

## Effect of climate on marine ecosystem

Frode Vikebø\*, Svein Sundby\*, Bjørn Ådlandsvik\*.

**Not to be cited without prior reference to the author.**

### Abstract

The spawning areas of the Arcto-Norwegian cod are located along the coast of mid and northern Norway, particularly in the Lofoten where up to 70% of the spawning occurs from mid March to early May. The larvae are carried northwards by the Norwegian Coastal Current to the nursery grounds in the Barents Sea. The year class strength is largely determined during this period of pelagic free drift of 600-1200km. Lateral spreading takes parts of the population out in the warmer Norwegian Atlantic Current and causes differences in the temperature experienced by the larvae. A three-dimensional baroclinic hydrodynamic model is set up for parts of the Norwegian Coast and the Barents Sea. Currents from this model move particles from the spawning grounds in the Vestfjord while keeping a record of the individual temperature histories. Temperature dependent growth is calculated using functional relationship known from ideal experiments. The model results are then compared to measurements.

---

\*Institute of Marine Research, P.O.Box 1870 Nordnes, N-5817 Bergen

# 1 Introduction

The spawning areas of the Arcto-Norwegian cod are located along the coast of mid and northern Norway, particularly in the Lofoten where up to 70% of the spawning occurs. Compared to other Atlantic cod stocks there is a long route of pelagic free drift for the offspring from spawning in March-April along the coast to the juveniles settle to the bottom in the Barents Sea in September- October. During this critical period with respect to formation of year-class strength, the eggs, larvae and juveniles drift from 600 to 1200 km.

The eggs and larvae are carried towards the northeast by the Norwegian Coastal Current (NCC). Lateral spreading takes parts of the population into the Norwegian Atlantic Current (NAC), which flows parallel to the NCC. Five months after spawning they are surveyed pelagically by the international 0-group survey. Then, they are spread out in the entire Atlantic watermasses of the Barent Sea (ICES, 1985-1986) . After this stage they settle to the bottom and become more stationary. During this period of life the year classes of cod are generally determined (Sundby et.al (1989).

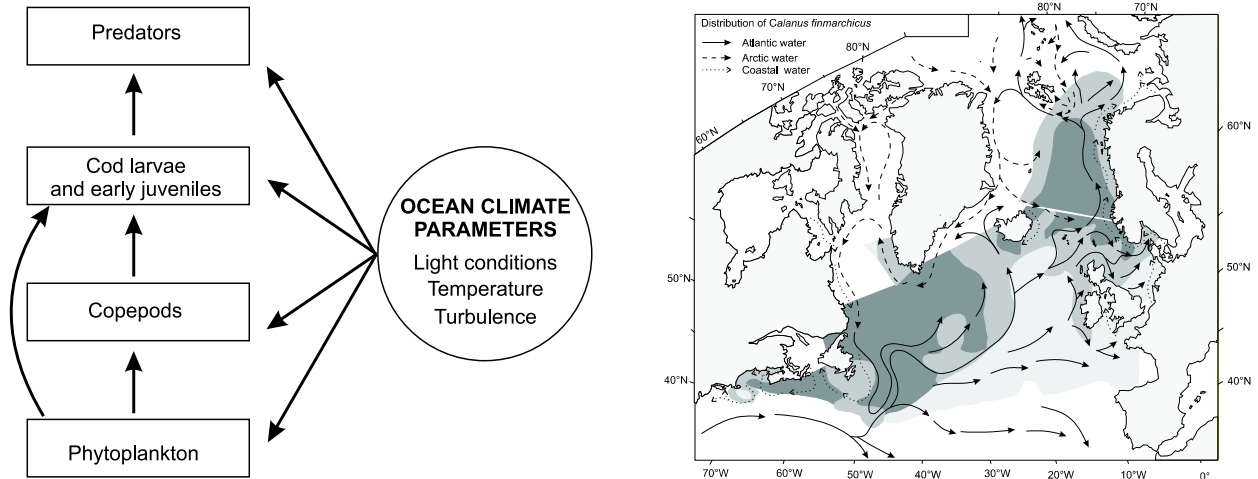


Figure 1: Influence of ocean climate parameters in trophic transfer. Habitat extent of *C. finmarchicus* in relation to the circulation of the northern North Atlantic (Sundby 2000).

