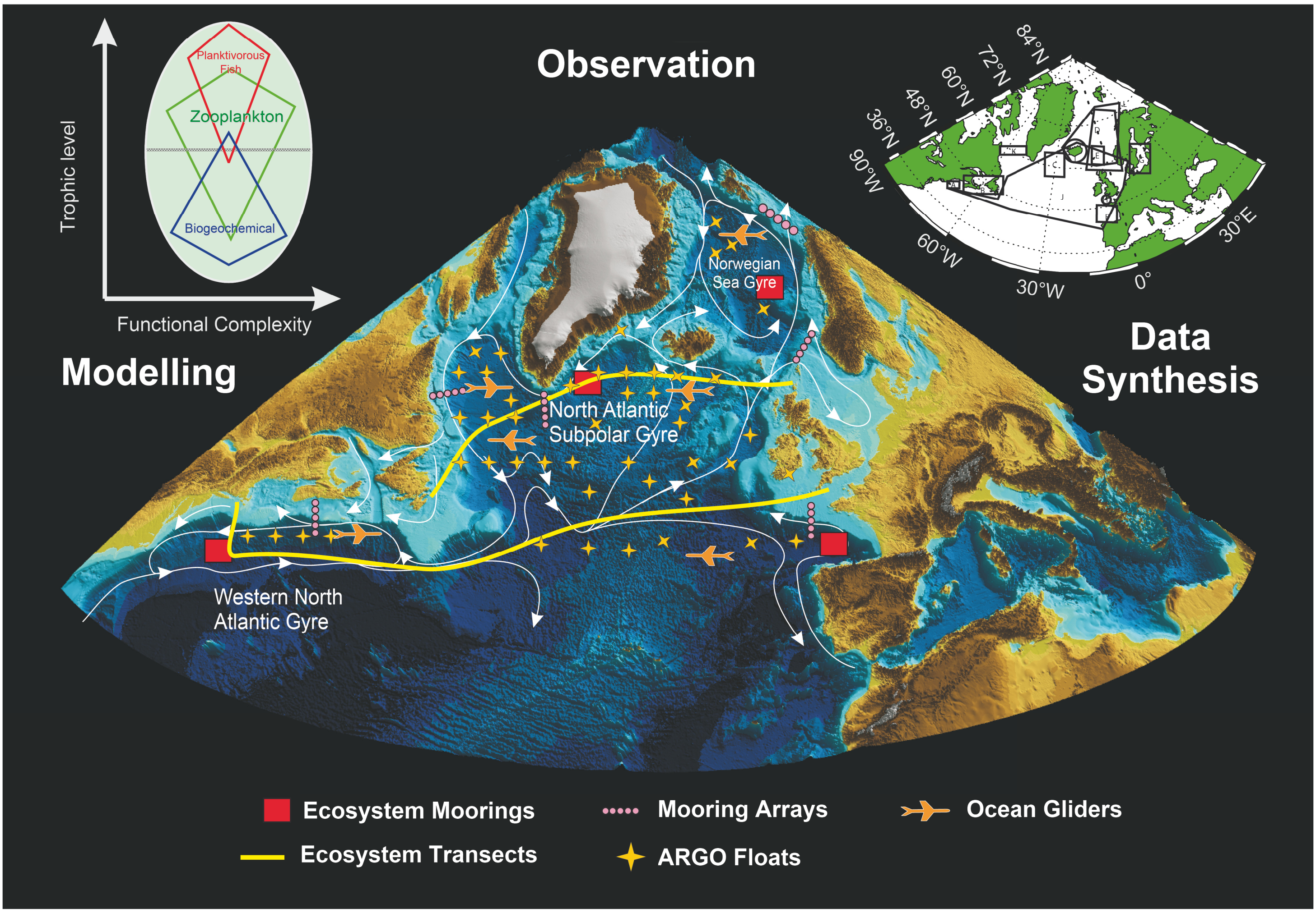
BASIN: Basin-scale Analysis, Synthesis, and INtegration

An international programme to resolve the impact of climatic processes on ecosystems of the North Atlantic basin and shelf seas

Science Plan and Implementation Strategy



GLOBEC Report No.27

GLOBAL OCEAN ECOSYSTEM DYNAMICS

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BASIN:
Basin-scale Analysis, Synthesis, and INtegration

Science Plan and Implementation Strategy

P.H. Wiebe, R.P Harris, M.A. St. John,
F.E. Werner, B. de Young and P. Pepin (Eds.)

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LIST OF ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler
AMO	Atlantic Multidecadal Oscillation
AMOC	Atlantic Meridional Overturning Circulation
AUV	Autonomous Underwater Vehicle
BASIN	Basin-scale Analysis, Synthesis and INtegration
BODC	British Oceanographic Data Centre
CCD	Charge Coupled Device
CLIVAR	Climate Variability and Predictability
CONAE	Comisión Nacional de Actividades Espaciales
COPEPOD	Coastal and Oceanic Ecology, Production and Observation database
CPR	Continuous Plankton Recorder
DMS	Dimethyl sulfide
DOC	Dissolved Organic Carbon
DNA	Deoxyribonucleic acid
EAFM	Ecosystem Approach to Fisheries Management
ECOMIP	Ecological Modelling Intercomparison Project
EST	Expressed Sequence Tag
EU	European Union
EUR-OCEANS	European network of excellence for OCean Ecosystems ANalysis
EWE	Ecopath with Ecosim
FAO	Food and Agriculture Organization of the United Nations
FVCOM	Finite Volume Coastal Ocean Model
GCMD	Global Change Master Directory
GEOSS	Global Earth Observation System of Systems
GLOBEC	Global Ocean Ecosystem Dynamics
GODAR	Global Oceanographic Data Archaeology and Rescue project
HMAP	History of Marine Animal Populations
HYCOM	Hybrid Coordinate Ocean Model
ICES	International Council for the Exploration of the Sea
ICOM	Imperial College Ocean Model
IPCC	Intergovernmental Panel for Climate Change
LED	Light Emitting Diode
LIDAR	Light Detection and Ranging
MARMAP	Marine Resources Monitoring, Assessment and Prediction program
MEECE	Marine Ecosystem Evolution in an Changing Environment
MIP	Modelling Intercomparison Project
MOC	Meridional Overturning Circulation
MOCNESS	Multiple Opening/Closing Net and Environmental Sampling System
MSVPA	Multispecies Virtual Population Analysis
NAFO	Northwest Atlantic Fisheries Organization
NAO	North Atlantic Oscillation
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEMO	Nucleus for European Modelling of the Oceans
NODC	National Oceanographic Data Center
NPZD	Nutrient Phytoplankton Zooplankton Detritus
OCB	Ocean Carbon and Biogeochemistry programme
OCMIP	Ocean Carbon-Cycle Model Intercomparison Project
OSSE	Observing System Simulation Experiments
POC	Particulate Organic Carbon
POM	Princetown Ocean Model
ROMS	Regional Ocean Modelling System
UAV	Unmanned Aerial Vehicles
VPA	Virtual Population Analysis
WCRP	World Climate Research Programme
WGZE	Working Group on Zooplankton Ecology
XBT	Expendable Bathythermograph

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EXECUTIVE SUMMARY

BASIN: Basin-scale Analysis, Synthesis, and Integration - Resolving the impact of climatic processes on ecosystems of the North Atlantic basin and shelf seas.

BASIN is a joint EU/North American research initiative designed to elucidate the mechanisms underlying observed changes in North Atlantic ecosystems and their services as well as to quantify and predict consequences of climate and environmental variability and change on the system. The ultimate goal is the development of an understanding of the links between climate and the marine ecosystems of the North Atlantic basin, including the associated shelf seas, and the services these ecosystems provide including exploited marine resources. The overall aim is to use this understanding to develop ecosystem based management strategies that will anticipate the effects of climate change on the living resources of the region.

The need for an integrated ecosystem approach to the management of renewable resources has been recognised by a number of states, including Canada, the EU, and the US. Given the importance of marine resources, the nations exploiting them face socio-economic and environmental challenges with ongoing crises in fisheries, and clear signals of global change. An ecosystem approach to management of marine systems and their services is being proposed in all jurisdictions surrounding the North Atlantic basin. The approach includes conservation of natural resources, coastal zone management, fish stock assessment, management, and regulation, and maintenance of ecosystem health. It also recognises the importance of the ocean basin in the global carbon cycle and the sequestering of greenhouse gases.

BASIN focuses on resolving the natural variability, potential impacts and feedbacks of global change on the structure, function, and dynamics of ecosystems, and as a result will improve the understanding of marine ecosystem functioning. The overarching aim of the BASIN initiative is **to understand and predict the impact of climate change on key species of plankton and fish, and associated ecosystem and biogeochemical dynamics in the North Atlantic basin and surrounding shelf seas, in order to improve ocean management and conservation**. The scope of this BASIN Science Plan is well-defined and achievable, retaining a focus on key processes and organisms, while maintaining a connection to key trophic interactions and their importance for exploited resources within a changing climate. The Science Plan is designed to develop new and improved approaches to ecosystem-based management, based on improved system understanding and modelling. In order to further our understanding BASIN seeks to:

- Understand and simulate the population structure and dynamics of broadly distributed, and trophically and biogeochemically important plankton and fish species in the North Atlantic Ocean;
- Resolve the impacts of climate variability on marine ecosystems and the feedbacks to the climate system;
- Develop understanding and models that will advance ocean management.

In order to address these scientific goals BASIN will address three key questions:

Theme 1. How will **climate variability and change**–for example changes in temperature, stratification, transport, acidification–influence the seasonal cycle of primary productivity, trophic interactions, and fluxes of carbon to the benthos and the deep ocean?

Theme 2. How do **life history strategies** of target organisms, including vertical and horizontal migration, contribute to observed population dynamics, community structure, and biogeography?

Theme 3. How does the **removal of exploited species** influence marine ecosystems and sequestration of carbon?

These goals and the associated questions will be addressed during two five year phases. The initial phase will emphasize modelling, data integration as well as include some initial field process studies and a preliminary synthesis. The second phase is expected to provide additional observations from the field, which are considered to be essential for further model development and verification of model results and a final synthesis of results.

Programmatic activities

Advancement of predictive capacities

A crucial element of the BASIN programme is the development of conceptual and quantitative models capable of elucidating ecosystem dynamics and responses on a broad range of space and time scales. There is currently no fully integrated ecosystem model that can address BASIN's goals nor is a single model likely to be successful at addressing all of the goals of the programme. It is expected that an ensemble of models will be developed that will be used to address particular issues and problems. Hence, one of the goals of BASIN will be to ensure interoperability between models so that researchers can take advantage of models developed around the Atlantic for application to particular problems. Basin-scale models intended to represent complex food webs must concentrate the biological resolution at the level of the species or trophic level of interest, and decrease the resolution, with distance both up and down the trophic scale from the target species. Following this approach, the focus of the BASIN modelling programme will be on selected key species and functional groups. We envisage a variety of models with differing focus on target species, trophic levels, and the relevant biogeochemical processes.

Retrospective analyses and data synthesis

Within BASIN, data will be required for several purposes. Long-term time series are necessary for retrospective analyses. BASIN activities will identify available historical data sets for integration and synthesis. These data sets will include climatological, oceanographic, chemical, and biological data. New data will be required in order to understand and better parameterize the physical and biological processes in the models and to address gaps in process knowledge. Such data will be critical for model improvements and the models will be used to help prioritize the data collections required both in the field and laboratory, as well as to identify the geographical locations where such measurements should be carried out and the frequency of sampling needed. Data are also required for model evaluation. There will be heavy reliance on historical data, but new measurements will also be required where existing information is limited or not available.

New data

Data and information gaps identified by the compilation and retrospective analysis of existing data sets will be filled by using a combination of new and traditional sampling technologies and observation platforms as well as focused experimental studies. Sampling programmes will be designed to collect biological, chemical, and physical data across multiple temporal and spatial scales. The programme will include long-term and broad-scale studies of key species and groups in the North Atlantic basin and associated shelf systems building on the existing national monitoring and resource assessment programmes. A broad-scale sampling programme will consist of a combination of Lagrangian samplers, long-term moorings, cross-basin research cruises, Continuous Plankton Recorder and ship-of-opportunity-programme surveys, and satellite remote sensing. A dominant and critical component of the broad-scale sampling programme will be the use of advanced platforms (Lagrangian drifters, gliders, and possibly long-range Autonomous Underwater Vehicles) outfitted with a suite of standard and new sensors. Field programmes focused on assessing, identifying, and quantifying critical processes influencing the dynamics of key species and groups will be performed in conjunction with laboratory experiments to obtain vital rates and limits as a function of environmental conditions. Resultant relationships will employed to further model development.

Deliverables

Ultimately, the principal deliverable of BASIN will be to contribute to the development of a holistic and integrated ecosystem approach to management of North Atlantic and shelf sea marine ecosystems and their services. In order to do so, BASIN will further the predictive understanding of the mechanisms by which climate change, biodiversity, and habitat dynamics and exploitation interact to influence the dynamics of the associated ecosystems. Thereby, BASIN will provide improved, scientific ecosystem-based approaches to conservation of natural resources (e.g. fish stocks), the regulation, and maintenance of ecosystem health (e.g. biodiversity) and sequestering of greenhouse gases. Specific deliverables and products toward this end are described in the body of this Science Plan.

The challenge of BASIN is to effectively portray the space and time variation of broadly distributed and dominant members of the North Atlantic plankton and fish communities and the relevant biogeochemical processes. An ocean-basin scale analysis through synthesis of observations and modelling will lead to a fundamentally new understanding of ecosystem dynamics and allow prediction of responses to climatic variation.

A. INTRODUCTION

The North Atlantic Ocean and the adjoining shelf-seas are critical for the ecological, economic, and societal health of the Americas and Europe. Its deep ocean and shelf seas support major fisheries. The basin where the Atlantic Meridional Overturning Circulation (AMOC) unfolds is a focal area for the effects of climate change, and it plays a key role in the global carbon cycle. The more northern regions are dominated by three major ocean current gyres that are interconnected, have similar water properties, and have species complexes that extend across the entire basin from the western to the eastern shores. The shelf seas and deep ocean populations are influenced by a common basin-scale atmospheric forcing, but there is a significant lack of information at a mechanistic level about how the forcing impacts the populations and how impending climate changes will alter the existing ecosystems and the biogeochemical role of the basin. Thus there is an urgent need to better understand the basin-scale processes within the North Atlantic, to be able to predict likely future changes due to climate change, and to be able to integrate from the basin-scale to the local scales of the economically important basin-rim shelf systems.

BASIN is a joint EU/North American research initiative to elucidate the mechanisms underlying observed physical and biological changes in the North Atlantic Ocean and to quantify and predict consequences of climate and environmental variability and change. The ultimate goals are i) the development of an understanding of the links between climate and the marine ecosystems of the North Atlantic basin and the services these ecosystems provide including exploited marine resources, and ii) the use this understanding to develop ecosystem based management strategies that will anticipate the effects of climate change on the living resources of the region. Thus the overarching aim of the BASIN initiative is **to understand and predict the impact of climate change on key species of plankton and fish, and associated ecosystem and biogeochemical dynamics in the North Atlantic basin and surrounding shelves, in order to improve ocean management and conservation**.

A major issue in marine ecology is how food webs are controlled or regulated by their environment and human activities. Understanding the governing processes and mechanisms has important implications for the management of marine resources, both for harvesting these resources and protection of species. Variations in physical forcing and ocean biogeochemistry over seasonal, interannual, and longer time-scales, are known to cause fluctuations at all trophic levels of the food web (Cushing and Dickson, 1976; Fasham *et al.*, 2001; Mann and Lazier, 2005; Lehodey *et al.*, 2006). As such, there is no "ecological steady state" on these time-scales. Recently, overfishing at higher trophic levels has resulted in fisheries in many parts of world switching to the harvest of lower trophic levels (Pauly *et al.*, 1998) and to the switching of some North Atlantic ecosystems from bottom-up (resource-driven) to top-down (consumer-driven) control (Frank *et al.*, 2007). Knowledge of ecosystem dynamics is required to make proper evaluation and prediction of the impact of environmental change and fishing on marine food webs, with a fundamental challenge being the determination of the interaction between large natural variations and the impact of man (Perry and Ommer, 2003). Additionally, the global scale of the climate, environmental, and anthropogenic forcings, in combination with the connections between continental shelf and deep ocean ecosystems either through transport by oceanic currents or the behaviour of the organisms requires that consideration be given to basin-scale processes rather than to focused regional programmes (Belkin *et. al.*, 1998; Greene and Pershing, 2007). Due to the complexity of this challenge, it can only be explored through the extensive use of, and extension of mathematical models in combination with retrospective data analysis and advances in observations and experimental parameterization. BASIN is a proposed 10-year multidisciplinary programme to improve the integrated understanding of the dynamics of the marine ecosystems of the North Atlantic and to produce tools to meet the future increasing demands for an ecological strategy for marine management based on the precautionary approach.

