# BASIN: Basin-scale Analysis, Synthesis, and INtegration

**Resolving the impact of climatic processes on ecosystems of the North Atlantic basin and shelf seas.**

Report of the meeting held at the University of North Carolina's Friday Center, Chapel Hill, North Carolina, 1 to 3 May 2007.

Financial support for the meeting provided by the EU Specific Support Action BASIN and the NSF as well as the FP 6 European Network of Excellence EUR-OCEANS.

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# I) EXECUTIVE SUMMARY

The Chapel Hill meeting was the second of four BASIN workshops being held during 2007 leading up to the development of a BASIN Science Plan. It was held from 1 – 3 May, and followed on from the first meeting, which had a primarily European focus, held in Hamburg from 23 – 25 January. The Chapel Hill discussions built on the conclusions detailed in the Hamburg meeting report (available at www.globec.org/structure/multinational/basin/basin.htm together with other BASIN related information and news).

At each of these BASIN workshops new ideas are brought forward and there is further consolidation of the central themes of the program. Each new grouping of potential investigators brings a new perspective to the program. It is these new ideas, and new conceptualizations that are most important as we move forward in further delineating the program.

Much of the general discussion in North Carolina was directed towards four general issues:

- How broad should the program be?
- What should be the geographic scope of the program?
- What are the central organizing questions that should be addressed?
- How should BASIN ensure its relevance to management concerns?

It was agreed that BASIN needs to build on earlier North Atlantic programs that have focused on targeted trophic levels. BASIN's objectives should include the development of an understanding of the links between climate and the marine ecosystems of the North Atlantic Basin and related shelf seas, and the services these ecosystems provide including exploited marine resources. The challenge is to ensure that the scope of BASIN 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 climate and exploited resources.

BASIN focuses on the marine ecosystems (lower and upper trophic levels) of the North Atlantic basin and associated shelf-seas. The geographic scale of a program as ambitious as BASIN is crucial in defining the interests and needs of the program, but can also generate debate because of the differing perspectives of potential investigators. It was agreed that the primary focus of BASIN would remain the sub-polar gyre system and associated shelf systems of the North Atlantic but that important connections to the sub-tropical gyre would not be neglected.

Building on the Reykjavik and Hamburg meetings (Wiebe *et al*. 2006), the aims and questions of BASIN defined in Chapel Hill are:

**BASIN AIM**: 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 Subpolar Gyre System, in order to improve ocean management and conservation.

- **Question 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? How will the 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 consequences of changes in ecosystem structure and dynamics for climate?*
- **Question 2.** How do life history strategies of target organisms, including both vertical and horizontal migration, contribute to observed population dynamics and community structure and how are these life history strategies affected by climate variability? How will life history influence the response of key species to anthropogenic climate change?
- **Question 3.** How does the removal of exploited species influence marine ecosystems? Under what conditions can such 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?

Providing useful and relevant results for management is an integral component of the BASIN program. Discussion on this issue indicated in particular the growing shift away from single-species management towards ecosystem based management. BASIN has the potential to offer data, analysis, and models that could be included in ecosystem management activities around the whole of the Atlantic basin in a fully integrated way. While the program contains direct links to management in its aim, this will be a challenge to realize given the separation that often exists between the management and science communities. It was agreed that this aspect of the BASIN initiative needs more attention and that explicit plans to coordinate the integration of science into management should be developed. BASIN should form partnerships and links to the appropriate management and research agencies in North America and Europe (e.g., NOAA/NMFS, DFO, ICES, NAFO, NEAFC and DG FISH) to ensure that the science developed is relevant to needs of management.

**BASIN will consist of two phases:**
**Phase 1:** develop and organize existing data for use in basin-scale marine ecosystem models. Gaps in data and knowledge will be identified necessitating the collection of new data in order to resolve crucial basin-scale problems.

**Phase 2:** substantial field effort with design guided by the modelling and synthesis activities accomplished during the first phase, as well as laboratory results.

## II) INTRODUCTION

This meeting was the second of four BASIN activities supported by the EU and NSF. The aim of this meeting was to start developing a BASIN Science Plan (BSP). The BSP should involve the integration and advancement of observation, monitoring, and prediction of ecosystems of the North Atlantic basin and shelf seas. The BSP should assess the impact of climate variability and change on the functioning of ecosystems of the North Atlantic basin and associated shelf seas as well as the potential feedbacks to climate. Two other meetings will follow. The meeting was held at the University of North Carolina's Friday Center in Chapel Hill, NC and hosted by Cisco Werner of the Marine Science Department at UNC. The meeting was attended by thirty-three scientists, nine from Europe, four from Canada, and nineteen from the USA (Appendix I). Full background information on the BASIN initiative can be obtained at: www.globec.org/structure/multinational/basin/basin.htm .

The steering committee for BASIN consists of Mike St. John, Roger Harris, Cisco Werner, Peter Wiebe and Brad de Young. Some members of this group met the day before the official start of the meeting to review the agenda, the opening presentation about the history of BASIN development, and to make final adjustments to the charge to the meeting working groups.

## III) NARRATIVE OF THE WORKSHOP

The meeting started at 0900h on 1 May (Tuesday) with welcoming remarks by Cisco Werner. After introductions around the room, Cisco Werner reviewed the agenda (Appendix II) and what the meeting was intended to accomplish. Peter Wiebe then described the history of development of the BASIN program and gave a review of the report of the March 2005 Iceland BASIN meeting that gave rise to the series of workshops currently funded by an EU Specific Support Action (SSA) and NSF. Cisco Werner then introduced the working groups and group leaders/Rapporteurs, and discussed the charge to the working groups.

Following morning coffee, a series of 30 minute talks were presented during the last half of the morning (See Appendix II). These talks provided background information on the effects of climate on marine ecosystems, basin biogeochemistry, and physical models. In the early afternoon after lunch there was another series of invited talks focused on the coupling of life histories and biogeochemistry, biological data sets relevant to BASIN, and a description of a new US program called CAMEO (Comparative Analysis of Marine Ecosystem Organization) that contains many elements that are relevant to the BASIN program. A series of 11 contributed talks were given by meeting participants who presented issues they felt were important to the development of the BASIN Science Plan.

In the late afternoon, the three working groups (See Appendix III for chairs, Rapporteurs, and group members) met to consider each of the four questions resulting from the Hamburg Meeting with regard to their appropriateness for the BASIN program and to see if there were additional questions that needed to be posed. The day's sessions ended about 1830h.

On Day 2 (Wednesday), the meeting was held in the Courtyard Marriott hotel conference rooms starting about 0830h with a plenary session (chaired by Roger Harris) in which the chairs from the three working groups provided a brief summary of the results of their deliberations. Ann Bucklin presented for Group 1, Jon Hare presented for Group 2 and Chuck Greene presented for Group 3.

Another series of four talks were presented during the morning. The two talks before morning coffee focused on microbial loop transfers and dynamics, and cross-shelf exchange. Those after the break focused on data assimilation methods in modelling and science for management in relation to the BASIN program. During this period, Brad deYoung produced a synthesized version of the suggested modifications to the questions generated at the Hamburg meeting (see Appendix II herein) from the working groups.

For about an hour before lunch the plenary discussions focused on the context for BASIN in terms of the geographic extent of the program and the revised questions. Additional changes to the questions were suggested. Over lunch the steering group reworked the questions and overall aim, and made a draft time-line (Appendix IV) for the program to provide guidance to the groups for the afternoon discussions.

Immediately after lunch the groups met again in plenary session and Brad deYoung presented the revised aim and questions below, which were considered to be finished for the time being.

**BASIN AIM:** To understand and simulate the impact of climate variability and change on key species of plankton and fish, as well as community structure as a whole, in the North Atlantic and to examine the consequences for the cycling of carbon and nutrients in the ocean and thereby contribute to ocean management.

- **Question 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? How will the 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 population dynamics?*
    - *What are the consequences of changes in ecosystem structure and dynamics to climate?*
- **Question 2.** How do life history strategies of target organisms, including both vertical and horizontal migration, contribute to observed population dynamics and community structure and how are these life history strategies affected by climate variability? How will life history influence the response of key species to anthropogenic climate change?
- **Question 3.** How does the removal of exploited species influence marine ecosystems? Under what conditions can such harvesting result in substantial restructuring of shelf or basin ecosystems, i.e. regime shifts? Do such changes extend to changes in primary productivity and nutrient cycling? How is resilience of the ecosystem affected?

Peter Wiebe then gave a new charge to the working groups: to develop plans to answer the questions given the suggested time-line for a BASIN program and to think about how this work needed to be articulated in the Science Plan. The groups were asked to cite appropriate research papers and illustrations that convey the current status of understanding about the basin ecosystems. The working groups then went to separate rooms to continue their deliberations. In the late afternoon, the groups reconvened in plenary session to share their findings and to have an extended discussion about the nature of the work to be done in BASIN and its geographical scope. The second day's sessions ended about 1845h.

A group dinner was held at a popular restaurant within walking distance of the hotel and conference center, the Azure Grill, which was enjoyed by all.

The working groups started day three (Thursday at 0830h) in plenary session with Cisco Werner leading a discussion about the rationale for doing a BASIN program that involves/requires coordinated and simultaneous international collaboration. Peter Wiebe was the Rapporteur for the session and recorded the main points made by the participants (See Box and following section). Many very good points were made about the need for a basin-scale approach to many current ecosystem problems and there was consensus that international collaboration was essential.

**Issue of large-scale forcing driving many of the ecological processes occurring on local and regional scales.**

- We cannot understand local physical and biological dynamics and processes without understanding the large scale forcing.
- Species with broad distributions and areas with similarity in ecosystem composition need to be studied following a comparative approach in order to understand their dynamics locally.
- Basin scale stratification and the overturning in subpolar regions have major influences on the entire North Atlantic system as well as global climate.
- We cannot study any shelf sea without understanding the entire basin system as fluxes between these domains are critical for local ecosystem dynamics.
- Advection around the basin on the order of a decade is the key to understanding ecosystem dynamics.
- Ecosystem management of widely distributed key species requires a basin-scale approach.
- Climate change will affect biogeographic distributions on the basin-scale and they need to be viewed and understood holistically.
- Looking at a pan basin suite of species whose abundance and biomass are important has to be done on a basin-scale. This requires a basin-scale assessment.
- For many species, a basin-scale approach is required in order to the entire domain of a population.
- In order to make predictions about carbon flux and sequestration, we need a basin-scale approach that captures the range of ecosystem types that characterize the North Atlantic.
- Biogeochemical tracers can be used for shelf/deep ocean exchanges – but shelf edges are not all the same. Studies need to have a holistic model applied to various areas to be valid. Shelf exchanges – GEOTRACES Program (http://www.ldeo.columbia.edu/res/pi/geotraces/) focuses on shelf-deep ocean exchange – room for collaboration with BASIN.
- Issue of ecosystem fluctuations around the basin and whether they are in concert or opposed – NAO linked. But other modes may be present and need to be understood. Dickson papers discuss some of this. Issue of eastern Atlantic being influenced by warm current from the south and the need for incorporation of subtropical gyre. Coupled ecosystem fluctuations are an important way to tie various BASIN regions together.
- The subtropical gyre also needs to be included from a fisheries and production view point (upwelling regions) in order to understand carbon dynamics. NAO forcing fluctuations in the subtropical gyre.
- A large number of LMEs are warming and species may be moving into the subpolar regions – so there is a need to include the subpolar gyre issue of complex food chains of low efficiency vs. simpler communities with high efficiency - their geographical shifts need a basin-scale approach.

Some comments about the program:

- How long should the field program be? Emphasis on the use of new technologies in order to optimize sampling so that ship use is most cost-effective.
- Issue of how broad the program can be? Need to have reasonable scope. Issue of what is to be included in BASIN – spatially and scientifically – will look at ecosystem from organisms' view point, rather than processes like nitrogen fixation.
- Time-scale should be dependent on the life stage development times.

- Vertical Rhomboid needed to address how deep to sample.
- Issue of long-term observing – useful to visit stations sampled in the past in order to continue punctuated time-series – like station M, station India.
- Areas of process studies – should be revisited as well. Many are remote and no single country can do the work.
- Basin vs. sub-basin – menhaden extend below 40˚N, but are big players on the shelf north of 40˚N – so need to enable BASIN to include such species. Similar species on east side of Atlantic include blue whiting.
- Issue of key species – a candidate list (page 29) has been created for subpolar gyre regions. There are about 15 species or functional groups for open-ocean and there are a few more to be added from the shelves. Also need to add in fish. Problem with getting at life histories for some of them – especially gelatinous zooplankton.
- A deliverable is an observing system that can handle the basin-scale effects on ecosystems. It is unlikely that BASIN itself will put an observing system in place. However at end of Phase 1, we will have identified gaps that need to be filled by other observing systems.
- Canadian perspective – problem area involves coupling between Arctic and subpolar area around Canada. Particularly the Labrador Sea. Need caution identifying key species – idea of working with functional groups more attractive. Canada is planning to start an Arctic hydrographic and biological monitoring program, which will be able to observe fluxes through the Canadian Arctic.

