Model code was provided for modelling hydrodynamic processes, larval drift and development of IBMs based on an earlier study on Georges Bank by Tremblay *et al.* (1994). The physical model was the frequency-based finite element model "Fundy" developed by Lynch *et al.* (1992) and the particle tracking model was that described in Blanton (1995); all written in FORTRAN. Pre- and post-processing was MATLAB®-based, using tools developed by B. Blanton. These codes are also publicly available from http://www-nml.dartmouth.edu and http://www.opnml.unc.edu.

A simple but illustrative exercise was carried out by the trainees where different environmental (forcing by winds, tides and baroclinicity) and biological (sources of larvae, high and low survival areas, losses due to advection, and growth rates) scenarios were tested based on the solutions computed for the Georges Bank study of Tremblay et al. (1994). All model runs were carried out on desktop PCs running Windows. Figure (1) is an example showing horizontal and vertical drift trajectories of larvae released at two sites (A & B) on Georges Bank. See http://www.cibnor.mx/grupo/gmd/ for a more detailed report of the results and other relevant information and links.

The outcome of the course included: (a) that the students were able to assess the strengths and limitations of these approaches using already existing flow fields, imposed behaviors, etc., and (b) that they were able to determine the feasibility of implementing these methods in their own study-sites. Over the next months we intend to follow-up on the projects that this course has spawned through the creation of a website (http://www.cibnor.mx/grupo/gmd/) to promote the exchange of experiences, problems, new developments, and opportunities. We also intend to look for additional funding to build on this introductory course by incorporating new people to the group with participation of different countries and disciplines, to carry a follow-up meeting for the group already formed, and to promote work visits of scientists and students between labs.

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GLOBEC SCIENCE

A column for scientific notes of relevance to the GLOBEC community

Major reorganisation of North Atlantic pelagic ecosystems linked to climate change

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Human activities have now become so pervasive that they influence all Earth's compartments and processes. In particular, the atmospheric concentration of carbon dioxide has risen from 280 ppm (parts per million) in 1750 to 367 ppm in 1999 (IPCC 2001). The effects of this increase in CO2 concentration are very likely to be responsible for the global increase in temperature seen over the last 50 years.

Effects of both the increase in CO_2 concentration and global warming on the ecosystems have just started to emerge. These may influence organisms in a direct way by acting on the physiology (e.g. photosynthesis, Keeling *et al*. 1996, Myneni *et al*. 1997) or on the species phenology (e.g. seasonal cycle, Crick *et al*. 1997, McCleery & Perrins 1998). It may also hit biological systems through indirect ways by modifying abiotic factors, in turn affecting the spatial distribution of species.

To investigate the potential impact of climate change on marine ecosystems, a new kind of biological indicators was needed, which allow the whole community structure to be monitored. Beaugrand *et al*. (2002a) have recently decomposed the diversity of calanoid copepod, one of the best taxonomic group sampled by the Continuous Plankton Recorder (CPR) survey, into species assemblages. This decomposition was done utilising geostatistics and multivariate analyses, in combination with the method 'Indicator Values' designed by Dufrêne and Legendre (1997). At the scale of the North Atlantic basin and a spatial resolution approaching the meso-scale, nine species assemblages were identified using three criteria: (1) spatial distribution of species, (2) similarity in the seasonal variability of species and (3) diel and ontogenic variations. The nine species assemblages were closely related to a stable-biotope component or a substrate-biotope component (van der Spoel 1994). As a result, a new partition of the North Atlantic pelagic environment was outlined (Fig. 1). This led Beaugrand *et al*. (2002a) to propose using the mean number of species belonging to each species assemblage as an indicator to monitor modifications in the structural organisation of North Atlantic marine ecosystems.

Using those species assemblage indicators, Beaugrand *et al*. (2002b) have recently reported substantial changes during the period 1960-1999 in the spatial distribution of calanoid copepod assemblages at an ocean basin scale and have provided evidence that this might have been influenced by the combined effect of the climatic warming of the Northern Hemisphere and the North Atlantic Oscillation. The number of species per assemblage was used as an indicator (1) of change in the biogeographical range of copepod communities and (2) of ecosystem modification.