The Science Plan and Implementation Strategy (SP/IS) developed in this document presents an overview of the components and phases needed to address key scientific questions and to achieve the programmatic goals. It also includes recommendations for the programme and data management. The SP/IS represents the outcome of three planning workshops (see http://www.globec.org/structure/multinational/basin/basin.htm for the reports) and is a community effort involving European and North American scientists, managers, and research agencies to develop the scientific programme needed to advance our understanding of the links between the atmosphere, ocean physics, population dynamics of marine organisms, and the associated biogeochemical processes in the context of climate change. It is our belief that the vision for a basin-scale scientific effort should be implemented and carried out collaboratively by international teams of investigators to address physical-biological objectives that are judged to have the greatest relevance to the pressing issue of climate change.

Scientific themes

Three main thematic questions are identified for examination:

Theme 1

How will **climate variability and change,** for example changes in temperature, stratification, transport and acidification, influence the seasonal cycle of primary productivity, trophic interactions, and fluxes of carbon to the benthos and the deep ocean?

- How will the ecosystem's response to these changes differ across the basin and among the shelf seas?
- How are the populations of phytoplankton, zooplankton, and higher trophic levels influenced by large-scale ocean circulation and what is the influence of changes in atmospheric and oceanic climate on their population dynamics?
- What are the feedbacks from changes in ecosystem structure and dynamics on climate signals?

Theme 2

How do **life history strategies** of target organisms, including vertical and horizontal migration, contribute to observed population dynamics, community structure, and biogeography?

- How are life history strategies affected by climate variability?
- How will life history strategy influence the response of key species and populations to anthropogenic climate change?

Theme 3

How does the **removal of exploited species** influence marine ecosystems and sequestration of carbon?

- Under what conditions can harvesting result in substantial restructuring of shelf or basin ecosystems, i.e. alternate stable states?
- Do such changes extend to primary productivity and nutrient cycling?
- How is resilience of the ecosystem affected?
- What is the potential impact on the sequestration of carbon?

BASIN deliverables

Ultimately the principal deliverable of BASIN will be the development of a holistic and integrated ecosystem approach to management of North Atlantic and shelf sea marine ecosystems and their services. BASIN will advance the predictive understanding of the mechanisms by which climate change, biodiversity, and habitat dynamics and exploitation interact to influence the dynamics of the associated ecosystems. Thereby, BASIN will provide improved scientific ecosystem-based approaches to conservation of natural resources (e.g. fish stocks), the regulation and maintenance of ecosystem health (e.g. biodiversity), and sequestering of greenhouse gases. Specific deliverables and products toward this end that are anticipated during the first phase of the BASIN programme are:

1. Enhanced basin-scale coupled climate/ocean/ecosystem modelling systems linking basin- and shelf-scale processes and identification of the climate forcing processes that have the greatest influence on ocean and ecosystem variability.
2. Hindcasts of the state and variability of North Atlantic ecosystems for the past 50 years or more and the construction of future scenarios based on the predicted evolution of climate (e.g. IPCC scenarios) as well as the ecosystems themselves.
3. Provision of all model results to the community for further analysis and comparisons.
4. Estimates of the current state, variability, and vulnerability of North Atlantic and associated shelf ecosystems and their services (e.g. fisheries and carbon sequestration) in response to climate change and exploitation patterns.

5. An assessment of the ecosystem and key species spatial connectivity throughout the North Atlantic and associated shelf seas.
6. An assessment of the top-down effects of upper trophic levels and effect of their exploitation on ecosystem structure and carbon cycling.
7. Identification of the key ecosystem and biogeochemical components and processes that modify population dynamics and their feedbacks to marine ecosystems and climate.
8. Estimates of local (shelf) versus remote (deep ocean) natural and anthropogenic impacts on ecosystem dynamics and exploited resources.
9. Improved assessment and management tools for exploited resources such as fish stocks based on basin-scale forcing.

This Science Plan and Implementation Strategy begins in Sections B and C with a rationale and a discussion of why a basin-scale approach to key problems in ecosystem research is needed. The main components of the required research programme (modelling, retrospective data analysis, and new observations and experimentation) are then presented in three sections. Central to the BASIN initiative are the coupled biological/physical models that will provide a means for synthesising and integrating field and laboratory data sets, and provide hindcasts and forecasts of the ocean system. These are described in Section D. A comprehensive effort to assemble, re-analyse, and synthesize relevant existing data sets to provide a context for model hindcasting and testing as well as scenario development, and identification of gaps in essential data are presented in Section E. Section F describes the technology and sampling strategies needed to provide basin-scale data on the distribution and abundance of key ecosystem properties for observing system simulation experiments (OSSEs), data assimilation, and model verification. A complementary effort to develop new information on key ecological processes through focused process studies is also described. A strategy for providing information and model results tailored to the needs of ecosystem and resource managers is presented in Section G. Finally, the BASIN programme's structure and timeline are outlined in Section H, with its management, data management, and outreach discussed in Section I, along with the relationships between this study and other national and international programmes.

B. BASIN JUSTIFICATION

It is now clear that changes in natural patterns or "modes" of the atmosphere and ocean, such as the *El Niño*/Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO), orchestrate large variations in weather and climate over much of the globe on interannual and longer time scales (Joyce, 2001; Visbeck *et al.*, 2001; Trenberth *et al.*, 2002; Kerr, 2005). For instance, much of the global warming in recent decades has been attributed to decadal changes in the phase and amplitude of these three dominant patterns of variability (Fig. 1). Moreover, it has been argued that the spatial pattern of the response to anthropogenic forcing may project principally onto such modes of natural climate variability (e.g. Corti *et al.*, 1999). The interaction of climatic forcing, ocean circulation, and changes in greenhouse gas concentrations influence the dynamics of the thermohaline circulation of the North Atlantic, a factor that has being identified as a key influence on global climate (e.g. Broecker, 1997; Clark *et al.*, 2002; Sutton and Hodsen, 2005) and ecosystem dynamics. For example, changes in the physical environment in the North Atlantic basin have been linked to fluctuations in the population dynamics of key species and exploited fish stocks in the basin itself as well as associated shelves (e.g. Reid *et al.*, 2001; Greene *et al.*, 2003; Beaugrand *et al.*, 2003, 2005; Richardson and Schoeman, 2004; Pedchenko, 2005; Fig. 2). Changes in population dynamics have been shown to be influenced by climatically driven changes in circulation patterns and physiological rates as well as in the timing of the spring bloom (e.g. Reid *et al.*, 2001). These studies clearly identify the importance of the North Atlantic basin for global change research and earth system science as well as the implications of changes in the structure and function of its ecosystems and their services.

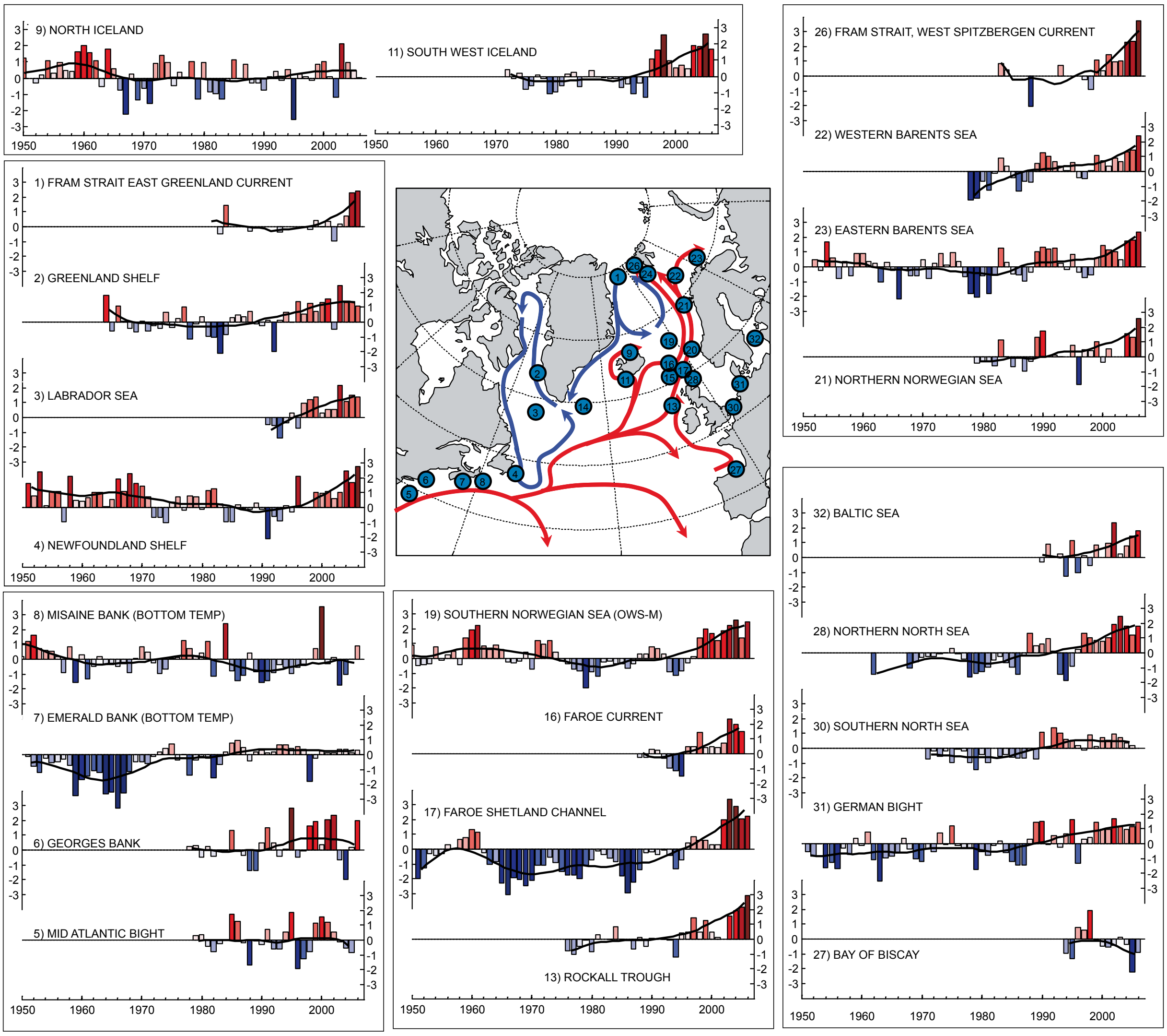

Figure 1. Upper ocean temperature anomalies relative to the long-term mean at locations around the North Atlantic basin (from Hughes and Holliday, 2007 – Figure 1 lower section). Temperatures at most locations have been well above the long-term mean during the past decade.

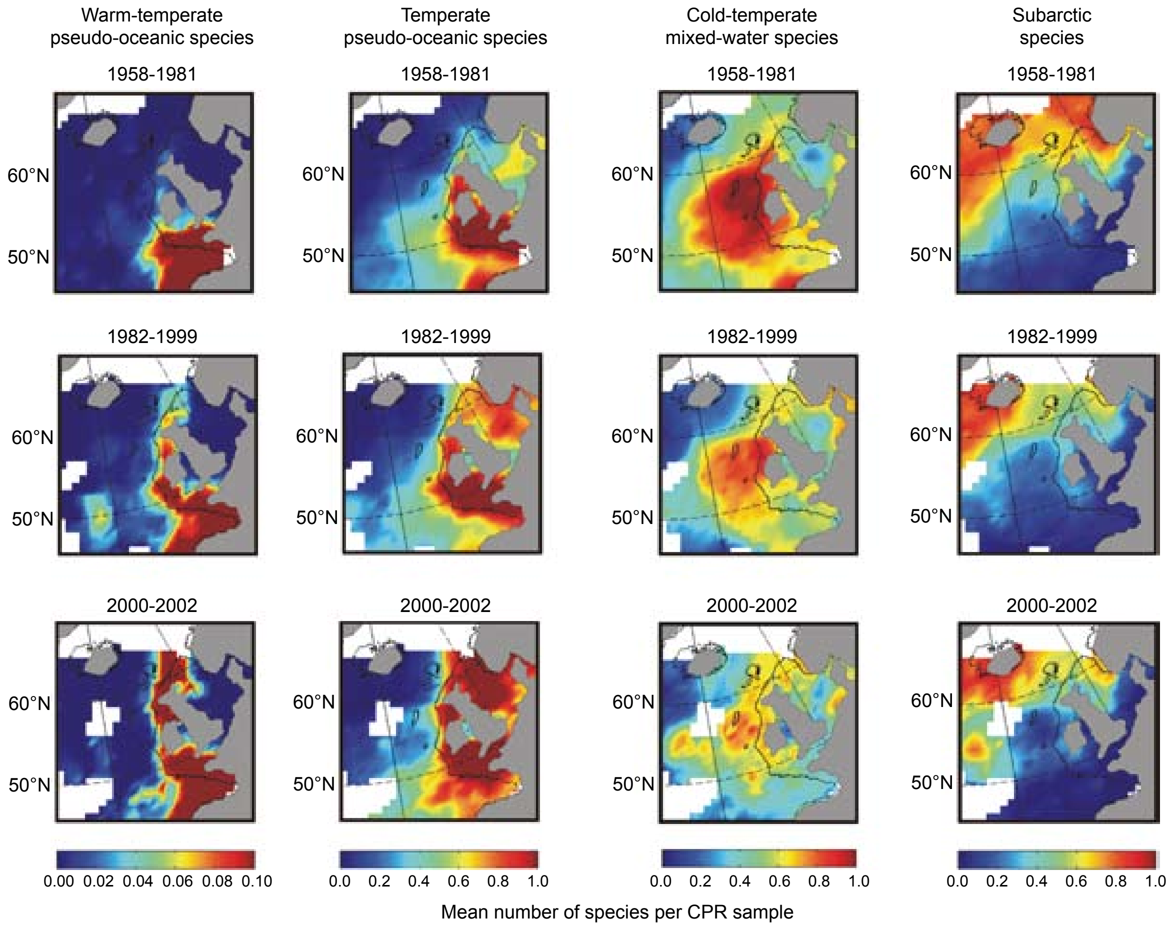

Figure 2. There is evidence that species assemblages have changed extensively during 3 periods over a forty-four year period (from Beaugrand, 2005 - Figure 3). Warm-water species in the northeast Atlantic have extended their distribution northwards by more than 10° of latitude, while cold-water species have decreased in number and extension.

Developing appropriate environmental policy in the face of global change is one of the greatest challenges facing public authorities and all sectors of society. Landings of the capture fisheries have now peaked at approximately 100 million metric tons, and according to the FAO (FAO, 2007) nearly 25% of these fisheries are considered to be overexploited. Nonetheless, these fisheries continue to be of substantial economic importance, particularly to countries around the North Atlantic. Trade in fisheries commodities, in the European Community amounted to 3.2 billion USD, and in Canada and the US the landed value of catches was nearly 2 and 4 billion USD respectively. Presently, a number of these exploited fish stocks indigenous to North Atlantic basin and shelf waters are at historically low levels and in danger of collapse as a result of the combined effects of unsustainable exploitation patterns and climate change.

The need for an ecosystem approach to the management of renewable marine resources has been recognised by a number of states, including Canada, the US, and the EU. Nations exploiting marine resources face socio-economic and environmental challenges with ongoing crises in fisheries and fisheries management, and clear signals of global change. Until recently, there has been a tendency to treat issues such as climate change, biodiversity, and habitat separately. However, ecosystem-based management strategies seek to develop a holistic and integrated approach. The development of these management strategies has been identified as a major research priority for the EU (IPTS-JRC 2000 Mega-challenge 2–Anonymous, 2000), Canada (Fisheries and Oceans Canada, 2007 [http://www.dfo-mpo.gc.ca/sds-sdd/2007-2009/goalc-butc-eng.htm]), and the US (Burgess *et al.*, 2005). Meeting these challenges will require improved scientific approaches to conservation of natural resources, coastal zone management, fish stock assessment, management, and regulation, and maintenance of ecosystem health and sequestering of greenhouse gases. In turn these approaches need to be based on genuine and sound understanding of the dynamics of ocean ecosystems and their response to human activities and natural climatic variation.

C. WHY IS A BASIN-SCALE STUDY NEEDED?

The challenge of BASIN is to develop the predictive capability necessary to understand the space and time variation of broadly distributed and dominant members of the North Atlantic plankton and fish communities, the relevant biogeochemical processes, as well as feedbacks between and within these components and climate. Analyses at ocean basin scales through synthesis of observations and modelling and targeted process studies will lead to a necessary and fundamentally new understanding of ecosystem dynamics and allow prediction of responses to climatic variability.

Connectivity in the North Atlantic is determined by the large-scale gyres that span the basin.

Stratification across the Atlantic and the Atlantic Meridional Overturning Circulation (AMOC) in subpolar regions influences both the local circulation and the larger-scale gyre dynamics (Fig. 3). The time-scale for recirculation within these gyres is decadal. Exchanges between the open ocean and shelves are determined by mixing processes at the shelf break. In order to understand marine ecosystem structure and function in the North Atlantic, the influences of the gyres in the horizontal and the vertical must be determined. Atmosphere-ocean coupling, such as through the North Atlantic Oscillation (NAO; Hurrell *et al.*, 1997; Marshall *et al.*, 2001), also plays a critical and varying role across the basin and strongly influences marine ecosystem characteristics.

Basin-scale forcing impacts biogeography and ecosystem structure and function both locally and across the entire region. A large number of regions within the North Atlantic basin are warming apparently in response to climate change and climate variability; new species are likely to move into the subpolar regions as a result of geographical shifts in their distribution, resulting in changes of ecosystem structure trophic interaction and ecosystem function.