At 1000h, the working groups separated to complete their writing assignments. A final wrap-up session took place from 1215h to 1245h, where the working groups presented brief summaries of their accomplishments. This was followed by a brief discussion of the next steps, which include preparation of the workshop report, starting to draft the science plan, and most important, planning and scheduling the third meeting with the program managers to discuss how joint international research programs can be implemented. The meeting ended on 3 May with a show of appreciation to Cisco Werner for his fine organization of the meeting and great southern hospitality.

After lunch, the steering committee met with Group chairs and Rapporteurs to review the products coming from the groups, logistical aspects for finalising the workshop report and organising the next meetings.

# IV) SYNTHESIS OF WORKING GROUP REPORTS

Three working groups were formed to:

1. Consider each of the four questions resulting from the Hamburg Meeting. Do these questions circumscribe the main thrust of a BASIN Program? Are there additional questions that need to be posed?

2. Address the questions citing appropriate research papers and illustrations that convey the current status of understanding.

3. Comment on and continue the development of the proposed structure of the BASIN science plan. Each group was asked to address the same three topics. The following is the integration of the information developed by the groups.

## Question 1.

**How will climate variability and change – e.g., 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 responses to these changes differ across the basin and among the shelf seas?**

## A) Working Group #1

Working Group 1 focused primarily on Question #1, a wide-ranging topic broadly addressing climate impacts on biological and biogeochemical patterns and processes in the North Atlantic basin and shelf seas. However, the group chose not to directly address or discuss the issue of feedbacks to climate, which was included as a sub-topic of this question. The issue of ocean impacts on climate will move BASIN into a different realm – in programmatic, scientific, and logistical terms. This expansion will be best accomplished through collaboration with ongoing and planned international programs, to reduce the need for significant additional resources. Also, Group 1 did not feel that it included all the expertise needed to provide valid and useful comment.

The group's discussion of Question 2 (life history) focused on new approaches and critical needs. The discussion of Question 3 (fisheries) is rather preliminary and will need fleshing out from the other Working Groups and BASIN steering committee members.

## a) Modelling

*Physics*: Climate-induced changes in the physics of the North Atlantic, including subduction/deepwater formation, stratification, meridional overturning, and major circulation patterns will have profound effects on the populations and ecosystems in the North Atlantic basin and adjacent shelf seas.

*Retrospective hindcasts*: In Phase I of the BASIN program, physical oceanographic modelling efforts should include retrospective hindcasts of the ocean circulation of the past 50 years. The output of these physical models will be used as boundary conditions in nested models for high resolution eddy resolving regional models (e.g., shelf seas or open ocean) that include biogeochemistry and ecosystem modules. These experiments will be used to gain understanding of how large scale changes in circulation and stratification in the North Atlantic that occurred in the past 50 years affected regional circulation and ecosystems.

Within the WCRP-CLIVAR program, 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 1/12$^{th}$ degree). Models that assimilate data typically have a coarser resolution (about 1 degree).

Data assimilation products presently show a large spread in the results for transports, heat, and fresh water transports, which indicates that either there is insufficient data to constrain the models on large scales or the model error is too large. With the increase of data from ARGO floats, altimetry, and other satellite products in the last decade the temperature, salinity, and sea level height of the Atlantic basin is better constrained, but the spread in volume transports is large. This requires an ensemble approach when using the data to downscale the large scale circulation in regional ocean models. Also, careful use of these products must be exercised as the increments produced by the data-assimilation efforts can result in physically unrealistic responses (e.g., internal sources and sinks of heat and salt when optimal interpolation is used).

Within the BASIN program 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.

*Future projections:* Early in 2007, the Working Group 1 of the Intergovernmental Panel on Climate Change (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, NAO index decreasing, weak MOC reduction, strong MOC reduction). Such scenarios will be used to force high resolution ocean-only models (as in Schweckendiek and Willebrand, Journal of Climate 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 the BASIN program, 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 grids will ensure regional high-resolution. Since internal ocean variability will be generated when resolving eddies, an ensemble approach will be followed. Data assimilation procedures will have been advanced as well and run at least at eddy-permitting 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.

*Future modelling approaches*: BASIN will greatly benefit from concerted international efforts leading to the development of fully-resolved earth system models. We can hope that full-ocean eddy-resolving models will become available during BASIN. Ecosystem models will surely continue their development, leading to increased capacity for representation of functional types at higher resolution and with added complexity, using full dynamic or semi-empirical approaches. A critical need for BASIN will be accurate models of exchange between the shelf and deep ocean, with specific applications for different regions to accommodate marked variation in these dynamics in different regions. Also on the BASIN ‘wish list’ are operational models with data assimilation, which have many applications including: to constrain parameters, to steer models operationally, to allow system analysis; to inform short-term forecasts; and to initialize long-term forecasts.

Ecosystem metabolism responses to climate change, in particular warming, can be addressed using the ecological metabolic theory approach. Based on first principles metabolic theory of ecology is a quantitative theory for how metabolic rates vary with body size and temperature (Brown *et al*., 2004). Although metabolic theory has been mainly applied to terrestrial organisms and ecosystems it is emerging as a powerful tool in marine ecosystems. For example, in the frame of question 1 metabolic theory of ecology might be used to predict variations in production and respiration and to evaluate how the primary production/respiration rate and implied changes in carbon flux vary with different climatic scenarios (Lopez Urrutia *et al*., 2006).

*Biology:* Biological models are only as good as their physical setting (Doney, 1999). BASIN will use state-of-the-art GCMs of the North Atlantic at eddy-resolving resolution. Nested grids will be used to provide increased resolution for particular areas of interest, such as the continental shelves. Resolution is in itself not enough to ensure realistic physics – attention must also be paid to physical parameterizations, such as mixed layer schemes, and to ensure that forcing is of sufficiently high frequency (Popova *et al*., 2006). A major challenge will be the combining of the deep ocean and shelf seas into a unified model of the North Atlantic basin. One promising avenue for the future is the development of unstructured grid models with adaptive meshes in which high resolution emerges in the places where it is most needed.

General circulation models will be run in both hindcast model (e.g., last 50 years) and for the future in order to predict changes in ocean circulation and stratification over decadal to centennial time scales (e.g., using IPCC climate scenarios). Coupling to atmospheric models will be required for this purpose. Different GCMs are being developed in the European and North American science communities. Model intercomparison will provide valuable information on model uncertainty, but will require rigorous protocols to be adhered to in terms of model setup and forcing.

*Ecosystems:* Recent years have seen a proliferation of marine ecosystem models and their implementation in 3D GCMs. In particular, a new generation of complex models have arrived in which phytoplankton and zooplankton are divided into multiple plankton functional types (e.g., Le Quéré *et al.*, 2005, Moore *et al.* 2002). However, complexity is no guarantee of improved predictive capability. Indeed complex plankton functional type models are prone to various difficulties, not least the parameterization of the plethora of interactions that occur when numerous state variables are set to interact as differential equations (Anderson, 2005). It is envisaged that a range of ecosystem models will be employed in BASIN. With emphasis on key species, the rhomboid approach (deYoung *et al*. 2004) is of particular relevance, such that complexity is targeted at trophic levels of particular interest, rather than having high complexity throughout. Basic NPZD-type models (i.e. with single state variables for each of phytoplankton and zooplankton) could for example form the basis of models onto which sophisticated representations of key species of zooplankton or fish could be bolted (the key species being the centre of the rhomboid). Individual based approaches to modelling key species (e.g. Speirs *et al.* 2005, 2006), again with decreased complexity at other trophic levels, provide an excellent opportunity to study how their life history and physiology may interact with changing circulation and climate to affect their distribution within the North Atlantic basin.

Addressing community structure will also require a new generation of models that target complexity at trophic levels of interest (in context of the questions being asked). Regarding phytoplankton, for example, robust and well-constrained parameterizations are needed, along with rigorous validation of the species or functional types themselves (not just bulk properties such as total chlorophyll) against field data. Laboratory or field-based experiments may be helpful in defining equations and parameter values. In particular, attention should be paid to the parameterization of trophic interactions.

Given the current difficulties of parameterising complex models (Anderson, 2005), a large effort is required both to develop new models that are realistic and robust, and to ensure that the data are available to test (validate) them in order to gain confidence in their predictive capacity.

*OSSE development:* An important research component of Phase I of BASIN is the development of Observation System Simulation Experiments (OSSEs) to aid in the design of the field program to be implemented during Phase II of the program. Long-term (e.g. 50-year) high-resolution ($1/6^{th}$ degree) hindcasts must be developed of the whole North Atlantic basin, including subpolar and subtropical gyres, adjacent shelf seas, and Arctic Ocean and tropical boundary regions. IPCC models can be used with atmospheric forcing to produce this higher resolution ocean model. This model can be used to suggest high-priority regions for field studies. The model should include existing simple biological models for food-web dynamics (e.g., NPZD-type) and population dynamics of key species (both concentration based and individual-based models). The resulting hindcast then can be used to conduct

OSSEs for determining the optimal sampling strategies for the field program. The OSSEs should be conducted during different dominant climatic or oceanographic regimes or phases during the 50 year hindcast. In addition, model runs should be made for scenarios for future climate change and OSSEs conducted using these runs. Future scenario projections may provide physically or biologically stable locations in N. Atlantic and how these locations may be affected or relocated by changing climate. Key sampling design elements to be evaluated include time-space distribution of sampling effort and key state variables and parameters in need of measurement. The type of sampling platform and the duty-cycle (data collection rate) need to be considered in determining the optimal time-space sampling strategy. Types of platforms to be considered should include drifters (e.g., ARGO), gliders, AUVs, profiling and fixed moorings, ships of opportunity, and research vessels. Multivariate statistical analysis of the model output for the state variables can be used to aid in determining various spatial and temporal sampling patterns to be tested in the OSSE. The output from the samplers should be assimilated into a clone of the first model and the resulting model output compared with the original model using skill assessment techniques to determine the model-model misfit. The optimal sampling design will be determined by the lowest resulting cost function. Use of the OSSE to determine key variables and parameters will enable assessment of which sensors are most critical for the observing system. Some of these “critical” sensors may not yet exist, thus this modelling will help guide sensor development.

The development of the 50-year hindcast and the forecast scenarios together with the subsequent use of OSSEs will allow for determination of critical data gaps.

Detailed population models for copepods now exist in the form of individual-based models (IBMs) (Lagrangian) and concentration-based models (CBMs) (Eulerian) forms. IBMs (e.g., Carlotti and Wolf, 1998; Batchelder *et al*. 2002) including super-individual and ensemble models have been used extensively to study interactions between physical transport and population growth and behavior. Important biological details can be included in the IBM models. IBMs do not provide continuous distributions of copepods for use as prey fields for larval fish and are not generally suitable for determining population sustainability in certain regions. CBMs (e.g., Davis, 1984; Hu *et al.*, 2007 submitted) have been developed on the other hand which contain less biological detail, but allow for mass or numerical balance and budgets as well as providing continuous distributions for larval fish models.

## b) New Technologies

New methods of sampling species distributions synoptically over large areas are needed. The ARGO drifters provide a potential platform for widespread coverage if species-level sensors can be developed. Such sensors could include compact low-power light-weight digital imaging systems, as well as DNA chips. These sensors need to be able to provide species counts and sizes of individuals and do the processing in situ with low power requirements. Other platforms could include gliders and long-range AUVs. Bioacoustical sensors, which are currently being proposed for ARGO, could also be used but do not provide sufficient taxonomic resolution.

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 microarrays. DNA barcodes can be used to design DNA microarrays 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 microarrays may be used in the laboratory or onboard ship to characterize species diversity and abundance in plankton samples. Eventually, protocols may 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 almost certainly 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.

Digital imaging systems have evolved rapidly over the past decade and there are numerous systems in existence that could be used in the BASIN field program (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; Davis and McGillicuddy, 2006, McGillicuddy *et al*., 2007). These systems provide high-resolution data and can sample delicate plankton, which often forms the bulk of mesoplankton-size particulate matter in the ocean but are destroyed by conventional sampling gear.

## c) Design of Field Program and Biological Field Data

*Field data for model validation*: A primary goal of the BASIN field program must be the collection of data, information, and samples to help validate the population and ecosystem models. Among the field observations and data needed are: phytoplankton distribution and abundance; ocean bottom topography; SeaWiFS satellite based data.

The BASIN plan for implementation will need to carefully consider the type of field collection strategies and datasets needed, including transects, monitoring, sampling frequency, and locations. Possible approaches include ARGOS drifters, ship-based sampling of biological data, ships of opportunity, long transects, time-series at single locations, time-series surveys of sampling grids to resolve small-scale variation, and large-scale surveys to sample basins simultaneously.

