal dimensions processes
- To model such processes through multi-disciplinary scientific groups (ecologists, oceanographers, economists, social scientists and fisheries experts), and with full participation of stakeholders
- To develop advisory, management and governance tools based on the approach outlined above, including addressing the social and economic consequences of decisions and conservation objectives.

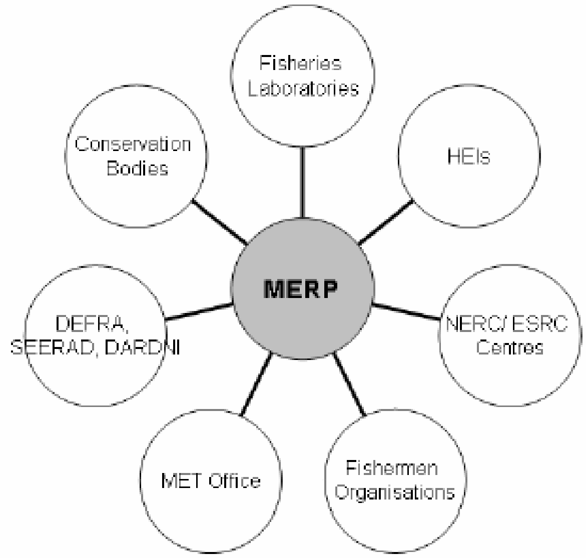
In turn this approach should:

- Reduce scientific fragmentation in the science base
- Increase the capacity and scientific basis of Marine Bioresources scientific advice
- Foster collaboration with Industry and conservation bodies, thus contributing to rebuild trust and scientific credibility.

This aim is to be undertaken predominantly through a set of multi-scale modelling activities so as to bring together the required integrative and synthetic understanding. It would need to be efficiently integrated with UK's marine monitoring efforts. This holistic approach is inspired by the concept of the ecosystem approach to fisheries (EAF, FAO 2003), in sharp contrast to previous philosophies for managing the marine environment that led to fragmented, sectoral and short-term driven scientific advice*.

*The ecosystem approach has its origins in Chapter 17 of Agenda 21 of the 1992 Rio Declaration on Environment and Development. It "...strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties about biotic, abiotic and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries" (FAO 2003).

Figure 2. ***The Marine Ecosystem Research Partnership would involve partners from Fisheries labaoratories, Research Council Centres, Higher Education Institutions (HEIs) and Government departments as well as conservation and user communities***

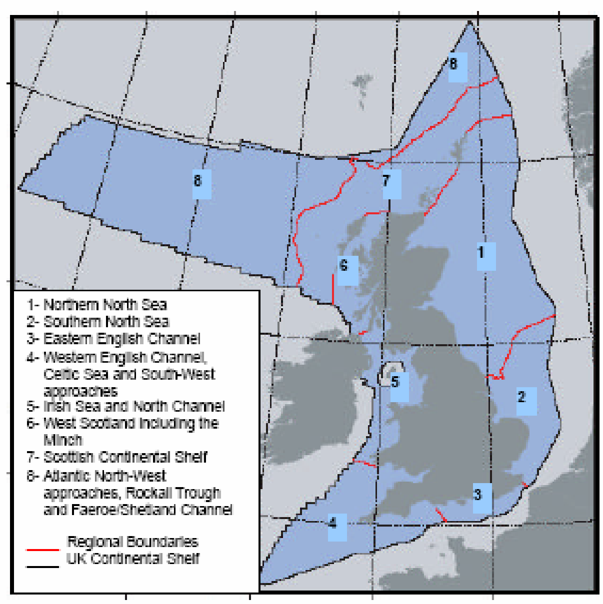


4.1 Geographical scale

The application of the Ecosystem Approach to marine bioresources requires the establishment of agreed geographical regions for which ecological objectives are to be defined and research activities conducted. Many of the activities needed to build integrative and synthetic understanding should be spatially and temporally explicit, while others will require the combination of data from functional geographical areas, in response to potential spatial management needs (e.g. EC Regional Advisory Councils, RAC).

For the purpose of this report, the proposition is to use the biogeographical regions defined by the Review of Marine Nature Conservation (DEFRA 2004, Fig 3), which are delineated in reference to physical and biological features such as tidal fronts, seabed flora and fauna and functional ecosystem properties. The RMNC classification is similar to the "Charting Progress" regional reporting areas (DEFRA 2005), and provides better ecological definition than the OSPAR or ICES Ecoregions, although it may not be appropriate in all situations. In any case, MERP should agree from the onset on a set of sub-ecosystems that would help shaping the proposed science, rather than leaving the geographical scale of operation open to the interpretation of individual scientists.

Figure 3. ***Biogeographical regions defined by the recent review of marine nature conservation (DEFRA 2004)***



4.2 Hydrodynamic framework

Hydrodynamic modelling has developed recently to such an extent that further investment would not be cost-effective under this initiative. MERP should adopt particular hydrodynamic modelling outputs as standard, and build ways of linking these to the biological/ ecosystem/ socio-economic modelling to be developed.

In UK waters, several model structures have been used extensively in recent years, providing an excellent base for further biological modelling, including:

- HAMSOM (HAMburg Shelf Ocean Model, www.ifm.unihamburg.de/~wwwsh/res/HAMSOM/hamsom.html). A three-dimensional shelf sea model developed at the Institute of Oceanography, University of Hamburg. An extended version of the model includes interactive coupling to a thermo-hydrodynamic sea-ice model. HAMSOM has been applied to the simulation of circulation and hydrography of the North Atlantic (e.g. NERC Marine Productivity Thematic).

- POLCOMS (Proudman Oceanographic Laboratory Coastal Ocean Modelling System, www.pol.ac.uk/home/research/polcoms/). The central core of POLCOMS is a sophisticated 3-dimensional hydrodynamic model that provides realistic physical forcing to interact with, plus transport, environmental parameters.

The UK Meteorological Office, the Proudman Oceanographic Laboratory, Plymouth Marine Laboratory, National Oceanography Centre Southampton and the Environmental Systems Science Centre at Reading have recently formed a strategic partnership through the National Centre for Ocean Forecasting (NCOF, www.ncof.gov.uk) with the mission to establish ocean forecasting as part of the national infrastructure. NCOF uses the Forecasting Ocean Assimilation Model (FOAM) and POLCOMS to make predictions of the 3D properties (temperature, salinity, currents) of the oceans and of sea ice. NCOF is able to make predictions of biological parameters for the global oceans through inclusion of the Hadley Centre Ocean Carbon Cycle (HadOCC) model in FOAM, and through the coupled POLCOMS-ERSEM system (see below) for UK and surrounding waters. While biological models must be built on the most adequate physical model for their purposes it would be strategic to use models that build on the forecasting capability of NCOF and its partners.

5. A scientific programme for the new *Marine Ecosystem Research Partnership (MERP)*

The proposed scientific programme of the Partnership is divided into 4 research modules, designed to address the strategic needs identified above (Fig 4, Table 3). The modules are designed to generate synthetic understanding through predominantly (but not exclusively) modelling approaches.

Justification for each Module, a research approach, and key issues to be investigated, are provided below. A selection of potential "blue skies" and "applied" outcomes are also identified for each module. This research structure would allow substantial community input in the design of specific research activities. These would have to be developed on the basis of consortia bids and possibly through planning workshops.

Modules 1-3 are reasonably self-contained, although they support each other through significant commonalities. In fact, the overall programme relies strongly on the synchronic development of each Module.

Module 1 will coordinate the use of the extensive climatological, oceanographical and biological datasets available in the UK to obtain estimates of baseline variability and to generate understanding of the broad forcings operating on marine ecosystems. The Module aims at moving away from specific correlations, which tend to be ephemeral and carry little process understanding, while recognising the parallel changes between many local, regional, basin-scale and planetary variables at decadal scale.

Module 2 will synthesize key aspects of biomass, production and energy flow, at all levels of the food web, by constructing simplified static and dynamic ecosystem models of UK regional seas. These models would be based on functional groupings of ecosystem elements, a process that has been successful for biochemical and phytoplankton modelling, but not as effective in capturing all aspects of the variability in higher trophic level species. The purpose of this Module is to provide a broad ecosystem context to interpret the more detailed dynamics of target species and components of UK marine ecosystems investigated under Module 3, and to provide functional answers to patterns observed under Module 1. This modelling needs to incorporate the top-down controls caused by exploitation practices, as well as bottom-up ecosystem processes.

Module 3 focuses on developing spatially and temporally-resolved models of target ecosystem species or components. This need is triggered by current developments towards spatial management in the European Area, including the establishment of Protected Areas and stock recovery plans, requiring a good understanding of the spatial and temporal dynamics of target resources and of their interactions. The approach proposed recognises the importance of scale in ecosystem processes affecting higher trophic levels, as well as the need to simplify the complexity of marine ecosystems in models by focusing on target species.

Module 4 addresses governance issues, management applications and management advice in the broadest sense, and would have to be largely inter-disciplinary. It will focus research on developing assessment methodologies to valuate ecosystem services and place fisheries in the broader context of multiple ecosystem use. It would also develop inter-disciplinary co-management tools with full buy-in, that recognise biological uncertainty and drives towards setting probabilistic management options rather than the current approach towards an optimal solution.

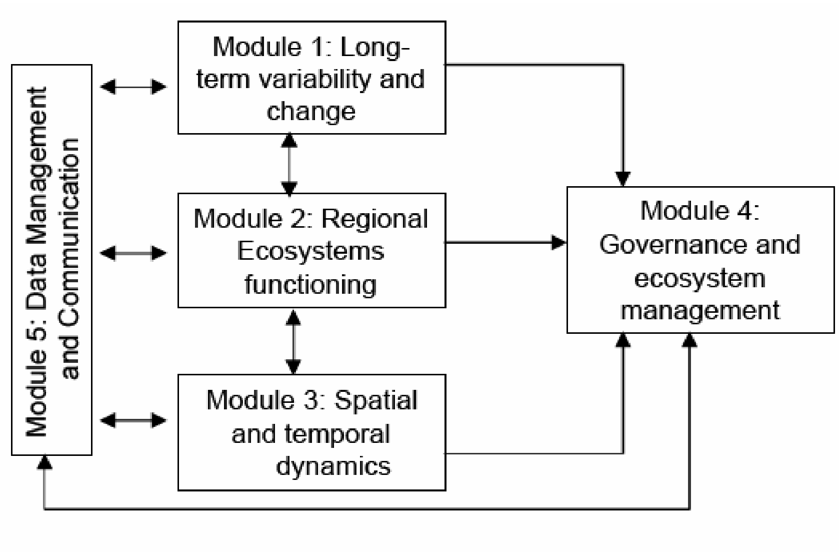
Finally, **Module 5** is a cross-cutting effort, providing overall support to the programme through effective data facilitation initiatives, communication and knowledge transfer. This Module needs strong Data access duties, in recognition of the diversity of data sources, banks, formats and access requirements that would need to be bridged in support of the research programme. A strong emphasis on communication and on the development of institutional platforms for stakeholder collaboration will be set up from the onset. This Module would have to liaise closely with UK and European management and advice bodies to facilitate the transfer of policy-driven knowledge. An adequate communication strategy is considered absolutely necessary to promote adequate buy-in from all stakeholders and to facilitate the integration of scientific and local knowledge into management and advice. It would also cement the role of the Partnership in driving the research agenda and providing independent advice on relevant marine ecosystem issues.