There are a number of key species distributed across the whole BASIN region (e.g. Heath *et al.*, 1999, 2008; Brander and Mohn, 2004; Beaugrand *et al.*, 2007; Helaoueet and Beaugrand, 2007; Fig. 4). Changes in their distribution and the species composition or trophic interactions resulting from shifts in the geographic range of ecosystem components will result in alterations of ecosystem resilience and productivity. Recent large-scale shifts have been observed in portions of the species ranges (Beaugrand, 2005; Lindley and Daykin, 2005; Bonnet *et al.*, 2005, 2007; Head and Sameoto, 2007; Valdes *et al.*, 2007; Fig. 2). Because of the complexity of systems, the observed changes represent the interaction of

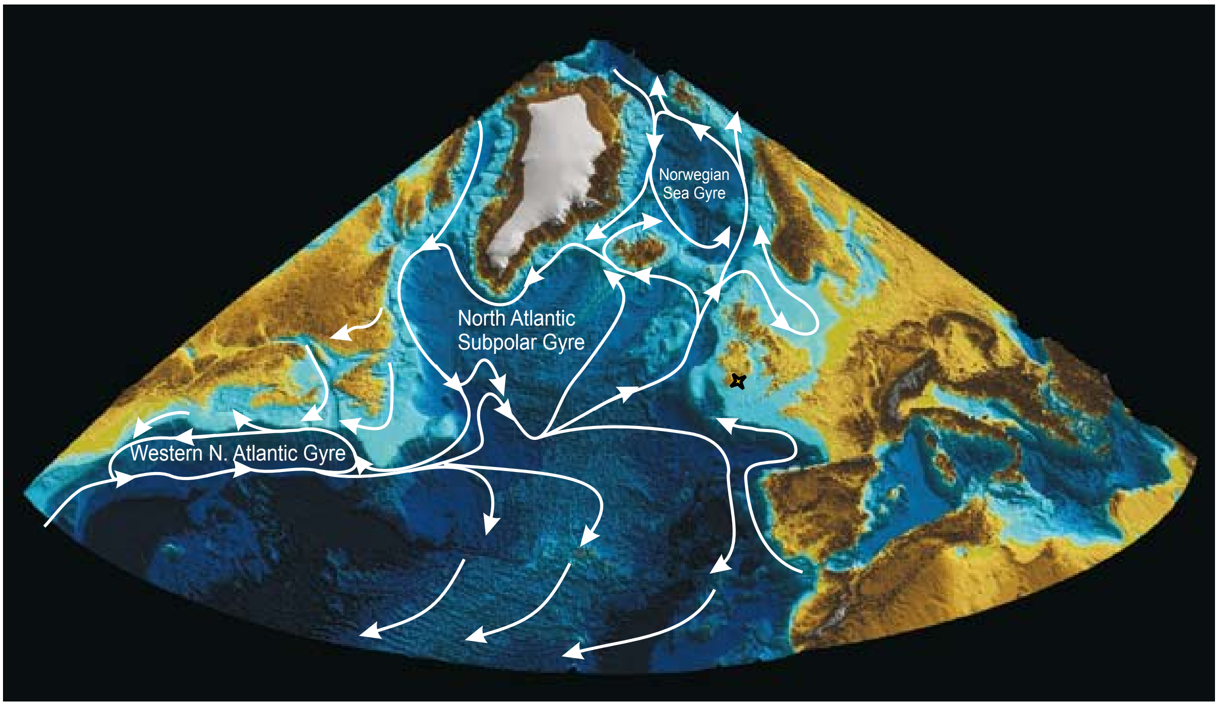

Figure 3. Topography and major circulation features in the North Atlantic.

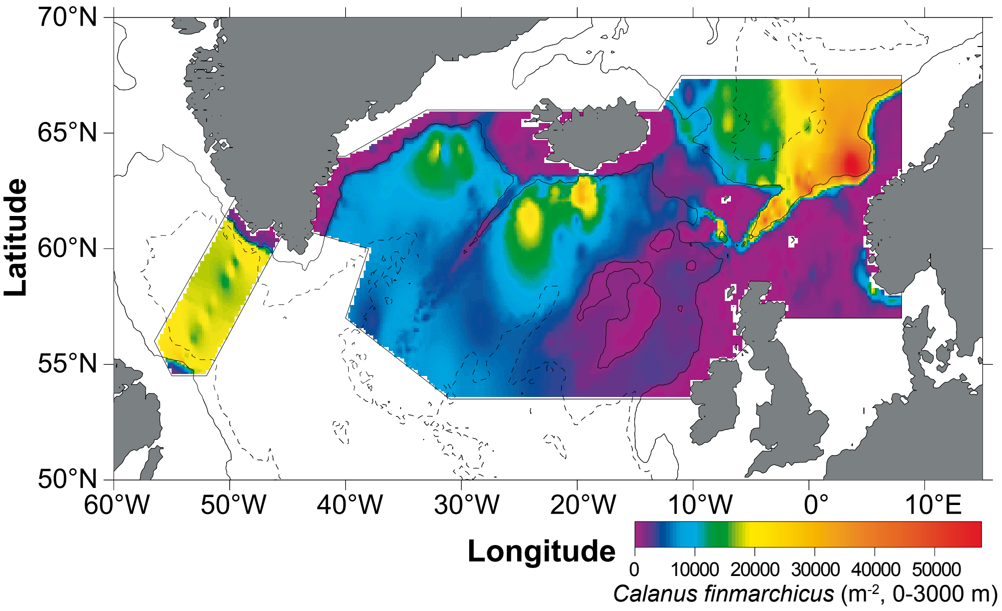

Figure 4. Abundance (m^{-2}) of stages CIV-CV *Calanus finmarchicus*, expressed as water column integrations (Heath *et al.*, 2004). The abundance is derived by vertical integration of horizontally gridded concentrations (m^{-3}) in each of fifteen 200 m thick layers between and the surface and 3000 m depth. The continuous black contour represents the 1000 m isobath; the dashed black contour the 3000 m isobath. These overwintering concentrations, determined from winter cruises, clearly demonstrate that *Calanus* is found in great abundance in the southern Norwegian Sea and Irminger Sea in the North Atlantic.

many biological and physical processes, the balance of which will differ among systems. In any one system, many factors fluctuate over different time scales, from interannual to long term changes, making it difficult to determine the relative impact of any single process on regional dynamics. Climate induced changes in advection and stratification affect basin-scale circulation and transport, and vertical processes important to ecosystem and population dynamics. Hence, discriminating between local and remote forcing requires studying key species and key functional groups, such as small pelagic schooling fish, whose abundance and biomass are important to ecosystem dynamics across the whole ocean basin. The basin-scale approach provides a stronger basis, e.g. through comparative studies, to understand the susceptibility of these systems to the appearance of alien and/or biogeographically shifted species. Movement of species into previously unoccupied regions depends on the physical suitability of the habitat for invasion, and is modulated by the presence of predators and prey as well as the level of ecological stress experienced by the existing key species. Thus, the observed shifts in species' biogeographic boundaries are an emergent property of interactions between physiological rates and limits, life history, and climate variability. Furthermore, community changes in the eastern and western Atlantic are likely to occur on different time and space scales because of the differences in the underlying physical processes that drive each region (Pershing *et al.*, 2005; Kane, 2007). By comparing and identifying the response of species to changes in the physical environment (driven by climate change) and regional lower trophic level productivity (biogeochemistry) across many regions, it becomes possible to evaluate the potential impact of changes in species interactions that result from the appearance of alien taxa.

The North Atlantic system is a key ocean basin globally for the sequestration of carbon (Behrenfeld and Falkowski, 1997).

Recognising this importance raises issues such as: i) how the biological pump (primary and export production) will be affected by climate change processes in the North Atlantic, ii) how do modifications of the biological pump impact the climate (carbon cycle), and iii) how could modifications of top down control, as driven by climate change and fisheries, change the biological pump (Körtzinger *et al.*, 2008)? A basin-scale budget of the biological pump in the North Atlantic in relation to ecosystem structuring should be a long-term goal

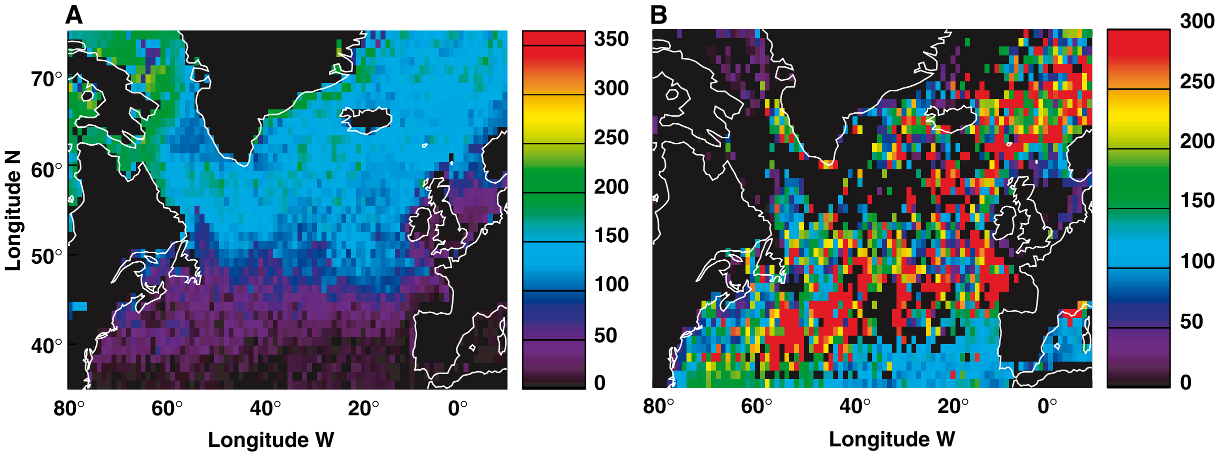

Figure 5. Spatial distributions of (A) year/day of bloom initiation YDinit: year day stating with January 1 and (B) mixed-layer depth in metres at YDinit . In general the bloom is later to the north, but the circulation and water column structure does also play some role (from Siegel *et al.*, 2002 - Figure 1).

of studies such as BASIN (Fig. 5). Particular emphasis should be placed on the marginal shelves around the basin, as these areas are still poorly constrained and account for a large portion of carbon export towards the deep ocean (Thomas *et al.*, 2004). The impact of the shelf/deep ocean exchanges on the water mass characteristics will also considered at the basin scale (http://www.loicz.org/) in collaboration with the GEOTRACES (http://www.ldeo.columbia.edu/res/pi/geotraces/) and OCB (http://www.us-ocb.org/) programmes, among others. To make reliable predictions about carbon flux and sequestration, a basin-scale approach is required to capture the range of hydrodynamic regimes, water masses, and ecosystem types that characterize the North Atlantic biogeochemical environment.

The ecosystem approach to management of widely distributed fish and other key species requires a basin-scale approach.

Climate variability and change have different effects on population dynamics (growth, migration and distribution, mortality, and recruitment) of pan-Atlantic species inhabiting both shelf and high seas areas (Fig. 6). This is caused by direct effects of the climate driven ocean physics on the individuals, indirect bottom-up effects through changes in lower trophic level production, and through changes in migration and thus possible overlap between prey and predators in the different systems. Effects are seen on interannual, decadal, and multi-decadal time-scales, and it is anticipated that changes on longer time scales are associated not only with changes in fish stocks, but also with more basic changes in the functioning of the ecosystems. Implementation of a basin-wide approach will enable the integration and comparison of present knowledge and data on climate, environment,

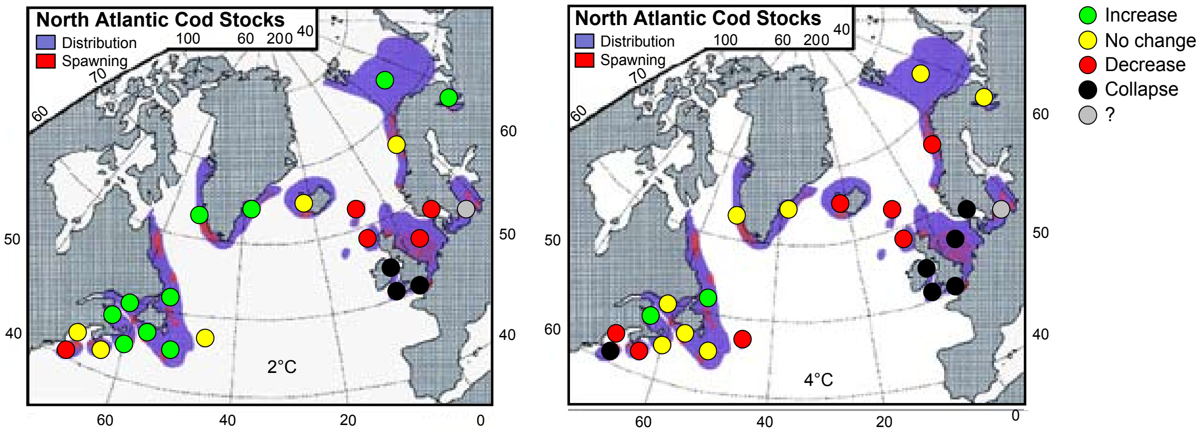

Figure 6. Expected changes in the abundance of the cod stocks with a temperature increase of 2°C (left) and 4°C (right) above current levels. Dot colour: green = increase; yellow = no change; red = decrease; black = collapse; grey = unknown (from Drinkwater, 2005 - Figure 5).

and ecosystems throughout the North Atlantic. It will also enable us to understand the processes needed to quantify and predict the complex variability of the different species and their interactions.

In addition to climate, fisheries are the other major driving force on marine ecosystems. Intensive fishing on key species affects not only the exploited fish communities, but also impacts lower trophic levels, i.e. through cascading effects down the trophic pyramid, effects of bycatch, and habitat modification by trawling. Today's fisheries management advice is mostly based on single stock assessment with little or no consideration of trophic interactions and climate effects. Since the climate prediction scenarios for the next century extend the limits of our experience, it is important that we base our ecosystem predictions as much as possible on basic process understanding.

Specific questions to be addressed

Ocean circulation and the distribution and variability of key species

How do the large-scale gyres influence the distribution of the populations of key species in the North Atlantic? What is the influence of large scale changes in basin-scale circulation on the habitat availability of pan-Atlantic species or pan-Atlantic functional groups? What is the relative importance of locally strong topographic features in the mean alongshore topography on the cross-shelf exchange of heat, mass, momentum and organisms? How do the dominant atmosphere-ocean coupled modes of variability, including the Arctic Oscillation and the NAO, influence the distribution, variability and adaptation of key target organisms in the North Atlantic?

Spatial distribution of populations

How are biogeographic regions maintained in the North Atlantic and how will they shift with climate change? How do pan-Atlantic population exchanges between shelf and ocean influence ecosystem dynamics? How are these exchanges influenced by climate change? What are the consequences for biodiversity? What maintains the biogeographic boundaries between congeneric species? What is the role of horizontal migration and transport on population connectivity in larval fish and other planktivores on a basin-scale? How are these basin-scale population patterns related to zooplankton prey distribution and transport? How are shelf populations of pan-Atlantic species influenced by exchanges between shelf and open ocean ecosystems? How are these exchanges influenced by remote and local forcing?

Ocean stratification and ecosystem function

How will climate change affect basin-scale spring bloom dynamics or primary production in other parts of the year and what are the consequences for zooplankton and implications for the survival of fish populations? Is an early spring bloom required for good trophic transfer (e.g. in the sense of Cushing's match-mismatch hypothesis; Cushing, 1972, 1990) and successful recruitment? Is primary production in other parts of the year equally important (Friedland *et al.*, 2008)? How will basin-scale changes in circulation and stratification change the phytoplankton community (lower food web structure) and what will be the consequences for the ecosystem? Changes in the vertical fluxes influence both the local stratification and the mesoscale structure of the horizontal circulation. How do such changes then influence basin-scale primary and secondary productivity?

Ecosystem structure and biogeochemistry

How do changes in ecosystem structure as driven by climate and exploitation patterns influence the dynamics of the biological pump (primary and export production)? How do changes in water column structure, transport, and convection influence species composition, export fluxes, and air sea exchange? How does spring bloom timing or primary production during other parts of the year influence biogeochemical cycling, and how do these changes propagate up the food chain? What are the resultant consequences for subsurface and thermocline water mass characteristics on interannual time scales, and what are the consequences for production in biological hot spots?

Food web dynamics

How do modifications of top down/bottom up control, as driven by climate change and fisheries, change the biological pump? How do changes in trophic cascades influence the population dynamics of key biogeochemical groups, e.g. diatoms, microbial loop and mesozooplankton? What determines the quality of food for fish and how are its effects transferred up the food chain? What are the differential effects of fisheries and secondary production on the structure and energy flow of marine shelf ecosystems?

Food web coupling

How does the impact of predation on community structure vary regionally? What is the role of predation by meso-pelagic fish species on the dynamics of open ocean zooplankton stocks (that play key roles in shelf ecosystems)? How or do large pelagic predators such as tuna restructure the pelagic ecosystems of the basin?

To address these questions and the associated basin-scale issues outlined above, a programme focused on modelling, data integration, and analysis, together with an observational programme are needed (Fig. 7). The following sections describe the programme elements and the implementation aspects that are required.