Biological field data will be required at multiple conceptual levels, for example energy flow, target species, and community structure, to be dictated by the particular questions being addressed. For overall synthesis, these levels should provide coverage of all trophic levels to allow end-to-end food chain ecological network analysis (Dunne, 2005). Because different conceptual levels or questions may require different currencies, improved conversion factors among the currencies will be needed to synthesize field data from different sources.

The conceptual levels of biological field data could include material flow, measured as biomass, carbon, nitrogen, or energy; nutrients; target species; and community structure. New approaches for rapid analysis of species composition (e.g. DNA, size spectrum, OPC, imagery, silhouette, acoustics, video, etc.) may facilitate analysis of community structure.

*Trophic Levels:* In order to distinguish climate impacts on populations and ecosystems, BASIN will require observation and analysis of all trophic levels, from microbes to fish. New technologies for observation and analysis will increasingly make such ‘laundry list’ approaches both feasible and affordable. Regardless, we recommend a scaled approach, with increasing detail at higher trophic levels.

Surprisingly there are still a number of trophic levels and functional groups where our sampling / enumeration techniques do not allow for a correct quantification. In some cases the techniques are so laborious (e.g., protists, microzooplankton) that samples are not counted at the spatial resolution needed to get realistic distribution and correct biomass estimates. In some other cases the organisms are not routinely sampled (e.g., crustacean microzooplankton, such as nauplii and small copepods, macrozooplankton, myctophid fish, etc). Finally there are groups for which routine sampling techniques destroy the organisms (e.g., gelatinous organisms).

A first milestone for the project should therefore be to set up the proper combination of sampling and analysis procedures so as to avoid gaps in the biomass estimates at different trophic levels. This will require a combination of improved sampling procedures (mesh size, trawling for larger organisms) and new technologies (e.g., image analysis systems such as Zoovis, SIPPER, LAPIS for gelatinous organisms (Samson *et al*. 2001, Benfield *et al*. 2004 and Madin *et al*. 2006) to be able to process the number of samples required for correct biomass estimation in all levels.

After a correct estimation of the distribution of the biomass, for each trophic level the following information will be required in order to address Question 2 (see page 25).

**Information required for each trophic level to address question #2**

Phytoplankton
- Abundance and biomass of the community (microscopic analysis and new technologies such as flow-cytometry and image analysis)
- Abundance and biomass of main species
- Predation pressure on phytoplankton in general and main groups in particular
- Growth rates of the community and main species
- Mortality rates due to copepod grazing
- Biochemical composition
- Limiting nutrients
- Transfer efficiency to higher trophic levels
- Stoichiometry
- Key species specific critical rates and limits

Microzooplankton:
- Abundance and biomass of the community (microscopic analysis and new technologies such as flow-cytometry and image analysis)
- Abundance and biomass of main species
- Predation pressure on phytoplankton in general and main groups in particular
- Growth rates of the community and main species
- Mortality rates due to grazing

Mesozooplankton:
- Abundance, biomass and size spectra distribution for the community, including gelatinous organisms
- Abundance of all species in sub-polar gyres and target species in the sub-tropical gyres
- Developmental stages for target species
- Vital rates (growth, reproduction as function of temperature and quality i.e. stiochiometry and biochemical composition of food,)
- Food web issues: top-down grazing on protozoa/microzooplankton; nutritional requirements and proxies (lipids, etc)
- Population processes / proxies (predator abundances, gut contents, infer mortality)

Predators and predation (e.g., amphipods, mysids, copepods, chaetognaths, jellies, fish):
- Copepods, cannibalism, and intra-guild predation
- Abundance and size distribution of potential predators taking into accounts groups whose distribution is poorly studied in the North Atlantic such as euphausiids, gelatinous plankton, and myctophid and planktivorous fish
- Estimate predation impact of such organisms as a function of size, temperature, and feeding behaviour
- Create predation risk maps: predator abundance, size, light field, and temperature-specific predation risk
- Compare with density-dependent approaches (quadratic with temperature dependence)

Fish (planktivores, myctophids):
- unexploited species should be included here

## d) Biological laboratory studies

Our ability to realistically simulate the dynamics of marine systems is dependent upon the parameterizations employed in our modelling tools. In order to further develop these tools targeted laboratory studies will be required during Phases I & II. In particular targeted laboratory activities are required including;

**Phytoplankton:**

*Rate processes / Phytoplankton -Nutrients*: Application of Redfield elemental composition multi-nutrient limitation and predator-prey interactions has been questioned and experiments to further substantiate the need to switch to a quota-type approach to resource limitation and transfer between trophic levels is necessary.

*Multiple stressors*: The interaction between nutrient and abiotic constraints such as temperature, pH and light on phytoplankton growth is at present limited. This information is critical for modelling population and community dynamics in the field as typically primary production experiences a range of conditions. Parameterizations used in PFT models are typically based on single nutrient controls under constant abiotic conditions hence are not suitable for simulating the temporal dynamics of primary production.

*Cell size*: carbon content: temperature. Many of the current generation of phytoplankton models have their basis in the Droop Equation which creates an envelope of potential doubling rates of diatom cells relative to temperature. However the coin of transfer in many ecosystem models is carbon. Carbon content is linked to cell size and not doubling rate. At colder temperatures phytoplankton cells are larger having a higher C content. A finding which therefore makes the suitability of many NPZD type models suspect.

**Other Primary Production issues**

- Respiration in phytoplankton is assumed to be constant, however evidence suggests that respiration at low light and low temperature is below the level of determination (Li, 1980).
- Buoyancy controls on sinking rates. A number of diatom species have exhibited the ability to become positively buoyant during specific stages of the bloom. This issue has implications not only for carbon flux but also for availability to higher trophic levels.
- Group/species specific food quality (FQ). (multiple controls). A number of studies have linked changes in nutrient regime and bloom stage with changes in food quality. This has implications for the modelling of higher trophic level dynamics which needs further examination.

**Microbial Loop:** The importance of the microbial loop for the sequestration of carbon has long been recognised however its importance for the production of higher trophic levels is yet not fully incorporated into ecosystem modelling. A number of key parameterisations are lacking including:

- Growth rates relative to prey biomass; temperature
- Prey selectivity
- Transfer efficiency to higher trophic levels
- Trophic upgrading

**Higher trophic levels:**

*Realistically coupling higher trophic levels (e.g. mesozooplankton and fish) to NPZD models requires the development of a number of parameterizations including*

- Food quality effects on growth and reproduction
- Qu10 although a general law like the Redfield ratio, examples of Q10 in excess of 10 have been seen in a number of marine species suggesting this issue needs to be revisited (Holste and Peck, 2005)
- Extrapolation of toxin effects (diatoms; ecotox) to reproductive potential of populations. Typically studies address effects on individuals; further research is required to incorporate these stressors in to the simulation of populations.
- Stressor effects (e.g., pH, temperature) on early life stages (e.g. egg, larvae, nauplii).

**Other key issues which need parameterization for key BASIN species include**

- Specific Dynamic Action
- Growth efficiency
- Basal Metabolic rates
- Multiple meal effects
- Conversion efficiency

**All trophic levels**

Physiological limits*:* It is highly probable that, due to global change, populations of a number of key species will be exposed to abiotic conditions not experienced during their evolution i.e. pH, temperature, light (UV). Resolving the limits and the plasticity of response requires targeted laboratory experiments to ascertain the limits/ranges at which key players:

- persist without influencing reproductive potential
- suffer a loss of competitive ability due to stress
- show plasticity of response relative to abiotic constraints (i.e. resilience)

## B) Working Group #2

### a) Data

Fundamental to the program 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.

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

Based on Phase I synthesis, field programs and processes studies for Phase II would be identified and proposed. We envision complementary process-oriented field programs that would be conducted at similar times in different regions across the basin. Although the specifics of these programs would evolve out of Phase I synthetic activities, these programs should have 1) an international group of investigators, 2) a coordinated sampling plan, 3) careful planning to ensure these programs build upon and leverage on-going and past research programs, 4) integration with modelling efforts, and 5) identification and systematic collection of important measurements that link climate, organisms and their life cycles, and biogeochemical cycles.

### b) Modelling

A 50-year reanalysis of the basin-scale 3D circulation fields should be created and accessible to all program PIs early on to provide the physical context for all synthesis activities of the Phase I program. This would be achieved by capitalizing on on-going basin-scale assimilative modelling and by downscaling into one or more shelf-sea regions. This fundamental 'backbone' information would support data synthesis and experimental design efforts in Phase I and future process-oriented modelling/field approaches in Phase II. Circulation models and flow fields should be selected for use in the program using systematic criteria that include, but are not limited to, Gulf Stream path, Turbulent Kinetic Energy levels

(TKE), meso-scale eddies, mixed layer depth and evolution, overturning circulation, etc. (Gangopadhyay *et al*. 1992, Taylor and Gangopadhyay, 2001.)

We also recommend that basin-wide NPZD-type modelling should proceed in order to provide prey and predator field for IBM models of key species and to provide boundary conditions for shelf models. These models should be judged by objective criteria (e.g., N flux, timing of events and dynamics of functional groups). Further aspects of IBM modelling are discussed in Question 2.

In order to address potential feedbacks between species/trophic groups/ecosystems to climate, an initial approach should be to use reduced complexity models (1D/2D) to identify the sensitivity of different systems to climate forcing and how changes in primary production, trophic structure, and population dynamics could influence carbon cycling, acidification, and other feedbacks to climate.

Analysis of basin-scale hindcast scenarios should be conducted in coordination with data synthesis efforts. A product of these activities would be a vision/plan that would help governments to identify critical long-term monitoring needs.

We anticipate that 3D coupled biophysical models will be an important part of Phase II activities. These models will continue to evolve throughout the program and become a primary synthetic tool to integrate existing and new (Phase II) data in the final synthesis phase of the BASIN program.

## C) Working Group #3

Working group #3 adopted a regional approach in approaching the questions. Particular focus was placed on climate variability and climate change effects firstly in relation to the Central Basin region of the North Atlantic, and secondly in relation to the Shelf Seas.

*A. Climate variability/change:*

1. Multiple modes of natural climate variability (e.g., NAO, high-latitude salinity anomaly events)
2. Global warming modifications of the above natural modes of climate variability and emergent processes

*B. Regional Approach:*

What we need to do to address questions by region:

1. Central Basin
   a. Multiple modes of climate forcing: Example 1: NAO
      i. NAO forcing of storm tracks and effects of wind mixing on stratification, nutrient limitation, and light limitation

ii. Differential Effects on subtropical gyre (nutrient limited), subpolar gyre (light limited), transitional region (both nutrient and light limitation)
iii. Impacts on primary production
   - Total annual production
   - Seasonal cycle
   - Composition
iv. Impacts on trophic interactions
   - Impacts on C export to deep sea
   - Impacts on energy flow to higher trophic level consumers
   - C and energy pathway considerations: Roles of different functional groups (e.g., small phytoplankton, large phytoplankton, microbial loop, microzooplankton, crustacean zooplankton, gelatinous grazers, and deep-living fishes)
v. Regime shifts

b. Multiple modes of climate forcing: Example 2: Arctic ice melting and export of freshwater as large salinity/temperature anomalies

i. Advection of salinity/temperature anomalies downstream
ii. Impacts most obvious in subpolar gyre
iii. Buoyancy effects on stratification/nutrients
iv. Impacts on primary production –
   - Total annual production
   - Seasonal cycle
   - Composition
v. Impacts on trophic interactions
   - Impacts on C export to deep sea
   - Impacts on energy flow to higher trophic level consumers
   - C and energy pathway considerations: Roles of different functional groups
   - C and energy pathway considerations: Roles of target species
vi. Regime shifts

c. How do we address these issues? Question and region-specific considerations:
i. CLIVAR-like models – climate forcing and boundary condition
ii. Assemble time series data sets: BATS, CPR, Ocean weather ships, Russian transects between Bermuda and Iceland, Groundfish and acoustic fish surveys
iii. JGOFS-type field studies, including primary production and sediment traps
iv. Open Ocean Observing Systems (esp. Labrador Sea)
v. Satellite remote-sensing products
   - Altimeter (ocean circulation)
   - Scatterometer (winds)
   - AVHRR (SST), Aquarius 2009 (salinity)
   - Ocean color (phytoplankton),
vi. ARGO and other drifters
vii. Tagging of Atlantic Pelagics (e.g., tuna and other large species)
viii. Importance of poorly sampled taxa (e.g., gelatinous zooplankton, naupli

2. Shelf Seas – higher latitude shelf ecosystems more closely coupled to subpolar gyre due to seasonal cycles, higher productivity, size structure, shared target species