Maps of the mean number of species present in an area for all species assemblages (Fig. 2, see cover) demonstrate that major biogeographical shifts for all species assemblages have taken place since the early 1980s to the south-west of the British Isles and from the mid 1980s in the North Sea. The mean number of warm-temperate, temperate pseudo-oceanic species increased by about 10° of latitude. In contrast, the diversity of colder-temperate, Subarctic and Arctic species have decreased towards the north. All the biological associations show consistent long-term changes, including neritic species assemblages. These changes have been linked to Northern Hemisphere Temperature (NHT) anomalies and to a lesser extent the winter North Atlantic Oscillation (NAO) index. Other studies have also revealed a northward extension of the ranges of many warm-water fish in the same region (Quero *et al*. 1998, Stebbing *et al*. 2002). This evidence tends to indicate a shift of marine pelagic ecosystems towards a warmer dynamic regime in the north-eastern North Atlantic.

West of the mid-Atlantic ridge, especially in the Labrador Sea, the trend is opposite and the number of both subarctic arctic species has increased while the number of warm-water oceanic species has decreased (Fig. 3). This result indicates a possible move of north-west Atlantic ecosystems towards a cooler dynamic regime.

To better understand how large-scale hydro-meteorological processes may have influenced the biogeographical shifts observed in the studied area, long-term changes in Sea Surface Temperature (SST) were investigated. Figure 4 displays the first two eigenvectors and principal components representing 40.9% of the total variability. The region south of a line from 40°N, 45°W to 60°N, 5°E and especially in the West European Basin was characterized by a decrease in SST from 1960 to about 1975 and then a strong continuous increase until 1997. Long-term changes in this signal are correlated positively with NHT anomalies. In the subarctic gyre the second principal component negatively covaried with the NAO, showing a decrease until 1993 and then an increase.

This analysis suggests that the shift in north-east Atlantic marine ecosystems towards a warmer dynamic regime has been influenced by the increasing trend in Northern Hemisphere temperature. However, the positive influence of the NAO on SST in the North Sea (Dickson & Turrell 2000) must have played a synergistic role with NHT anomalies. Our results are concordant with other biological changes reported for the European region in the terrestrial realm (Beebee 1995, Parmesan *et al*. 1999, Thomas and Lennon 1999). In the subarctic gyre, the shift in north-west Atlantic marine ecosystems towards a colder dynamic equilibrium tends to be more related to the influence of the North Atlantic Oscillation.

Climate warming therefore appears to be an important parameter that is at present governing the dynamic equilibrium of pelagic ecosystems in the north-east Atlantic. If the increase in Northern Hemisphere temperature predicted by the Intergovernmental Panel on Climate Change (2001) continues, a marked change in the organization of pelagic ecosystems from phytoplankton to fish can be expected with a possible impact on biogeochemical cycles.

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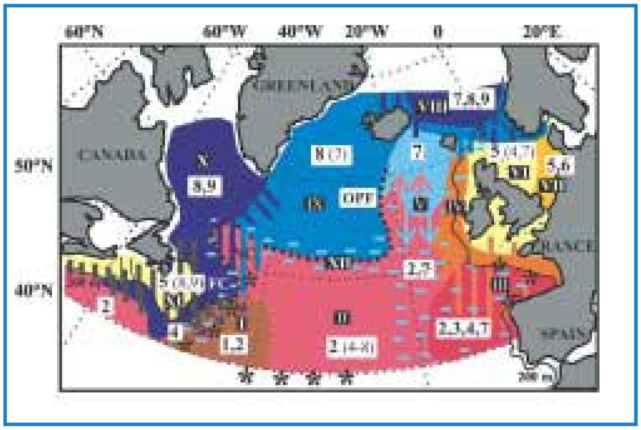