The scientific focus and objectives of the Modules have not been discussed extensively with the community, but were developed as a result of the consultation process.

Table 3. ***Structure of the scientific programme of the Marine Ecosystem Research Partnership in its first phase***

SCIENTIFIC PROGRAMME OF THE MARINE ECOSYSTEM RESEARCH PARTNERSHIP (MERP)
Module 1 – Long-term patterns of marine ecosystem variability and change
Issue 1 - Large-scale earth system drivers of variability
Issue 2 - Detecting and quantifying climate change impacts
Issue 3 - Estimating baseline ecosystem variability at decadal to multi-decadal scales
Module 2 – Comparative ecosystem functioning of UK's regional seas
Issue 1 - Mass- or energy-balanced food web models
Issue 2 - Dynamic ecosystem models
Module 3 – Spatially and temporal dynamics of key bioresources and ecosystem units
Issue 1 - Individual-based models (IBM)
Issue 2 - Demographic or age-structured models
Issue 3 - Multi-species predator-prey models
Module 4 – Governance, ecosystem co-management, and the development of innovative scientific advice
Issue 1 - Ecosystems services assessment methodology
Issue 2 - Participatory governance and management policy
Issue 3 - Fisheries management frameworks in the face of uncertainty
Issue 4 - Scientific frameworks for providing ecosystem-based advice
Module 5 – Data Management, Communication and Knowledge-transfer

Figure 4. ***Scientific elements of MERP and their interconnection***



5.1 Module 1 – LONG-TERM PATTERNS OF MARINE ECOSYSTEM VARIABILITY AND CHANGE

Overarching questions: ***Are biological processes in the marine ecosystem interconnected and responding to atmospheric or oceanographic signals at decadal time scales? How is climate change affecting these interconnections? What are expected levels of decadal baseline natural variability?***

Marine ecosystems and their components are impacted by a number of factors, including intrinsic natural cycles, biological interactions, climatic impacts and anthropogenic activities. Determining the relative importance of these factors is both difficult and urgent, particularly now that ecosystem health appears under threat from both over-exploitation and climate change. In order to apportion responsibilities to driving factors at appropriate temporal and spatial scales, a comprehensive analysis of past records providing a full picture of the dynamics of UK ecosystems over past decades is needed. A coordinated analysis of multi-agency, long-term data sets would provide some basic principles regarding the role of internal and external forcings in determining trends and dynamics in the marine ecosystem at broad scales. These data sets should include multi-scale climatological, atmospheric, oceanographic and biological variables from all available monitoring programmes (including phyto- and zooplankton, benthos, nekton, fisheries-dependent and fisheries-independent surveys, as well as bird and mammal assessments). It must be noted that the UK has, thanks to historical interest in monitoring the marine environment, unparalleled data series available for this purpose, which could be exploited more effectively.

The UK has a substantial body of knowledge linking environmental variables to changes in species biomass and distribution patterns, with significant ecological breakthroughs. For example, the concept of synchronic ecosystem cycles (Russell 1973), the interpretation of ecosystem dynamics through the 1920-40s warm periods (Cushing 1982), identification of changes in production (Fromentin & Planque 1996, Coombs 1975), diversity (Beaugrand *et al*. 2002) and phenology (Reid *et al.* 1988, Edwards & Richardson 2004) of plankton communities, the linkages between sandeels and seabirds (Fredriksen *et al.* 2004), or the causes of the 1960-70s gadoid outbursts (Heath and Brander 2001) among others. While causal relationships are not often resolved (e.g. Southward *et al.* 1995, Beaugrand *et al.* 2002, Attrill & Power, 2002), this body of knowledge provides useful stepping stones towards building ecological theory on broad patterns of ecosystem functioning and on the relative importance of climate change on assemblage composition (Hawkins *et al. 2*003).

A common characteristic of long-term studies is that the species or units analysed are selected (only results from those showing a trend are published), and that only a few of all possible ecosystem interconnections are explored at any given time, often through simple correlations. In the end, full ecosystem understanding cannot be arrived at through specific correlations which provide no evidence for direct causal links and are ephemeral in nature. However, when we see parallel changes in climate, oceanography and biology we are forced to accept (or explore) the nature of the connectivity at broad scales. Ecosystem-wide analyses and synoptic meta-analyses of different compartments are therefore encouraged to provide significant scientific advancement in this area.

The ultimate objectives of this module are: the identification of linkages between external forcings and ecosystem dynamics; the quantification of baseline variability at multiannual to decadal scales; the selection of key processes, periods of change, variables and indicators; and the development of general ecological theory on marine ecosystem functioning. These objectives require a new research platform to facilitate interdisciplinary analysis of long-term data, involving observational scientists, modellers, theoretical ecologists and statisticians, to combine sufficient critical mass. This platform would work towards developing ecological theory on the functioning of open ocean ecosystems, an area that clearly lags behind terrestrial ecological research. For example, terrestrial ecology has demonstrated that the sensitivity to climate variation increases with trophic level (Voigt *et al.* 2003), a crucial concept when exploring potential climate impacts across entire ecosystems. While models have suggested a similar dynamics in the marine ecosystem (Taylor *et al.*2002), this requires considerable development before it is fully understood.

This module would provide scientific underpinning and feedback to existing monitoring programmes by providing a functional basis for monitoring variables at ecosystem level. This functional basis is expected of most monitoring programmes (e.g. the EU ‘Habitats Directive’,92/43/EEC, for the conservation of natural habitats and wild fauna requires member states to monitor and promote the maintenance of biodiversity as a means of assessing the ecosystem health), but is not always achieved.

Specific issues to be investigated through this module include, *inter alia*:

- **Large-scale earth system drivers of variability in the marine ecosystem.** There is widespread recognition that the global climate drives ecological dynamics at large temporal and spatial scales, but we are still learning to disentangle the mechanisms involved. Indices of the Earth’s rotation rate (Stephenson & Morrison 1995), surface air temperature anomalies (Bell *et al*. 2000) or patterns in air pressure systems (Hare

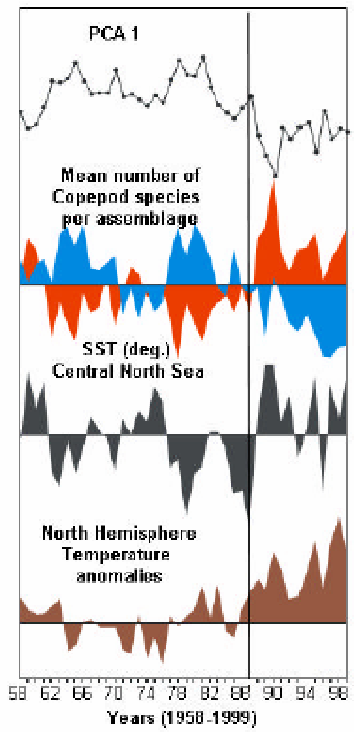
& Mantua 2000, Stenseth *et al.* 2003) have revealed both long-term trends and multi-decadal fluctuations in planetary dynamics. These have been linked to biological indicators at the multi-decadal to centennial (e.g. Baumgartner *et al.* 1992), decadal to multidecadal (e.g. Chavez *et al.* 2003) and interannual to decadal scales (e.g. Stenseth *et al*. 2003). Some conceptual hypotheses linking indices to biological processes have been developed, but they appear to operate only at particular time/space scales, such as the "Optimal Environmental Window" (Cury & Roy 1989), proposed to explain fish recruitment variability in upwelling areas, or the links between the North Atlantic Oscillation and the recruitment of cod and herring in the Barents Sea (Hjermann *et al.* 2004a). Most hypotheses are still conceptually tenuous, like the climate causes of herring variability in the Bohuslan region during the Little Ice Age (Alheit & Hagen 1997), or the remarkable – and unexplained- synchronies in decadal to multi-decadal variability in pelagic fish production in distant ecosystems (Lluch-Belda *et al.*1992). Closer to home, the mechanisms that gave rise to the 1960's gadoid outburst remain unclear, although the links with oceanographic patterns at the North Atlantic scale (NAO, North Atlantic and slope currents indices, Sea Surface Temperatures, etc.) are well known (Heath & Brander 2001). Understanding and ultimately predicting large-scale forcings and their impacts throughout the UK regional Seas is an urgent ecological need, and one capable of providing for substantial development of ecological science in the marine (particularly open ocean) environment.

- **Climate change impacts in the marine environment.** Recent revelations that the rate of increase in atmospheric concentrations of carbon dioxide are even greater than predicted by worst-case scenarios have further heightened concerns over potential effects on biological diversity and its provision of ecosystem services. Models suggest that sea surface temperature will increase by 1-4°C over the next century in some parts of the ocean (Bopp *et al*., 2001). This is likely to have a direct impact on marine ecosystems, including changes in productivity (lower export production in a warm ocean, Bopp *et al.* 2001), biodiversity (O'Reilly *et al.* 2003), food web dynamics (McGowan *et al*., 2003) and biogeographical ranges (Holbrook *et al.* 1997). High-latitude sea ice melting could additionally alter the food web dynamics of sub-arctic ecosystems, making climate change impacts one of the most critical research areas for the foreseeable future. Since the 1950s, Arctic sea-ice extent has declined by about 10–15%, and in recent decades, there has been about a 40% decline in Arctic sea-ice thickness during late summer to early autumn (Houghton *et al.* 2001). However, it would be important to study climate impacts *in the context* of the substantial exploitation of UK regional seas, as causing, respectively, "bottom-up" and "top-down" controls. Adapting our management procedures to the cycles of climate-driven productivity of the marine ecosystem is crucial to reduce the risk of resource collapses (Barange *et al.* 2004, O'Brien *et al*. 2000). Priority research issues include investigating impacts of changes in circulation, ventilation and stratification (e.g. Hansen *et al.* 2003, Curry *et al.* 2003), impacts of changes in frequency and intensity of extreme and episodic events (Urban *et al*. 2000), and direct effects of changes in ocean temperature and light environment, (e.g. phenotypical changes, Edwards & Richardson 2004) on the productivity of marine ecosystems. This research should be linked to climate modelling initiatives by the Meteorological Office's Hadley Centre and other groups (Cox *et al.* 2000) which are expected to produce climate change scenarios for the UK/ European shelf by 2005.