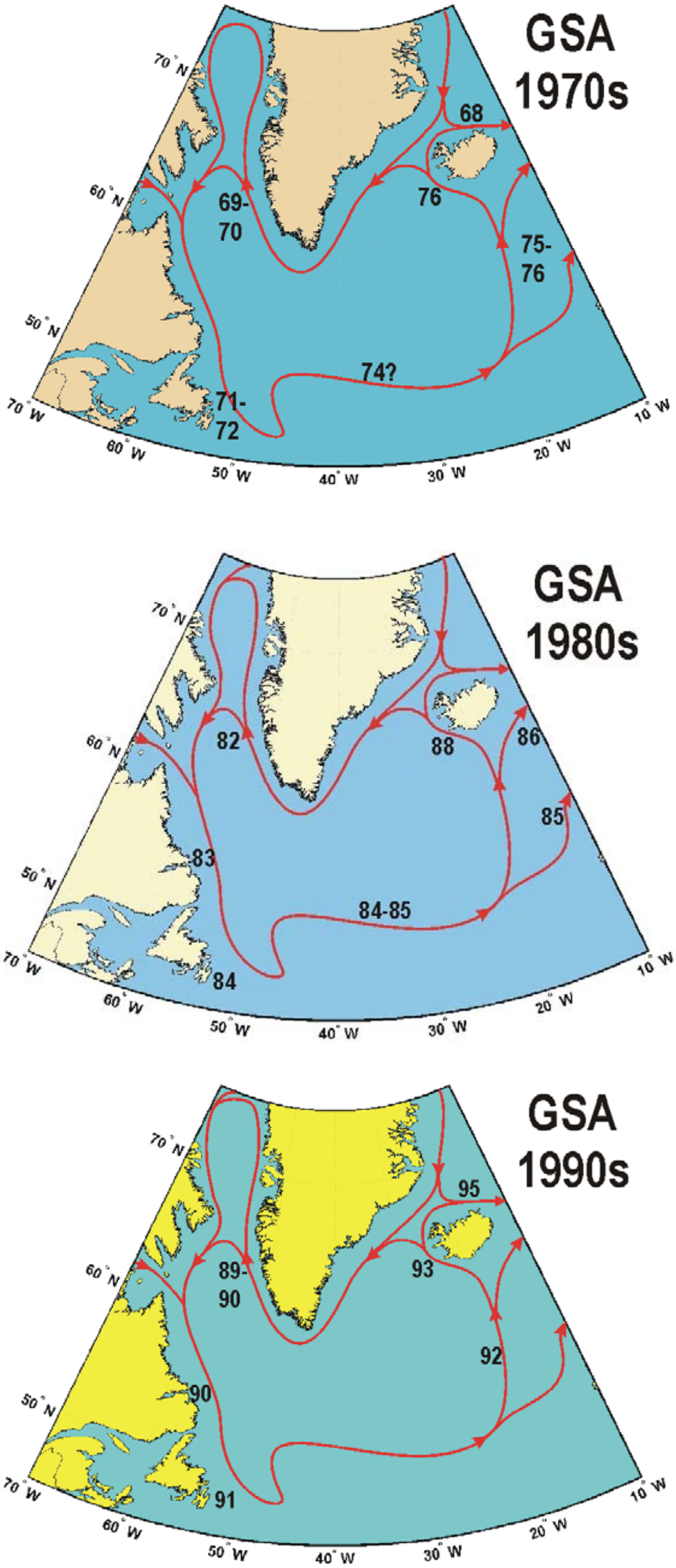


Figure 1. Propagation of decadal-scale GSAs around the Subarctic Gyre. Numbers are years-1900.

a. Modes of climate forcing: NAO

i. Impacts on ocean circulation/advection
ii. Impacts on slope-shelf exchange processes
iii. Impacts on precipitation, wind mixing, and stratification
iv. Impacts on primary production
    - Total annual production
    - Seasonal cycle
    - Composition
v. Impacts on trophic interactions
    - Impacts on C export to deep sea
    - Impacts on energy flow to higher trophic level consumers
    - C and energy pathway considerations: Roles of different functional groups
    - C and energy pathway considerations: Roles of target species

b. Modes of climate forcing: Arctic ice melting and export of freshwater as large salinity/temperature anomalies

i. Advection of salinity/temperature anomalies downstream
ii. Impacts most obvious in NW Atlantic shelf ecosystems: Regime shifts, biogeographic range expansions and contractions
iii. Buoyancy effects on stratification/nutrients
iv. Impacts on primary production
    - Total annual production
    - Seasonal cycle
    - Composition
v. Impacts on trophic interactions
    - Impacts on C export to deep sea
    - Impacts on energy flow to higher trophic level consumers
    - C and energy pathway considerations: Roles of different functional groups
    - C and energy pathway considerations: Roles of target species

c. Modes of climate forcing: Global warming

i. Air-sea heat flux gradients
ii. Impacts most obvious in southern regions, especially in NE Atlantic shelf ecosystems: Regime shifts, biogeographic range expansions and contractions
iii. Buoyancy effects on stratification/nutrients
iv. Impacts on primary production
    - Total annual production
    - Seasonal cycle
    - Composition
v. Impacts on trophic interactions
    - Impacts on C export to deep sea
    - Impacts on energy flow to higher trophic level consumers
    - C and energy pathway considerations: Roles of different functional groups
    - C and energy pathway considerations: Roles of target species

d. How do we address these issues? Question and region-specific considerations:

i. Coupled regional/basin-scale models

ii. Assemble time series data sets: CPR, NMFS surveys, DFO lines and survey
iii. Coastal Ocean Observing Systems
iv. Satellite remote-sensing products
  - Altimeter (ocean circulation)
  - Scatterometer (winds)
  - AVHRR (SST)
  - Aquarius 2009 (salinity)
  - Ocean color (phytoplankton)

v. High-frequency radars (surface currents)
vi. Ocean Tracking Network (e.g., shelf migrating species)
vii. Importance of poorly sampled taxa (e.g., gelatinous zooplankton, nauplli)

Ocean Observing Systems: Importance of Labrador Sea in mediating physical processes impacting NW Atlantic

- ❐ Deep Ocean Mooring
- ❐ Glider Lines, AUV Lines

## Question 2.

**How do life history strategies of target organisms, including both vertical and horizontal migration, contribute to observed population dynamics and community structure and how are these life history strategies affected by climate variability? How will life history influence the responses of key species to anthropogenic climate change?**

## A) Working Group #1

### a) Life History Pattern & Climate Change

The objective is to identify the patterns in life history that are more susceptible to alteration in a scenario of climate change. This includes comparison of strategies between specialized and generalist strategies (fidelity to spawning sites or reliance on specific circulation features to close the cycle). Furthermore we should consider the ratio between exploited and non-exploited species and the impact of fisheries on those ratios through intra-guild predation or other mechanisms (Hsieh *et al*. 2006).

The work would involve:

- Identification and synthesis of life history patterns
- Evaluation of trajectories, including early stages in relation to ocean climate and circulation (e.g., tracers in otolith; Campana 1999)
- Evaluation of risk of the strategies in the different climate scenarios
- Evaluation of the impact of fisheries on the community composition through predation and competition mechanisms. (Polis *et al*., 1989)

## b) Biogeographic Boundary Shifts

Shifts in species' biogeographic boundaries will be an emergent property of the interactions between life history and climate variability. These shifts may be driven by changes in the probability of life cycle closure in certain regions. Temporal shifts in community structure may also occur, such as taxa with life histories that are less sensitive to new environmental conditions becoming more effective competitors (for example, shifts from species with specialist life histories to generalists).

Examples of life history traits in potential target species include embryo- and juvenile-stage dormancy in copepods, egg broadcasting versus brooding in copepods, solitary and colonial reproduction in salps, and midwater versus benthic spawning in fish.

These traits may influence the plasticity, sensitivity, or resilience of populations to climate change, for example allowing populations to shift their phenology in response to warming, to store individuals in 'egg banks' (Hairston, 1996, Katajisto, 1996, Kerfoot *et al*. 1999) or to shift the timing of migration in response to predators, all buffering the population against climate change. Life history responses may also be subject to natural selection on time scales of years (Hairston & Walton, 1986), buffering populations from changes in their environment or community.

## c) Population & Community Responses to Climate Variability

Novel approaches to life history analysis will be required to identify, understand, and predict how life histories will mediate population and community responses to climate variability. Possible approaches could include analysis of microevolutionary controls and variability associated with particular life history patterns; neutral theory of diversity, and niche theory. Methodologies from theoretical and mathematical ecology could also be applied, for example, dynamic energy budgets (DEB) (Kooijman, 2000), incorporation of microscale feeding dynamics to parameterize larger-scale models, hybrid modelling linking super-IBMs to concentration-based modelling, and comparison of the results among different model approaches.

## d) Neutral Theory of Diversity

Contrary to niche theory, neutral theory of diversity (Hubbell, 1997; Hubbell, 2001; Condit *et al*., 2002) suggests that dispersion is more important to explain the spatial variation in species abundance than habitat specialization. Neutral theory predicts that similarity between sites (beta-diversity) decreases logarithmically with geographical distance due to organisms' dispersion limitation (Condit *et al*. 2002). On the other hand niche theory predicts that specific differentiation between communities is due to the adaptation of the species to the environment. In niche theory species should distribute as a function of their fundamental niche defined by the range of environmental conditions; this distribution being either unimodal or along a gradient of environmental conditions (Oksanen & Minchin, 2002). At present Neutral theory of diversity is subject of an intense debate in scientific literature. However it is not a purely theoretical issue as a good empirical and theoretical understanding of beta-diversity is essential for the correct determination of protected areas (Williams *et al.*, 2004, Myers *et al.*, 2000 and Cabeza and Moilanen, 2001).

For many of the potential target species of the BASIN program, the critical details of life history traits required to understand life cycle closure are currently unknown and will require additional investigation, for example control of entry into and exit from diapause in copepods. For potential target fish species, information about migration patterns, spawning and feeding regions, geographic fidelity to spawning regions and migration patterns, and effects of temperature on spawning success will be required.

## e) Predictive Habitat Modelling

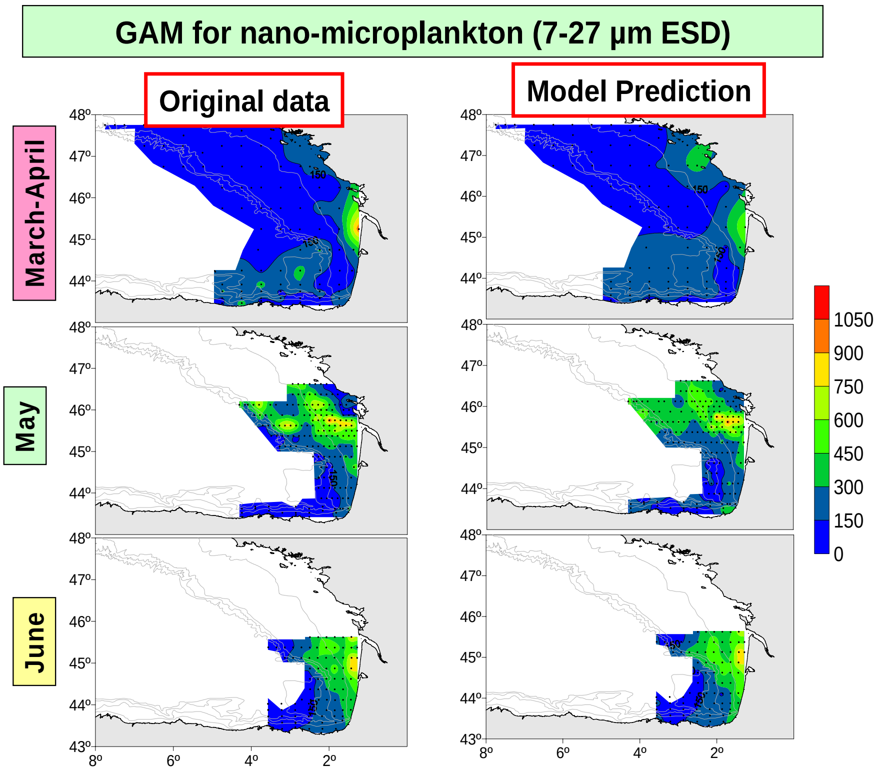


Figure 2. Application of the predictive habitat modelling approach to the nano-microplankton distribution in the Bay of Biscay. The GAM model explains 81% of the observed variance (Zarauz *et al.*, in press).

New statistical methods have allowed the development of predictive habitat models. Such models are static and probabilistic in nature, since they statistically relate the geographical distribution of species or communities to their present environment (Guisan & Zimmerman

2000). There are a large number of statistical methods available (GAMs, TREE, ENVELOP, BAYES) permitting flexible and powerful models with good predictive capacities for the distribution of species and communities. Models incorporating different environmental factors (e.g., temperature, salinity, depth, etc) over a wide range of values can be used to obtain robust predictions of changes in the distribution of both species and communities. However, care has to be taken that the conditions to be simulated were originally included in the development of the model. As an example, a zooplankton species composition model developed in the North Sea will not have predictive capacity for the North Sea with increasing temperature, whereas a model developed with data from areas south of the North Sea will have that capacity (Figure 1). Such models can be applied to all type of organisms, from bacteria to fish.