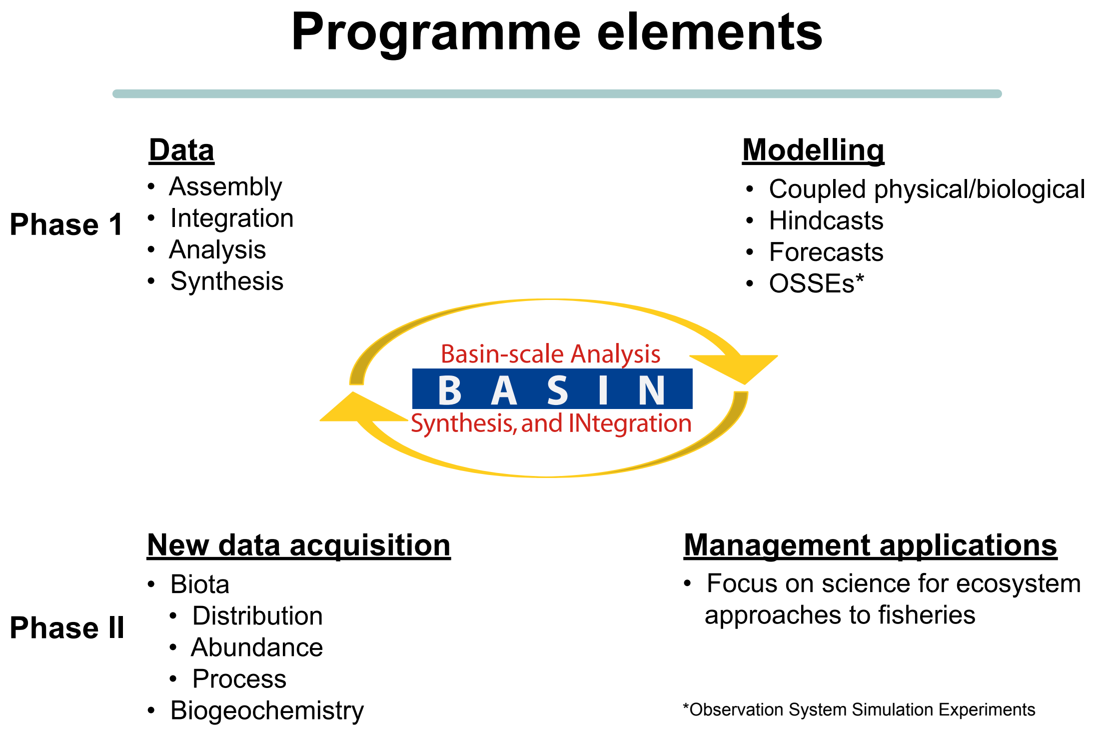

Figure 7. Schematic of the BASIN programme elements illustrating the emphasis on data synthesis and modeling in Phase I and the addition of new data acquisition and development of management applications in Phase II.

D. MODELLING NEEDED FOR THE BASIN PROGRAMME

General approach

There is currently no fully integrated ecosystem model that can address BASIN's goals nor is a single model likely to be successful at addressing all of the goals of the programme. It is expected that an ensemble of models will be developed that will be carefully selected from to address particular issues and problems. One of the goals of BASIN will be to ensure interoperability between models so that researchers can take advantage of models developed around the Atlantic for application to particular problems. Interoperability and intercomparison between models will be an important aspect of the BASIN modelling activities.

The key steps in representing complex food webs in basin-scale models are to concentrate the biological resolution at the level of the species or trophic level of interest, and to decrease the resolution, with distance both up and down the trophic scale from the target species (deYoung *et al.*, 2004; Fig. 8). The target species can for example be represented by developmental-stage-structured representations in which the key life history stages and their links to the environment are explicitly formulated. Competitors, prey, and predators can be represented by less detailed structures, perhaps based on species-aggregated, bulk biomass properties, or even external forcing data, leading to a rhomboid shaped representation of detail. The coupling between levels of differing biological resolution or representation is a necessary focus for research. The physical models, in which the biological representations are embedded, should have resolution, characteristics, and complexity matched to the species and process of interest, although they should also consider the requirements of the lower and higher levels. Existing physical circulation models have differing strengths and so it is likely that several different models will be considered within BASIN including the Nucleus for European Modelling of the Oceans (NEMO), the Regional Ocean Modelling System (ROMS), the Hybrid Coordinate Ocean Model (HYCOM), and Unstructured Grid Models such as the Imperial College Ocean Model (ICOM) and the Finite Volume Coastal Ocean Model (FVCOM), among others.

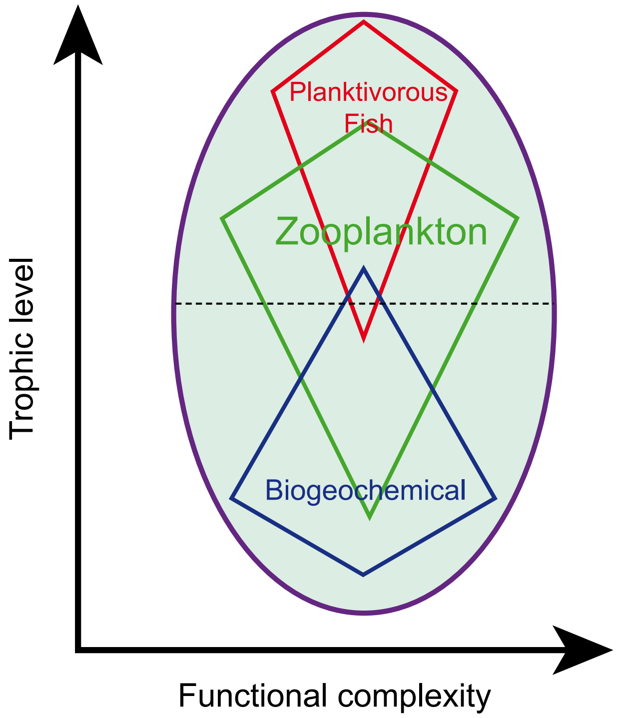

Figure 8. Conceptual rhomboid diagram (deYoung *et al.*, 2004) showing the possible different strategies for studies of planktivorous fish, zooplankton, or biogeochemical processes. The rhomboid is widest, indicating the greatest focus and complexity, at the trophic level of primary interest, narrowing in complexity and detail away from the region of primary interest. Within BASIN it is expected that there will be different models developed and applied with differing rhomboidal structures as illustrated here. A study of planktivorous fish would require substantial attention to the life history of the fish and would also include some consideration of the impact of fishing. In contrast, studies of biogeochemistry would likely not include fishing, but would require substantial detail and complexity for key biogeochemical processes.

Following this approach, the focus of the BASIN modelling programme will be on key species and functional groups for which the most detailed spatially explicit models will be developed. However, relative to these key ecosystem and biogeochemical species and groups significant efforts in modelling the neighbouring lower and higher levels will be made. A major research element of the programme will be to identify the required level of detail for the models at the respective levels and the best approaches to couple the biological models with the circulation models. This will entail a sustained effort in inter-comparing models against common data sets, e.g. an ECOMIP (Ecological Modelling Intercomparison Project, similar to previous MIP efforts such as the OCMIPs described in http://www.ipsl.jussieu.fr/OCMIP/) and dedicated efforts to focus specifically on the required two way flows of information across the interfaces between the ecological levels.

BASIN will support continuing improvements in hindcasting the past 50-year record of climate and ecological conditions (longer if appropriate forcing information is available) and in developing ecosystem and key species and groups response windows over the coming decades. A key goal should be a common modelling environment for basin-scale operation of diverse ecological models of coupled open-ocean and shelf systems. One possible avenue for this common environment is the development of a coupler that exchanges information among heterogeneous models, similar to that which is already being developed for Earth System models (http://www.cisl.ucar.edu/research/2005/esmf.jsp) and within the EU 7th Framework programme Marine Ecosystem Evolution in a Changing Environment (MEECE; http://www.meece.eu/). Much of what is proposed here would place ecological modelling studies on the path already taken by climate and physical oceanographic models (e.g. model intercomparison, nesting/interfacing between different models, hindcasting/forecasting scenarios).

Elements of the modelling programme

State of the art physical and ecological models will be used to address BASIN's goals (Fig. 9). Reviews for physical models, ecological models, coupled models, modelling challenges, and data assimilative models are provided in some detail in Appendices B-F respectively of the Reykjavik Meeting Report (Wiebe *et al.*, 2007; http://www.globec.org/structure/multinational/basin/basin.htm). Perhaps more importantly at this stage for BASIN are the challenges we face in extending these approaches and integrating them to obtain new insights at the larger spatial and temporal scales implied by the basin-scale questions.

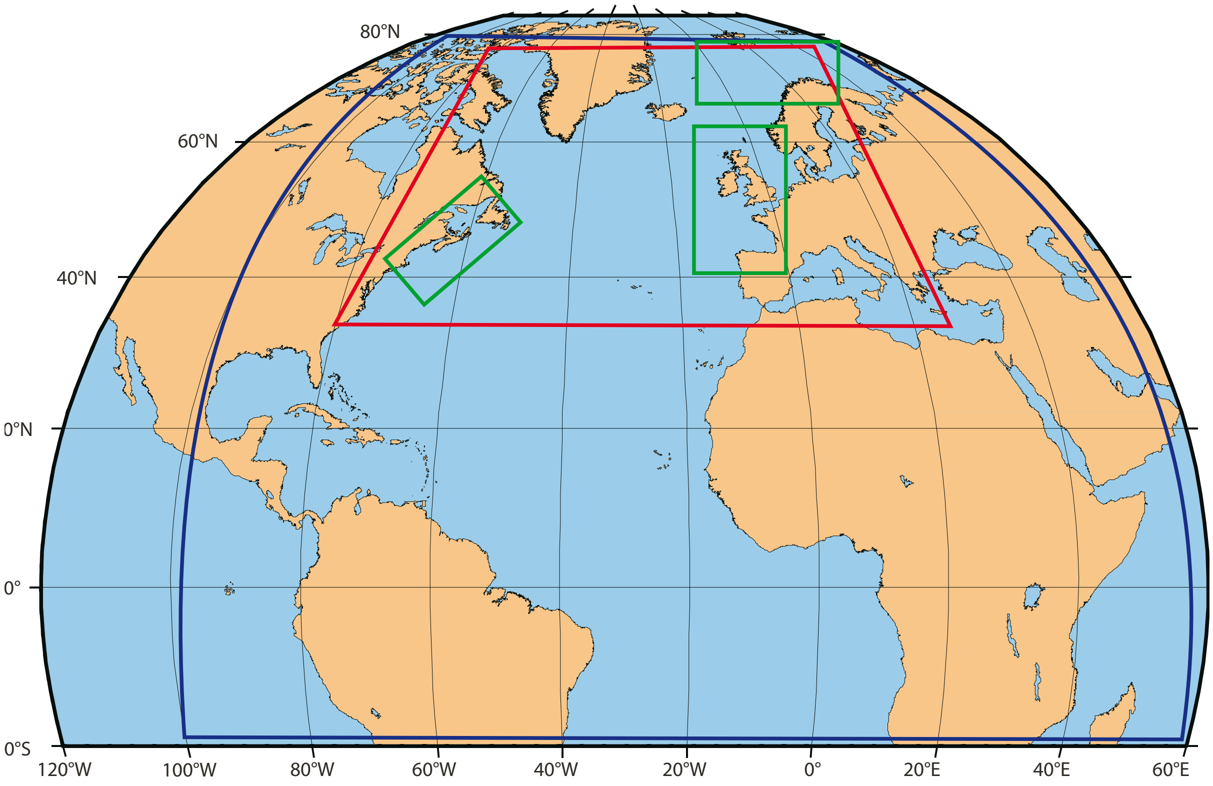

Figure 9. A schematic illustration of a possible nested physical/biological modelling strategy for the BASIN programme.

Integration across trophic levels

In order to develop the understanding and tools necessary to simulate population structure and dynamics of key species and biogeochemical processes that span the basin of the North Atlantic, BASIN will develop a suite of models needed to capture the relevant ecosystem and biogeochemical dynamics on the continental shelves as well as at the North Atlantic basin scale. BASIN will approach the problem of understanding basin-scale ecology by selecting key targeted species and functional groups, and then building an ecosystem approach focused on these key components.

The selection of the targeted species and functional groups will require additional analysis and review as it is important that they are both ecologically and biogeochemically significant and scientifically tractable. The approach for the identification of targeted species will include a review based upon a suite containing the following criteria:

- Functionally important (e.g. biogeochemical or trophic)
- Extensive existing data sets (spatial and temporal)
- Concurrence with other relevant data sets
- Understanding of life history and physiology
- Well resolved taxonomy
- Widely distributed across the basin
- Economic and societal importance

The targeted components in BASIN will span the trophic levels from microbes and phytoplankton through to fish. The BASIN approach will explicitly include an integrated strategy spanning the range between lower trophic level biogeochemical processes and top predators following the rhomboidal modelling approach (deYoung *et al.*, 2004). Four major components are envisaged focusing on differing trophic levels (described in greater detail in Appendix C of Wiebe *et al.*, 2007):

- Primary production and biogeochemical cycles
- Zooplankton
- Planktivorous fish
- Demersal fish

At present, of the four components, those of zooplankton and planktivorous fish are the most heavily studied and form an integral part of BASIN in particular as our existing databases contain most information on these two components and due to their importance for resource management. However, BASIN recognises that expansion in the areas of primary production and the microbial loop is necessary for advancing our understanding the importance of top down and bottom up controls on ecosystem structure and function (e.g. Frank *et al.*, 2006) in particular with respect to the sequestering of greenhouse gases and the carbon cycle. On the shelves, the demersal fish component (e.g. cod and haddock) is significant because of the importance of these fishery resources to society as well as the predatory controls these species exert on marine ecosystems (e.g. Frank *et al.*, 2005). In the central basin focus will be placed on large pelagic predators such as tuna that have the potential to perform a similar ecological role to demersal fish on the shelves as well as representing an important economic component of the system.

Following the rhomboid strategy, each component from the microbial loop to top predators will include some aspect of data or modelling from neighbouring trophic levels, either above or below the component of emphasis. Thus, for example, the zooplankton component will include some elements of primary production, but at a greatly simplified level relative to the effort describing primary production. Likewise the zooplankton component will include data or perhaps simplified models to provide bottom up controls for planktivorous fish and other predators. Although each of the four components has a different primary area of interest there is, through necessity, substantial overlap between them.

Modelling activities

Interfacing the models

The last few decades have seen important advances in coupling physical models, from 1D to 3D, to multi-trophic-level ecological models. Although there are still many outstanding and difficult questions in these areas, our capabilities are advancing rapidly (Werner *et al.*, 2004). In contrast, there is comparably little experience in interfacing models for different trophic levels other than at the primary producer and herbivore levels. To progress, the challenges are substantial. For example, models for the population dynamics at different trophic levels operate at fundamentally different time and space scales (phytoplankton days; zooplankton weeks to months; small pelagic fish annual to multi annual; demersal fish annual to decadal) and within very different ecological realities as a result of different habitats or different modes of life history closure (Werner *et al.*, 2007). At this stage, it is difficult to envisage a concentration based approach or an individual based approach that would work across all trophic levels. Even if we can express biological dynamics across all trophic levels in the same currency (e.g. carbon), fundamental differences in the way the chosen currency flows within each level (e.g. continuous versus discrete transfers) prevents a single unified approach. Also, limitations to ecological knowledge and computational power force a rhomboidal approach leading to a proposed focus on developing the interfaces between NPZD-zooplankton, zooplankton-planktivore, and planktivore-piscivore components of different levels of complexity.

Research nodes

BASIN will consider the mechanisms needed to coordinate and implement research on interfacing the various trophic level models in basin-scale models. The charge will be to identify the required information flows and controlling processes and feedback processes from one level to the next, and the time and space scales (horizontal and vertical) at which these flows must be transferred. The research might proceed by examining first bottom-up flows (in isolation from top-down feedbacks), then top-down flows (isolated from bottom-up feedbacks), and then reconciling these research strands into a coherent view of required bottom-up and top-down feedbacks. Investigations will be fostered with a diversity of modelling approaches within and between levels (e.g. empirical algorithms, functional groups, size spectra, and dynamic energy budgets) and with development of specific research activities driven by advances and gaps identified during progress in model development and identification.

Common modelling environment

BASIN will by necessity deal with multiple trophic level models interacting with multiscale circulation models operating over a range of environments and institutions around the North Atlantic basin and associated shelves. This will strain existing arrangements for collaborations and exchange of information that usually deal with coupling two models (physics and NPZD or single species modules) for regional issues. In order to make the BASIN goals a reality, a modelling environment that can be accessed transparently from a range of institutions using diverse models will need to be developed.

Collaborative environments for multidisciplinary modelling are beginning to appear. A similar approach has been used for 3D modelling, e.g. ROMS, POM, HYCOM, and others. These modelling environments include a range of ecosystem type models from simple NPZD models to models focused on the dynamics of higher trophic levels such as tuna. The expanded open source environment developed in BASIN will provide an excellent tool for the rapid improvement of models and their dissemination through the community. This would be an important first step towards improved collaboration among modelling community around the North Atlantic basin.