Figure 1. Scheme of the geographical position of centres of distribution of the associations, ecosystems and ecotones. A number identifies each association. In some areas such as in the Bay of Biscay, several assemblages overlap. Asterisk indicates the location where very rare species were found during the 40 years CPR sampling. Grey arrows (west of Great Britain) denote the seasonal change in the northern position of Species Association 2. Black arrows (above the Canadian shelf) indicate that extrusion of water related to the high hydrodynamics of this region happen and lead to expatriation of species belonging to assemblages 4, 5, 8 and 9 towards the Gulf Stream Extension region. The thick black dotted line indicates the position of the Oceanic Polar Front. Numbers into brackets indicate the possibility to find species belonging to adjacent species association. OPF: Oceanic Polar Front; FC: Flemish Cap; NC: Worthington's Northern Corner. Species associations 4 and 7 seasonally progress northwards with a high aggregation of species in the south in spring and in the North in autumn. Modified. From Beaugrand et al. (2002a).

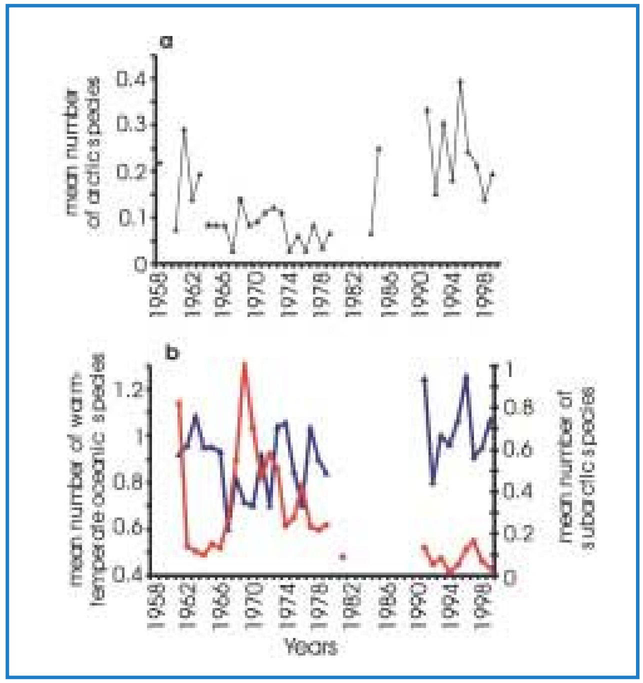

Figure 3. Long-term changes in the mean number of arctic species in the Labrador Sea (a) and the mean number of subarctic (blue) and warm-temperate (red) species in an area around the Oceanic Polar Front area (b). Modified from Beaugrand et al. (2002b).