Pelagic juveniles are generally more abundant in the north-eastern parts of the nursery grounds. However, the juveniles are in general smaller in the north-east than closer to the spawning grounds further west (Bjørke & Sundby 1986, Suthers & Sundby 1993). It is suggested that this is because the juveniles further east have experienced lower temperatures, and therefore have a slower growth.

Individual growth of cod larvae and juveniles show functional relationships to biotic and abiotic parameters. In the Nordic Seas ecosystem the prey copepod species *Calanus finmarchicus* are a particularly important component of the biota. The abiotic parameters are ocean climate parameters like advection, temperature, wind-induced turbulence, and light conditions induced by cloud conditions and latitude (Figure 1, Sundby 2000). Fish stocks are influenced by climate in a multitude of ways. The simplest and most direct effects are through the influence of temperature on feeding intensity, metabolic rates and growth (Otterlei et.al 1999). Moreover light conditions and wind-induced turbulence are other climate parameters of importance in relation to metabolic rates and behavioral responses of fishes (Fiksen 1998,

Suthers & Sundby 1996). Indirect effects, through trophic interaction between its predators and prey are, however, similarly important to growth and reproduction in fishes. Particularly, the production at lower trophic levels is important. The copepod species *C.finmarchicus* is the dominant mesozooplankton in the Subarctic Gyre of the northern North Atlantic and the main prey item for the Arcto-Norwegian Cod larvae and juveniles. It is adapted to the spring bloom ecosystem of the region with feeding and reproduction during spring and summer and hibernation at deep layers during winter. By advection of the Atlantic Current the *C.finmarchicus* production spills over from the two core regions onto the adjacent shelves, e.g. the shelf off Norway and the Barents Sea. Sundby (2000) suggested therefore, that the recruitment-temperature relation of the Atlantic cod is a proxy for the food abundance during the early stages, explained by the advection of warm *C.finmarchicus* rich waters from the core production regions to the habitat of cod.