However, this may not by itself bring the BASIN vision to reality. This will require a more structured environment that deals explicitly with multidisciplinary hindcast and forecast modelling at basin scales. We will explore the synergy between the models developed and explore the potential through defining the quantitative relations between differing models. One possibility for such an environment is the exchange of information from heterogeneous models through a coupler. Such an approach is, however, very challenging and represents a research area requiring collaboration with computer scientists. The coupler allows models running at different time steps on different resolution grids to exchange information. This gridded information can also be used to assimilate data that have been appropriately scaled and interpolated. The idea behind these couplers is that they can easily deal with replacing one model with another. Such a concept is already used at NCAR (e.g. the Earth System Modelling Framework, http://www.esmf.ucar.edu/) and other sites to couple atmospheric, oceanic, sea ice, and land surface models for climate scale simulations and is at present in its infancy inside the EU funded programme MEECE. MEECE will provide BASIN with a preliminary BASIN coupler through the participation of MEECE PIs inside BASIN.

Ecological Model Intercomparison (ECOMIP)

A number of approaches are available to BASIN to model the different trophic levels, from concentration based models of bulk properties to individual based and structured population simulations. These diverse models provide different views of ecosystem dynamics and have different relationships to observations. Currently, there is no structured programme in oceanography to assess the predictions of various ecological models and their relationships to data. It is arguable that the absence of such an activity is a major impediment to further advances in ecological modelling and that it makes it difficult to quantify the uncertainty in ecological simulations.

Intercomparison exercises have become increasingly common in the physical and earth sciences. Examples are the CLIVAR Pilot Ocean Model Intercomparison Project, the Arctic Ocean Model Intercomparison Project and the Ocean Carbon-Cycle Model Intercomparison Project (see a list of MIPs at http://www.clivar.org/organization/aamp/publications/mips.htm) and the Regional Ecosystem Modelling Testbed Project (Friedrichs *et al.*, 2007; http://www.ccpo.odu.edu/RTBproject/index.html). There is a particular need for such formal intercomparison exercises in ecosystem models. When data are available to test the models, intercomparison exercises accelerate the repetitive loop of model development, evaluation, and reformulation. Model intercomparison also allows research to focus on important components where data are sparse or on mechanisms that are poorly understood. Through model intercomparison important differences between models can be identified and their causes investigated. Regarding predictions, model intercomparisons provide more information concerning uncertainties than would a single model simulation. The goal of the intercomparisons is not necessarily to falsify any particular model, but rather to explore the differing strengths of models.

A programme such as BASIN depends critically on accelerating the development of ecological modelling approaches for hindcasting at basin scales. Also, projections of ecosystem changes will require better estimates of the uncertainties associated with ecological models. Therefore, BASIN will take the lead in initiating an ecological version of the physical intercomparison model exercises, an ECOMIP initiative. This initiative will identify a limited suite of ecological models that cover multiple trophic levels and the major modelling approaches. It will implement these models in a common physical framework. It will also identify data sets (see section on Data Availability and Needs above) against which the models can be compared. The ECOMIP also needs to develop common metrics to assess the model simulations and their degree of agreement (quality measures) with data. It is also crucial given the aims of BASIN that this intercomparison exercise includes both hindcasts and forecasts as targets in comparing models.

Given the diversity of approaches available, ecological modelling is a much more complex task than is the case with physical or biogeochemical models. This is why ECOMIP would have to start early in the programme with a pilot test project with initially very limited aims and then expand gradually as better understanding is gained of how such an intercomparison exercise would work with ecological models. Eventually, the ECOMIP should address the coupled models that are developed through the activity on interfacing models.

Fifty year hindcast and analysis

In recent years, re-analysed meteorological products that go back 50-years or more, improvements in oceanic circulation models, and increases in computing power have made hindcasting ocean conditions over the climatic scale feasible. Such hindcasting exercises with complex and adaptive NPZD type models are now possible. This may also be the case for simulations that directly couple circulation models with stage structured zooplankton models. Climate scale hindcast simulations with interacting trophic levels are still far off, but must be a central longer term goal of BASIN.

Within the WCRP-CLIVAR programme, hindcasts are produced with and without assimilation of observational data (coordinated by the Global Synthesis and Observation Panel and the Working Group on Ocean Model Development of CLIVAR). Global high resolution ocean-only models are used at a resolution of about 0.25 degrees to hindcast the ocean circulation from the 1950s to the present using atmospheric reanalysis data as surface forcing (air/sea fluxes). The prescribed forcing includes historical fluctuations in the atmospheric circulation. At the North Atlantic basin scale higher resolution data are available (up to 1/12th degree). Models that assimilate data typically have a coarser resolution (about 1 degree).

Within BASIN both data from these data-assimilative hindcasts and hindcasts without data assimilation will be used as boundary conditions for higher resolution models to study changes that occurred from seasonal to decadal time scales in the past 50 years.

Scenario production (links to Intergovernmental Panel for Climate Change)

The Intergovernmental Panel for Climate Change (IPCC) has begun the production of climate change scenarios in response to the possible levels of greenhouse gas emissions. These scenarios include responses of the ocean with respect to temperature, salinity, currents, etc. that can be used to drive models of ocean biology and biogeochemistry (Sarmiento *et al.*, 2004; Vikebo *et al.*, 2006; Hashioka and Yamanaka, 2007). As the resolution and detail of the projections improves, the coupling to ocean models that capture ecologically relevant scales will be possible and will be part of BASIN.

Early in 2007, the Working Group 1 of the IPCC published results on projections for future climate from state-of-the-art coupled atmosphere-land-ocean-space models. These global models project major changes in the North Atlantic basin, such as a decrease of the Meridional Overturning Circulation (MOC) of 25%, increase in stratification and disappearance of sea ice cover in the summer in the Arctic. The weakening of the MOC causes temperature rise in the North Atlantic to be weaker than elsewhere and a freshening of the North Atlantic. The models project a variety of responses of the main pattern of variability in the North Atlantic: the North Atlantic Oscillation (NAO).

IPCC-class models typically have a coarse resolution of about 1 degree. For BASIN, higher resolutions in the ocean are needed. Therefore ocean-only models will be forced with air/sea fluxes and winds from IPCC coupled models. The response of the North Atlantic circulation and the forcing of the ocean circulation to enhanced greenhouse gases vary between models. Within BASIN a number of relevant future forcing scenarios will be derived from the coupled models (e.g. NAO index increasing or decreasing, weak or strong MOC reduction, etc.). Such scenarios will be used to force high-resolution ocean-only models (as in Schweckendiek and Willebrand, 2005). Just as with the data-assimilative models and hindcast data, nesting into regional models using boundary conditions from the basin-scale models will be made to deduce the impact at regional scales.

In Phase 2 of BASIN truly eddy resolving global ocean-only models are expected to be in use regularly and new hindcasts will become available. In general, these models will include biogeochemistry and ecosystem modules. Unstructured and nested grids will provide regional high-resolution. Since internal ocean variability will be generated when resolving eddies, an ensemble approach will be followed. Data assimilation procedures will have advanced as well and run at least at eddy-permitting and perhaps higher (e.g. 1/12th degree) resolution.

The CLIVAR community will have started to produce decadal forecasts with coupled atmosphere-ocean-land-sea-ice models. Currently, potential predictability (that is, within ideal model experiments comparing a control run with an ensemble of runs with perturbed initial conditions) has been shown to exist for the Atlantic MOC and its climate responses. Within 5 years, true initial value predictions will be made. These data can be used to construct decadal nested forecasts.

Comprehensive earth system models will be available to the BASIN community. These models will include atmospheric physics, atmospheric chemistry, land, hydrology, terrestrial vegetation and biogeochemistry, sea-ice, ocean physics. A new generation of climate change scenarios will be available including earth system feedbacks (e.g. Denman *et al.*, 2007).

BASIN Observing System Simulation Experiments (OSSEs)

[Adapted from the ORION Modelling Report, 2006]

As the paradigm for observational system implementation begins to evolve, OSSEs are considered part of observational network design strategies and will contribute significantly to the Global Earth Observation System of Systems (GEOSS) 10-year Implementation Plan via the development of comprehensive, coordinated, and sustained observations of the earth system, improved monitoring of the state of the earth, increased understanding of earth processes, and enhanced prediction. BASIN is ideally suited to embrace this paradigm and enhance it in terms of encouraging coupled ocean-atmosphere, ecological and biogeochemical OSSEs.

Observation System Simulation Experiments (OSSEs) first entered meteorology almost forty years ago (Charney *et al.*, 1969). Such experiments model the observation system with the aim of quantifying its sampling properties and optimising its design. OSSEs usually require simulating the atmospheric or oceanic environment itself. Oceanic OSSEs are therefore challenging by definition: one aims to simulate unknown ocean properties so as to best measure and discover them. An example of the use of an OSSE oceanographically is given by McGillicuddy *et al.* (2001).

The technical OSSE procedure in the ocean usually involves: 1) a 'true' ocean (observations or its simulation); 2) a sub-sampling scheme modelling the observation system including measurement uncertainties; 3) a data assimilation or analysis scheme that maps measurements into fields or incorporates measurements into a predictive model, and; 4) measures of skill or evaluation criteria to quantify the results. In some cases, sufficient historical ocean data are available for the sub-sampling the 'true' ocean. In other cases, a forecast model, possibly driven by real data to increase accuracy, is utilised to generate the 'true' ocean, leading to synthetic sub-sampled data. Finally, an OSSE where the model that assimilates these synthetic data is the same as the model that created the data is usually referred to as an identical twin experiment.

As discussed in GLOBEC (1994), OSSEs can be utilised for multiple purposes including: i) guiding the design of an observation system and its components; ii) optimising the use of observational resources; iii) assessing the impact of existing or future data streams, e.g. for nowcasting and forecasting of requisite accuracies; iv) understanding the interactions of system components and improving system performance; v) evaluating and validating system performance using quantitative error estimates; vi) comparing data assimilation methods.

Status of OSSEs

- OSSEs have been, and are being, utilised to assess, for example, physical oceanographic array designs in the tropical oceans.
- The use of OSSEs to support ocean observing systems programmes has been generally absent. This absence presumably resulted from the lack of readily available modelling and data assimilation systems with adequate capabilities.
- Based on the present status of modelling and data assimilation systems, at least for physical processes, the development of adequate capabilities for implementation of useful OSSEs for BASIN observing systems may be achievable on the time scale of a few (2–5) years.

OSSE capabilities and requirements for BASIN

Given the focus of BASIN on marine ecosystems and their services, OSSE performance based on observations will as a result be heavily dependent upon the development and application of new biological (e.g. nutrients, DNA sensors, video, as well as rate measurements) and biochemical (e.g. CO_2, O_2, nutrients) observational technologies as well as advances in the measurement technologies for abiotic parameters. BASIN will serve as a catalyst for the development of these measuring systems providing a forum in which technology developers and users can interact to define observational needs and thereby aid in the advancement of measurement technologies. The success of OSSEs within BASIN will be dependent upon:

- Model and data assimilation capabilities, in both existing and their future more advanced forms.
- Field and parameter estimates being of sufficient quality and quantity to be useful for scientific guidance and comparison with simulations.
- Close collaboration between ocean modellers, observationalists, and technology developers.

Multiple roles for OSSEs within BASIN

Within BASIN OSSEs will perform multiple roles to:

- Provide input to the selection of observing sites based on the projected occurrence of key ecosystem or biogeochemical processes.
- Evaluate individual data sets (observation and simulation) and their role in constraining estimates of ocean state (abiotic, biotic, and biogeochemical).
- Refine and optimise details of the observing network.
- Adapt the network as ocean dynamics evolves, as model inaccuracies are found, or as new platforms and sensors are developed.
- Adaptive sampling-OSSEs in real time.

E. RETROSPECTIVE/REANALYSIS

Data availability and needs

Within BASIN, data will be required for several purposes including:

Retrospective analyses

- *Long-term time series* are necessary for retrospective analyses and to this end BASIN activities will identify what historical data sets are available and where they can be accessed for integration and synthesis. These data sets will include climatological, oceanographic, chemical, and biological data. While many of these data are already archived in databases, the programme will also identify, locate, and attempt to rescue historical data sets that are not presently accessible or are in danger of being lost. This will include the processing of data collections that are considered critical (in type, time, or space) that have not yet been processed, such as preserved, but as yet unanalysed, biological samples.

Surveys and process studies

- *New data* will be required in order to understand and better parameterise the physical and biological processes in the models as well as to address gaps in process knowledge. These data will be critical for model improvements and the models will be used to help prioritise the data collections required both in the field and laboratory, as well as to identify the geographical locations where such measurements should be carried out and the frequency of sampling needed. See Section F for additional detail.

Model assessment and development

- *Data required for model verification and validation.* While most of these will be in the form of presently available data sets, new measurements will also be required where existing information is limited or non-existent, either in type, space, or season or where process understanding is lacking.

Fundamental to the programme is the identification and synthesis of existing data into basin wide data sets that will allow identification of gaps in knowledge, provide critical information for model assimilation and verification, and provide guidance for identifying key species, functional groups, and potential focus regions.

Historical data and recently collected measurements will form the basis of the retrospective analysis, synthesis, and integration within BASIN. As a first step, key data sets required to carry out these activities will be identified as well as strategies for their assembly, for example via meta-database development. Climate and hydrographic data have already been assembled by many groups and organizations. Links to these databases at such locations as the World Climate Data Center, ICES, CLIVAR, etc., will be made to facilitate ready access to the data. This will not only include station measurements, but also gridded data such as those provided by the climate re-analyses.

Most available physical and biological oceanographic data have been collected only over the past 50 years. This allows us to examine interannual and decadal scale variability with some degree of certainty. For example, interdecadal temperature shifts have been observed during this period in several regions of the North Atlantic, and large ecological changes occurred during the warming and cooling periods (Beaugrand, 2005; Hughes and Holliday, 2007). However, to examine biological responses to multi-decadal climate scale variation, longer data sets of the order of 100 years or more are required. While low-frequency changes are generally not captured by most of the available data sets because of the relatively short record lengths, one data set that does exist over longer time scales than 50 years and at the geographical scale of the basins is the Continuous Plankton Recorder (CPR) data (Reid *et al.*, 2003). Without such data we would not have been in a position to begin to detect certain relationships between plankton and climate.

There are a number of data sets on species abundance and distributions available together with other environmental data sets. During the initial programme phase, data synthesis will involve making these data sets available to the BASIN community and searching out additional data sets. Data sets on physiological rates (e.g. growth, reproduction, etc.) will also be inventoried. The aim of these syntheses is to provide inputs for the initial modelling, to point to data gaps that need to be filled, and to create an initial synthesis of large spatial and temporal scale patterns of variability. Investigations will also be undertaken to synthesize existing data from different regions to examine such issues as the effect of differences in temperature/light cycle etc. on rate processes and phenology.

Data synthesis priorities

Initially the programme will identify target species/functional groups with a systematic, quantitative approach. Target species/groups should be identified by applying a qualitative Expert System Analysis based on factors such as numerical abundance, biomass, resilience, trophic importance, potential biogeochemical importance, exploitation, response to climate signals, etc.

A critical component of data synthesis will be to identify gaps in existing biological and physical data coverage, with special emphasis on key properties that are needed for modelling and prediction, but were not systematically assessed in previous process-oriented studies. This process has begun and should continue. Examples include, but are not limited to: physiological rates and limits, nutrient fluxes from organisms, and biogeochemically important processes like excretion flux and remineralization. A product of this synthesis activity will be a publicly accessible international archive of relevant data sets.

The use of satellite data will be another critical element to understanding the movement of species and shifts in community composition relative to ocean temperatures, chlorophyll distributions, and ocean fronts during the 1990s to 2000s. This time period also has an increasing amount of remote sensing data to contribute to observing basin scale changes in biological productivity and physical climate changes in the ocean. Remote sensing ocean colour data should be an essential part of data synthesis. Existing observational observations will also be used to identify indices suitable for describing changes in species distribution and behaviour in response to known climate fluctuations such as the NAO. Such indices could be critical in determining success of any coupled biological-physical model.

Key data features to model

Data requirements are strongly linked with the BASIN modelling approach. Several features in the observations that need to be modelled include:

- Changes in stratification and nutrient fluxes.
- Changes in the distribution of food web types, e.g. shifts between microbial loop and classic short food chains dominated by diatom production.
- Seasonal and interannual variability in the spatial and temporal distribution and abundance of key species under different climate conditions, i.e. changes in biogeographical boundaries and phenology.
- Trophic linkages, including a) changes in phytoplankton group composition and their effects on higher trophic levels as well as flux of carbon to depth, b) the effects of zooplankton abundance on growth, condition, and survival of fish larvae, c) the predation of adult planktivorous fish on zooplankton populations, and d) consumption of small pelagic fish by higher trophic levels.
- Changes in the size spectra observed in the Continuous Plankton Recorder data set.
- The spatial scales of coherent variability for zooplankton (approximately 1000 km) and fish (approximately 500 km) abundance.
- The advection of organisms, both as a result of cross-shelf and along-shelf transport, and whether the process is continuous or episodic.
- The observed exchanges and fluxes at the shelf break and their relative importance to the overall primary and secondary production and sequestration of greenhouse gas materials.
- The estimated retention times of zooplankton and fish on continental shelves and banks, as well as zooplankton in the deep basins in the open ocean.
- The connectivity of zooplankton and fish populations across the North Atlantic basin over relevant time scales and under climate change induced changes in circulation.
- Regional differences in ecosystem productivity and fish stock size (e.g. the largest populations of cod occur in cold waters whereas maximum individual productivity occurs in the warmest waters they inhabit).