- **Estimating baseline ecosystem variability at decadal to multi-decadal scales: the concept of "stable ecosystem states".** Throughout most of the 20th century, marine ecosystems were regarded as fundamentally stable entities, with fishing considered the only factor capable of upsetting that essential natural stability in a major way (but see Southward 1980). However, this conventional view has been challenged. Around 1977 many zooplankton, invertebrates and fish populations throughout the North Pacific underwent rapid changes in distribution, productivity and abundance (Hare & Mantua 2000). These changes persisted for a decade, followed by a new decade of broad positive productivity (King 2004). The fact that these changes were pervasive and widespread pointed to climate or ocean conditions as the causal factors. In the late 1980s, scientists observed dramatic biological changes in the North Sea, coinciding with the highest positive NAO index records for more than a century (Fig 5). Indicators of such a shift are increased phytoplankton and zooplankton abundances and horse mackerel fish catches (Beaugrand 2004). Alterations in the centre of deep water convection from Greenland to the Labrador Sea and increases in the flow of oceanic water into the North Sea through the Shelf Edge Current appear to be the main drivers for such changes. The events in the North Pacific, North Sea, and other areas (e.g. Baltic Sea, Köster *et al.* 2001) helped to coin the concept of "regime shifts" between "stable ecosystem states" (Steele & Harris 2004).

The existence of alternate 'stable ecosystem states', either driven by climate dynamics or pushed by excessive removals of ecosystem components, is now well accepted in the ecological scientific literature. However, the process by which ecosystems change state by demonstrating dramatic and differential changes in the productivity of many species is poorly understood. Also in need of research are issues such as the regional variability of changes of state, the interactions between climate and fishing pressures in driving (or speeding up) state shifts, and ultimately their predictability. Are shifts driven by common mechanisms affecting both the open ocean (traditionally controlled from the bottom up) and shelf seas (commonly seen as controlled

Figure 5. ***First Principal Component Analysis of biological indicators in the North Sea, mean number of copepod species per assemblage (temperate species in red, sub-arctic species in blue, sea surface temperature in the Central North Sea, and North hemisphere temperature anomalies, 1958-1999, supporting the existence of a regime shift in the North Sea around 1987 (modified from Beaugrand 2004)***



from the top down)? Are changes in state preceded by a loss of resilience (Scheffer *et al*. 2001), and therefore provide some avenue for predictability? Failure to tackle this issue adequately would leave the UK's marine bioresources in a vulnerable state. For example, it is only recently that scientists have recognised that, at the time of the collapse of the North Atlantic cod stocks off the East coast of Canada, the northwest Atlantic Ocean was suffering from widespread ecosystem change (Choi *et al.* 2004, 2005). Decadal scale variability in ecosystem productivity exacerbated excessive fishing pressure, with well known consequences for the sustainability of cod stocks. To resolve the dynamic interplay between ocean physics, biology and exploitation patterns, and avoid similar resource collapses, we need ecosystem understanding at decadal scales, with emphasis placed on the identifying inflexion points that apply across marine ecosystems (Scheffer *et al.* 2001, Choi *et al.* 2005).

- ***Strategic and "blue skies" outcomes:***
  - **Identification of medium (interannual) to long-term (decadal) changes in UK regional seas across several ecosystem levels**
  - **Characterisation of drivers for large-scale ecosystem change**
  - **Climate change impacts on marine ecosystem components**
  - **Interactions between climate-driven cycles of productivity and exploitation patterns as contributing to causing changes in ecosystem stable states**
  - **Generation of hypotheses on linkages between ecosystem elements to be explored through trophic models**
  - **Development of ecological theory on marine ecosystem functioning**
  - **Definition of 'stable ecosystem states'.**

- ***Applied and policy-driven outcomes:***
  - **Provision of baseline variability for model parameterisation at decadal scales;**
  - **Selection of interannual to decadal scale indicators of ecosystem function;**
  - **Exploratory scenarios of ecosystem changes resulting from global change;**
  - **Development of responses to changes in ecosystem stable state;**
  - **Underpinning and value-adding UK monitoring efforts;**
  - **Provision of datasets for modelling activities under Modules 2, 3 and 4.**

5.2 Module 2 – COMPARATIVE ECOSYSTEM FUNCTIONING OF UK REGIONAL SEAS

<u>Overarching questions:</u> What are the main pools and flows of energy in UK regional seas? What are the differences in the functioning of UK regional seas? How are these patterns affected by excessive fishing and how would they determine ecosystem responses to climate and anthropogenic forcing?

This module will attempt to synthesize key aspects of biomass, production and energy flow, at all levels of the food web, by constructing simplified static and dynamic ecosystem models of UK regional seas. The ultimate goal is to provide a broad ecosystem context to interpret the dynamics of key species and ecosystem units under Module 3, and to provide functional answers to patterns observed under Module 1. This will require investigating spatial and temporal differences and similarities in ecosystem functioning, with particular attention to transitions between stable states at the inter-annual to decadal scale, across food webs. This effort requires both extensive data integration and critical examination of model assumptions, particularly conditions of quasi-equilibrium. It must consider the large changes in ecosystem structure and functioning that have been brought about by intense harvesting. While fundamentally hind- and now-casting, some of the models developed under this Module may supply some forecasting ability, thus providing significant synergies with the efforts of the recently created National Centre for Ocean Forecasting (NCOF). This has the potential to further UK leadership in the area of forecasting capability.

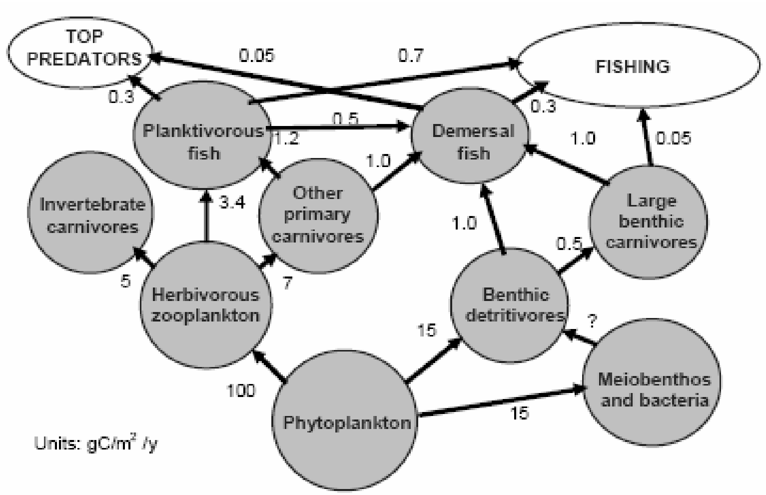
Simplified ecosystem functioning models at decadal scales would assist the interpretation of systemic changes in terms of ecosystem functioning investigated under Module 1. For example, how do changes in zooplankton composition and seasonality (Beaugrand 2004), anchovy and sardine abundance in the North Sea (Beare *et al.* 2004), or declines in white fish biomass affect the functioning of our seas? How do these changes interact with patterns in fishing effort? Can we synthesise these effects in terms of indicators of trophic structure (Pinnegar *et al.* 2002, Jennings *et al.* 2002); and can we use the results to feedback into existing monitoring and data collection efforts?

This module should include several methodological approaches. Energy or mass-balanced models with different degrees of spatial and temporal resolution are particularly good at addressing top-down (consumption-driven) issues. They would be useful to investigate, for example, the broad consequences of shifts in ecosystem structure, changes in carrying capacity, and fisheries impacts on trophic flows. Spatially-resolved dynamic production models are particularly effective to investigate bottom-up (production-driven) issues, including climate change scenarios and fisheries impacts on benthic biodiversity and nutrient cycling (Widdicombe *et al.* 2005). Although the complexity of high trophic level species has limited their ability to reflect fully the dynamics of ecosystems (de Young *et al.* 2004), a combination of dynamic and static mass models should be supported to advance our understanding of the functioning of UK's regional seas.

- **Mass- or energy-balance food web models** – Mass- or energy-balance food web models provide a way for evaluating the importance of predator/prey relationships. The roles of top-down and bottom-up forcing in modelled ecosystems, and the changes in ecosystem structure resulting from environmental perturbations (natural or anthropogenic). Such models have been developed in the past (Steele 1974, Jones *et al.* 1982, Greenstreet *et al.*1997), balancing energy budgets constructed from biomass estimates, diet analysis, evacuation and consumption rates (Fig 6). They provide useful tools to compare seasonal and decadal snapshots of energy flows and standing stock biomasses at different geographical scales. Such models are constructed on simplified functional groupings of species which share similar traits and display similar responses to multiple environmental conditions and therefore can contribute to improving services predict-ability without having to model every species in detail, particularly at decadal scales.

A similar approach, but with a different structure, is the ECOPATH model (Christensen & Pauly, 1992) which has the advantage of having been used in over 160 ecosystems, thus providing ample opportunity for comparative analysis. ECOPATH creates static mass-balanced snapshots of trophically-linked biomass

Figure 6. ***North Sea food web in the 1960-1970s, in Carbon/ year units (from Mike Heath, SEERAD, after Jones 1984 and Bryant et al. 1995). Note that the microbial loop is absent.***



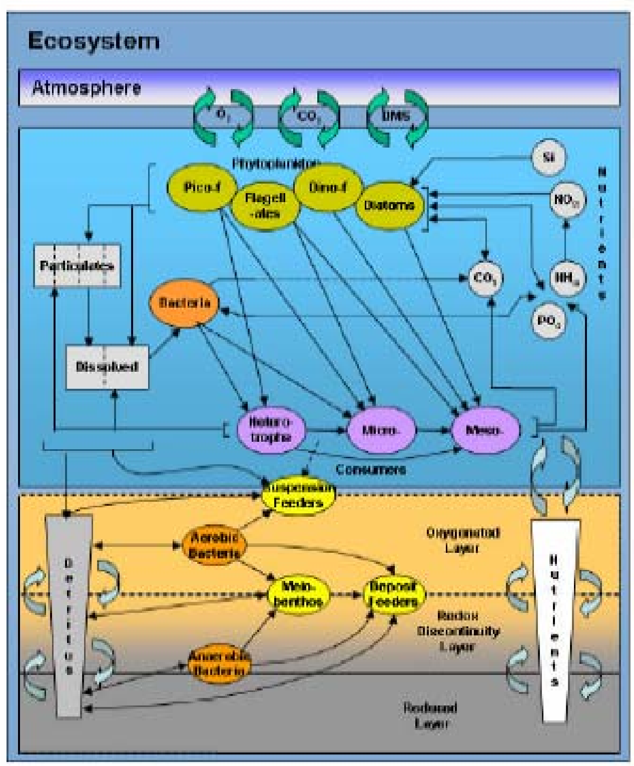
groups and their interactions. Each biomass group may consist of a single species or species groups, potentially split into age groups. ECOPATH is used to address ecological questions, ecosystem effects of fishing and to explore management policy options (Pauly *et al.* 2000). The evaluation of multifaceted policy goals are explored through the ECOPATH extension ECOSYM, a time dynamic simulation module which has built-in policy exploration methods. ECOSIM expresses biomass flux rates as a function of time varying biomass and harvest rates, and predator-prey interactions are moderated by prey behaviour, so that flux patterns can show either bottom-up or top down controls. ECOSIM simulations allow for the fitting of predicted biomasses to time series data, thereby providing more insights into the relative importance of ecological, fisheries and environmental factors in the observed trajectory of one or more species or functional groups. Further development of this suite of models includes the EwE (ECOSIM with ECOSPACE). The latter is a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas (Walters *et al.* 1999). ECOPATH models have been used, for example, to evaluate responses to fisheries management as part of a broad Fisheries Ecosystem Plans, but cannot be used to predict individual species trajectories reliably.