## 2 The model system

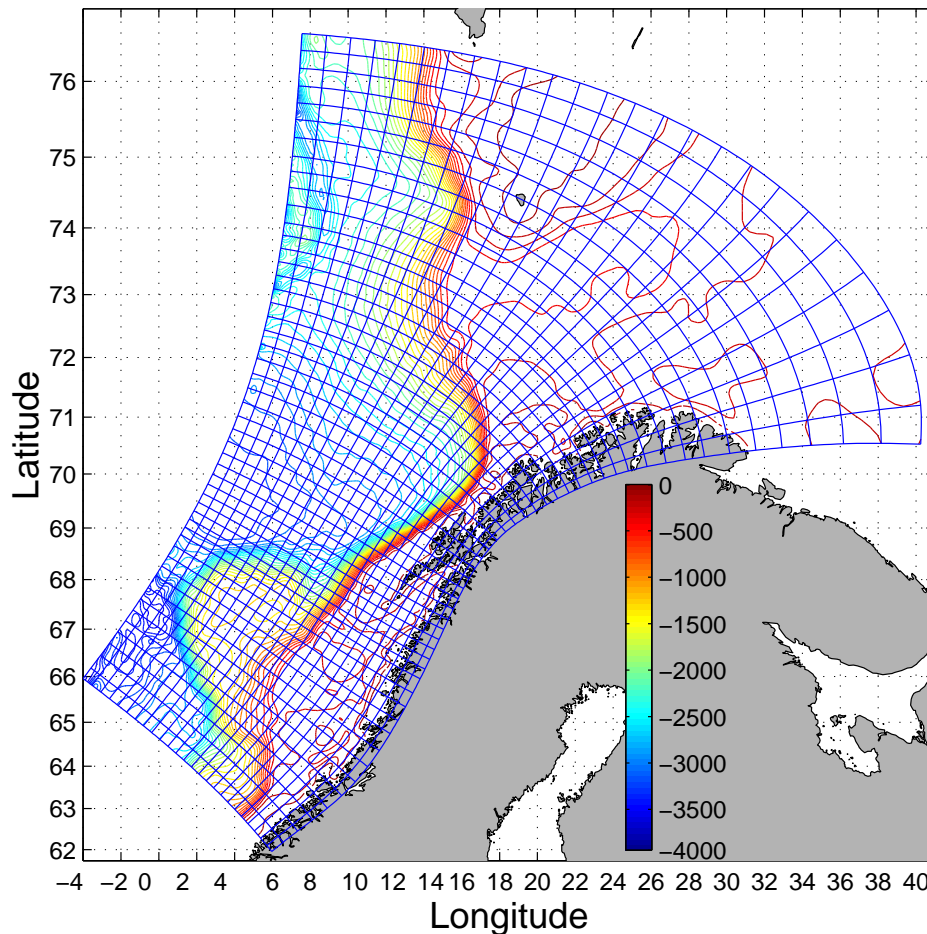


Figure 2: *The model area showing every 5 grid-cell.*

The physical finer-scale modelling of spawning grounds and larval drift routes will be done with ROMS (Shchepetkin & McWilliams 2000), <http://marine.rutgers.edu/po/mod->

els /roms /), a free-surface, hydrostatic, primitive equation ocean model that uses stretched, terrain-following coordinates in the vertical and orthogonal curvilinear coordinates in the horizontal. ROMS is based on the S-coordinate Rutgers University Model (SCRUM). The model solves the primitive equations by the finite differences method on a Arakawa C-grid. Mode splitting between the external barotropic mode and the internal barotropic mode is applied. The leapfrog technique is used for the timestepping. In the vertical a 2.5 Mellor-Yamada turbulence closure scheme parametrize turbulence. In addition to the initial and boundary description of the model variables, the model forcing includes wind stress, air pressure, tidal forcing with 4 tidal constituents and river-runoff from 12 freshwater sources along the coast. The initial description of sea surface elevation, currents, salinity and temperature is taken from the DNMI-IMR diagnostic climatology (Engedahl et.al 1998). Relaxation towards climatology at the boundaries is done with FRS (Martinsen & Engedahl 1987) for the baroclinic variables including tracers (implemented by Bjørn Ådlandsvik, IMR), Chapman condition for the free surface and flather condition for the barotropic variables. The model grid consists of 125x250 cells with 25 vertical sigma-layers (Figure 2). The resolution increases from about 4.5km in Lofoten to about 12km north-east in the Barents Sea. The bottom topography is taken from Etopo2 which gives about 3.5km resolution.

An individual-based model are implemented into the larval drift module to simulate how growth and survival are influenced by changes in the ocean climate. The individual-based model enable us to simulate individual growth of larvae and juveniles from the functional relationships to biotic and abiotic parameters e.g. Fiksen (1998). Presently, it includes only temperature-dependent growth. Particles are released in 10m depth at April 1 inside Vestfjorden and moved forward by the updated velocity fields from the hydrodynamical model, while tracking temperature. Growth of the larvae is then estimated by the equation fitted to fielddata and presented in Otterlei et.al (1999):

$$\ln DW(t) = \ln DW_0 - A + A \times \left[ \frac{\ln DW_{inf} - \ln DW_0 + A}{A} \right]^{(1 - e^{-(a+bT)t})} \quad (1)$$

where  $DW_0(\text{mg})=0.030$ ,  $DW_{inf}(\text{mg})=250$ ,  $A=0.198$ ,  $a=0.0061$  and  $b=0.0044$ .  $DW_0(\text{mg})$  is the initial weight of the larvae,  $DW_{inf}(\text{mg})$  indicate the range of the dataset used to fit the dataset and  $T$  is temperature. This functional relationship between larvae growth and temperature is based on fixed temperature throughout the growth, though this is obviously not the case for the particles in our simulations. Therefore the equation is used in a loop where  $\ln DW_0$  is updated daily.

## 3 Results and discussion

### 3.1 Model performance

The development of kinetical energy indicates initial adjustment of the initial fields to the model grid (Figure 3 left). The climatology is on a coarser grid and it seems to take about 15-20 days before it settles. A spin up periode of 30 days is run before introducing particles. It may seem to be a slight increase in the average kinetical energy subsequent to the first 25 days. This could be due to a varying forcing of monthly mean climatology on the boundaries or accumulation of energy due to spin up of meso-scale eddies. Longer simulations have to be done to answer this question. This will be part of work in progress. Inflow to the Barents