It is also recognised that the ecosystem response to climate forcing is most likely a function of the frequency of the forcing. Although few long-term data sets are available, other local and shorter data sets can provide insights into responses to climate variability that will be used to develop conceptual models about ecosystem responses to climate forcing. These can be used together with the numerical models to help us understand and hindcast past observations as well as predict potential impacts of anthropogenically-induced climate changes. Similarly, the existing (shorter) time series help set the present ecological baseline, although it is recognised that this baseline may have been established under a specific ecosystem regime that was heavily affected by human activity such as fishing and pollution.

Information on the key predators and their consumption rates on for example zooplankton are needed, particularly information on consumption rates due to small pelagic fish. While historical time series on fisheries catches and surveys are generally easy to access, hydroacoustic surveys have been conducted in a number of countries that could supply valuable spatial information for modelling. Many of these data are archived and could be accessed for analysis. Data on abundant non-commercial fish such as myctophids from the open ocean are rarer, but some are available, e.g. the Woods Hole collections of Backus (Backus *et al.*, 1977) and the more recent information available through the Census of Marine Life programme.

Metadata associated with the measurements are very important and will also have to be recovered or generated from existing information. For zooplankton and fisheries data for example, this will include such things as mesh size, tow speeds, any known biases in the gear, time of day, etc.

Data archaeology and recovery

In addition to the readily available historical data, there are data sets that are not in electronic format or have not yet been processed. This is especially true of zooplankton data although other types of data also need to be recovered. Several zooplankton data sets have been identified that are not readily available or in electronic format, e.g. off West Greenland extending back to the 1920s; Swedish collections from the North Atlantic extending from the 1800s to 1920; from Weather Station M in the Norwegian Sea; French cruises to the Newfoundland area in the 1920s and 1930s; early collections from the Gulf of Maine as well as some MARMAP data; data from around Iceland, Russia, Ukraine, Canada, and Norway. More recent video data on zooplankton also need to be recovered and made accessible. Additional data sets will be added, as they become known. Some data sets, e.g. oil company data from Davis Strait, the Labrador Shelf, and Newfoundland region, have recently been digitized.

Data quality is often an issue with recovered data as the data may be uncalibrated or not directly comparable with other available data sets. This is especially true for very early collections. In some such cases old instruments can be reconstructed for calibration against more up-to-date instrumentation.

Complementary recovery efforts

Several programmes or projects are already involved in data archaeology and recovery. GODAR has been working primarily with physical oceanographic data. The number of large scale efforts for biological data are few. One exception is the Census of Marine Life History of Marine Animal Populations (HMAP), which has focused on the recovery of fish data. Another is the Coastal and Oceanic Ecology, Production & Observation Database (COPEPOD), http://www.st.nmfs.gov/plankton/, a global plankton database that is presently residing on a server at the US National Marine Fisheries Service. It contains abundance, biomass and species composition data. This programme is presently putting into electronic format all of the NORWESTLANT data from the Labrador and Irminger Sea regions collected in the 1960s. There is an ICES project to digitise the plankton tables in the ICES 1902–1912 reports. Within the EUR-OCEANS Network of Excellence an active programme of data rescue has been launched. The objectives of the programme are 1) to rescue historical data by funding research institutes directly to help them transform and/or create digital data sets and to give networked access to these data sets through EUR-OCEANS data portal; and 2) to encourage institutions to develop long-term capacity for preparing/archiving data and metadata, thus increasing their level of integration in the Network and fostering their collaboration with European and international research scientists (http://www.eur-oceans.org/dataportal).

Plankton databases have also been or are being assembled (including those gathered by the ICES Working Group on Zooplankton Ecology-WGZE) and zooplankton status reports are being produced (O'Brien *et al.*, 2008). Although the CPR transects dominate, other data sets are also identified, particularly coastal time-series stations. Additional plankton data sets will also be identified within BASIN.

Several GLOBEC programmes have been, or are presently, involved in field programmes. Their different areas of operation are identified, along with the area of the CPR transects (Fig. 10). These programmes have assembled or collected relevant physical and biological data and metadata are being deposited with Global Change Master Directory (GCMD), which is a comprehensive directory of descriptions of data sets of relevance to global change research. Additional relevant data sets will be sought and the scientists familiar with the data will be solicited to help to carry out the integration and synthesis of the data.

Extensive fish and fisheries data are available through ICES and NAFO working groups, national assessment committees, and within specific programmes such as the ICES/GLOBEC Working Group on Cod and Climate Change. These data, which include some egg and larval data, but mostly juvenile and adult data, must form an integral part of the BASIN data set for the integration and synthesis.

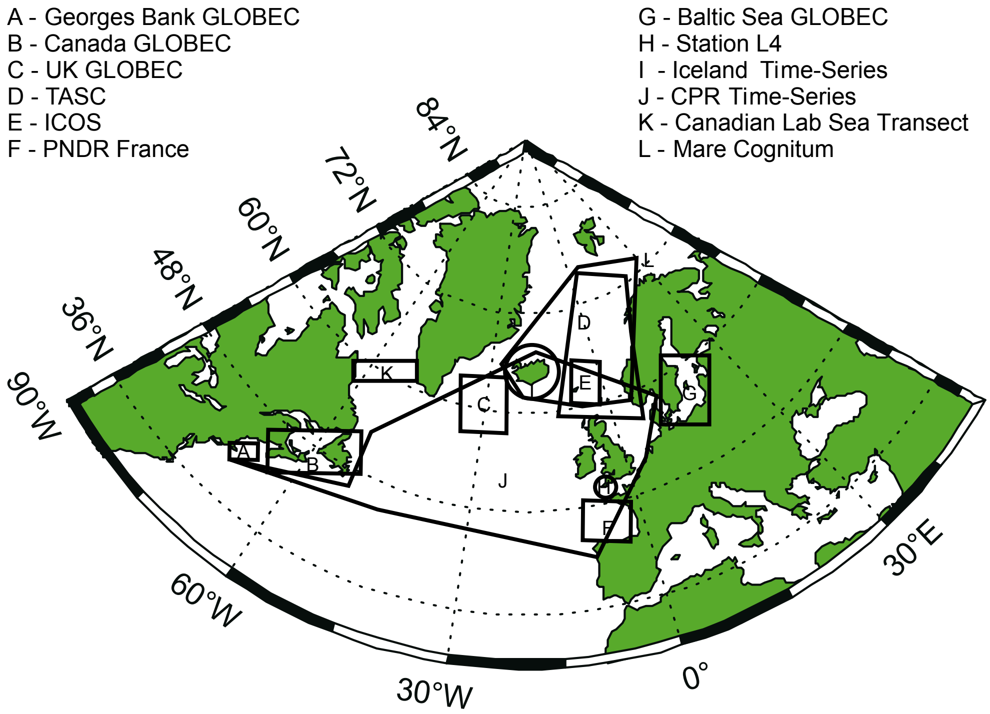

Figure 10. GLOBEC study sites in the North Atlantic.

F. BASIN OBSERVATIONS

A major challenge in marine ecology today is the development of explanatory and predictive capabilities. Pressing societal issues, such as over-fishing, pollution, and global warming require basic research, and scientists need to have a solid understanding in order to provide predictions of the effects of human impacts on the health of the environment.

It is now clear that existing sampling methods are inadequate in providing the high-resolution data on species abundances needed to model and predict their population sizes. Traditional specimen collections require long acquisition and processing times, which limit sample number, resulting in sparse data coverage. For plankton, acoustic samplers provide high-resolution backscatter data for estimating biomass concentrations, but do not provide information on component species. For fish, acoustics is a standard tool for assessing population biomass in certain species (e.g. whiting). New optical imaging samplers provide high-resolution data on size and taxonomic composition of plankton. For larger organisms, including micronekton and nekton (e.g. shrimp, squid, and fish), recent advances in optical imaging and processing have yet to be applied to automated species identification and counting, but hold promise for the future. Finally, molecular analysis is a powerful new tool for determining species composition of plankton, and new *in situ* techniques are becoming available as described below.

Data and information gaps identified by the compilation and retrospective analysis of existing data sets will be filled by using a combination of new and traditional sampling technologies and observation platforms. The use of OSSEs (Section D above) will be critical for determining which variables and parameters are important to measure and the optimal sampling strategy in time and space. New sampling programmes will be designed to collect biological, chemical, and physical data across multiple temporal and spatial scales. This programme will include long-term and broad-scale monitoring of key species and groups in the North Atlantic basin and associated shelf systems. Although the specific design of the BASIN observational programme will depend on the retrospective data analysis and OSSE modelling as well as the geographic domain or sub-system, it is clear that existing data coverage is sparse relative to what is needed for understanding and predicting the ecosystem dynamics and population dynamics of key species of plankton and fish.

In order to achieve the BASIN goal of understanding how climate change impacts ecosystems and populations across the North Atlantic subpolar gyre and adjacent shelf systems, a suite of new and existing sampling technologies and platforms will be needed to measure a broad range of physical and biological variables across a broad range of time and space scales.

Measurements needed

Many different types of measurements will be required within this programme. The examples below illustrate the range of measurements required. Not all of these measurements will be made in, or will be necessary for different components of the overall programme.

Sampling technologies – new approaches

Physics

Remote sensing of global sea surface salinity through the new Aquarius satellite is planned for 2009. This capability represents a major advance as it will provide for the first time a global view of surface salinity variability. Aquarius will yield high resolution multi-scale data linking climate forcing with the water cycle and oceanographic processes. Aquarius/SAC-D is a space mission developed by NASA and the Space Agency of Argentina (Comisión Nacional de Actividades Espaciales, CONAE).

Chemistry

Recent breakthroughs in the development of *in situ* nutrient sensors now allow for towed and autonomous acquisition of nutrient data with high resolution in time and space (Nelson, 2006). An optical-based nutrient sensor has been designed to measure nitrate at concentrations of 0.5 to 2000 µM (Johnson and Coletti, 2002; Johnson *et al.*, 2006, 2007). Reagent-based *in situ* sensors are now available and provide nM detection levels for a suite of nutrients (Nelson, 2006). Presently these systems are deployed in moored or ship-based applications due to size and power limitations. Further development and miniaturization of these sensors will enable use on small autonomous platforms including drifters, gliders, and AUVs.

Biology

Optical imaging systems. Digital imaging systems have evolved rapidly over the past decade, and there are numerous systems in existence that can be used in the BASIN field programme (Davis *et al.*, 2004; Benfield *et al.*, 2007). These systems employ CCD and line-scan cameras together with strobe, LED, and laser illumination and produce high-quality images of plankton and seston. The parallel development of automatic image analysis methods has allowed these new imaging systems to become mainstream sampling tools in biological oceanography (e.g. Davis *et al.*, 2004, 2005; Grosjean *et al.*, 2004; Hu and Davis, 2005, 2006; Davis and McGillicuddy, 2006; McGillicuddy *et al.*, 2007; Sosik and Olson, 2007). These systems provide high-resolution data and some can sample delicate plankton, which usually comprises the bulk of the mesoplankton-size particulate matter in the ocean, but are destroyed by conventional sampling gear. New digital holographic systems now exist that can image micro-to meso-plankton in a 3D volume for better quantification of morphology, abundance, and behaviour (Watson *et al.*, 2004, 2006; Pfitsch *et al.*, 2005, 2008; Jericho *et al.*, 2006; Dominguez-Caballero *et al.*, 2007; Li *et al.*, 2007; Loomis *et al.*, 2007; Sun *et al.*, 2007). In addition, new optical imaging methods for sampling larger organisms such as fish and benthic habitats include photo-mosaic seafloor mapping (Pizarro and Singh, 2003; Singh *et al.*, 2004, 2007; Armstrong *et al.*, 2006), range-gated laser imaging (Mazel *et al.*, 2003; Yoklavich *et al.*, 2003; Dalgleish, *et al.*, 2006). Airborne LIDAR has been demonstrated for quantification of zooplankton and imaging of fish (Churnside and Wilson, 2004; Churnside and Thorne, 2005) and holds promise.

Molecular methods. Molecular genetic and genomic research will yield new technologies that will be useful for BASIN. Ongoing efforts to determine a comprehensive library of DNA barcodes (i.e. short sequences for species recognition and discovery) for marine organisms will enable rapid and routine analysis of species diversity in selected regions and realms using DNA micro arrays. DNA barcodes can be used to design DNA micro arrays that can be used to detect the presence and quantify known species in particular regions or for particular taxonomic groups. In the near future, DNA micro arrays may be used in the laboratory or onboard ship to characterize species diversity and abundance in plankton samples. Eventually, protocols could be adapted to remote or autonomous deployments on moorings, gliders, and other vehicles. A particular application of DNA barcodes is the analysis of marine trophic webs, through identification of prey species or species groups in the guts of predators. These protocols are currently in development, and will be available for the BASIN field years. Molecular genomic analysis may yield new proxies for complex biological and physiological processes, including growth, condition, and reproduction; senescence and mortality; diapause and over-wintering. Quantitative measures of target gene expression and genomic patterns in expressed sequence tags (ESTs) will allow parameterization of these complex phenomena in population and ecosystem analysis and models that seek to document impacts of climate change. *In situ* molecular probes have been used on moorings to identify species of phytoplankton and meroplanktonic larvae (Scholin *et al.*, 2001; Goffredi *et al.*, 2006; Greenfield *et al.*, 2006). At present these *in situ* systems are used in moored applications and are too large for drifters, AUVs, or gliders, but this limitation will be overcome as miniaturization of the samplers occurs.

Sampling technologies – existing approaches

Physics

The standard meteorological sensor suite is needed on ships and moorings for measuring air temperature, humidity, wind speed/direction, and irradiance. Oceanographic sensors available include CTDs, XBTs, ADCPs, radiometers, and turbulence sensors. In addition, remote sensing from satellites provides sea surface temperature, elevation, and winds (scatterometry). Multi-beam acoustics are available for high-resolution bathymetric mapping.

Chemistry

Standard ship-based analytical methods are available for determining a suite of chemical properties from trace elements to macronutrients and organic and inorganic constituents.

Biology

Standard methodologies for quantifying plankton abundance and biomass includes a range of samplers including CTD rosettes for pico-to micro-plankton and plankton nets (bongos, MOCNESS) for micro-to macroplankton (Wiebe and Benfield, 2003). Plankton pumps also can be used for collection of pico-to mesoplankton samples. Fluormeters and turbidometers are commonly used to quantify phytoplankton biomass and particulate concentrations while estimates of phytoplankton production can be obtained using fast repetition rate fluorometry or standard C14 techniques. Remote sensing from satellites provides basin-scale synoptic observations of sea surface chlorophyll concentration and information on phytoplankton composition (Brown and Yoder, 1994; Kahru, 1997; Subramaniam *et al.*, 2002; Sathyendranath *et al.*, 2004). The CPR is an invaluable tool for obtaining basin-scale patterns of surface mesoplankton while video plankton recorders and other video techniques as well as optical and laser particle counters provide information about the abundance and sometimes interaction of plankton taxa at finer temporal and spatial resolutions. Single and multi-frequency bioacoustical samplers are commonly used to provide high-resolution backscatter data from which plankton biomass patterns can be inferred when backed by adequate ground-truthing from net samples or optical imagery (e.g. Lawson *et al.*, 2004; Warren and Wiebe, 2008). For nekton, a range of standard sampling methods exist from trawls to bioacoustical systems.

Observation platforms – new approaches

Recent advances in development of autonomous robotic platforms provides a new generation of ocean sampling platforms that allow for high-resolution synoptic multi-scale sampling of ocean physics, chemistry, and biology (e.g. Rudnick and Perry, 2000; Perry and Rudnick, 2003). These platforms include drifters, gliders, and AUVs as well as autonomous profiling moorings. ARGO drifters in particular provide a unique opportunity for a basin-scale ensemble platform upon which a suite of physical, chemical, and biological measurements can be made. Gliders and long-range AUVs serve as robotic platforms that can be programmed to sample along repeated transects or within designated ocean regions. Ocean gliders offer the potential for sampling both on both the shelf and in the open ocean in winter and during storms, independent of shipboard sampling. The gliders offer the potential for sampling of physics, chemistry, and biology, with the development of new sensors. These platforms now carry a variety of standard sensors including CTDs, fluorometers, ADCPs, and radiometers and bioacoustical sensors are being incorporated as well. New sensors that are critically needed on these platforms include optical imaging systems, molecular sensors, and nutrient sensors. The combination of these sensors would allow for a continuum of measurements including hydrographic, currents, irradiance, nutrients, phytoplankton and particulate biomass, plankton morphology, size, and species abundance and biomass, micronekton and nekton size and biomass. Autonomous profiling moorings can also house these sensors and have more power, and so can incorporate the new sensors in their present state of development. In addition to these autonomous *in situ* samplers, as mentioned above, the new Aquarius satellite will provide space-based sea surface salinity measurements for the first time. Finally, unmanned aerial vehicles UAVs, have become widely used in many fields and now have long range capability. These UAVs could conceivably incorporate airborne LIDAR for autonomous imaging nekton and quantifying near-surface zooplankton biomass (Churnside and Wilson, 2004; Churnside and Thorne, 2005).