Updated functional food web models would allow comparisons between the functioning of the different Regional seas at different temporal scales, thus addressing issues such as differential carrying capacity and responses to change.

- **Dynamic ecosystem models** - The tools to study ecosystem functioning over relevant temporal and spatial domains have been developing at a considerable pace in recent years. NERC, for example, has funded (partly through the Thematic programme Marine Productivity) the development of a community model system comprising POLCOMS (Proudman Oceanographic Laboratory Coastal Ocean Modelling System) and ERSEM (European Regional Seas Ecosystem Model, Fig 7). This system is considered state-of-the-art in shelf seas coupled physical- lower ecosystem models. This system was designed to address the complex processes involved in simulating and understanding the three-dimensional physical-biogeochemical interactions involved in the pelagic and benthic ecosystems, making it possible to assess conflicting hypotheses rigorously. ERSEM is based on the concept of "functional groups", which has been successful in modelling biochemical processes. This approach is particularly useful to simulate changes in ecosystem function, but is currently limited to the dynamics of lower trophic levels, up to mesozooplankton (despite early attempts to include fish, Bryant *et al.* 1995).

The development of ERSEM to higher trophic levels is a challenge, and the ability of the "functional group" approach to encapsulate the dynamics of zooplankton and fish species has been questioned (de Young *et al.* 2004). The main difficulty in predicting changes in higher trophic species through mass models is that the

Figure 7. Structure of the present PML ERSEM model (courtesy of I. Allen, PML)



processes are demographic rather than biomass-based, and the variation in vital rates between juvenile and adult stages is significant, not linear with body size and difficult to parameterize with confidence. The combined use of mass models with explicit species-based demographic models (proposed in Module 3) would be particularly useful, and would be able to clarify whether the new generation of mass models are capable of detecting and explaining major changes in fish biomass.

The modelling approach proposed in Module 2 is aimed at providing a more detailed comparative understanding of production processes in UK regional seas, and of factors controlling the dynamics of broad ecosystem units. Reconstructing food webs and energy budgets during contrasting decadal time periods will provide added value to the work undertaken under Module 1 (e.g. by investigating transitions between critical periods), and will generate hypotheses to be tested under Module 3. The static and dynamic modelling approaches discussed will rely on past and present survey programmes of UK continental shelves. However, given the changes that have occurred over the last decades, it would be important to ensure that existing field programmes conduct low intensity diet monitoring of as many fish species and areas as possible. This is in order to develop models that reflect present trophic linkages. This low intensity monitoring is apparently not available at present (Joe Horwood, CEFAS, pers. comm.).

- ***Strategic and "blue skies" outcomes:***
  - **Comparative functional dynamics of regional seas (carrying capacity, turnover rates, ecological implications of the balance between pelagic/ demersal energy flows in different regional seas, stability and vulnerability, resilience to external impacts, among others)**
  - **Investigate transitions between decadal cycles of productivity across regional ecosystems**
  - **Consequences of differential pelagic versus demersal flows in shelf ecosystems**
  - **Potential assessment of differential responses to climate regimes and fishing pressures at community and ecosystem level**
  - **Optimal trophic strategies for exploiting regional ecosystems.**

- ***Applied and policy-driven outcomes:***
  - **Description of "viable ecosystems"**
  - **Provision of indicators of ecosystem functioning at regional scale**
  - **Evaluation of ecosystem effects of fishing on benthic and pelagic energy flows and turnover rates**
  - **Explore broad ecosystem management options**
  - **Contribute to Fisheries Management Plans**
  - **Provision of datasets for modelling activities under Modules 3 and 4.**

5.3 Module 3 – SPATIAL AND TEMPORAL DYNAMICS OF TARGET BIORESOURCES AND ECOSYSTEM UNITS

<u>Overarching questions:</u> What are the spatial and temporal structures and dynamics of key marine bioresources and ecosystem units? Can we model the interactions between these structures and the dynamics of user communities? Can we use these models to investigate impacts of management decisions on these resources and on the user communities exploiting them?

The importance of incorporating spatial dynamics in stock assessment is well recognised both to avoid misinterpreting fisheries statistics and to design spatial management tools. For example, decreases in fishing mortality estimates through VPA could result in fishing out particular sub-stocksif the species is managed disregarding potential sub-stocks (Daan 1991). Current developments towards developing spatial management tools for fish resources in the European Area, including the potential establishment of Protected Areas, the implementation of stock recovery plans and the regionalisation of scientific advice, requires a good understanding of the spatial and temporal dynamics of these resources and of their interactions. Spatial understanding has been dwindling through time in the ICES area as a result of the present management procedures that only require statistics per "fishing area" and that disregard spatial dynamics inside each area.

Concerns over loss of genetic diversity due to differential fishing impacts, further supports research on spatial dynamics. Intense harvesting causes rapid genetic changes in life history parameters (e.g. age at maturity, Hutchinson *et al.* 2003). Changes in genetic structure are likely to be reflected in behavioural differences, reduction in evolutionary potential (Hauser et al. 2002), and therefore may affect recovery rates. A combination of demographic spatial modelling using traditional and innovative units (e.g. numbers per genetic sub-stocks), should be encouraged to develop spatial management tools based on adequately-resolved and meaningful biological processes.

However, spatially and temporally-resolved models are difficult to implement because of knowledge gaps. This has been successfully overcome by concentrating modelling resolution on specific key bioresources whilst decreasing resolution with distance up and down the trophic scale, in models of skipjack tuna in the Pacific (Lehodey *et al.* 2003) and *Calanus finmarchicus* in the North Atlantic (Gurney *et al.* 2001). It is possible to make solid synthetic advances in our understanding of the dynamics of key bioresources and ecosystem units by concentrating model resolution as illustrated above, and by making full use of existing databases and monitoring programmes. An effective partnership with the fishing industry to get access to high resolution vessel and catch information would be useful. It is, however, likely that some additional field work may be needed, because of the limited available knowledge of the most basic processes affecting our fish resources. This field work should be limited to providing data for model parameterisation of processes such as:

- Recruitment processes (location, distribution, abundance and survival of spawners)
- Migration processes from larval stages to adults (including the use of microsatellite genetic markers to determine routes and rates, Nielsen *et al.* 2001, and other innovative technologies)
- Fishing fleet dynamics.

Other processes requiring specific field work may be identified during the process of model definition. Limited exercises to test model results would also be needed.

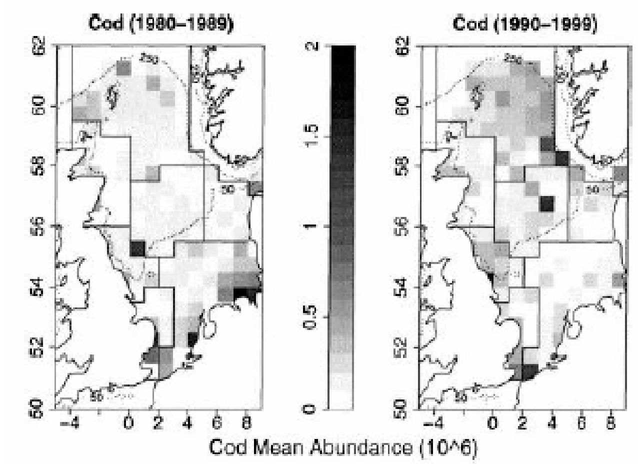
The overall goal of this Module is to generate a comprehensive understanding of the functioning of key bioresources and ecosystem units, through the following modelling approaches:

- **Individual-based models (IBM)** - Individual Based Models are particularly useful to synthesise information of processes between spawning and recruitment. Understanding recruitment success, the most important factor in determining inter-annual variability in spawning stock biomass, remains one of the most challenging scientific areas in fisheries. IBMs are based on the release of particles, endowed with biological properties (e.g. buoyancy, swimming, growth, feeding relationships, dispersion patterns, etc.) in the virtual currents resulting from the output of hydrodynamic models. Features are generally age-dependent and sensitive to the ambient fluid state (temperature, salinity, stratification, turbulence) and to the biological environment (e.g. prey concentrations, predation). The particles can be tracked through virtual time and space and their final locations assessed in terms of previously defined criteria. For MERP these models should be coupled with physical models (such as HAMSOM or POLCOMS), and should benefit from outputs from ERSEM and other lower trophic level models developed under Module 2. IBM models could be used to examine hypotheses relating biotic (e.g., zooplankton prey production, predation, cannibalism) and abiotic (e.g., temperature, salinity, advective patterns, the role of the cold pool and fronts, climate change) factors to the population dynamics of key species, particularly with respect to recruitment success. It is understood that, in addition to past and existing egg and larval field programmes conducted by fisheries laboratories, a new 4/5-year long research programme of fish egg surveys is about to be established in the Irish Sea (C Fox, CEFAS, pers. comm.), with the main objective of monitoring cod stocks during the recovery programme. Adequate modelling support to this activity would add substantial value to it, both academically and in terms of applications.