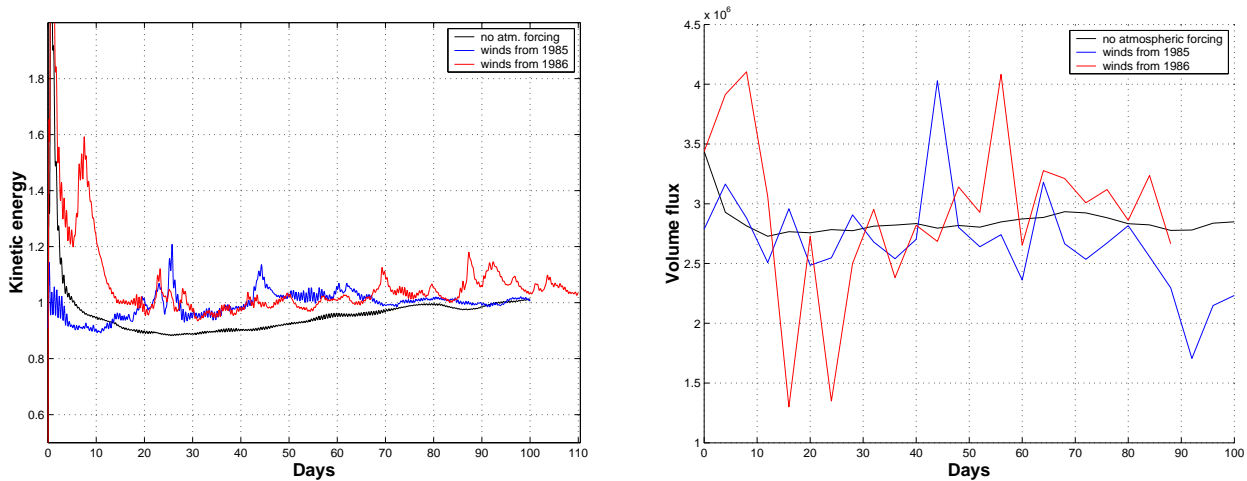


Figure 3: *Development of kinetical energy in the model (left) and estimated volume flux into the Barents Sea (right). The two irregular curves are with atmospheric forcing.*

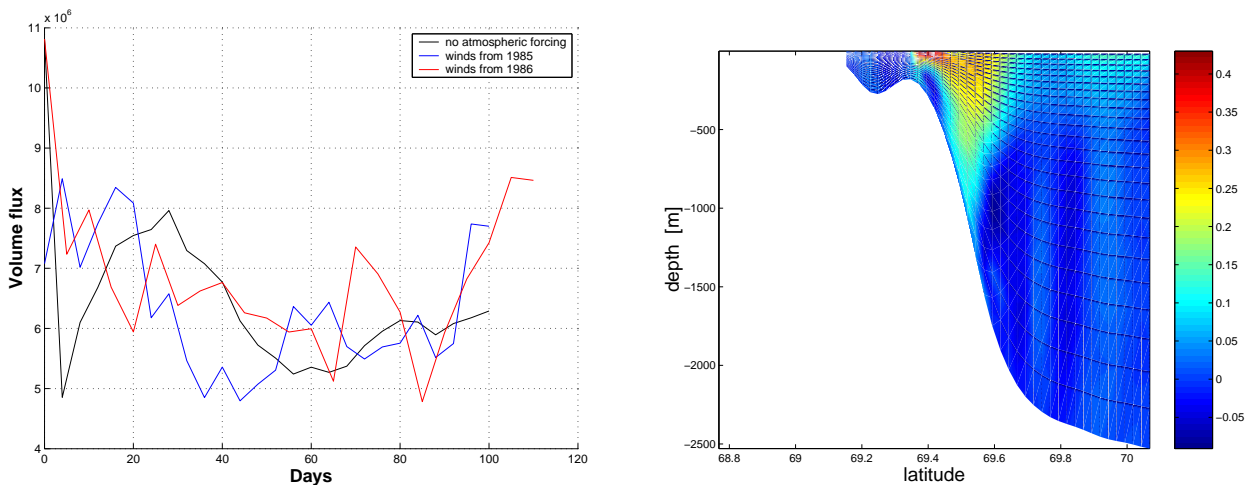


Figure 4: *Estimated volume flux through a section east-west outside Lofoten (left) and the velocity field through the same section (right).*

Sea varies around  $2.8\text{Sv} \pm 1.5\text{Sv}$  (Figure 3 right). This is estimated simply by multiplying the velocity in each cell by its width and height. Measurements with current rigs indicate an average inflow of Atlantic Water to the Barents Sea of about  $1.5\text{Sv} \pm 0.8\text{Sv}$  (Ingvaldsen, Asplin & Loeng n.d.). This flow does not include the NCC or the warm core retrograde jet on the southern slope of the Svalbard Bank. The estimate of the inflow to the Barents Sea from the model covers all flows across the section from the Bear Island to the Norwegian mainland.