*Metabolic ecological theory*: The metabolic theory of ecology can be further applied to analyse and predict several aspects of the organism's life history. In terrestrial ecology examples of the application of the metabolic theory can be found for development and mortality rates, life span, population growth rate, carrying capacity , rates of competition and predation, and patterns of trophic dynamics (Brown *et al*., 2004). In marine ecosystem its application is still limited, but other than production/respiration (Lopez-Urrutia *et al*., 2006) it has been successfully applied to copepod egg hatching time (Hirst and Lopez-Urrutia 2006) and planktonic larval development and dispersion rate (O'Connor *et al*., 2006). It has therefore a strong potential to provide basic understanding of the observed patterns and to cross the bridge between terrestrial and marine ecology.

## B) Working Group #2

## Question 2

## a) Coupled physical IBM modelling of life history strategies

Part of the BASIN aim is to understand and simulate the impact of climate variability and change on key species of plankton and fish, as well as community structure as a whole. One approach is to identify and model the life history of individual species that clearly must have a dominant role in the ecosystem. Species of lesser dominance or for which the details of the life history cannot be feasibly acquired within the BASIN program, can be pooled together in functional groups. By conducting individual based modelling (coupled to the advective and hydrographic fields) of the key species and functional groups, the impact of climate variability on the community structure as a whole will emerge from the integration of the results. A listing of candidate key species or functional groups, based on perusal of representative studies across the N. Atlantic, is given in Table 1.

| **Candidate Key Taxa** | **A. North Atlantic Deep Ocean** | **Northwest and Northeast Atlantic Coastal shelves** |
|---|---|---|
| **Copepods** | *Calanus*<br>*C. finmarchicus*<br>*C. glacialis*<br>*C. helgolandicus*<br>*C. hyperboreus*<br>*Oithona* spp. (as functional group)<br>*Pseudocalanus* spp. (as functional group)<br>*Oncaea* spp. (as functional group)<br>*Metridia* (as functional group)<br>*M. longa*<br>*M. lucens*<br>*Euchaeta norvegica* | *Calanus*<br>*C. finmarchicus*<br>*C. glacialis*<br>*C. helgolandicus*<br>*C. hyperboreus*<br>*Oithona* spp. (as functional group)<br>*Pseudocalanus* spp. (as functional group)<br>*Metridia* (as functional group)<br>*Centropages typicus*<br>*Acartia (as functional group)*<br>*Euchaeta norvegica* |
| **Gelatinous taxa** | *Aglantha digitale*<br>Salp spp. (as functional group)<br>Larvacean spp. (as functional group)<br>*Oikopleura vanhoeffini*<br>*O. labradorensis* | Salp spp. (as functional group)<br>Larvaceans spp. (as functional group) |
| **Euphausids** | *Meganycthiphanes norvegica*<br>*Thysanoessa longicaudata* | *Meganycthiphanes norvegica*<br>*Thysanoessa* spp. |
| **Gastropods** | *Limacina* spp. | |
| **Sarcodina** | *Globigerina* spp. | |
| **Fish**<br>**Source:** BASIN Reykjavik Workshop Report 2006 | Redfish<br>Myctophids | Herring<br>Capelin<br>Sandlance<br>Sprat<br>Mackerel<br>Blue whiting<br>Cod<br>Haddock<br>Anchovy<br>Sardine |
| **Other taxa, intermediate prominence** | *Pleuromamma robusta* (copepod)<br>*Scolecithricella minor* (copepod)<br>*Microcalanus/Paracalanus* (copepod)<br>*Heterorhabdus norvegica* (copepod)<br>*Sagitta* spp. (as functional group) | *Microcalanus/Paracalanus* |
| | | |

**Table 1.** Candidate key taxa for life history modelling and analysis of climate impacts on community structure in the North Atlantic deep basin **(A)** Zooplankton sources: Bainbridge and Corlett, 1968; Digby 1954; Wiborg 1954; fish sources: Basin Reykjavik Workshop Report 2007) and in Northwest and Northeast Atlantic shelf seas **(B)** Preliminary criterion for zooplankton candidacy is relative numerical dominance in 165-333µm mesh plankton tows. Consideration also needs to be given to other dominant zooplankton found in Atlantic Westerly Winds Biome (Longhurst 1998), not included in the analysis here.

One approach for hindcasting and predicting impacts of climate variability on the life histories is to downscale the results from the IPCC model (for example SST and winds for the deep ocean) and use these results as forcing for the coupled life history model in order to look at sensitivity of different systems to climate forcing of C, acidification, and temperature.

In the data synthesis phase, key species for which sufficient knowledge is available (or can be obtained within a short term project of measurements) can be modeled in hindcast mode. If the results of sensitivity of the life histories are consistent with observations, then there is confidence in the model and approach for forecasting. An example may be the hindcast of distributional shifts in *Calanus finmarchicus* and *Calanus helgolandicus* in the N. Atlantic.

Another approach that was discussed was “generic” life history modelling to examine which life histories are more vulnerable to fishing and climate perturbations. This would apply especially to functional groups for which there is not sufficient knowledge for species specific life history modelling.

Temporal and spatial variability is explicit in the zooplankton coupled physical-life history models. However, modelling of the entire life history fish (including bioenergetics, e.g. maternal effects and growth, and distribution of juvenile and adult populations) is presently an active area of research. The spatial explicit modelling of life histories of the key fish species will require development in order examine sensitivity to past and future climate change. Combining results of spatially explicit life history models of the key harvested species would be an important management tool in the context of ecosystem based management strategies.

The results of the phase I life history modelling will guide identification of knowledge gaps and sampling strategies. The modelling could also be used in real time to guide sample. For example, in Norway presently a spatially explicit life history model of cod is being developed to predict distributions of cod eggs and larvae.

## b) Data

NPZ models are needed to provide prey and predator fields for key species and boundary conditions of shelf models – $N_2$ flux timing dynamics of functional groups. In Phase I, NPZ models will use existing datasets. The variables to be modelled should include nutrients, phytoplankton, bacteria, DOM, nanoflagellates and microzooplankton and the appropriate forcing fields should be used to drive the models. Phytoplankton should be sub-divided into at least two size classes, and in some cases functional groups (e.g., diatoms, coccolithophores, *Phaeocystis*, nanoflagellates) where appropriate.

Aims of the modelling should be to reproduce the dynamics of phytoplankton blooms, seasonal cycles of microzooplankton biomass. These will provide prey fields that can be coupled to (for example) IBM models of large zooplankton. Biogeochemical fluxes to DOM, sedimenting POC and recycling rates will also be outputs.

There are a number of datasets on species abundance and distributions that were described during the presentation given by Erica Head at the BASIN Chapel Hill meeting (Biological Data Availability and Needs). As well as these, there may be other datasets that were not included in this list (data archaeology). During Phase I, data synthesis would involve making these datasets available to the BASIN community and searching out additional datasets. It is also anticipated that datasets on physiological rates (e.g., growth, reproduction etc.) would also be inventoried. The aim of these syntheses would be to provide inputs for Phase I modelling and to point to data gaps that need to be filled. Some of these gaps can already be identified, e.g. the general scarcity of data on microzooplankton biomass, lack of information on deep-water pelagic predators (invertebrate and fishes). Collection of samples/data could go ahead in Phase I, if data gaps are known to be such as to impede modelling efforts, and on an opportunistic basis (e.g., extension of programmes on ongoing monitoring missions (geographical or scope).

Investigations should also be made in Phase I by synthesising existing data from different regions to examine such questions as; the effect of differences in temperature/light cycle etc. on rate processes and phenology.

In Phase II, we anticipate that dedicated field sampling and process studies should be undertaken preferably on a pan-basin, multi-trophic level basis. We anticipate that a prescribed suite of measurements should be made, e.g. of biomass and abundance of key species (functional groups) from phytoplankton to fish.

Another element is the use of satellite data to understand the movement of species and shifts in community composition relative to ocean temperatures, chlorophyll distributions and ocean fronts. As an example, there should be enough existing data to determine change from the cold early-1990s to the warm early/mid 2000s. This time period also has increasing amount remote sensing data to contribute to observing basin scale changes in biological productivity and physical climate changes in the ocean. Remote sensing ocean color data should be an essential part of data synthesis. There should also be an analysis of existing observational data important in identifying indices suitable for describing the species behavior as a response to known climate fluctuations (NAO; the cold 1990s to the warm 2000s). Such indices could be critical in determining success of any coupled biological-physical model.

## *Working Group 3*

Life history considerations:

- Climate effects on larval recruitment and survivorship
- On-shelf/off-shelf migrations (esp. far-northern coastal seas)
- Interaction of ontogenetic vertical migration with physical transport processes (effects on seeding populations, energy and C subsidy to shelf ecosystems)
- Open-ocean spp. (*Calanus*) versus shelf-associated copepod diapause strategies
- Continual reproducers with low overall mortality (e.g. *Oithona*)
- Seasonal pulses of planktivorous fishes
- Sexual/asexual bloomers such as salps can affect ecosystems radically

Functional group approach:

- Viruses
- Bacterioplankton
- Phytoplankton
    - Diatoms
    - Coccoliths
    - N-fixers (Cyanobacteria)
    - Microflagellates
    - Dinoflagellates
    - Pico/nannoplankton
- Secondary production
    - Gelatinous:
        - Mucus feeders
        - Planktivores
        - Piscivorous
    - Crustaceans
        - Copepods
        - Euphausiids
        - Amphipods
    - Pteropods?
    - Missing forms? Nauplii, gelatinous zooplankton, larvacea
    - Microzooplankton
        - Protists: flagellates, ciliates
        - Metazoans: nauplii, larval forms
- Planktivorous fish
    - Oceanic: Myctophids, hatchetfish, herring, redfish
    - Coastal: Anchovies, mackerels, herring, capelin, sandlance, menhaden
- Planktivorous decapods
- Higher-level exploited taxa
    - Blue whiting
    - Large pelagics (tuna, billfishes, sharks)
    - Squid
    - Benthic crustacea
    - Groundfish
- Mammals/seabirds

Phase I suggestion:

- Make back-of-the-envelope calculations to determine relative importance of net C export from shelf to deep sea.
- Go back to old records and data (literature surveys, data mining) and develop operational databases for retrospective analyses (US military, Denmark, Russia, Germany, Norway, and Iceland).
- Importance of poorly sampled taxa.

## Question 3.

**How does the removal of exploited species include marine ecosystems? Under what conditions can such harvesting result in substantial restructuring of shelf or basin ecosystems, i.e., regime shifts? Do such changes extend to changes in primary productivity and nutrient cycling? How is resilience of the ecosystem affected?**

## A) Working Group #1

The resilience of marine ecosystems is a result of the many strong and weak interactions between and within species as well as with the environment. Resilient ecosystems, typically those of a high diversity, are dominated by primarily weak connections between species with few strong interactions while ecosystems susceptible to change are those which are dominated by strong interactions and having a low species diversity (McCann *et al*., 1998). One of the major controversies in biodiversity research concerns the fact that some species exert stronger control (i.e. strong interaction strengths) over ecological processes than others these typically being the higher trophic level keystone species such as predatory fish species. Analyses suggest that on average species loss does affect the functioning of a wide variety of organisms and ecosystems, but the magnitude of these effects is ultimately determined by the identity of species. Fishing has targeted abundant strong interactions predator species whose removal can destabilize the food web and lead to unforeseen consequences for the biomass, productivity, and community composition of lower trophic levels (Frank *et al*. 2005, 2006). This is the trophic cascade. Furthermore, heavy exploitation in marginal or stressed environments dominated by strong interactions i.e ecosystems with little resilience has the potential to result in transformation of the ecosystem to an alternate stable state (e.g. Northern Cod).

Historically fisheries have been assessed and managed primarily as single species and stocks and, as our knowledge of predator-prey relationships were better understood, through multispecies assessments. The ecosystem-based approach to fisheries management (EAF) has evolved from this, and takes into account the fact that fisheries are embedded into the environment and cannot be managed in isolation (Cury, 2005). A variety of models are available in various levels of complexity and usefulness for evaluating the ecosystem effects of fishing (Robinson and Frid, 2003). These models have been used to make predictive estimations ultimately for management purposes, particularly in the last few years. This has been undertaken with non-dynamic models for testing scenarios, and the response of the ecosystem to changes in effort and spatio-temporal area closures (e.g. Dinmore *et al*., 2003, Hiddink *et al*., 2006, Zeller and Reinert, 2004). Dynamic ecosystem models had been identified as potentially powerful tools, but limited in their immediate applicability to consideration of ecosystem effects of fishing through the lack of detailed representation of higher components of the food web (Robinson and Frid, 2003). Furthermore, the ecosystem approach to fisheries (focus on living resources) and ecosystem management (as required in the Maritime Policy), needs simultaneous consideration of major ecosystem drivers. This can only be achieved by coupling fisheries models with models of the various climate and ecosystem drivers and will allow management measures to be developed and tested.