- **Demographic or age-structured models –** The development of spatio-temporal models of fish populations is essential for spatial management. These models track the numbers of fish in each length or age class in each spatial and temporal unit, and allow the inclusion of specific behavioural traits during the life cycle (e.g fecundity, maturation, transport to feeding grounds, etc.), which could be specified for each sub-stock or geographical area. This flexibility is important because experimental work has showed that, for example, cod in the North and Irish Sea display contrasting behaviour in relation to their foraging ecology (Righton *et al* 2001). However, our knowledge of the spatial and temporal dynamics of our main resources remains extremely patchy. The continuation and expansion of tagging programmes to elucidate behavioural patterns, and genetic identification techniques to investigate the existence of sub-stocks and the degree of exchange between them, are thus strongly supported. To illustrate this, it has been hypothesised that cod has separate stocks in the North Sea favouring different optimal environments. Combined with observed shifts in the distribution of cod between decades (Hedger *et al.* 2004, Fig 8) this suggests that the southern North Sea may be becoming too warm to support a large resident cod population (Fig 7). Capturing the environment-fish sensitivities in the spatial models to be developed would be essential to predict distributional changes (as in the Newfoundland cod stocks, Rose *et al.* 2000), and to determine the success of spatial management tools, and to influence monitoring programmes.

These models should rely in particular on data from the International Bottom Trawl Surveys (IBTS), and from the different pelagic surveys conducted in the ICES area (see collation efforts in ICES 2005b). An effort must be made to avoid exclusively physico-biological models, by incorporating sufficiently-resolved models of fleet dynamics. This is in recognition that fishing interacts, and thus may also affect the spatio-temporal dynamics of the stocks. The use of high-resolution vessel positioning and catch information to understand the spatial component of the fleet (and the resources targeted), can provide an extra dimension to the outcome. However, accessing such data may not be straight forward. Substantial interaction with government

Figure 8. ***Spatial distributions of mature cod, 1980-1989 and 1990-1999 (Hedger*** **et al.** ***2004)***



laboratories of other European member states may be required, as well as with local fleet managers. It is suggested that MERP uses the excellent relationships between CEFAS, DARDNI and SEERAD and other European counterparts to access such data under some collaborative arrangements.

Some of the biological models suggested above are currently under development, for example for cod (Andrews *et al*., in prep.), but do not incorporate the dynamics of the fleet in the way proposed here. The development of socio-economic models of the fleets, and possibly of the social communities exploiting the resources, would provide an extremely innovative avenue for interdisciplinary work, adding substantial scientific underpinning to investigate alternative management options such as MPAs and seasonal closures. Changes in the social structure of the fishing communities, from the use of migrant workers to the relative importance of part-time *versus* full-time fishers in the exploitation of the different bioresources may need to be incorporated in the models.

- **Multi-species predator-prey models –** Biological components of ecosystems interact with each other through complex food web dynamics, driven by differential climatic and anthropogenic forces. Yet, the majority of the world's fisheries are managed ignoring these dynamic ecological feedbacks. The single-species TAC approach that dominates European fisheries is unable to work effectively in the mixed fisheries that characterise the sea, leading to discarding and blackfish landings. The need to incorporate ecological considerations is particularly evident in dealing with inter-dependent components of some ecosystems (ecosystem units), to evaluate and reconcile exploitation patterns and conservation needs.

Community models capable of capturing crucial interactive processes (species-species, species-fisheries) while accommodating major sources of uncertainty are a crucial necessity*. For example, the dynamics of Barents Sea capelin *Mallotus vitosus* has been proven to be strongly influenced by direct harvesting, ecological interactions with herring and cod (both subject to differential harvesting), and climate impacts. Modelling the three species together, taking into account the climate as well as differential harvesting has been recognised as essential to address the short-comings of single-species management (Hjermann *et al.* 2004b).

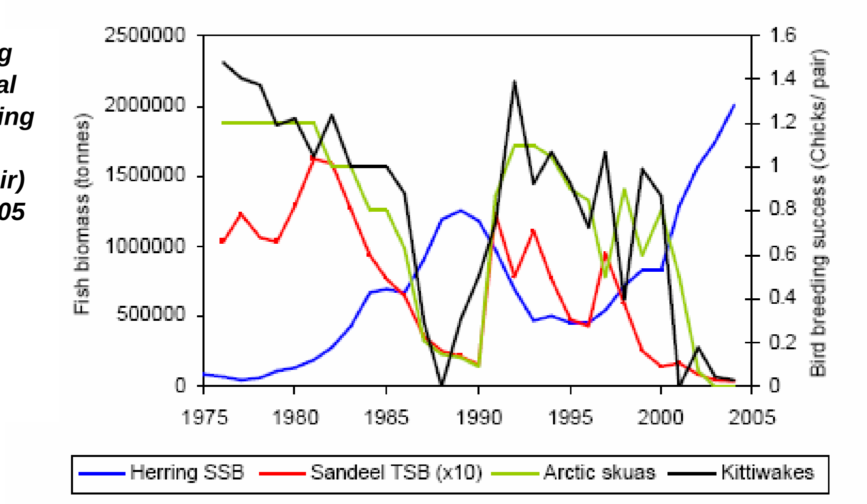
In the UK, a classic example of this inter-dependent "ecosystem units" is the herring-sandeel-seabird component of the North Sea (see Fig 9). In addition to substantial environmental influence, differential harvesting on sandeels and herring appears to play a considerable role in driving the dynamics of this unit (Fredriksen *et al*. 2004). An EU-funded project (IMPRESS) is currently developing coupled physical-biological numerical models to determine whether variability in oceanographic features and primary production can influence both seabird breeding success and sandeel population characteristics. This multidisciplinary approach should be supported further, but with the addition of models of fleet dynamics to fully capture the complex nature of these processes. This analysis should focus on establishing interactive hypothesis and build observational models capable of quantifying structural and parameter uncertainties, rather than rely on correlative approaches. These hypotheses would feed to field programmes and into operational management models as described in Module 4, aimed at developing conservation and exploitation co-management strategies. The research outlined would be significant in advancing multi-species management plans.

- ***Strategic and "blue skies" outcomes:***

  - **Synthetic understanding of the spatial and temporal dynamics of key elements of UK ecosystems**
  - **Genetic loss and sustainability of resources**
  - **Differential behavioural traits among fish populations**

*Note that in this case the modelling conducted may not be spatially-resolved, as may be expected from the title of this module. However, community-level modelling fits better under this module because of its focus on species dynamics.

Figure 9. ***Herring spawning stock biomass, sandeel total stock biomass (x10), breeding success of kittiwakes and Arctic skuas (chicks per pair) in Foula, Shetland, 1975-2005 (Data courtesy of Bob Furness, Univ of Glasgow)***



- **Estimate direct impacts/links of climate forcing on ecosystem components at local/regional scales**
- **Relative importance of natural versus human activities in the dynamics of key interlinked ecosystem components**
- **Development of quantitative understanding of multi-species interactions**
- **Dynamics of fishing communities and the social structure of fishing.**

- ***Applied and policy-driven outcomes:***

- **Provision of quantitative tools to investigate recovery scenarios of key resources**
- **Development of spatial management tools marrying social and biological objectives**
- **Investigate the minimum size, location, timing and effectiveness of MPAs, as well as their natural and socio-economic impacts**
- **Ecological support to the development of innovative stock assessment/management methodologies based on full error estimation and species interactions**
- **Potential to assess impacts of fishing on dependent ecosystem units and elaborate common exploitation and conservation strategies with stakeholders**
- **Provision of datasets for modelling activities under Module 4.**

5.4 Module 4: GOVERNANCE, ECOSYSTEM CO-MANAGEMENT AND THE DEVELOPMENT OF INNOVATIVE SCIENTIFIC ADVICE

***Overarching questions**: What are the management and governance implications of an increased regionalisation of fisheries management? What is the socio-economic feasibility and what are the consequences of alternative advisory scenarios? What marine ecosystem assessment methodology do we need in the UK? Is it possible to develop management policies that reconcile fisheries needs and conservation obligations?*

The UK has been a pioneer in fisheries management. The UK was a founding member of the ICES in 1902, and one of the first countries to establish regulations on minimum landing sizes (1933). London hosted a conference on overfishing as far back as 1946. However, fisheries have developed to such an extent that nowhere in the world is the crisis surrounding fisheries and their management more explicit than in North Atlantic waters. Media and public attention on management failures, overfishing, dumping of by-catch and impacts of fishing on the marine ecosystem (see RCEP 2005) has lead to broad questioning of the performance of fisheries management and, as a result, of our stewardship of the commons.

There is general world-wide acceptance that governance is the weakest link in the management chain (Cochrane 2004, Mace 2004), a fact that is compounded by the inherent complexity of European fisheries (centralised decision-making, multi-national ownership, access, exploitation and scientific advice). Governance is used here in its most general interpretation, including issues such as poor implementation of advice, conflicting policy strategies, poor follow-up of management decisions, and failure to recognise the importance of people and people's management, among others. Addressing governance through MERP is even more essential to effect change than filling science gaps.

Over the last few decades we have developed policy strategies, at European as well as at national level, with contrasting (and sometimes opposed) objectives and outcomes. Structural policies aimed at expanding and modernising the fishing industry have been promoted hand in hand with attempts to address conservation issues. Policy decisions have been taken in support of a lean and efficient industry, easy to monitor and control, while at the same time we encouraged the development of a vibrant and diverse collection of fishing villages with their associated cultural values. A concerted effort is needed (perhaps through a future Marine Act) to develop a strategy for our seas and their use. The type of marine ecosystems we want to have and the kind of Industry we want to see develop are very much lacking debate and policy alternatives. As a result, management struggles to deal with the multiple and conflicting objectives that a diverse stakeholder base provides, having to handle extremely polarised views on a regular basis without an appropriate decision-making framework.

One of the disturbing results of the present state of affairs is the loss of confidence in scientific advice in support of fisheries management. Frequently the science is blamed for management failures even though the protracted policy process in Brussels often results in decisions that do not necessarily follow the letter of the scientific advice. However, it is also true that mistrust has sometimes been fuelled by scientific procedures that understated (or hid) uncertainty, as well as some simplistic examinations of the overfishing problem. In addition, the increasing pressures for short-term management solutions have driven scientific advice towards fast-response, "quick fixes", allowing little time, space and capacity to treat uncertainty and natural variability adequately or address lags between observation and implementation measures. Confidence in scientific advice requires the development of co-management solutions with acceptable "buy-into" which take consideration the socio-economic consequences of the advice and that reduce stakeholders' interest in short-term gains by increasing interest in the long-term.

It is also increasingly apparent that fisheries need to be managed in the context of wider ecosystem health and balance issues. Changes in governance frameworks may be required in order to create the conditions for effective management while accounting for the need for greater cross-sectoral cooperation, such as (MA 2005):

- Integration of ecosystem management goals within other sectors and within broader development planning frameworks
- Increased transparency and accountability of government and private-sector performance in decisions that affect ecosystems, including through greater involvement of concerned stakeholders in decision-making
- Development of institutions that devolve (or centralize) decision-making to meet management needs while ensuring effective coordination across scales
- Development of institutions to regulate interactions between markets and ecosystems
- Development of institutional frameworks that promote a shift from highly sectoral resource management approaches to more integrated approaches.