Observation platforms – existing approaches

The standard observational platforms available for use in the programme include research vessels, fishing vessels, ships of opportunity (SOOP), fixed moorings, and satellites.

Observational programme

The programme needs a nested sampling strategy tailored to the questions being addressed in BASIN, including broad-scale and process sampling strategies. A broad-scale programme will provide the large-scale context within which the process studies can be evaluated. The process studies will examine critical physical-biological interactions in a key region or regions across the domain and will provide vital rates for key species as well as rates of mass and energy flow between trophic levels. A conceptual geographic layout of elements of a BASIN observational programme is depicted in Figure 11.

Broad-scale sampling elements

A broad-scale sampling programme will consist of a combination of Lagrangian samplers, long-term moorings, cross-basin research cruises, CPR SOOP surveys, and satellite remote sensing.

The dominant and critical component of the broad-scale sampling programme will be the use of advanced platforms (Lagrangian drifters, gliders, and possibly long-range AUVs) outfitted with a suite of standard and new sensors. These samplers are essential for providing the high-resolution multi-scale synoptic

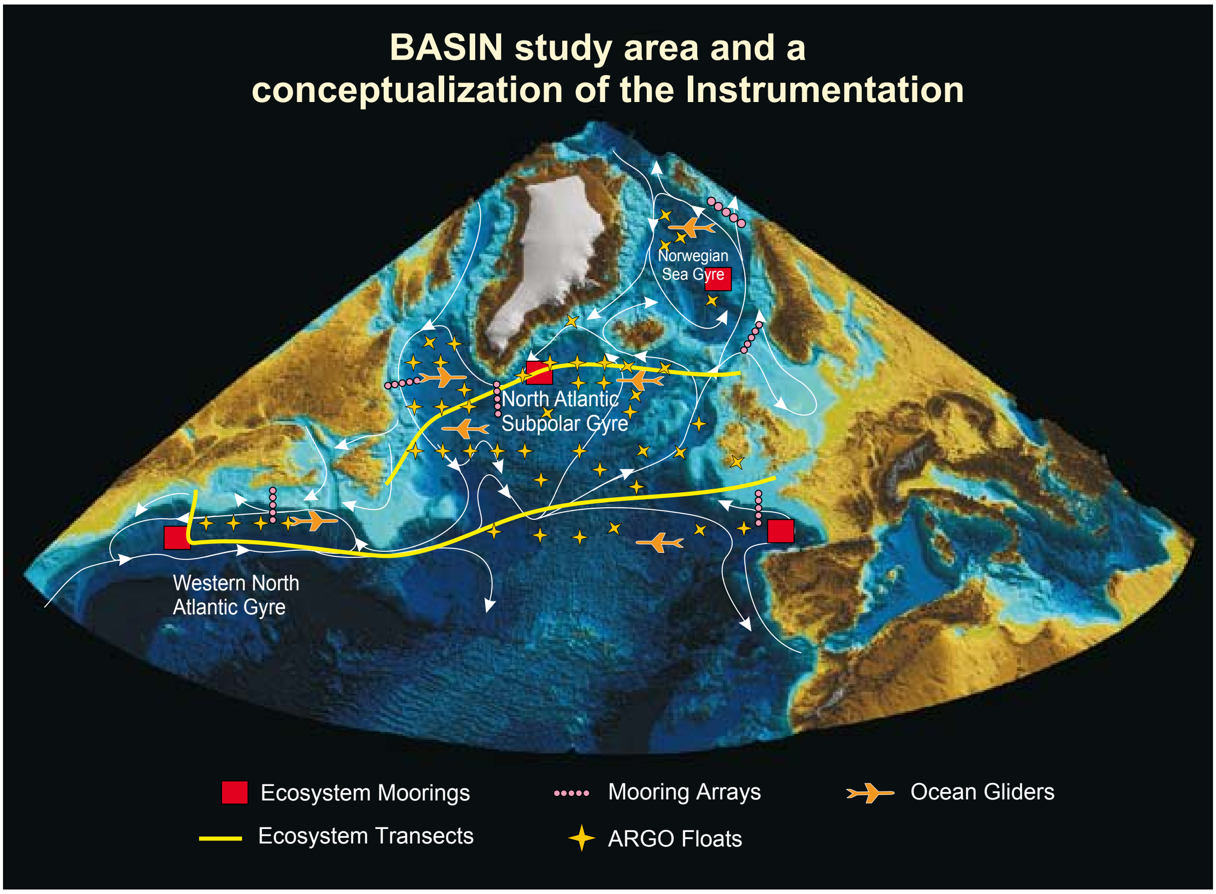

Figure 11. A schematic illustration of a possible nested broad-scale and process sampling strategy for phase II of the BASIN programme.

data necessary for the BASIN programme. The drifters and gliders will contain CTD, fluorometer, and low power imaging system for micro-mesozooplankton sampling. This sampling will help close the data gaps that limit our ability to quantify the multiscale processes that determine how climate forcing affects marine ecosystems. The data will be used in multivariate statistical analyses as well as providing critical information needed to initialize and validate high-resolution 3D coupled biological-physical numerical models. In the conceptual sampling programme (Fig. 11), 40 profiling Argo drifters are suggested to cover the BASIN sub-regions. In addition to the use of these Lagrangian platforms, fixed and profiling moorings will be located in key regions for measurements of atmospheric and oceanographic properties. At least four long-term moorings will be located in the BASIN sub-regions (Fig. 11) and will include meteorological stations and include vertical profiling capacity on the main or adjacent moorings. These moorings should also include CTD, current meters, radiometers, fluorometers, and optical imaging sensors for micro-mesozooplankton. A series of shelf-basin mooring lines will be needed to quantify the shelf-basin exchange of physical, chemical, and biological properties at selected study sites around the basin, such as (but not exclusive to) the Scotian Shelf/Georges Bank region, the Labrador Shelf/Sea, East Greenland Shelf/sub-polar gyre, Barents Shelf (western margin), and the North Sea (northern margin) and Celtic Sea Shelf/Bay of Biscay.

Cross-basin surveys on research vessels will be used to provide critical missing data on ecosystem structure and function including abundance and biomass of target species across the entire basin. Spring and autumn E-W transects are envisioned to cover southern and central portions of the BASIN domain (Fig. 11). A suite of physical, chemical, and biological variables should be measured using new and existing instrumentation listed above. In addition to these cruises, Norwegian, Icelandic, Canadian, and other cruises are already in place and provide the same suite of data to be obtained on the envisioned cross-basin surveys. These cross-basin and other cruises also could service the long-term moorings at 6 to 12 month intervals. The cruises will be linked with CLIVAR and GEOTRACES activities, but will provide species determinations, primary production, species specific and gross grazing dynamics, and species-specific flux contributions.

Existing CPR surveys on SOOP will provide a vital link to the long-standing CPR database. These CPR surveys generate surface abundance estimates of large phytoplankton and mesozooplankton species as well as a colour index for phytoplankton biomass. The possibility of augmenting these surveys with undulating recorders to obtain vertical distribution information will be explored. Incorporation of optical or molecular techniques into the CPR vehicle will be evaluated as this advance would allow for automated data processing and faster turnaround. In addition to the CPR SOOP surveys, opportunistic sampling on transit legs of research vessels can also be done on a not-to-interfere basis using through-hull sampling or fast tow instruments (e.g. Davis and McGillicuddy, 2006).

Satellite remote sensing is an important component of the broad-scale sampling programme. It provides synoptic coverage over vast ocean areas for SST, ocean colour, surface wind, and sea level height. The launch of the Aquarius satellite will be a great asset to the BASIN programme, allowing for synoptic sea surface salinity observations across the entire region.

The physical measurements related to the biological processes will also be obtained within other programmes in which the physical system is a major focus. BASIN will take advantage of existing measurement programmes and piggyback on these as much as possible in the collection of new data. Examples of existing or planned sampling programmes include CARBOCEAN and MERSEA that already have moorings in the Irminger Sea (http://www.soc.soton.ac.uk), hydrographic transects that are routinely run within CLIVAR, CPR sampling, which may be expanded into new areas, and sampling during annual fisheries surveys and monitoring programmes. Examples of the latter are the Canadian Atlantic Zone Monitoring Programme, which includes seasonal hydrographic and biological sampling along transects on the Scotian and Newfoundland Shelves and in the Gulf of St. Lawrence and semi-monthly sampling at coastal stations (http://www.meds-sdmm.dfo-mpo.gc.ca/zmp/main_zmp_e.html) and an annual occupation of the AR7W section across the Labrador Sea.

Process studies

The identification and quantification of key processes relative to the BASIN themes is critical for model development, validation, and the furthering of predictive capacities. Hence, field programmes focused on assessing, identifying, and quantifying key processes influencing the dynamics of key species and groups will, in conjunction with laboratory experiments be used to obtain vital rates and limits as a function of environmental conditions. These approaches will contribute to model parameterization thereby furthering our predictive capacities. During field studies, research vessels will be the main field platform. However, AUVs, gliders, and short-term moorings may also be employed as well as Airborne LIDAR. Process studies for biogeochemical processes will include seasonal mesoscale sampling in grids centred on sediment trap moorings. This sampling approach can provide seasonal coverage of, e.g. phytoplankton dynamics relative to mesoscale processes in a large-scale gradient of dynamic conditions. Mesopelagic process studies will study the fate of organic matter (e.g. remineralization) relative to water mass type (e.g. subsurface, mixed layer, thermocline).

The process studies will focus on key processes that determine how climate forcing impacts population dynamics of target species as well as key aspects of ecosystem-biogeochemical dynamics within the North Atlantic basin (Table 1). The processes to be studied will range from effects of small-scale turbulence on predator-prey interactions in the plankton to the interaction of mesoscale physical processes on population abundance, and distributions and biogeochemical dynamics. The effects of key basin-scale dynamics on population and ecosystem dynamics can also be targeted with process studies. Process studies also will be used in conjunction with laboratory experiments to obtain vital rates and limits of target species as a function of environmental conditions and thereby contribute to model parameterization.

Climate variability and change: Targeted process studies will improve and advance predictive, mechanistic understanding of how climate variability and change influence the seasonal cycle of primary productivity, trophic interactions, and fluxes of carbon to the benthos and the deep ocean. For example, changes in climatic forcing will significantly affect the water column stratification and hence the spatial and temporal dynamics of key ecosystem features such as the timing and intensity of the spring bloom, food web structure and energy flow, and vital rates of target species. The principal objectives of these studies will be to resolve variations in lower trophic level production including the microbial loop and classic short food chain relative to climatic forcing and mesoscale and large scale oceanographic processes.

The proposed studies will address the production of key auto and heterotrophic species in relation to quantity and quality of available nutrients (including those from terrestrial and atmospheric sources) and food resources as well as suspended and sinking POC, and organic and inorganic DOC in different oceanographic regimes. Studies will be made of growth rates and nutritional status of key species in relation to the production of suitable prey. Trophic transfer rates and processes influencing trophic transfer efficiency (e.g. toxins, food quality) among planktonic and micronektonic organisms from both the microbial loop and classical food webs in different hydrographic regimes will be quantified. Estimates of consumption and production rates of key species and the impact of variability in mesoscale oceanographic processes on growth and nutritional status will be compared.

Life history strategies: Process studies will focus on how life history strategies of target organisms contribute to observed population dynamics and community structure. The dynamics of populations of organisms with complex life history strategies are closely coupled to the occurrence and variability in the quality of specific habitats or regimes and interaction between behaviour (e.g. vertical migration, diapause) and transport processes, which influence the overlap of these key species with their optimal habitats. On this premise, the principal objective in this component is the identification of optimal and sub-optimal environmental conditions impacting upon the population dynamics and vital rates (e.g. reproduction, growth, survival) of key species and the mechanisms by which organisms optimise their overlap with these features.

Both field and laboratory activities are envisaged. In the field surveys, which will be performed to link organism distributions and vital rates to specific oceanographic regimes, research vessels will be the main field platform, although AUVs, gliders, and short-term moorings could also be employed as well as airborne LIDAR. In the laboratory, realistic and extreme combinations of environmental conditions, as derived from the field observations and model outputs, will be tested for their impact on developmental rates and survival. Experiments on the effect of physical and chemical conditions on individual activity, metabolic processes, somatic growth, reproduction, and survival will be carried out. There is need to determine the effect on key rates of prey quality and quantity, excretion rates, carbon consumption, DOC production in combination with abiotic environmental conditions, In addition, the tolerance and preference levels of key organisms for important environmental variables will be determined, and realistic combinations of them will be used to define habitat limits and habitat utilisation.

Effects of the removal of exploited species: Studies will address the issue of how the removal of exploited species influences marine ecosystems and sequestration of carbon. Clearly the removal of top predators from the system either through exploitation or due to the effects of climatic change has heavily impacted upon ecosystems globally, from terrestrial to marine. Hence the focus of these studies is to identify and quantify the effects of exploitation on population dynamics of indicator/key species as well as ecosystem structure and dynamics. This will have the aim of predicting the consequences of pronounced changes in predator abundance and their propagation through the food web and impacts on carbon flux.

Combined laboratory and field experiments will be performed to resolve a number of issues. First, critical for the development of phytoplankton group and species dynamics, the effects of light and nutrient regimes on the structuring of the phytoplankton community must be known for the establishment of trophic linkages and carbon flux. Secondly the prey species/size selection process and corresponding prey preferences of predators according to species and size need to be determined either from direct observation of feeding behaviour, diet composition analysis, or biochemical tracers. Thirdly establishment of the encounter and capture probability of preferred and alternative prey considering the distribution of predator and prey on different spatial and temporal scales as well as the effecting ambient physical environment (e.g. light conditions, turbulence); and finally individual consumption rates of predators must be determined in relation to internal processes (e.g. overwintering, spawning), physical environmental conditions (e.g. temperature, oxygen) and prey availability (i.e. quantity and quality).

Table 1. Key BASIN processes and associated relevant issues to be addressed.

Process	Issues relevant to the process
Climate effects on thermal stratification and transport	• Nutrient flux • Deep convection • Advection and dispersion to and from optimal/sub optimal habitats • Shelf-basin exchange/transport processes • Migration (e.g. capelin, herring-between feeding and spawning areas)
Climate effects on realised, optimal and sub-optimal habits during ontogeny	• Identification of key habitats and their variability • Habitat partitioning niche theory • Key species vital rates and limits • Effects of multiple stressors • Plasticity of response • Distribution relative to hydrographic regime, species fidelity species resilience • Population responses (e.g. recruitment)
Climate effects on life history	• Vertical migration • Diapause • Modification of reproductive potential • Reproductive habitat variability • Phenology • Migration pathways
Trophic control and transfer	• Trophic cascade • Trophic upgrading • Bottom up/top down controls • Predatory and harvesting effects on trophic structure and transfer efficiency • Prey switching • Energy budgets • Food quality effects • Feedbacks within the food web • Ecosystem and species resilience • Ecosystem phenology, i.e. match/mismatch-phytoplankton-zooplankton-fish (larval, juvenile, adult)
Nutrient controls on production and flux of materials	• Food web structure • Variable Redfield ratios • Connection between microbial loop and higher trophic levels • Food web structure influences on carbon flux
Species and group mediated variability in carbon flux	• Species mediated sinking rates • Re-mineralization • Trophic upgrading • Buoyancy controls • Ballasting • Trophic feedbacks to climate (e.g. DMS, thermal stratification; biological turbulence)
Ocean acidification	• Reproductive success • Physiology and energetics • Ecosystem structure • Flux of materials • Habitat modification (e.g. dissolution of deep water corals) • Species viability (e.g. ostracods, pteropods)

Biogeochemical fluxes: The process studies for biogeochemical analysis will include seasonal mesoscale sampling in grids centred on sediment trap moorings. This sampling can provide seasonal coverage of phytoplankton dynamics relative to mesoscale processes in a large scale gradient of dynamical conditions. Mesopelagic process studies will study the fate of organic matter (e.g. remineralization) relative to water mass type (e.g. subsurface, mixed layer, thermocline).

Fisheries related studies: Field programmes with an emphasis on fisheries will occur in a number of focus areas where there will be shelf-basin mooring sites. For example, the Norwegian Sea and inflow to Barents Sea; (Barents Sea surveys), the Irminger Sea and the connection between Iceland and East Greenland (redfish survey; biennial in June/July); the northern North Sea and Faeroe/Shetland Channel area; (hydro-acoustic survey in June/July; some pelagics from IBTS September/February), the Labrador Sea and Newfoundland Shelf; the spring acoustic survey on Georges Bank, and Bay of Biscay studies (anchovy egg larvae juvenile surveys). Finally, open ocean surveys focused on mesopelagic fish and top predators such as tuna will be supported both within BASIN as well as by national programmes.

