International Council for the Exploration of the Sea

C.M. 2004/P:01
Theme Session P: Physical-biological Interactions: Experiments, Models and Observation

Modelling of dynamic processes influencing the Barents Sea cod (*Gadus morhua morhua L.*) survival in early life history

by

A.G. Trofimov, V.A. Ivshin, and N.V. Mukhina

Polar Research Institute of Marine Fisheries and Oceanography (PINRO),
Knipovich Street 6, 183763 Murmansk, Russia
Tel: +7 8152 47 25 32 Fax: +7 8152 473331, e-mail: inter@pinro.ru

ABSTRACT

The dynamics of the water is of great importance for fish in their early life stages, when passive transportation prevails over their active movement. The effect of dynamic processes on eggs starts right after spawning. The model of eggs ascent from the spawning depths to the surface and hydrodynamic model for the Barents Sea were applied to study this effect. The analysis of spatial distribution and estimation of cod eggs and larvae abundance index is performed basing on the data of ichthyoplankton surveys in the area of Lofoten shallow waters for 1959-1993.

The conditions of eggs ascent, variability of fluxes in different current brunches and the results of further transport of ichthyoplankton in the years different in abundance of cod year-classes during the period under study were compared.

It was found that oceanographic conditions in spawning time vary significantly for years with different in abundance cod year-classes. The most abundant year-classes occurred in years with high heat content when the water density is low. Under these conditions eggs rise slowly, which to some extend allows them to adapt to new thermal environment and eggs do not undergo through large temperature changes while coming to the surface.

The calculation of water fluxes showed that poor year-classes of cod occurred in the years when the Norwegian current was weakened, drift component of the Spitsbergen current had positive values and that of the North Cape was negative. Rich year-classes of cod occurred in the years when the Norwegian current was strengthened, drift component of the North Cape current had positive values and that of the Spitsbergen was negative or poorly positive.

INTRODUCTION

It is difficult to underestimate the importance of environmental conditions for early life stages of fish and for North-East Arctic cod (*Gadus morhua morhua L.*) in particular. Among many factors that effect survival of eggs and larvae the dynamic conditions arouse especial interest and in particular the velocity of eggs ascent from the spawning depths to the surface and general water circulation, which forms further drift of eggs and larvae (Okubo, 1962; Fortier, Leggett,1983; Checkley et all, 1988; Bartsch et all, 1989; Neilson, Perry, 1990). The effect of physical and hydrochemical factors on eggs while it moves up to the surface as well as spatial and time differences in juvenile distribution influence the development and survival of fries. In its turn the survival of fish in early stages of development acts as a major factor for abundance of year-classes (Houde, 1987; Anderson, 1988; Koutsikopoulos, Fortier, and Gagne, 1991; Van der Lingen, Huggett, 2002; Mukhina, Marshall, Yaragina, 2002).

Main spawning areas of North-East Arctic cod (*Gadus morhua morhua L.*) are situated in the Lofoten shallow waters in the area of the Norwegian costal current. The major part of cod stock (50% of mature fish) spawns in the limited costal area near the Røst and Vesterålen islands, where fish spawn up to 60-70 % of eggs and the most intensive spawning is observed in Vestfjord at the southern side of the Lofoten islands (Spawning and Life History…, 1994; Ozhigin et al., 1999). Spawning starts in early March. Cod spawns most intensively in the first week of April and by the end of May spawning is over (Pedersen, 1984; Ellertsen et all, 1987). In the northern spawning area near the Malang and Fugløy banks intensive spawning starts two weeks later than near the Lofoten islands (Sundby, Bratland, 1987). Eggs and larvae of cod distribute in the upper 30 meters layer (Solemdal, Sundby, 1981; Serebryakov, Aldonov, 1984; Bjorke, Sundby, 1984; Ozhigin et al., 1999). The transport of eggs and larvae from spawning areas is determined by dynamic processes of the surface waters, which have year-to-year variations and specific features (Ellertsen et all, 1981; Dvinina, Mukhina 1984; Mukhina, Mukhin, Dvinina 1987; Trofimov, Ivshin, Mukhina, 2003).

Since 1980s the transport of juveniles of such fish species as cod, herring and halibut in first months of their life has come into a sharper scientific focus (Tereschenko, 1980; Aadlandsvik, 1989; Averkiev, Chantsev, 1995; Svendsen et all, 1995; Aadlandsvik et all, 1999; Trofimov, Ivshin, Mukhina, 2003). However, even today this issue still lacks a clear-cut understanding and therefore it needs further research work to study the effect of dynamic processes on formation of abundant year-classes of target-species and cod in particular.