## B) Working Group #2

### Question 3

Question 3 addresses the top-down effects of fishing on marine ecosystems and the potential impact for climate change to affect fishery management objectives. The first point of discussion was the question itself. The group felt that **climate** should be included and the question was modified to: How does the removal of exploited species influence marine ecosystems? Under what **climatic** conditions?

### a) Top-down Processes

Two approaches were discussed for elucidating the role of top-down processes. One is a time series correlation approach recently used by Frank *et al*. (2005) on the eastern Scotian Shelf. Proxies for biomass and concentration of important ecosystem elements were assembled and then compared to infer the impact of fishing on the ecosystem. These efforts should be expanded to the basin scale using similar proxies across the basin. Exploitation rates should be included explicitly to compare the effect of exploitation history on ecosystem structure. This approach could be extended to develop hindcast comparisons of the effect of removal on the system in concert with the 50-year hindcast modelling performed as part of Question 1. For example, this approach could look at the impact of industrial fisheries on pelagic species as a vector of ecosystem change over the past 50 years.

The second approach is biomass/trophic modelling. Models have been developed in specific regions (Georges Bank, Norwegian Sea/Barents Sea). These models should also be developed across the Basin including both shelf and open ocean systems. They can then be used to identify data gaps, conduct network analyses to examine resiliency, the impact of fishing pressure upon the system, and the impact of lower trophic level changes on fish biomass.

Such models certainly have their weaknesses, but should be viewed as one tool for examining top-down effects.

## b) Scientific Advice for Management

The group also discussed linking ecosystem/climate effects to fish population models to use in the development of scientific advice for management. For example, MSVPA models should be developed to incorporate the effects of environmental and trophic variability on model parameters (natural mortality, age-at-maturity, fecundity, recruitment). These models would then allow the results of BASIN to be framed and applied in specific fisheries management contexts.

Fish population models also need to include spatial dynamics. The spatial scale of the model should reflect the range of the species and incorporate information from across the Basin if appropriate (e.g., cod, herring, tuna, blue whiting, lobster, scallops, squid). The impacts of climate and fishing on the spatial dynamics can then be investigated, linked to the results of the BASIN program and used directly in management. An important issue is how does climate forcing impact a species over its range or over a stock complex in combination with spatially varying removals.

The group also discussed the need to consider how the program contributes to Ecosystem Approaches to Fisheries Management. A group (sub-committee, task force) should be tasked with this focus from the beginning to ensure that the results of BASIN are applied to the development and application of EAFM on both sides of the Atlantic. This sub-committee and BASIN PI's should also directly participate in the development of scientific advice for single species fisheries management. The emphasis should be a targeted application of BASIN results in situations where they will have the greatest impact.

Field programs and coordination with ongoing monitoring efforts should work towards developing spatially and temporally explicit information regarding the predation effect of fishes on lower trophic levels both benthic and pelagic.

## c) New Technology

Our perception of marine ecosystems is influenced by our sampling methods. As part of BASIN, new technologies will be developed and applied to obtain a more complete and a better integrated view of marine ecosystem structure and function. A number of limitations exist with current sampling methodologies. Biological sampling techniques acquire data at scales very different than those for physical data. A number of taxa are not well sampled with current techniques (microzooplankton, gelatinous zooplankton, late larval/early juvenile fishes). Taxonomy is difficult in some situations and identification to necessary taxonomic levels can be time consuming or impossible (fish eggs, invertebrate larvae). The cost of actual sample collection is high. There are a host of technologies under development that are designed to overcome these limitations. BASIN should supplement these efforts and support their trial application in Phase I, and then use these technologies in Phase II for the field programs to obtain a more complete representation and understanding of marine ecosystem structure. We anticipate that several new technological approaches will be instrumental to the success of the BASIN program, including, but not limited to, optics, genetics, acoustics, and biological *in situ* samplers. Especially important would be *in situ* tools for measuring abundance and biomass of key species/functional groups.

## d) Question for Steering Committee

What about nutrient loading at coastal areas? (likely to increase in future more populations migrating to the coasts – at least in US).

# REFERENCES CITED

Anderson, T. 2005. Plankton functional type modelling: running before we can walk? J. Plankton Res. 27, 1073-1081.

Bainbridge, V. and J. Corlett. 1968. The zooplankton of the NORWESTLANT surveys, ICNAF (NAFO) Spec. Publ. 7 (I), pp. 101–122

Batchelder, H.P., C. A. Edwards and T. M. Powell. 2002. Individual-based models of copepod populations in coastal upwelling regions: implications of physiologically and environmentally influenced diel vertical migration on demographic success and nearshore retention. Progress in Oceanography 53: 307-333.

Benfield, M.C., C.J. Schwehm, R.G. Fredericks, G. Squyres, S.F. Keenan, and M.V.Trevorrow. 2004. Measurement of zooplankton distributions with a high-resolution digital camera system. In "Handbook of Scaling Methods in Aquatic Ecology: Measurement, Analysis, Simulation". [Eds] Seuront, L. and P. G. Strutton CRC Press. ISBN: 0849313449 Publication Date: 8/27/2003. Pgs 17-30

Benfield M.C. P. Grosjean, P. Culverhouse, X. Irigoien, M.E. Sieracki, A. Lopez-Urrutia, H.G. Dam, Q. Hu, C.S. Davis, A. Hansen, C.H. Pilskaln, E. Riseman, H. Schultz, P.E. Utgoff and G. Gorsky. 2007. RAPID: Research on Automated Plankton Identification. Oceanography in press

Brown, J.H., J.H. Gillooly, A.P. Allen, V.M. Savage and G.B. West. 2004. Towards a metabolic theory of ecology. Ecology 85, 1771–1789.

Cabeza, M. and A. Moilanen. 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology & Evolution, 16, 242-248.

Campana, S.E. 1999. Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Mar Ecol Prog Ser 188: 263-297.

Carlotti, F. and Wolf, U. 1998. A Lagrangian ensemble model of *Calanus finmarchicus* coupled with a 1-D ecosystem model. Fisheries Oceanography, 7: 191-204.

Condit, R., N. Pitman, E.G. Leigh, J. Chave, J. Terborgh, R.B. Foster, P. Nunez, S. Aguilar, R. Valencia, G. Villa, H.C. Muller-Landau, E. Losos and S.P. Hubbell. 2002. Beta-diversity in tropical forest trees. Science, 295, 666-669.

Cury P. 2005. Marine ecosystems and climate variation. Science 308. 358-358

Davis, C. S. 1984. Interaction of a copepod population with the mean circulation on Georges Bank, J. Mar. Res. 42

Davis C.S., F. Thwaites, S.M. Gallager and Q. Hu. 2005. A three-axis fast-tow digital Video Plankton Recorder for rapid surveys of plankton taxa.

Davis C.S., Q. Hu, S.M. Gallager, X. Tang and C.J. Ashjian. 2004. Realtime observation of taxa-specific plankton distributions: an optical sampling method. Mar Ecol Prog Ser 284:77–96

Davis, C.S. and D.J. McGillicuddy. 2006. Transatlantic abundance of the N2-fixing colonial cyanobacterium *Trichodesmium*, Science, 312, 1517 – 1520.

de Young, B., M. Heath, F. Werner, F. Chai, B. Megrey, and P. Monfray. 2004. Challenges of Modeling Ocean Basin Ecosystems. Science.Vol. 304. no. 5676, pp. 1463 - 1466

Digby, P.S.B. 1954. The biology of the marine planktonic copepods of Scoresby Sound, East Greenland. Journal of Animal Ecology 23: 298-338.

Dinmore, T.A., D.E. Duplisea, B.D. Rackham, D.L. Maxwell and S. Jennings. 2003. Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities. ICES Journal of Marine Science, 60: 371-380.

Doney, S.C. 1999. Major challenges confronting marine biogeochemical modelling. Global Biogeochemical Cycles 13, 705-714

Dunne, J. A. 2005. The network structure of food webs. In: Ecological Networks: Linking Structure to Dynamics in Food Webs, eds. Pascual, M. and Dunne, J. A. Oxford University Press, pp. 27-86.

Frank, K.T., B. Petrie, J.S. Choi and W.C. Leggett. 2005. Trophic Cascades in a Formerly Cod-Dominated Ecosystem. Science 308, 1621-1623

Frank, K.T., B. Petrie, N.L. Shackell and J.S. Choi. 2006. Reconciling differences in trophic control in mid-latitude marine ecosystems Ecology Letters 9 (10), 1096–1105.

Gangopadhyay, A., P. Cornillon, and D.R. Watts. 1992. A Test of the Parsons-Veronis Hypothesis related to the Separation of the Gulf Stream from the Coast, Journal of Physical Oceanography, 22(11), pp. 1286-1301.

Grosjean, P., M. Picheral, C. Warembourg, and G. Gorsky. 2004. Enumeration, measurement, and identification of net zooplankton samples using the ZOOSCAN digital imaging system. ICES Journal of Marine Science 61:518–525.

Guisan A. and N.E. Zimmermann. 2000. Predictive habitat distribution models in ecology, Ecological Modelling 135, pp. 147–186.

Hairston, N.G. Jr. 1996. Zooplankton egg banks as biotic reservoirs in changing environments. Limnology and Oceanography 41(5): 1087-1092.

Hairston, N.G. Jr. and W.E. Walton. 1986. Rapid evolution of a life history trait. PNAS 83(13): 4831-4833.

Hiddink, J.G,. T. Hutton, S. Jennings and M.J. Kaiser. 2006. Predicting the effects of area closures and fishing effort restrictions on the production, biomass, and species richness of benthic invertebrate communities. ICES Journal of Marine Science: Journal du Conseil 63(5):822-830.

Hirst, A. and A. López-Urrutia. 2006. Effects of evolution on egg development time. Mar. Ecol. Prog. Ser. 326, 29-35.

Holste, L. and M.A. Peck. 2006. The effects of temperature and salinity on egg production and hatching success of Baltic *Acartia tonsa* (Copepoda: Calanoida): A laboratory investigation. Marine Biology 148**:** 1061-1070.

Hsieh, C.H., C.S. Reiss, J.R. Hunter, J.R. Beddington, R.M. May and G. Sugihara. 2006. Fishing elevates variability in the abundance of exploited species. Nature 443: 859-862.

Hu, Q., C. Davis and C. Petrik. 2007. A simplified age-stage model for copepod population dynamics. Mar Ecol Prog Ser. (accepted with revision)

Hubbell, S.P. 1997. A unified theory of biogeography and relative species abundance and its application to tropical rain forests and coral reefs. Coral Reefs, 16, S9-S21.

Hubbell, S.P. 2001. A Unified Neutral Theory of Biodiversity and Biogeography. Princeton University Press, Princeton.

IPCC 4th Assessment Report, Working Group 1 (official reference to come)

Katajisto, T. 1996. Copepod eggs survive a decade in the sediments of the Baltic Sea. Hydrobiologica 320(153-159).

Kerfoot, W.C., J.A. Robbins and L.J. Weider. 1999. A New Approach to Historical Reconstruction: Combining Descriptive and Experimental Paleolimnology Limnology and Oceanography, Vol. 44, No. 5 (Jul., 1999), pp. 1232-1247

Kooijman, S.A.L.M. 2000. Dynamic Energy and Mass Budgets in Biological Systems. 2[nd] ed. Cambridge Univ. Press, 424 pp

Le Quéré, C., S.P. Harrison, I.C. Prentice, E.T. Buitenhuis, O. Aumont, L. Bopp, H. Claustre, L. Cotrim da Cunha, R. Geider, X. Giraud, C. Klaas, K.E. Kohfeld, L. Legendre, M. Manizza, T. Platt, R.B. Rivkin, S. Sathyendranath, J. Uitz, A.J. Watson, and D. Wolf-Gladrow. 2005. Ecosystem dynamics based on plankton functional types for global ocean biogeochemistry models. Global Change Biology, 11, 2016-2040.

Li, W.K.W. 1980. Temperature adaptations in phytoplankton: cellular and photosynthetic characteristics. In: Primary Productivity in the Sea (Ed. P.G. Falkowski), pp. 259–279. Plenum Press, New York.

Longhurst A., 1998. Ecological geography of the Sea. Academic Press, London

López-Urrutia, A., E. San Martin, R. Harris and X. Irigoien. 2006. Scaling the metabolic balance of the oceans. Proc. Nat. Acad. Sci. USA 103, 8739-8744.

Madin, L.P., E.F. Horgan, S. Gallager, J. Eaton and A. Girard. 2006. LAPIS: A new imaging tool for macro-zooplankton. OCEANS '06 MTS/IEEE Boston September 19-21, 2006.

McCann, K., A. Hastings and G.R. Huxel. 1998. Weak trophic interactions and the balance of nature. Nature 395:794-798.