Week-long process cruises will be needed to observe influx of meso/macro zooplankton onto shelves in spring/early summer using optical imaging and hydrographic transect sampling monthly for four months in each area. We anticipate other work will include:

- Hydro-acoustic data collection of pelagic and demersal piscivorous fish for distribution and abundance, and plankton/hydrographic measurements on standard fish stock monitoring cruises with incremental additional days for plankton sampling (complemented by logbook analysis to get a qualitative impression of seasonality of fish migrations).
- Energy transfer from meso/macro zooplankton to fish (adults and juveniles) on shelves based on sampling of prey availability and predator diets on standard cruises and/or complemented by samples from commercial vessels (some incremental costs, but no vessel time)
- Energy transfer from meso/macro zooplankton to fish off the shelf based on sampling of prey availability and predator diets on standard cruises.
- Fisheries impact on ecosystem–handled with existing information from monitoring of fisheries.
- Bioenergetic studies in the laboratory; grazing experiments at sea.
- Examination of maternal fish condition to explore the hypotheses that maternal effects contribute significantly to the survival of offspring in fishes.
- Distribution, abundance, and survival of fish early life stages covered on above cruises, additional surveys not feasible within the budget frame.

In addition to the process field work and laboratory studies, mesocosm experiments will be used to study the effects of multiple stressors on plankton food quality, biochemical composition, and competition, coupling phytoplankton and grazers, and remineralization of particulate matter in the water column.

G. MANAGEMENT APPLICATIONS OF BASIN

Providing useful and relevant results for management of marine ecosystems is an integral component of the BASIN programme. BASIN will offer data, analysis, and models to be included in implementing the ecosystem approach to fisheries and ecosystem management around the whole of the Atlantic basin in a fully integrated way (Fig. 12). To utilise existing knowledge and deliver results, BASIN will form partnerships and links with the appropriate management and research agencies in North America and Europe (e.g. NOAA/NMFS, DFO, ICES, NAFO, NEAFC and DG FISH).

Potential changes in fundamental production characteristics of regional subsystems driven by basin-scale climate events require adaptation strategies in integrated ocean management. Management considerations include those for highly migratory fish species (which in some instances span the entire North Atlantic) and those for regional population or metapopulation structures for individual fish species which exhibit some level of basin-scale synchrony. The need for a basin-scale perspective is particularly clear for trans-boundary stocks. For regional populations and metapopulations exhibiting coherence in population fluctuations related to large-scale forcing, substantial improvements in predictive capability may be obtained by considering basin-wide effects.

Understanding the potential for synergistic interactions between basin-scale climate forcing, ecosystem productivity, and exploitation regimes is critical in devising appropriate management approaches. Populations of exploited marine species are strongly shaped by environmental variability on a broad range of space and time scales. High frequency variation in environmental forcing plays an important role in variability of growth and survival of young fish and shellfish. These variations in conjunction with high fishing pressure may result in abrupt changes in upper trophic ecosystem structure, if affected species are key trophic components of the ecosystem. Lower frequency forcing on broad spatial scales affects overall levels of productivity on multidecadal time scales, changing ecosystem structures and exploitation opportunities. Fishery management strategies must contend with the uncertainties introduced by both high and low frequency forcing of climate-induced changes.

Commercially important pelagic fish species are mostly planktivorous and can be expected to exert important grazing effects on zooplankton species also selected as target species under BASIN. Further, they play an important role as a forage base for higher trophic levels, e.g. exploited demersal fish as well as marine birds and mammals and therefore occupy the nexus of many marine food webs. Many of these

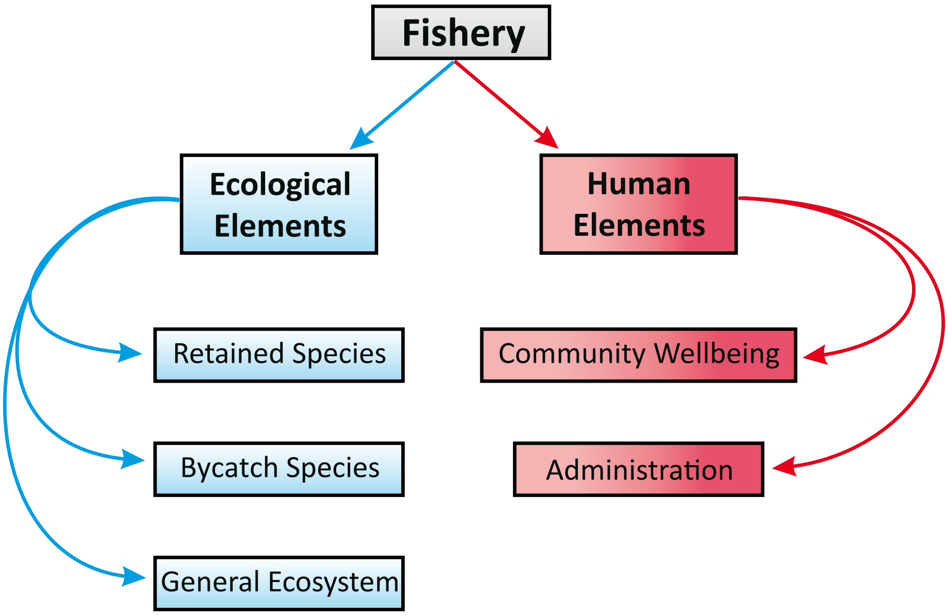

Figure 12. There are five key components to an Ecosystem Approach to Fisheries Management (EAFM) structure, three within the ecological sphere and two within the human sphere (Fletcher *et al.*, 2005). All five need some consideration in a fishery approach that accounts for the range of factors that influence a fishery. BASIN seeks to contribute to the improvement of our ecological understanding of fish and fisheries, but will work with those who are applying the EAFM strategy to the problems.

pelagic fish species undergo extensive seasonal migrations, emphasizing the need for a broad (and often trans-boundary) perspective in management of living resources and conservation of biodiversity.

Ecosystem-based management recognises the importance of essential fish habitats, multi-species interactions, and nutrient cycling as parameters of the growth, abundance, and distribution of exploitable fish stocks. Accordingly, it is critical to understand and predict both direct and indirect effects of human activities on marine ecosystems including alterations in food web structure and changes in biodiversity that may result from fish harvests or nutrient over enrichment, thereby altering food supplies or predation rates. The recognised importance of the development of ecosystem-based management approaches highlights the need to develop operational models for the purposes of fisheries management.

Resource management modelling

The development of conceptual and mathematical models has played a central role in marine biology and ecology as a tool for synthesis, prediction, and understanding. This activity has encompassed the development of models for single species, multi-species communities, and for whole ecosystems. The use of models has proven especially important because marine systems are typically not amenable to controlled experimental manipulation, so that alternate strategies involving the interplay of observation and modelling are critical.

For applied problems such as fishery management and environmental protection, models are essential for predicting outcomes of proposed management actions. Models applied in fishery management have typically focused on single-species dynamics e.g. VPA, although multi-species (e.g. MSVPA, BORNICOM SMS) and ecosystem models mass balance models (e.g. EWE) are available for exploited marine systems. Present assessment models depend on an extensive observing system designed to monitor catches, fishing effort, and demographic characteristics of the catch (size and/or age structure). In many areas, fishery-independent scientific surveys are also conducted to monitor ecosystem status.

Considerable attention has recently been directed to the development of models and management strategies to meet broader ecosystem-based management goals (including protection of vulnerable habitats and preservation of ecosystem structure and function). BASIN will make an important contribution to the development of models and management strategies directed at these higher levels of organization (multi-species and ecosystem levels) by providing detailed information on the dynamics of lower trophic levels and system-wide production levels that could then be used as ‘drivers’ in management-oriented models or in fully integrated models linking the dynamics of the upper trophic levels under exploitation to the lower trophic levels. Furthermore, BASIN will further the development of an earth ocean ecosystem key species model coupler environment. This advance will significantly enhance the incorporation of bottom up and climate processes into the development and implementation of an ecosystem approach to resource management of exploited resources in the Atlantic basin and associated shelf seas.

Explicit representation of species groups or assemblages in multi-species models has been undertaken in a number of marine systems. Most often, these models consider interactions among members of identified communities of organisms and typically span a limited number of trophic levels. Predator-prey and competitive interactions have been most extensively modelled. In contrast to individual species models, these models provide explicit representations of interacting species and can be used, therefore, to examine the implications of changes in the relative abundance of species within biological communities. In the context of BASIN, the pelagic and demersal fish components are clearly linked through predator-prey dynamics and multi-species models can be refined through the anticipated benefits of BASIN research. BASIN will contribute to a mechanistic understanding and forecasting of recruitment dynamics of the target pelagic and demersal species and will determine its potential utility in prediction of multi-species assemblages and related fisheries.

Models of whole ecosystems have been developed for a number of marine systems with direct consideration of nutrient inputs and representation of each trophic level from primary producers through top predators. Most ecosystem network models provide static snapshots of ecosystem processes under certain mass balance assumptions. However, dynamic ecosystem simulation models have also been developed and applied to these fisheries. Due to the complexity of marine ecosystems, aggregate species groups are often used to represent at least some trophic levels, thus reducing the overall number of compartments in the model to a more manageable size.

H. PROGRAMME DESCRIPTION AND TIME-LINE

The BASIN programme is planned to take place in two 5-year phases (Fig. 7). The initial phase will emphasize modelling and data integration and synthesis, and some initial field work. During the second phase, additional observations from the field will be essential for further model development and verification of model results.

Phase I (2010–2014):

- Data synthesis.
- Model hindcasting and scenario simulations.
- Identification of information and data gaps, experimental design (OSSEs).
- Development and exploitation of new technologies.
- Develop management mechanisms and begin implementation, knowledge transfer and outreach.
- Initiation of broad-scale, process, and laboratory studies.
- Integration and synthesis of scientific results and management advice.
- Design and initial implementation of a basin-scale modelling/observing system.
- Identification of mechanisms of variability and assessment of predictability.

Phase II Operational Implementation of Phase I Science (2015–2019):

- Skill assessment of models.
- Extension and refinement of the basin-scale field programme.
- Integration of observational capabilities with other international observational programmes.
- Operationalize data and model information flow to management.
- Synthesis of scientific results and integration into management advice.

Specific deliverables and products that are anticipated during the BASIN programme are presented in Section A. The suggested sequencing of activities in the first 5-year phase of the BASIN programme is summarized in Table 2.

Table 2. Activities anticipated and their phasing during the first 5-years of BASIN

Activities	Year 1	Year 2	Year 3	Year 4	Year 5	Contributes to deliverables
Modelling						
Hindcasting	░	░				1, 2, 3
Identification of information and data gaps, experimental design (OSSEs)	▓	▓	▓			1, 2, 8
Coupling of basin–regional-scale physical models	░	░	░	░		1, 7
Integration of biological and physical models	░	░	░	░	░	1, 2, 3, 4, 5
Development of data assimilation methods	▓	▓	▓			1, 2
Skill assessment and predictability			▓	▓	▓	1, 8
Development of trophic interaction models	▓	▓	▓			1, 5, 6, 7, 8
Design and initial implementation of a basin-scale modelling/observing system				▒	▒	1, 8
Synthesis						
Retrospective data synthesis.	▒	▒				2, 3
Develop management mechanisms and begin implementation, knowledge transfer and outreach			▒	▒	▒	7, 8
Identification of mechanisms of variability and assessment of predictability			▒	▒	▒	1, 2, 8
Physics-field						
Identify the state of the ocean in key basins (glider deployments)	░	░	░	░		1, 3, 4
Cross-shelf moorings (transport, salt, heat)		░		░		1, 3, 4, 7
Argo floats	░	░	░	░		1, 3, 4
Atmosphere-ocean coupling: CLIVAR-BASIN collaboration	░	░	░	░	░	1, 2
Biogeochemistry-field						
Mooring scale studies		░		░		5
Cross-basin transects-biogeochemistry		░	░	░		1, 3, 5
Laboratory rate studies	░	░	░			1, 5
Ecosystem-field						
Cross-basin transects-zooplankton		░	░	░		3, 4, 5, 6, 8
Vital rates–cross-basin transects		░	░	░		1, 3, 5
Fisheries-field						
Cross-shelf monitoring of spring transport of organisms into regions		░		░		1, 3, 4, 6, 7, 8
Fish-zooplankton feeding interactions (shelf)	░	░	░			1, 6, 7, 8
Fish-zooplankton feeding interactions (deep ocean)			░	░		1, 4, 6
Laboratory studies of bioenergetics	░	░	░			1, 5, 6

I. PROGRAMME MANAGEMENT AND OUTREACH

International Steering Committee

As with any large international scientific programme, BASIN will need effective coordination and management. This will be particularly important for BASIN, which seeks to integrate observational and modelling studies that span the North Atlantic. It will be necessary to coordinate sampling strategies and to ensure the effective and timely sharing of data and other results. While each national programme contribution to BASIN will develop its own approach to management, there will also be an International BASIN Steering Committee to guide the overall programme. The role of this committee will be to identify and suggest relevant research activities and scientific gaps, periodically re-evaluate the priorities of the programme, ensure coordination with other programmes, assess progress towards programme objectives, and to support international coordination of the research. The coordination of the multinational field programmes and the analysis and interpretation of the results will be particularly crucial given the international scope of the programme and the need to bring the nationally funded programmes together. This International Steering Committee should also serve to ensure that the results of the programme are properly integrated and disseminated to the potential users of the research.

The International Steering Committee will be composed of ~8–10 scientists and marine resource managers representing the funded programmes from North America and Europe. Representatives from key funding agencies will have the opportunity to sit as *ex officio* members of the committee. The committee will meet once or perhaps twice a year to foster integration among the various programme elements. The Steering Committee will plan and, with the national programme managers and national steering committees, coordinate regular scientific meetings of groups with special interests within the programme (e.g. the modellers, resource managers). The Committee will organize bi-annual science meetings open to all the researchers of the programme. The Committee will also sponsor special sessions at appropriate international scientific meetings. These special sessions will be open to all interested scientists and provide an opportunity to share the results of the BASIN programme with the wider scientific community and allow interaction and discussion with scientists working in related programmes.

The Steering Committee and the researchers will be supported in their work by a Programme Office that should include an Executive Director and secretarial assistant. Funding for the Programme Office and for the meetings and work of the Steering Committee will come from the National Programmes, which will contribute a portion of their funding in support of international coordination. The request for this funding should be included in the proposals to funding agencies at the time of application.

The Steering Committee will serve to connect scientists within the programme and to enhance and ensure data and information sharing among different scientists and teams. Essentially the role of the committee will be to actively coordinate among different separately funded programme initiatives. The development of a true pan-Atlantic synthesis will require sharing of both results, data, ideas, and approaches. The Steering Committee will support activities that lead to such sharing.

The Steering Committee will also work to encourage and ensure collaboration between government and academic scientists with a focus on aligning the programme goals with the needs of ocean and fisheries management. It will be important to develop the programme jointly to ensure that the activities of the programme are relevant to needs of managers and later, as the programme is ongoing, to provide opportunities for communication focused on addressing key management concerns and taking advantage of the new understanding and tools developed within BASIN.

Outreach will take several different forms within BASIN. We will develop web material that will be made available both to the public and to other researchers with an interest in the North Atlantic and the research results of BASIN. As noted below, we will share our data both within the programme and with all other interested parties who could benefit from data collected within BASIN and the modelling results of the researchers. The work that we do is of broad scientific and societal importance and the sharing of data and results is essential.

BASIN will hold regularly scheduled workshops on ecosystem based management bringing together natural and social scientists with managers and other interested stakeholders to share and explore the results of the scientific research. These workshops will serve to bring the results of the scientific research to the management and policy communities in an environment in which there will be a discussion of the implications of the results and consideration of other possible appropriate scientific studies to improve the development of our scientific understanding for application to ecosystem based management. These workshops will be developed both nationally and internationally, as appropriate, recognising the differing national approaches to ocean and fisheries management.

Database management

BASIN will collect and organize large amounts of data including selected model output. While it is not considered a requirement to centrally manage these data sets, a person or group will undertake responsibility for 1) coordinating assembly of the historical data bases and linking to data collected during relevant recently completed and ongoing programmes such as GLOBEC regional and national studies, 2) ensuring data collected during BASIN are made available and shared as quickly as possible, 3) fostering the establishment of data portals to help BASIN scientists access the data, and 4) undertaking local archiving of new data and model results. It is anticipated that the data will be in the form of distributed databases with a BASIN website supplying seamless access to the data links.

Several programmes and projects have already dealt with many of the data management issues anticipated within BASIN, e.g. GLOBEC, JGOFS, CLIVAR. Within the US National Science Foundation (NSF), the Biological and Chemical Oceanography Data Management Office (BCO-DMO) (http://www.bco-dmo.org) was recently created to serve Principal Investigators (PIs) funded by the NSF's Biological and Chemical Oceanography sections. It is a facility where marine biogeochemical and ecological data and information developed in the course of scientific research can easily be disseminated, protected, and stored on short and intermediate time-frames, and may serve as a model for data management in BASIN.

There will be a policy of open access to all data. The implementation and support of such a policy is crucial to the success of BASIN. It is recognised, however, that some of the historical or recently collected data sets, particularly fisheries related ones, may require some restricted access for a limited time period. BASIN will examine and adopt policies that other large programmes (e.g. CLIVAR, GLOBEC, GEOTRACES) have already established and comply with the laws of the EU, Canada, and the US. Regarding data obtained during BASIN, steps will be taken to ensure quick access to such data while still maintaining high quality calibration and processing standards.

While local archiving of the new data will be carried out, steps will be taken to discuss the permanent archiving of the data with centralised database managers such as BODC, NODC, ICES, and others. This is essential to ensure that the data are available long after BASIN is completed.

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