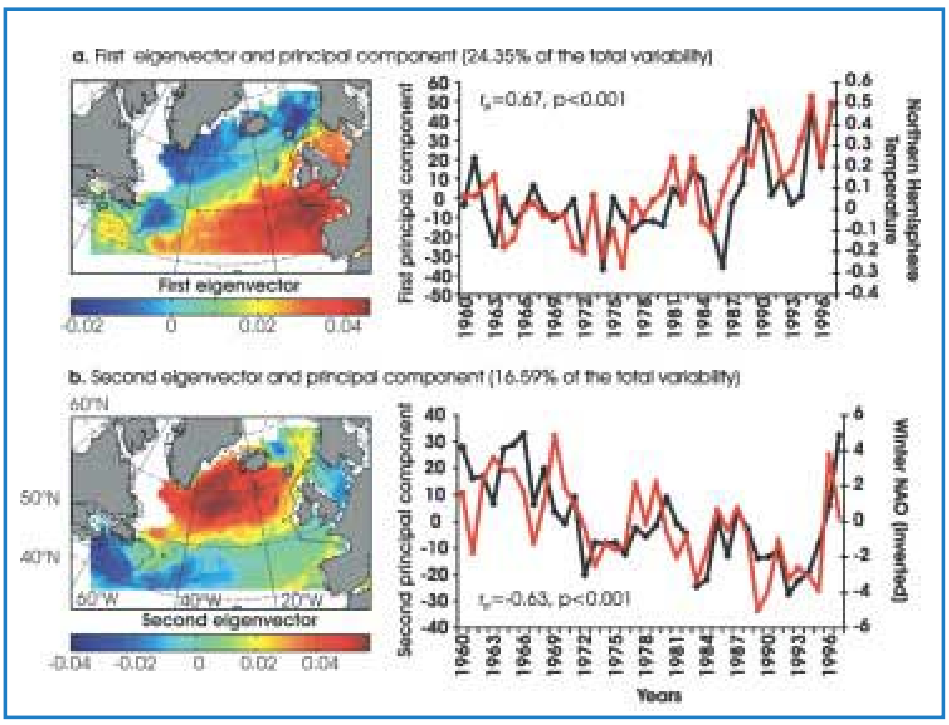

Figure 4. Standardised Principal Component Analysis of long-term changes in sea surface temperature in the North Atlantic Ocean. a) First eigenvector and principal component. Long-term changes in NHT anomalies and Pearson correlation coefficient between the first principal component and NHT anomalies are indicated. b) Second eigenvector and principal component. The long-term changes in the winter NAO and the Pearson correlation coefficient between the second principal component and the NAO index are indicated. The signal displayed by the first principal component (PC) is highly correlated positively with NHT anomalies (rp=0.69, p<0.001). In the subarctic gyre, the values of the second PC decreased until about 1993 and then increased. The long-term change in the second PC is highly correlated negatively with the NAO index (rp=-0.63, p<0.001). Probability was corrected to account for temporal autocorrelation using the method recommended by Pyper & Peterman (1998). Modified from Beaugrand et al. (2002b).

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Cod and Climate Change Workshop on Transport of Cod Larvae Hillerød, Denmark 14 - 17 April 2002

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Cod (Gadus morhua) are widespread over most shelf seas of the North Atlantic where the annual mean temperature is between about 2 and 15oC. They migrate and concentrate to spawn, often over distances greater than 1000 km. The eggs are slightly buoyant and are transported with the water masses in which they are spawned. The larvae and early juveniles remain pelagic for the first 3-5 months of life, during which time they may be carried long distances away from their spawning site. In some cases spawning occurs in areas where transport is slow or there is a gyre which retains the eggs and larvae close to the position of spawning.

The workshop attracted 25 participants from 9 countries, representing a range of disciplines. Much of the material, in the form of working documents, references, data sets and charts, was assembled on the ICES/GLOBEC website (http://www.ices.dk/globec/workshops/transport) prior to the meeting. The aim was to exchange information and ideas in advance so that the three days could be spent in discussion, synthesis and report writing.

The aims of the workshop were to:

- evaluate the effects of variations in transport during early life on subsequent recruitment
- examine the coupling of circulation models with early life history models to determine the physical and biological processes responsible for the transport or retention of cod larvae;
- develop interannual transport indices based on physical variables that reflect the magnitude of the larvae drift or retention;
- attempt to incorporate these indices into the cod assessment process;
- collate and synthesize existing direct and indirect observational information about egg and larval transport for all stocks and years

The workshop dealt with interannual variability in transport within a stock as well as transport across stock boundaries. Rapid advances in circulation models at a variety of scales have improved the prospect of developing scenarios for changes in circulation under different conditions of climate change. There are also improving prospects for operational now-casting and forecasting of circulation.

A compilation of the data on variability in recruitment and distance travelled during the pelagic stage shows no obvious relationship between them. In other words longer distances travelled do not seem to result in more variable survival. The Icelandic cod stock has the lowest variability in recruitment (coefficient of variation 39%) and the Greenland stock the highest (136%), but these two stocks are in fact linked by very regular transport of larvae across the Denmark Strait, which on average carries 17% of Icelandic pelagic juveniles to E. Greenland. Variability in survival at Greenland probably arises due to extreme temperature conditions, which are at the limit of survival