McGillicuddy, D.J., L.A. Anderson, N.R. Bates, T. Bibby, K.O. Buesseler, C. Carlson, C.S. Davis, C. Ewart, P.G. Falkowski, S. Goldthwait, D.A. Hansell, W.J. Jenkins, R. Johnson, V.K. Kosnyrev, J.R. Ledwell, Q.P. Li, D.A. Siegel, and D.K. Steinberg. 2007. Mid-ocean plankton blooms modulated by eddy-wind interactions. Science, 316, 1021-1026.

Moore, K.J., S.C. Doney, J.A. Kleypas, D.M. Glover and I.Y. Fung. 2002. An intermediate complexity marine ecosystem model for the global domain. *Deep-Sea Res. II*, **49**, 403-462.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. Nature, 403, 853-858.

O'Connor, M.I., J.F. Bruno, S.D. Gaines, B.S. Halpern, S.E. Lester, B.P. Kinlan and J.M. Weiss. 2006. Temperature control of larval dispersal and the implications for marine ecology, evolution, and conservation. Proc. Nat. Acad. Sci. USA 104, 1266-1271.

Oksanen, J. & Minchin, P.R. 2002. Continuum theory revisited: what shape are species responses along ecological gradients? Ecological Modelling, **157**, 119–129.

Polis, G.A., C.A. Myers and R.D. Holt. 1989. The ecology and evolution of intraguild predation: Potential competitors that eat each other. Ann. Rev. Ecol. Syst. 20: 297-330.

Popova, E.E., A.C. Coward, G.A. Nurser, B. de Cuevas and T.R. Anderson. 2006. Mechanisms controlling primary and new production in a global ecosystem model – Part II. The role of the upper ocean short-term periodic and episodic mixing events. Ocean Sci. 2, 267-279

Robinson, L.A. and C.L.J. Frid. 2003. Dynamic ecosystem models and the evaluation of ecosystem effects of fishing: can we make meaningful predictions? Aquatic Conservation: Marine and Freshwater Ecosystems vol 13 pp 5-20

Schweckendiek, U. and J. Willebrand. 2005. Mechanisms Affecting the Overturning Response in Global Warming Simulations. J. Climate 18, Nr. 23, S. 4925-4936

Samson, S., T. Hopkins, A. Remsen, L. Langebrake, T.Sutton and J. Patten. 2001. A system for high-resolution zooplankton imaging. IEEE Journal of Oceanic Engineering, 26, 671-676.

Speirs, D.C., W.S.C. Gurney, M.R. Heath, W. Horbett, S.N. Wood and B.A de Cuevas. 2006. Ocean-scale modelling of the distribution, abundance, and seasonal dynamics of the copepod *Calanus finmarchicus*. Mar. Ecol. Prog. Ser. 313, 173-192

Speirs D.C., W.S.C. Gurney, M.R. Heath and S.N. Wood. 2005. Modelling the basin-scale demography of *Calanus finmarchicus* in the north-east Atlantic. Fisheries Oceanography 14: 333-358.

Taylor, A.H. and A. Gangopadhyay. 2001. A Simple Model of Interannual Shifts of the Gulf Stream, Journal of Geophysical Research, 106(7), 13,849-13860.

Wiborg, K. F., 1954. Investigations on zooplankton in coastal and offshore waters of western and northwestern Norway. FiskDir. Skr., ser. Havunders., 11:5-246.

Wiebe, P.H., R.P. Harris, M.A. St. John, F.E. Werner and B. de Young. (Eds.). 2007. BASIN. Basin-scale Analysis, Synthesis, and INtegration. GLOBEC Report 23 and U.S. GLOBEC Report 20. 1-56pp

Williams, J.C., C.S. ReVelle and S.A. Levin. 2004. Using mathematical optimization models to design nature reserves. Frontiers in Ecology and Environment, 2, 98-105.

Zeller, D. and J. Reinert. 2004. Modelling spatial closures and fishing effort restrictions in the Faroe Islands marine ecosystem. Ecol Modell 172 (2-4):403-420.

Zarauz, L., X. Irigoien, A. Urtizberea and M. Gonzalez. (In press) Mapping plankton distribution in the Bay of Biscay during three consecutive spring surveys Mar. Ecol. Prog. Ser. (In Press).

## SOME USEFUL ADDITIONAL REFERENCES

Attrill, M.J. and M. Power. 2002. Climatic influence on a marine fish assemblage. Nature 417: 275-278.

Barton, A.D., C.H. Greene, B.C. Monger and A.J. Pershing. 2003. Continuous plankton recorder survey phytoplankton measurements and the North Atlantic Oscillation: interannual to multidecadal variability in the Northwest Shelf, Northeast Shelf, and Central North Atlantic Ocean. Prog. Oceanogr. 58: 337-358.

Beaugrand, G., F. Ibañez and P.C. Reid. 2000. Spatial, seasonal and long-term fluctuations of plankton in relation to hydroclimatic features in the English Channel, Celtic Sea and Bay of Biscay. Mar. Ecol. Prog. Ser. 200: 93-102. Beaugrand, G., P.C. Reid, F. Ibanez, J.A. Lindley, and M. Edwards. 2002. Reorganization of North Atlantic marine copepod biodiversity and climate. Science **296**: 1692-1694.

Belkin, I.M., S. Levitus, J. Antonov and S.A. Malmberg. 1998. "Great Salinity Anomalies" in the North Atlantic. Progress in Oceanography **41**: 1-68.

Belkin, I.M. 2004. Propagation of the "Great Salinity Anomaly" of the 1990s around the northern North Atlantic, Geophysical Research Letters **31**, L08306, doi: 10.1029/2003GL019334.

Carton, J.A., G. Chepurin, X. Cao and B.S. Giese. 2000. A Simple Ocean Data Assimilation analysis of the global upper ocean 1950-1995, Part 1: methodology, J. Phys. Oceanogr., 30, 294-309

Chao, Y., A. Gangopadhyay, F.Bryan and W.R. Holland, 1996: Modeling the Gulf Stream System,
How Far from Reality? Geophys. Res. Letts. 23(22), 3155-3158.

Conversi, A., S. Piontkovski and S. Hameed. 2001. Seasonal and interannual dynamics of *Calanus finmarchicus* in the Gulf of Maine (Northeastern US Shelf) with reference to the North Atlantic Oscillation. Deep-Sea Res. II 48: 519-539.

Drinkwater, K.F., A. Belgrano, A. Borja, A. Conversi, M. Edwards, C.H. Greene, G. Ottersen, A.J. Pershing and H. Walker. 2003. The response of marine ecosystems to climate variability associated with the North Atlantic Oscillation. In: J.W. Hurrell, Y. Kushnir, G. Ottersen, and

Greene, C.H., and A.J. Pershing. 2000. The response of *Calanus finmarchicus* populations to climate variability in the Northwest Atlantic: basin-scale forcing associated with the North Atlantic Oscillation (NAO). ICES J. Mar. Sci. 57: 1536-1544.

Greene, C.H., and A.J. Pershing. 2003. The flip-side of the North Atlantic Oscillation and modal shifts in slope-water circulation patterns. Limnol. Oceanogr. 48: 319-322.

Greene, C.H., and A.J. Pershing. 2004 . Climate and the conservation biology of North Atlantic right whales: the right whale at the wrong time? Front. Ecol. Environ. 2: 29-34.

Greene, C.H., A.J. Pershing, R.D. Kenney and J.W. Jossi. 2003. Impact of climate variability on the recovery of endangered North Atlantic right whales. Oceanography 16 (4): 98-103.

Greene, C.H., and A.J. Pershing. 2007. Climate drives sea change. Science 315: 1084-1085.

Greene, C.H., A.J. Pershing, T.M. Cronin and N. Cecci. In press: Arctic climate change and its impacts on the ecology of the North Atlantic. Ecology.

Hakkinen, S. 2002. Freshening of the Labrador Sea surface waters in the 1990's: another great salinity anomaly? Geophys. Res. Let. 29:24, 2232, doi:10.1029/ 2002GL015243.

Hurrell, J.W., Y. Kushnir, G. Ottersen and M. Visbeck. 2003. An overview of the North Atlantic Oscillation. In: J.W. Hurrell, Y. Kushnir, G. Ottersen, and M. Visbeck (Eds.), pp. 1-36, The

North Atlantic Oscillation: Climatic Significance and Environmental Impact, Geophysical Monograph 134, AGU, Washington, DC.

Jones, P.D., T.J. Osborn and K.R. Briffa. 2003. Pressure-based measures of the North Atlantic Oscillation (NAO): a comparison and an assessment of changes in the strength of the NAO and its influence on surface climate parameters. In: J.W. Hurrell, Y. Kushnir, G. Ottersen, and M. Visbeck (Eds.), pp. 51-62, The North Atlantic Oscillation: Climatic Significance and Environmental Impact, Geophysical Monograph 134, AGU, Washington, DC.

Loder, J.W., J.A. Shore, C.G. Hannah and B.D. Petrie. 2001. Decadal-scale hydrographic and circulation variability in the Scotia-Maine region. Deep-Sea Res. II 48: 3-35.

MERCINA. 2001. Oceanographic responses to climate in the Northwest Atlantic. Oceanogr. 14 (3): 76-82.

MERCINA. 2003. Trans-Atlantic responses of *Calanus finmarchicus* populations to basin-scale forcing associated with the North Atlantic Oscillation. Progr. Oceanogr. 58: 301-312.

MERCINA. 2004. Supply-side ecology and the response of zooplankton to climate-driven changes in North Atlantic Ocean circulation. Oceanogr. 17 (3): 10-21.

Mountain, D.G. 2003. Variability in the properties of Shelf Water in the Middle Atlantic Bight, 1977-1999. J. Geophys. Res. 108, C1, 3014, doi:10.1029/2001JC001044.

Mylius, S.D., K. Klumpers, A.M. de Roos and L. Persson. 2001. Impact of intraguild predation and stage structure on simple communities along a productivity gradient. Amer. Nat. 158: 259-276.

Ottersen, G., and N.C. Stenseth. 2001. Atlantic climate governs oceanographic and ecological variability in the Barents Sea. Limnol. Oceanogr. 46: 1774-1780.

Ottersen, G., B. Planque, A. Belgrano, E. Post, P. C. Reid and N.C. Stenseth. 2001. Ecological effects of the North Atlantic Oscillation. Oecologia 128: 1–14.

Perry, A.L., P.J. Low, J.R. Ellis and J.D. Reynolds. 2005. Climate change and distribution shifts in marine fishes. Science 308: 1912-1915.

Pershing, A.J., C.H. Greene, B. Planque, and J.-M. Fromentin. 2004. The influence of climate variability on North Atlantic zooplankton populations. In: N.C. Stenseth, G. Ottersen, J. Hurrell, and A. Belgrano (Eds.), pp. 59-69, Ecological Effects of Climatic Variations in the North Atlantic, Oxford University Press.

Pershing, A.J., C.H. Greene, J.W. Jossi, L. O'Brien, J.K.T. Brodziak and B.A. Bailey. 2005. Interdecadal variability in the Gulf of Maine zooplankton community with potential impacts on fish recruitment. ICES J. Mar. Sci. 62: 511-523.

Piontkovski, S. and S. Hameed. 2002. Precursors of copepod abundance in the Gulf of Maine in atmospheric centers of action and sea surface temperature. Glob. Atmos. Ocean System 8: 283-291.

Reid, P.C., N.P. Holliday and T.J. Smyth. 2001. Pulses in the eastern margin current and warmer water off the northwest European Shelf linked to North Sea ecosystem changes. Mar. Ecol. Progr. Ser. 215: 283-287.

Reid, P.C., and G. Beaugrand. 2002. Interregional biological responses in the North Atlantic to hydrometeorological forcing. Pages 27-48 in K. Sherman and H.R. Skjoldal, editors. Large marine ecosystems of the North Atlantic. Changing states and sustainability. Elsevier Science, Amsterdam, NL.

Reid, P.C., D.G. Johns, M. Edwards, M. Starr, M. Poulin and P. Snoeijs. Submitted. A biological consequence of reducing Arctic ice cover: arrival of the Pacific diatom *Neodenticula seminae* in the North Atlantic for the first time in 800,000 years?

Rose, G.A., B. deYoung, D.W. Kulka, S.V. Goddard and G.L. Fletcher. 2000. Distribution shifts and overfishing the northern cod (*Gadus morhua*): a view from the ocean. Canadian Journal of Fisheries and Aquatic Sciences **57**: 644–663.

Sameoto, D. 2001. Decadal changes in phytoplankton color index and selected calanoid copepods in continuous plankton recorder data from the Scotian Shelf. Can. J. Fish. Aquat. Sci. 58: 749-761.

Schmittner, A., M. Latif and B. Schneider. 2005. Model projections of the North Atlantic thermohaline circulation for the 21st century assessed by observations. Geophys. Res. Lett., 32, L23710, doi:10.1029/2005GL024368.