The NAC is trapped along the Norwegian continental shelf slope and estimated from the model to be on the order of around  $6\text{Sv}$ . However, the estimate is highly variable and does not seem to reach a steady state. Looking more closely in to the data reveal horizontal fluctuations of eddy-structured flow off the shelf and may explain the fluctuating volume flux.

The temperature fields from the model describe the flow field at the surface and at 100m depth (Figures 5, left and right). The NAC is trapped along the continental shelf edge

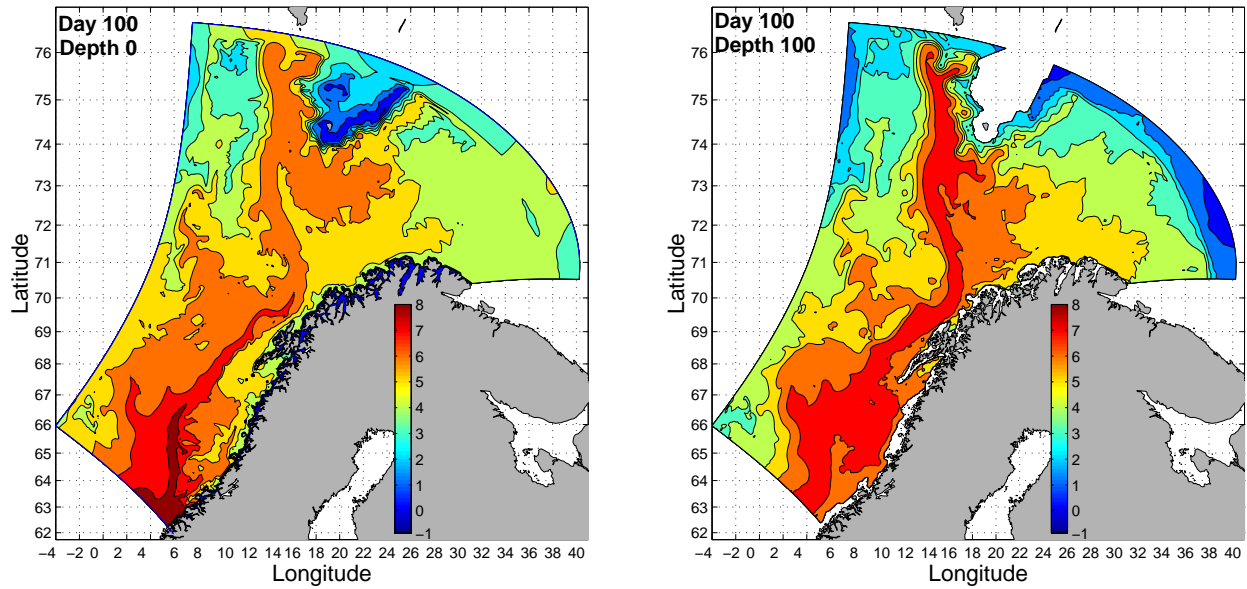


Figure 5: *Daily averaged temperature after 100 days of integration, surface (left) and 100m depth (right).*

and flow northwards, though bifurcating both north of Tromsøflaket and by the Bear Island trough. Also flow around The Vøring plateau is revealed by the temperature fields. Atlantic water off the shelf slope west of Lofoten/Vesterålen is caused by the above mentioned eddy structure, but may partly be a numerical error due to the narrowing of the model grid and thereby accumulation of energy. In the proceeding work the model grid will be altered to see whether this is true. Keep in mind that eddies have been observed in this area as described by Gascard (2003).