In the case of marine bioresources management this new approach requires a paradigm shift that considers fisheries as an important ecosystem use that interacts with other commercial and non-commercial uses. This shift must include new ways of engaging stakeholders, providing alternative advisory and implementation mechanisms and developing innovative management plans.

A multi-sectoral, multi-disciplinary effort towards this paradigm shift would provide UK leadership in the management of European marine resources. However, the pan-European ownership of many of the resources considered in this report, adds a considerable degree of complexity that cannot be addressed from the UK alone. Much of the research to be developed under Module 4 requires the cooperation of other European Member States, through flexible and pragmatic research partnerships. Nevertheless, substantial work can be conducted from the UK, both to provide intellectual leadership in the governance of European resources, and to address resource use in the 6-12 n. mile UK territorial waters.

Several avenues are considered under this module, addressing ecosystem assessment valuations, participatory management and the development of more experimental management plans:

- **Development of fisheries ecosystems services assessment methodology –** Although the impacts of fisheries activities are well established (RCEP 2005), fishing is just one of the many human uses of the marine environment, others include extractions of aggregate resources, deployment of fixed platforms, pipelines and sub-marine cables, etc. So far, these uses are managed by different government departments, devolved administrations and advisory bodies, involving different stakeholder groups with different policy objectives. Fisheries and conservation are addressed by separate Units within DEFRA and most of its devolved equivalents (with contributions from advisory organisations such as the Joint Nature Conservation Committee). Oil and gas extractions and the regulation of offshore wind, waves and tidal energy generation sit with the Department for Trade and Industry. The Department for Transport and its agencies oversee ports, harbours and shipping and the Office of the Deputy Prime Minister manages aggregates extraction. There are also over a hundred Parliament Acts governing the marine environment with often confusing and overlapping spatial jurisdictions. The current development of a Marine Act may assist in placing fishing in its relevant framework, a process that would require an ecosystem assessment exercise to decide what services have to be secured (for example, the protection of small cetaceans is not an option but a statutory obligation), what ecosystems we want to promote as a result of the services that need to be secured and therefore what policy objectives we need to develop.

This assessment exercise must consider all ecosystem services and their benefits, encompassing several temporal, spatial and functional scales from species to ecosystems and habitats, across services, from conservation to commercial fisheries and to aggregate and oil extractions etc. (see MA, 2003). What marine ecosystem we want to support will be driven by compromises on the services we want to secure. Research on valuing and assessing provisioning (e.g. fish catches), regulating (e.g. ocean's role as a climate regulator), and cultural services (e.g. UK's marine culture as a source of identity and stability) is required to contribute to cross-sectoral management and governance plans.

A number of technical approaches are viable under this topic, in a framework that combines concepts of equity, sustainability, livelihood, capability and ecosystem stewardship (MA 2003). One specific useful methodology is the livelihoods approach, which has been used to achieve a better understanding of natural resource management systems (Allison 2005), and which involves, *inter alia*:

- Placing social and economic activities of end users at the centre of the analysis
- Address economic, social and political marginalisation
- Transcend sectoral boundaries and incorporate over-arching issues (health, education, etc.) in the valuation of management alternatives
- Link local and national economic and social benefits.

Another approach is the development of the economic valuations based on the concept of Total Economic Value (TEV, Barbier *et al*. 1997). This approach deals with the difficulties posed by the need to evaluate, on one hand, changes in the properties of exploited populations and their habitats and on the other hand to estimate non-use values as expressed in concepts of "option value" and "existence value". TEV provides a framework to comprehensively evaluate natural and environmental resources, which distinguishes between use values and non-use values for marine ecosystems, incorporating the *willingness to pay* for specific services and the *willingness to accept* specific outcomes of service use. Issues to be investigated from an interdisciplinary point of view include:

- Ecological, social and economic advantages and adverseness of protecting specific habitats or species throughout the UK, including cross-sectoral issues.
- Evaluation of new spatial and temporal management tools (e.g. MPAs), including ecological and socio-economic impacts at UK level.

- **Development of participatory governance and management policy** – While fisheries policy formulation and decisions are centralised in Brussels, management implementation in the UK is based on a complex set of arrangements. Outside "territorial waters" (the 6-12 n. mile zone) management is through the EC Common Fisheries Policy, regulated through a quota system managed by the Producers Organisations (PO). Territorial waters are largely marginal to the CFP, regulated nationally, and traditionally exploited by vessels under 10 m. These vessels are excluded from the main sectoral quota system and catch instead against a combined quota. In England and Wales responsibility for the management of this 'non-sector' quota is devolved to the 12 Sea Fisheries Committees (SFC) and the Environment Agency (EA), while in Scotland this management is consolidated centrally (Phillipson & Symes 2001).

In this sense there is considerable devolved management in the UK through the 19 PO, responsible for the administration of sectoral quotas and, in England and Wales, the SFC, responsible for inshore management. However, considerably less progress has been made towards effective user participation in the area of policy formulation at national and local level. Despite recent efforts, consultation arrangements still lack transparency, significance and formality. This is a clear paradox between delegated responsibilities combined with poor consultation. The increasing regionalisation of fisheries, both at sub-European (the EC Regional Advisory Councils) and sub-national level, offers good opportunities for the development of integrated co-management plans, from policy formulation to implementation, with a view to integrate fisheries management and marine nature conservation. Integrated management plans should set objectives for the ecological, biological, economic, social, cultural and administrative aspects of management, through the adoption of an ecosystem-based approach, with full participation (not just consultation) of all key stakeholders.

Research on management options must include trade-offs between exploitation and conservation in terms of multi-annual and multi-fleet management *versus* annual management, effort *versus* catch controls and stock-based *versus* area-based management. It would be important to evaluate:

- Past failures in assessment, decision making and management implementation

- o Potential use (or consequences of not using) social, economic and environmental knowledge in the decision making process (Perry & Ommer 2003)
- o Management options in data-poor situations.

- **Development of appropriate fisheries management frameworks in the face of uncertainty –** The points above have specifically referred to the need to broaden fisheries policies to incorporate other needs and uses of the marine environment, most notably nature conservation. However, there is still a need to modernise and improve single and multi-species scientific advice. The scientific information on the functioning of UK's regional seas to be obtained through Modules 1 to 3 will need to be considered, but it would also open up new layers of scientific uncertainty. These must be recognised, and incorporated through cross-sectoral analysis, in the development of the ecosystem approach to fisheries (Rice 2001). Of particular use in this context is the development of operational management procedures in line with those that have emerged in the International Whaling Commission (Kirkwood 1997), and that have been followed in other regions, like Australia (Smith *et al*.1999) and South Africa (Butterworth *et al.* 1997). Management procedures are not commonly used in fisheries at present, but their principle is straightforward. All stakeholders (scientists, policy makers, fishers, conservationists) should agree to a set of clearly defines rules before the management game is played. What characterises a management procedure, however, is that the selection of steps to be taken is determined by the inspection of the trade-offs among anticipated levels of medium term reward (catch/profit), risk of stock collapse, interannual catch variability, etc., arrived at through simulation. The philosophy behind these procedures is based on dealing explicitly with uncertainty, on the development of co-operative management objectives, and on evaluating the consequences of alternative strategies instead of seeking "optimal" solutions. Some work along these lines is currently under development in the UK, pointing to important shortcomings in current management systems. For example, Kell *et al.* (2005) have developed a management procedure for North Sea roundfish stocks, concluding that the inclusion of realistic sources and levels of uncertainty can result in sub-optimal management outcomes based on current procedures.

- **Development of scientific frameworks for providing ecosystem-based advice** – There is worldwide recognition that an adequate scientific framework to evaluate and protect ecosystem components, structure, and function is lacking, thus requiring a paradigm shift as indicated throughout this report. In recent times a number of quarters have requested management decisions that would reduce the ecosystem impacts of fishing (RCEP 2005) as well as provide ecological forecasts to decision-makers in the selection of policy choices (Clark *et al.* 2001). These needs require the development of appropriate scientific analysis at ecosystem level, which would form one of the scientific cornerstones of the application of the Ecosystem Approach (Gislason *et al.* 2000). Specific management plans or management procedures, as outlined above may be appropriate in some cases, while in others an overarching assessment of ecosystem health and impacts may be required to address other –probably medium to longer term- objectives. This assessment framework should have four main objectives:

- o to maintain predator-prey relationships
- o to maintain a balanced energy flow
- o to maintain biological diversity, and
- o to maintain the integrity of the essential habitats of exploited species

taking full cognisance of the role of climate as well as human forcing as agents of ecosystem change, and accepting that sustainability depends on the retention of the integrity of ecosystems. Each one of these objectives would require a set of sub-objectives tailored to the ecosystem under assessment, and each of these a set of indicators with associated threshold levels. Such a framework would take information from existing environmental and fisheries monitoring programmes, as well as the outputs of the modelling approaches conducted in modules 1-3 above. It would also benefit from integration of existing research initiatives in this area, like the European-wide INDECO project, funded by the European Union. INDECO aims at a) identifying quantitative indicators for the impact of fishing on the ecosystem state, functioning and dynamics, as well as indicators for socio-economic factors and for the effectiveness of different management measures, b) assessing the applicability of such indicators; and c) developing operational models with a view to establishing the relationship between environmental conditions and fishing activities.

The traffic light system proposed by Caddy (1999) may be an appropriate way of integrating the results of numerous indicator trends and of providing a structured way of making management decisions, at least initially. This approach has been applied by the Regional Ecosystem Study Group for the North Sea (ICES 2004a), and is used in the management of Alaskan fisheries (Livingston *et al* 2005). The traffic light approach has also been used to develop a framework for the use of indicators of single species, multispecies, habitat and ecosystem functioning in data-poor developing countries (Dengbol & Jarre 2004). A similar approach, based on the integrated assessment of biotic and abiotic variables extracted using empirical, reductionist and holistic methods, has recently been successfully used in the Canadian East coast (Choi *et al.* 2005).