Schollaert, S.E., T. Rossby and J.A. Yoder. 2004. Gulf Stream cross-frontal exchange: possible mechanisms to explain interannual variations in phytoplankton chlorophyll in the Slope Sea during the SeaWiFS years. Deep-Sea Res. II 51: 173-188.

Smith, P.C., R.W. Houghton, R.G. Fairbanks and D.G. Mountain. 2001. Interannual variability of boundary fluxes and water mass properties in the Gulf of Maine and on Georges Bank: 1993-1997. Deep-Sea Res. II 48: 37-70.

Stammer, D., R. Bleck, C. Boning, P. DeMey, H. Hurlburt, I. Fukumori, C. LeProvost, R. Tokmakian and A. Wenzel. 2001. Global ocean modelling and state estimation in support of climate research. In: Observing the Ocean in the 21st Century, C.J. Koblinsky and N.R. Smith (Eds.), Bureau of Meteorology, Melbourne, Australia, 511--528.

Stenseth, N.C., G. Ottersen, J. Hurrell, and A. Belgrano (Eds). 2005. Ecological effects of climatic variations in the North Atlantic. Oxford University Press, Oxford, UK.

Williams, P., D. Gibbons, C. Margules, A.Rebelo, C. Humphries and R. Pressey. 1996. A comparison of richness hotspots, rarity hotspots and complementary areas for conserving diversity using British birds. Conservation Biology, 10, 155-174.

Visbeck, M., E.P. Chassignet, R.G. Curry, T.L. Delworth, R.R. Dickson and G. Krahmann, 2003. The ocean’s response to North Atlantic Oscillation variability. In: J.W. Hurrell, Y. Kushnir, G. Ottersen, and M. Visbeck (Eds.), pp. 113-146, The North Atlantic Oscillation: Climatic Significance and Environmental Impact, Geophysical Monograph 134, AGU, Washington, DC.

# V) APPENDICES

## Appendix I. BASIN Meeting Participants

| Name | Affiliation/Country | Email |
|---|---|---|
| Tom Anderson | National Oceanography Centre, UK | tra@noc.soton.ac.uk |
| Olafur S Astthorsson | Marine Research Institute, Iceland | osa@hafro.is |
| Igor Belkin | University of Rhode Island, USA | ibelkin@gso.uri.edu |
| James J. Bisagni | University of Massachusetts, USA | jbisagni@umassd.edu |
| Delphine Bonnet | Université Montpellier II, France | dbonnet@univ-montp2.fr |
| Ann Bucklin | University of Conneticut, USA | ann.bucklin@uconn.edu |
| Cabell Davis | WHOI, USA | cdavis@whoi.edu |
| Edward Durbin | University of Rhode Island, USA | edurbin@gso.uri.edu |
| Katja Fennel | Dalhousie University, CA | Katja.Fennel@dal.ca |
| Avijit Gangopadhyay | University of Massachusetts, USA | avijit@umassd.edu |
| Charles Greene | Cornell University, USA | chg2@cornell.edu |
| Dale Haidvogel | Rutgers Univ., USA | dale@imcs.rutgers.edu |
| Sirpa Hakkinen | NASA Goddard Space Flight Center, USA | sirpa.hakkinen@nasa.gov |
| Jon Hare | NOAA,NEFSC,NMFS, USA | jhare@mola.na.nmfs.gov |
| Roger Harris | Plymouth Marine Laboratory, UK | rph@pml.ac.uk |
| Wilco Hazeleger | Royal Netherlands Meteorological Institute, Netherlands | Wilco.Hazeleger@knmi.nl |
| Erica Head | Department of Fisheries & Oceans, CA | HeadE@mar.dfo-mpo.gc.ca |
| Xabier Irigoien | AZTI, Spain | xirigoien@pas.azti.es |
| Catherine Johnson | University of Brittish Columbia, CA | c.johnson@unh.edu |
| Trond Kristiansen | University of North Carolina, NC | Trond.Kristiansen@bio.uib.no |
| Laurent Memery | LEMAR/IUEM, France | memery@univ-brest.fr |
| David Mountain | NOAA/NEFSC/NMFS, USA | dmountai@whsun1.wh.whoi.edu |
| Elizabeth North | University of Maryland, USA | enorth@hpl.umces.edu |
| Todd O'Brien | NOAA-NMFS, USA | todd.obrien@noaa.gov |
| Pierre Pepin | Department of Fisheries & Oceans, CA | pepinp@dfo-mpo.gc.ca |
| Jeffrey A. Runge | Gulf of Maine Research Institute, USA | jrunge@gmri.org |
| Deborah Steinberg | Virginia Institute of Marine Science, USA | debbies@vims.edu |
| Mike St. John | Univ. of Hamburg, Germany | michael.st.john@uni-hamburg.de |
| Tracey Sutton | Harbor Branch Oceanographic Institution,, USA | TSutton@HBOI.edu |
| Cisco Werner | University of North Carolina, USA | cisco@unc.edu |
| Peter Wiebe | WHOI, USA | pwiebe@whoi.edu |
| Brad de Young | Memorial Univ. of Newfoundland, Canada | bdeyoung@physics.mun.ca |

# Appendix II. Agenda of Chapel Hill Meeting

## BASIN Aim

***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 to resolve the impacts of climate variability on marine ecosystems, and thereby contribute to ocean management.***

**Goal of the Chapel Hill meeting: address the following Key Questions from the Hamburg Meeting as they relate to the BASIN Aim.**

- How will climate change as manifested in temperature, stratification, transport and other ocean features influence the spring bloom, the flux of carbon to the deep ocean, and interactions between trophic levels? How do these dynamics differ from the shelf to the open basin? What are the potential feedbacks to climate?

- Has the harvesting of resources such as fish stocks resulted in a restructuring of marine ecosystems? How do these changes in ecosystem structure influence the sequestering of carbon in the deep ocean and on the continental shelves as well as the resilience of these ecosystems?

- How are the populations of phytoplankton, zooplankton, and icthyoplankton influenced by the present large-scale basin circulation and what is the influence of changes of the oceanic and atmospheric climate on their population dynamics?

- How do the overwintering strategies of organisms, involving both vertical and horizontal migration, lead to the observed patterns of community structure?

## May 1

**Venue**: UNC's Friday Centre for Continuing Education Conference Facility

**09:00-09:15**
- **Welcome:** Cisco Werner and Mike St. John

**09:15-10:30**
- **BASIN: Introduction, review and status of the SSA/NSF initiative to build BASIN Science Plan (see Appendix), and results of Hamburg Workshop in January –** Peter Wiebe and Roger Harris
- **The NSF Agency Long-term View:** Phil Taylor
- **Workshop Objectives and Open Discussion**

**10:30-11:00**
- **Coffee Break**

**11:30-12:30 Plenary Talks (15 minutes plus 5 mins discussion)**
- **North Atlantic Climate Dynamics** - Sirpa Hakkinen
- **Basin biogeochemistry** – Laurent Memery
- **Basin-Scale Physical Models** - Dale Haidvogel

**12:30-13:30**
- **Lunch on site**

**13:30-15:30 Plenary Talks (15 minutes plus 5 discussion) and Short Contributed PresentationsContinued**
- **Coupling life history and biogeochemistry –** Jeff Runge
- **Biological Data Availability and Needs –** Erica Head
- **CAMEO** Comparative Analysis of Marine Ecosystem Organization – Steve Murawski (David Mountain)
- **Short (~ 4 slides each) Contributed Presentations by participants on topics of importance for the generation of the BASIN Science plan.**

1. **Avijit Gangopadhyay:** Ongoing NASA and NSF/GLOBEC projects.
2. **Tracey Sutton:** Mesopelagic fishes- Role of Mid-Atlantic Ridge.
3. **Olafur Astthorsson:** Climate change in Icelandic waters.
4. **Roger Harris**: Safeguarding and exploiting the data we already have.
5. **Tom Anderson:** Green Ocean versus Rhomboid Model approach.
6. **Delphine Bonnet**: Current and recent research on zooplankton in NATL and Euro waters.
7. **Charles Greene:** Climate drives sea change in the Northwest Atlantic.
8. **Igor Belkin:** Northwest SST Fronts and their changes in last 20 years.
9. **Erica Head:** Observations from Canadian Plankton Monitoring Programs (1995-2007)
10. **Debbie Steinberg:** Impact of Eddies on Zooplankton Community Structure and Biogeochemical Cycling in the Open Ocean.
11. **Elizabeth North:** Thoughts for BASIN.

**15:30–16:00 Coffee Break**

**16:00-18:30 Formation of Breakout Groups and Discussion of Charge and Initial Breakouts**

**Breakout group Discussion Leaders and Rapporteurs:**

**Ann Bucklin (lead); Jim Bisagni (rapporteur)**
**Elizabeth North (lead); Jon Hare (rapporteur)**
**Chuck Greene (lead); Tracey Sutton (rapporteur)**

**18:30 Adjourn for the evening**

## May 2nd
**Venue: Courtyard by Marriott**

**08:30-09:00 Reconvene – brief reports and questions from Day 1 breakouts**

**09:00-10:15 Plenary Presentations (12 minutes plus 5 minute discussion)**
- **Microbial loop transfers and dynamics –** Debbie Steinberg
- **Cross-shelf exchange –** David Mountain
- **Data Assimilation –** Katja Fennel

- **Science for management** - Pierre Pepin

**10:15-10:45**
- **Coffee Break**

**10:45-12:30**
- **Reassemble breakout groups continue meeting**

**12:30 – 2:00 Lunch on site**

**14:00-15:00 Plenary Session - Status reports and discussion of the activities of the breakout groups.**

**15:00-17:00**
- **Continue working groups or rearrange to address new issues.**
- **Break as needed**

**17:00-18:00**
- **Plenary with working group reports and introduction of Science Plan Outline.**

**18:00 Adjourn (Steering Committee meets to discuss progress and plans for last day)**

**20:00 Group Dinner at the Azure Grille Restaurant (http://www.azuregrille.com/)**

## May 3rd
## Venue: Friday Center

**08:30-11:00 Groups reconvene to prepare written reports and discussion (Coffee break available on site at 10:00)**

**11:00-12:30 Closing Session:**
- **Status reports and discussion of the activities breakout groups.**
- **Summary of next steps and progress towards development of the science plan.**
- **Identification of experts to contribute the science plan.**

**12:30-14:00**
- **Lunch on site**

**14:00-1600**
- **Steering Committee Meets to discuss results of workshop and plan next steps**

## Agenda attachment:

# Draft outline for Science Plan

Executive summary

1) Introduction

1.1) Discourse on why a Basin-Scale approach to key problems in ecosystem research ocean is needed. Issue of large-scale forcing driving many of the ecological processes occurring on local and regional scales.

1.2) Problem sets/Questions that need a basin-scale approach to answer them.

1.2.1) Issue of coupling biogeochemistry processes with higher trophic level dynamics. How to connect the different rhomboid models?

2) Program Description and timeline

Discussion of interconnectivity of the program components including building blocks and linkages - figures illustrating points.

3) Retrospective/Reanalysis -

Data archaeology

Data issues - how to aggregate the data and make them available for analysis and synthesis?

Hindcasts

Observing system simulation experiments (OSSEs)

Data assimilation and model verification

4) Observations: filling of data and information gaps.

New technologies and new observation platforms.

New sampling programs.

Long-term monitoring and broad-scale

5) Focused Processes studies (field and lab).

Rate measurements, growth studies, metabolic studies.

Identification of realized and optimal habitats.

6) Modelling: Models needed for the BASIN program. Rhomboids - schematic.

7) Synthesis and Integration

# Appendix III. Breakout groups: Chairs, Rapporteurs, and members

Group I
Ann Bucklin (lead)
Jim Bisagni (Rapporteur)
Cisco Werner
Mike St. John
Wilco Hazeleger
Tom Anderson
Xabier Irigoien
Delphine Bonnet
Cabell Davis
Catherine Johnson

Group II
Elizabeth North (lead)
Jon Hare (Rapporteur)
Peter Wiebe
Dale Haidvogel
Sirpa Hakkinen
Olafur S Astthorsson
Erica Head
Jeffrey A. Runge
David Mountain
Todd O'Brien
Trond Kristiansen

Group III
Chuck Greene (lead)
Tracey Sutton (Rapporteur)
Roger Harris
Brad deYoung
Laurent Memery
Pierre Pepin
Katja Fennel
Igor Belkin
Edward Durbin
Deborah Steinberg

# Appendix IV. Strawman Time-line.

**Phase I (2009-2012):**
- data synthesis,
- model hindcasting and scenario definition,
- identification of information and data gaps, experimental design (OSSEs),
- identification and development of new technologies,
- develop management mechanisms and begin implementation, knowledge transfer and outreach

**Phase II (2012-2017):**
- process studies, field program,
- deployment of new sampling technologies,
- implementation of models

**Phase III (2017-2020): synthesis**