### 3.2 Particle tracking and larvae growth

Two different years with distinct western and eastern distribution of 1/2-year old cod were chosen. Both simulations capture the spreading of larvae from the major spawning grounds of the Vestfjorden, the importance of tides at the spawning grounds (tested spreading with and without tides, though not shown here), the increase of transport time due to complex bank structure at the shelf (easily seen by comparing particles released close to the coast and close to the shelf edge) and bifurcation north-west of Tromsflaket. Monthly mean NAO index for the month of May shows that 1986 had the highest index throughout a 30-year period. High NAO index gives strong south-westerly winds, which cause an enhanced inflow of AW to the Barents Sea (Dickson 2000) and may very well be the reason for the distinct easterly distribution of 1/2-year old cod that year. Average longitude for the larvae gives a more eastern distribution for 1986 than for 1985 (22.8 compared to 20.7 degrees) (Fig. 6). The colour scale on the particles indicate weight and show in general a higher weight of the larvae in the western parts of the Barents Sea, than further east. This is consistent with measurements presented in Suthers & Sundby (1993). The authors of this paper discuss two hypotheses causing the observed distribution; differences in water temperature and food availability. Only temperature were measured at the surveys where the data were collected, and they found a high correlation between growth and temperature. However, Sundby (2000) argues

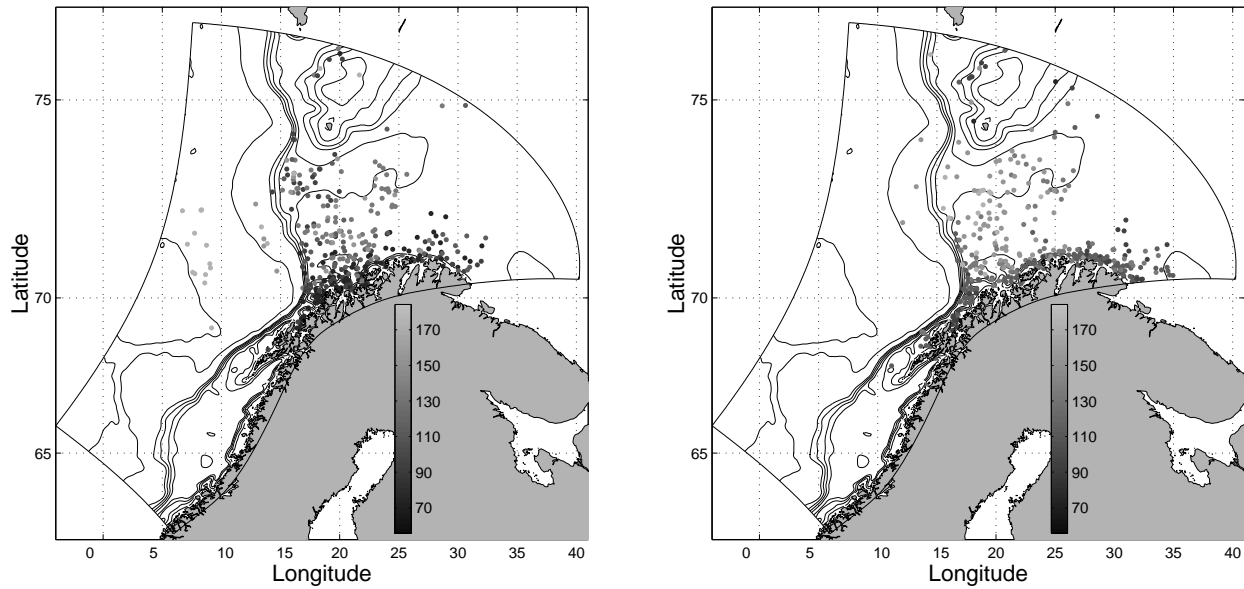


Figure 6: Individual-based modeling using ROMS, showing the distribution of larvae 3 months after spawning, with atmospheric forcing from 1985 (left) and 1986 (right) and particles released inside and outside the Vestfjorden, the main spawning site. The colour scale indicates larvae weight in milligram.

that temperature is a proxy for food abundance as the core region for the *C. finmarchicus* has a higher temperature during the early juvenile stages and that the high correlation is due to advection of warm *C. finmarchicus* rich water on to the shelf were the spawning and nursery grounds of cod is located.

Figures 5 show how Atlantic water enters the Barents Sea, both along with the wedge-shaped NCC close to the Norwegian coast and steered by the topography in the Bear Island through. As mentioned earlier in the paper, the spawning in Lofoten occurs in the NCC, which at this time is colder than the NAC, and will be until about June. The larvae drifts northwards both in the NCC and the Norwegian Atlantic Current (NAC) due to horizontal mixing caused by wind and topographic effects. Larvae transported northwards may therefore flow either along the colder NCC into the eastern parts of the Barents Sea or follow the warmer NAC into the Bear Island through and the western parts of the Barents Sea. This will greatly affect the degree-day (integrated temperature) and thereby the growth.