- ***Strategic and “blue skies” outcomes:***
  - **Ecological and socio-economical assessments of UK’s fisheries ecosystems**
  - **Formal definition of “healthy ecosystems”**
  - **Policy implications of regional fisheries management.**

- ***Applied and policy-driven outcomes:***
  - **Development of operational fisheries management advice using an ecosystemapproach**
  - **Contribution to assessments of new spatial and temporally-explicit management tools**
  - **Development of innovative stock assessment methodology with full error estimation, species interactions and socio-economic impacts**
  - **Development of multi-sectoral Management Plans to reconcile fisheries needs and conservation obligations.**

5.5 Module 5: Data management, Communication and Knowledge-Transfer

Ecosystem science and management are information-intensive activities. Databases are continuously managed and extended at the Fisheries research laboratories in England, Northern Ireland and Scotland, environmental monitoring agencies, data Centres and research institutions. There are also output data from computer-based predictive models (e.g. POLCOMMS/FOAM/ERSEM), which can be regarded as data even though they do not constitute measurements. These data have different degrees of protection and access rules, and some are accessible only through purchase. In addition, data from completed research projects are occasionally deposited in data Centres (e.g. data from most NERC-funded marine research sits at BODC), but many are held by individual scientists in their PCs. Finally, there is a vast amount of data on fishing and fisheries operations, available in vessel logbooks, ICES and national databases, and others. Aggregated data are easily accessible, but high resolution information is generally difficult - if not impossible - to access. The MERP Partnership should focus on developing mechanisms to facilitate access to data for research purposes, and should rely on the data basing procedures of partner institutions for protection, curation and stewardship of existing and newly-collected data. Data management efforts under the MERP must focus on:

- Search, identify and catalogue existing data sets relevant to MERP
- Facilitate access to and maximise use of these data sets by developing rules for data access and use with the data owners, while protecting the rights of the collectors and owners of the data
- Develop a strategy for long-term data management and use of MERP products, in consultation with data management plans of MERP partners.

Insufficient or inadequate communication between public, users, policy makers and scientists has long been recognised as an important issue in the promotion of co-management arrangements and the development of scientific credibility, legitimacy and user compliance. Fisheries management is a closed-information activity in the sense that only a small circle are capable of accessing and understanding all the relevant information on which decisions are taken, as a result of the complexity of the process. The science of fisheries management is highly technical and difficult to understand; the decision-making process from the ICES working groups to the European Commission recommendations, and the implementation of these recommendations at national level is opaque to say the least. Confidence and acceptability needs to be built on a platform of clarity of information. MERP needs to emphasise this need and actively improve the flow of information between users, science and policy.

Communication and Data Management issues have to be addressed in parallel in a determined attempt to open up the scientific and management process, from advice to implementation. For this reason, a cross-cutting module on Data Management and Communication is proposed.

5.5.1 Data Management node – MERP’s data management node would facilitate access and use by: collating catalogues of datasets; developing a data portal; and designing tools and mechanisms of data access in close coordination with those managing data banks. The portal would provide a central method of browsing and searching the contents of all the available data resources. After rules of access, use, and data protection have been agreed upon with each data bank, a system of e-certification should be developed to ensure that only certified MERP scientists make use of the data bases for the purpose of the research project they are involved with. Specific objectives of this node include:

- Identify what existing data sets are needed, where are they based, how to access them and under what conditions
- Develop strategies to store, manage and steward MERP products
- Develop tools for shared access and analysis of data sets by MERP scientists
- Clarify the rules and procedures of a MERP central data node.

The development of e-Science applications would be encouraged and facilitated through the node. E-Science was conceived to conduct collaborative science using distributed computing and data resources, thus mapping well with MERP's objective to facilitate collaboration between partners. E-Science involves the sharing of computers and data across the Internet, and has been strongly supported from UK's central government. Appropriate linkages between MERP and existing UK Centres of Excellence on e-Science would be consistent and synergistic (see www.nesc.ac.uk/).

5.5.2 Communication node – Besides facilitating the communication of MERP products, the goal of this cross-cutting unit would be to engage stakeholders in building two-way communication systems that allow the development of co-management schemes in parallel to the implementation of Module 4. The development of a communication strategy would be important to identify specific Objectives and Outcomes of the communication effort, as well as expected Actions from those receiving the communication and Evaluation procedures to assess communication success.

The ultimate objective of this node if to develop MERP as a 'knowledge-based' partnership through the strategic development and implementation of effective approaches to knowledge management, communication, exchange and transfer both externally and internally.

Investment in these cross-cutting issues of MERP is important to secure success.

6. Implementation Strategy

The move towards sustainable management and the application of the ecosystem approach must involve the development of "fit-for-purpose" Institutional changes (S. Garcia in ICES 2004b), whereby multi-disciplinary scientists and stakeholders (from Industry to conservation bodies) are aligned and implicated in multi-disciplinary teams of problem solvers. Success requires removing the polarisation between industry and scientists, and between natural and socio-economic science by agreeing on the direction and speed of movement towards specified goals.

The research programme proposed above provides a collection of scientific objectives through which new mechanisms to conduct marine ecosystem research will evolve. This process should develop in parallel to the conventional fisheries assessment process, with a progressing interaction between both approaches. In other words, the MERP would not be replacing present methodologies, but rather would initiate a step-wise progression so as to combine present tools with more innovative, ecosystem-based methods, in synchrony with the medium-term view of the European Commission (A. Astudillo, DGFISH, pers. comm. February 2005). It is expected that the proposed cross-sectoral, inter-disciplinary science of MERP would provide intellectual leadership in Europe by providing the paradigm shift and step-wise development requested by the sponsors of the scoping study. It is suggested that the basic operating principles of MERP would be as follows:

1. MERP is intended to broaden the science base for fisheries and ecosystem management advice and to address scientific and Institutional fragmentation. Therefore, it would be essential to ensure that research teams are developed from a diverse number of scientific institutions and across disciplines. Teams must include representatives of the conservation and user communities. It is thought that favouring a small number of strong institutions at the expense of smaller or more specialised ones would continue the process of fragmentation.

2. MERP is aimed at driving a paradigm shift around the way we research, interpret and manage marine ecosystems. As such it requires broad support from research bodies (NERC and ESRC in particular) as well as government agencies (DEFRA and its devolved bodies). Furthermore, should it prove itself, MERP should develop over a period in excess of the standard 3-year research grants. The only useful existing parallels are the Centres of Excellence established by the Research Councils through the UK, to address similar issues of critical mass and science maximisation.

3. Should MERP be implemented along the concept of a Centre of Excellence, it should consist of a number of **distributed centres** or nodes, perhaps along the lines of research modules. A **Central node** would be established, in charge of its cross-cutting management, data and communications, knowledge-transfer and resource mobilisation activities.

4. Partners of MERP should demonstrate a strong commitment to the process through, for example, secondments of scientists to work for MERP for a period of time, commitment to provide berths or modify field programmes should the need arise, etc. Research Council Centres may consider including aspects of MERP's research programme in their Core Programmes. Other ways of expressing commitment may be explored by the partners. However, substantial funding would be needed to fund central activities and to top-up partner's contributions. The process of identifying funding needs and their source must follow this report, as it should be driven by the leading partners.

5**.** A particular novelty of MERP, required to address fragmentation issues and to break the culture of division between fisheries laboratories and academic institutions, would be to find mechanisms for the mobilisation of resources through the partners, such as:

a. To fund mobility of scientists between the government and non-government sectors that would facilitate, for example,access to ICES working groups by non-government scientists and the participation of government scientists in research council funded meetings.
b. To fund mini-sabbaticals of academic scientists in Fisheries laboratories, and fisheries laboratories scientists at Universities and NERC research centres, to conduct research under MERP.
c. To facilitate access to facilities not generally accessible to fisheries laboratories, such as genetic or microbiological facilities and NERC supercomputing facilities, and to share available vessel berths.

6. The first phase of MERP's research programme, as outlined above, would be strongly driven by the development of new integrative and synthetic understanding, and the expansion of the tools for scientific advice and management. Subsequent phases would have to be driven more specifically towards providing management advice and establishing two-way links with monitoring programmes of the marine ecosystem.

7. MERP advice along ecosystem considerations would not supplant conventional fisheries management advice, but should be used to modify regulations along ecosystem concerns (as in Murawski 2000). With time, as metrics of ecosystem structure and function develop into more provide practical implementation tools (Hall and Mainprize 2004), this parallel process would evolve towards a single ecosystem-based advice, in line with the European Commission vision (A.Astudillo, pers. comm., EC DGFISH, Feb 2005). Given the European nature of many of the policy drivers of MERP (CFP, Habitats Directive, etc), and of the resources considered, MERP should play a pivotal role in contributing scientific advice to ICES, RACs, and any other regional and European advisory bodies that may be established in the future.

8. Because many marine bioresources are owned by the "European commons" it would be fundamental to involve other European teams in the research projects, albeit at their cost (similar to the way European Framework programmes handled collaborations from outside the ERA). The development of MERP-led proposals for funding under EU Framework 7 should be strongly encouraged.

9. The research programme of MERP should be steered by an inter-disciplinary, cross-sectoral committee that includes not only members of the scientific communities, but conservation and user bodies. This committee should have sufficient powers to influence the research rather than rubber-stamp approved proposals. It is suggested that this committee includes external advisors from countries that are actively involved in developing science programmes in response to the Ecosystem Approach, such as Australia, Canada or the USA.

The research programme proposed for MERP provides a scientific umbrella identifying areas of science, research approaches, common objectives and deliverables. Specific research activities need to be developed from the bottom up, precisely through the mechanisms that the MERP partnership aims to provide. Therefore, it would not be appropriate to provide specific details of manpower required, equipment to be mobilised or costs of the different activities. However, the design of each research Module provides some suggestions as to the type of investment that would be required to succeed. Basic implementation approaches for each Module are provided below:

Module 1 – Long-term patterns of marine ecosystem variability and change
- Would require several scoping and data analysis workshops.
- Based on a small number of Consortia bids.
- Involve no new field work but substantial data rescuing/ formatting.
- Require investment on statistical analyses and data interpretation.
- Mobility of scientists important (targeted fellowships and training opportunities).

Module 2 – Comparative ecosystem functioning of UK regional seas
- Workshops required to agree on model framework and structures, parameterisation, testing, ground-truthing and interpretation.
- Based on a small number of Consortia bids.
- Very limited field work required, specifically to parameterise models and test hypothesis (e.g. to estimate changes in benthic-pelagic fluxes as a result of fishery-driven changes in benthic fauna from suspension feeders to deposit feeders and scavengers). Adaptations to existing field work probably needed (e.g. to obtain better diet information and spatial coverage).
- Mobility of scientists essential, as well as access to shared computer facilities.

Module 3 – Spatial and temporal dynamics of key bioresources and ecosystem units
- Workshops required primarily to plan incorporation of new field data to models, and to agree on methodology for the natural and social science interfaces.

- Based on several Consortia bids, possibly with wide institutional participation.
- New fieldwork may be required, to fill gaps in spatial and temporal dynamics, to incorporate strategic tag-release programmes, apply specific genetic tools for stock identification and diversity loss, to test hypotheses related to recruitment success and to collect social science information on fishing communities and fleets.
- Because of the need to access high resolution catch information, the involvement of fishing organisations is essential.
- Mobility of scientists is essential as well as access to shared computer and analytical resources.