Ongoing work includes NCEP/NCAR daily heatflux, sensitivity study to various depths and time for the release of particles and inter-annually differences. Increasing the complexity of the individual-based modelling may give answers to the questions raised above concerning causes for differences in weight. Finally, extensive comparison with measurements of physical and biological parameters will give an estimate of the accuracy of the model performance.

## References

Bjørke, H. & Sundby, S. (1986), 'Abundance indices and distribution of postlarvae and 0-group cod.', *Contribution to the third Soviet-Norwegian symposium in Murmansk, 26-30 May 1986: "The effect of oceanographic conditions on distribution, and population dynamics of commercial fish stocks in the Barents Sea."* p. 19.

- Dickson, R. R., Osborn, T. J., Hurrell, J. W., Meincke, J., Blindheim, J., Ådlandsvik, B., Vinje, T., Alekseev, G. & Maslowski, W. (2000), 'The Arctic Ocean Response to the North Atlantic Oscillation', *Journal of Climate*, *13*. pp. 2671–2696.
- Engedahl, H., Ådlandsvik, B. & Martinsen, E. A. (1998), 'Production of monthly mean climatological archives of salinity, temperature, current and sea level for the Nordic Seas', *J. Mar. Syst.* *14* pp. 1–26.
- Fiksen, Ø., Utne, A. C. W., Aksnes, D. L., Eiane, K., Helvik, J. V. & Sundby, S. (1998), 'Modelling the influence of light, turbulence and ontogeny on ingestion rates in larval cod and herring', *Fisheries Oceanography* *7*. pp. 355–363.
- Gascard, J. C., Mork, K. A., Sequeira, S., Loeng, H. & Rouault, C. (2003), 'The Norwegian Current in the ofoten Basin: External influences.', *Report to the European Commission. Maia project.* p. 31.
- ICES (1985), 'Preliminary report of the international 0-Group Fish Survey in the Barents Sea and Adjacent Waters in August-September 1985', *ICES CM 1985/G*, *75* .
- ICES (1986), 'Preliminary report of the international 0-Group Fish Survey in the Barents Sea and Adjacent Waters in August-September 1986', *ICES CM 1986/G*, *78* .
- Ingvaldsen, R., Asplin, L. & Loeng, H. (n.d.), 'The seasonal cycle in the Atlantic transpor to the Barents Sea', *submitted to Continental Shelf Research* p. 22.
- Martinsen, E. A. & Engedahl, H. (1987), 'Implementation and testing of a lateral boundary scheme as an open boundary condition in a barotropic ocean model', *Coastal Engineering, Vol.11* pp. 603–627.
- Otterlei, O., Nyhammar, G., Folkvord, A. & Stefansson, S. O. (1999), 'Temperature- and size-dependent growth of larval and early juvenile Atlantic cod: a comparative tudy of Norwegian coastal cod and northeast Arctic cod..', *Can.J.Fish.Aquat.Sci.* *56* pp. 2099–2111.
- Shchepetkin, A. F. & McWilliams, J. C. (2000), 'The Regional Ocean Modelling System: A split-explicit, free-surface, topography-following coordinates ocean model', *Draft* .
- Sundby, S. (2000), 'Recruitment of Atlantic cod stocks in relation to temperature and advection of copepod populations.', *Sarsia* *85* pp. 277–298.
- Sundby, S., Bjørke, H., Soldal, A. V. & Olsen, S. (1989), 'Mortality rates during the early life stages and year class strenght of the North-East Arctic cod.', *Rapp. P.-v-Reun. Cous.int.Explor.Mer.* *191* pp. 351–358.
- Suthers, I. M. & Sundby, S. (1993), 'Dispersal and growth of pelagic juvenile Arcto-Norwegian cod, inferred from otolith microstructure and water temperature.', *ICES J.mar.Sci.*, *50* pp. 261–270.
- Suthers, I. M. & Sundby, S. (1996), 'Role of the midnight sun: comparative growth of pelagic juvenile cod (*Gadus morhua*) from the Arcto-Norwegian and a Nova Scotian stock.', *ICES J.mar.Sci.*, *53* pp. 827–837.