Module 4 – Governance, ecosystem co-management, and development of innovative scientific advice

- Workshops required for: building cross-sectoral teams to develop management frameworks, to research participatory governance projects and to agree on service assessment methodologies. Workshops would be strongly cross-sectoral, interdisciplinary, and interfaced with policy bodies.
- To be based on a number of diverse and probably small Consortia bids focused on pilot studies.
- Probably no field work required (some pilot studies may need new data, but only at small scales)
- Mobility of scientists essential.

Module 5 – Data Management, Communication and Knowledge-Transfer

- Cross-cutting module requiring initial workshops and consultation throughout.

7. The international context

The scoping study was specifically requested to place the research proposal in an international context. There is a general international move towards Ecosystem-Based Management (EBM), recognising that the necessary framework for protecting the structure and function of ecosystems has been lacking. The implementation of EBM worldwide is intended to ensure that large-scale impacts on ecosystems do not result in detrimental consequences to human societies. The application of EBM approaches is in its infancy, and most countries are adapting the concept to their own needs and requirements. MERP is intended to provide underpinning to EBM of UK waters. In this section we place this view in context by briefly outlining how EBM is applied in Canada, USA, Australia and South Africa, as well as in the Commission on the Conservation of the Antarctic Marine Living Resources (CCAMLR).

7.1 Canada

Canada enacted their Oceans Act in 1997, outlining a new approach based on the premise that oceans must be managed as a collaborative effort amongst all stakeholders that use the oceans, and accepting that new management tools and approaches were required. The Oceans Act has changed the legislative basis for management and now requires consideration of the impacts of human activities on Canada's ecosystems in marine resource management plans. A number of initiatives have since emerged in support of EBM stemming from the Oceans Act. Canada's Oceans Strategy was published in 2002 (Anon., 2002), including the need for coordinated Integrated Management (IM) programmes to define how best to manage designated areas. "Integrated Management" is defined as "a commitment to planning and managing human activities in a comprehensive manner while considering all factors necessary for the conservation and sustainable use of marine resources and the shared use of ocean spaces" (Anon 2002). IM is in its initial stages in Canada, and some research needs have already been identified (Jamieson *et al.* 2001), including:

- Develop sustainability objectives (environmental, biological, social, economic, cultural)
- Define indicators and reference points for ecosystem-level objectives
- Identify conservation objectives for specific ecosystem components
- Compilation of ecosystem-level data and study their use in ecosystem function measurements.

7.2 USA

Two recent reports echoed the calls for ecosystem based fisheries management in the USA. The official US Commission on Ocean Policy (2004) recommended "to strengthen the use of science and move toward a more ecosystem-based management approach". Such approach needs to, "be regionally directed, take account of ecosystem knowledge and uncertainty, and consider multiple external influences". Prior to the Ocean Policy Commission an Ecosystem Principles Advisory Committee was formed to recommend measures to Congress (NMFS EPAP, 1999). Its main recommendation was that Fishery Ecosystem Plans should form the basis for advancing ecosystem-based management in US regional fisheries. The following scientific issues were flagged as requiring attention for these Plans to succeed:

- Improve predictive capacity with regard to climate and human impacts on ecosystems: model refinement and regime shift analysis to drive recruitment scenarios
- Develop ecosystem-based management objectives
- Develop indicators and objective criteria to measure success in achieving desired ecosystem states

- Develop formalised decision-making frameworks, including standardised tools for objective analysis.

Jamieson & Zhang (2005) provides a full description of the implementation of ecosystem-based fishery management in the USA.

7.3 South Africa

Much of the ecosystem-oriented research in the southern Benguela took place under the umbrella of the Benguela Ecology Programme, established in 1982 with the objective "to provide scientific information on the structure and functioning of the constituent ecosystems, to complement the knowledge which is required for the management of the renewable natural resources of the Benguela Current region". The programme has had many successes (Payne *et al*. 1997; Payne *et al*. 1992; Pillar *et al* 1988) that have modified single species and ecosystem management approaches. Key examples are the assessments of the impact of cape fur seal on Cap hakes (Punt & Leslie 1995), work on Marine Protected Areas (Attwood & Harris 2003), seabird survival and population size in relation to availability of food (Crawford 2004), and the development of subsistence fisheries in South Africa (Branch 2002). The South African Marine Living Resources Act of 1998 provides the mandate for progressing towards an Ecosystem Approach to Fisheries, in synchrony with the scientific developments that preceded the Act. The major concern over the application of EAF in South Africa is that its implementation will make additional demands on already stretched political and social will, capacity and resources. To address these concerns the FAO and the South African government are currently conducting pilot studies to identify where changes and enhancements of the existing management strategies will be required (K. Cochrane, FAO, pers. comm. Jan 2005).

7.4 Australia

Australia's Oceans Policy was launched in 1998 to develop an integrated and ecosystem based approach to planning and management in Australia's entire marine jurisdiction for all ocean users. The Policy is currently under revision. The primary mechanism for implementation of this ecosystem approach in Australia is through Regional Marine Plans (RMPs) for areas consistent with ecosystem boundaries. In research terms, the most recent and innovative application of the EA is the North West Shelf Joint Environmental Management Study (NWSJEMS), began in 1999 and jointly funded by the Western Australian Government and CSIRO Marine Research. The general objective of this four-year study was to develop and demonstrate practical science-based methods that support, under existing statutory arrangements, integrated regional planning and management of the NWS marine ecosystem, to:

- compile, extend and integrate the scientific information and understanding of the coastal marine ecosystems of the NWS; and
- develop and demonstrate practical science-based methods that support integrated regional planning and multiple-use management for ecologically sustainable development.

A computer-based Management Strategy Evaluation (MSE) framework is used in the Study, to evaluate prospective multiple-use management strategies for the NWS. This is the first time an attempt has been made to develop and apply MSE to multiple-use management of a large coastal marine ecosystem. The MSE is applied to four sectors: oil and gas, conservation, fisheries, and coastal development. For each sector, a selection of development scenarios, provided by the relevant interest group, is represented. These scenarios include prospective future sectoral activities and their impacts, and the sectoral response to management policy and strategies.

Preliminary results allow interactions between ecosystem users and regulators to examine the consequences of multiple-use management and the cumulative impacts of human uses on the ecosystem. The MSE framework relies on a biophysical model that emulates the physical and biological features of the natural marine ecosystem (McDonald *et al.* 2004), which is arrived at through research similar to the scientific programme proposed for MERP.

7.5 CCAMLR

The example of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) is mentioned because it is the only international Convention that specifically makes use of the 'Ecosystem Approach' and because of the UK's involvement and leadership in CCAMLR through NERC's British Antarctic Survey. In the mid-1970s, it was realised that the conservation of krill was fundamental to the maintenance of the Antarctic marine ecosystem. Consequently, serious concerns were raised about effective management and sustainable utilisation of Antarctic marine living resources. These concerns were taken up and resulted in the CCAMLR Convention, which came into force in 1982. In common with other international agreements, CCAMLR does not impose regulations, but rather attempts to reach agreement on issues which Members of the Convention are then obliged to implement. However, in contrast to other multilateral fisheries conventions, CCAMLR is concerned not only with the regulation of fishing, but also has a mandate to conserve the ecosystem. This 'ecosystem approach', which considers the whole Southern Ocean to be a suite of interlinked systems, is what distinguishes CCAMLR from other multilateral fisheries conventions. The Convention applies to all marine living resources (except seals south of 60°S and whales in general) inside an area whose northern boundary is roughly delineated by the mean position of the Antarctic Polar Front and thus follows the physical and biological boundaries of the Antarctic. Article II of the Convention establishes a number of conservation principles, including:

- "maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources…/…"
- "prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades…/…, taking into account …/… the effects of associated activities on the marine ecosystem and of the effects of environmental changes…/…"

Article II embodies two concepts that are vital to CCAMLR's approach to management: the precautionary approach (reversal of the burden of proof) and the ecosystem approach. By pioneering the ecosystem approach, CCAMLR has chosen to deal with the difficulty of describing the full complexity of marine ecosystems by designating species considered to be most important in the food chain (so-called 'indicator' species) or by focusing on stocks within somewhat arbitrarily defined geographic regions or management areas. In the case of krill, CCAMLR has considered not only krill but also a subset of dependent species, including seabirds and seals, which are monitored by the CCAMLR Ecosystem Monitoring Program (CEMP).

8. Conclusions

Marine ecosystems are under threat from the combined impact of excessive resource exploitation and global environmental change. The pace of this impact is challenging our ability to provide timely and effective scientific advice. In addition, there are increasing demands to place exploitation of bioresources in the broader context of the multiple human uses and conservation needs of the marine ecosystem. In order to address these issues, a paradigm shift in the way we manage marine ecosystem goods and services is required. This shift would include a broader interdisciplinary science base in support of management and the development of science and management alternatives in synergy cooperation with stakeholders. Of concern is the fact that the marine ecosystem science base in the UK is poorly integrated and highly fragmented. This historical fragmentation has been entrenched through an effective separation in the funding mechanisms and research priorities between research councils and government departments. After observation and consultation it is concluded that greater interagency coordination and a more cohesive scientific response is required, in order to exert greater leadership both nationally and internationally.

The creation of a new Marine Ecosystem Research Partnership (MERP) is recommended as a platform to achieve scientific integration, and to spearhead the development of the ecosystem approach to resource management in the UK. The ultimate aim of MERP is to provide scientific management advice that reconciles exploitation and conservation needs based on interdisciplinary ecosystem knowledge. MERP would evolve in parallel to conventional fisheries management advice, initiating a step-wise progression towards ecosystem-based management. This evolution recognises that the necessary framework for understanding and protecting the structure and function of marine ecosystems is currently lacking. The Marine Ecosystem Research Partnership should be implemented as a virtual Centre of Excellence seeking to demonstrate the long-term commitment of the partners to its objectives and goals.

For the first phase of MERP, a strategic and holistic ecosystem-oriented research programme is proposed. The programme is based on four research modules, primarily constructed on a set of multi-scale modelling activities, and one cross-cutting data, communication and knowledge transfer module. It is suggested that specific research activities under each module be implemented on the basis of consortia bids that address not only integrative scientific needs but also the structural and institutional issues mentioned above. The research needs to be strongly coordinated with activities of other European partners, in recognition of the European ownership of most marine resources. The first research phase of MERP would be driven by the need for integrative ecosystem understanding and to expand tools for scientific advice. Subsequent phases should focus on delivering ecosystem management advice linked to monitoring strategies.

In conclusion, the UK is facing a window of opportunity to respond to the conservation and sustainable exploitation needs of the marine ecosystem with a holistic and inclusive vision. MERP is proposed as a mechanism to harness this vision. Science and policy agencies and institutions must use this opportunity to implement fit-for-purpose changes to build upon and maximise the value and quality of scientific advice.

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