In the previous work (Trofimov, Ivshin, Mukhina, 2003) we described specific features of ascent and further distribution of cod eggs and larvae in different in water temperature conditions years using 1987-1989 as example. It was noted that eggs ascent occurred slower in warm years and therefore the thermal impact on eggs is lower than in cold years, which is favourable for development of embryos. It was also found that in warm year 1989 were more intensively transported to the southern Barents Sea comparing with cold year 1987 and besides a better survival of year-classes was observed.

In this work our purpose is to identify the dynamic conditions that determine occurrence of different in abundance year-classes of cod.

For this purpose long-term values of water physical parameters were calculated and values of velocity and time of ascent were obtained using the model of eggs ascent. The characteristic of oceanographic conditions in the period of intensive spawning near the Lofoten islands was given and comparison with conditions in the northern spawning areas (the Malang bank) in the years with different in abundance cod year-classes was carried out. The conditions of cod juveniles' distribution for the same years were estimated using the calculations of fluxes in the Norwegian, Spitsbergen and North Cape currents obtained with the hydrodynamic model.

MATERIALS AND METHODS

In this work oceanographic conditions under which North-East Arctic cod spawns near the Lofoten islands and in the northern spawning areas on the Malang bank are described. The description of conditions in Vestfjord was composed using oceanographic data collected for standard depth intervals on Skrova station (68º07'N, 14º39'E) and given by Norwegian Institute of Marine Research for the period 1972-1992. The choice of this period is based on the fact that at the end of 1971 the standard depth intervals used for observations changed. The depth interval of 25 meters was excluded and two intervals of 20 and 30 meters were added. It enabled us to have a better identification of the boundaries between the stratification elements, which is an important factor for modelling of eggs ascent.

The conditions in the northern spawning areas were estimated using observation data on the Malang bank, which was collected in complex ichthyoplankton surveys (1959-1993) by the specialists of PINRO. This data is unique in the sense that it was collected in surveys conducted approximately in the same are and time. For instance, the surveys on the Malang bank were conducted in different years in the period 19-24 April. Identical time interval with data from the Lofoten islands collected in 1971-1992 was used in the analysis for commensurability of the obtained results.

Despite the fact that many target fish species have certain differences in their spawning pattern the incubation of eggs in most cases occur in the surface layers. The buoyancy of eggs makes them rise passively from the depths where they were laid to the surface. Eggs ascent is caused by the difference of their density and the water density (Coombs, 1981). The model of eggs ascent was used in this work (Trofimov, Ivshin, Mukhina, 2003), which is based on well-know laws of physics (Yavorskiy, Detlaf 1971; Kukhlin, 1985).

The velocity of eggs ascent (υ) was calculated as:

$$\upsilon = -(\frac{9\eta}{2\rho_1 R^2} \pm \sqrt{\frac{81\eta^2}{4\rho_1^2 R^4} - \frac{18}{S}(g(1-\frac{\rho_2}{\rho_1}) - \frac{\upsilon_0^2}{2S})})S\,, \qquad (1)$$

where υ_0 is the starting velocity of eggs ascent;
ρ_1, ρ_2 is the density of eggs and sea water correspondingly;
R is the radius of egg;
S is the passed distance;
g is the acceleration of gravity;
η is the viscosity of sea water.

The time of eggs ascent (t) from the spawning depth to the surface was calculated with the equation:

$$t = \frac{2S}{\upsilon + \upsilon_0}\,. \qquad (2)$$

The density of sea water was calculated with Knudsen equation (Oceanographic tables, 1975). The values of dynamic viscosity coefficients were taken from corresponding oceanographic tables (Oceanographic tables, 1975). Physical parameters of eggs of NEA cod were taken from the work by T.S. Rass (1949). Following eggs parameters were used in the modelling:

- the density 1.02475 g/cm^3;
- the radius 0.695 mm.

The water circulation in the Barents Sea was calculated using three-dimensional numerical hydrodynamic model (Trofimov, 2000) for the period 1961-1993 (drift circulation) and for 1970, 1978-1993 (total circulation). The choice of the years in the second period was based on the amount of available oceanographic data necessary for calculations and the requirement to cover both poor and rich year-classes of cod. Obtained currents velocities were used for calculation of fluxes in the upper 30 meters layer by the main current brunches, which is the Norwegian brunch (a section along 68° N within 6-12° E), the Spitsbergen current (a section along 73°40' N within 12-16° E) and the North Cape current (a section along 20° E within 70°40'-73°20' N) (Fig. 1). The flux for the Norwegian current was calculated for April, which is related to the intensive cod spawning and the fluxes for the Spitsbergen and North Cape currents were calculated for June-July and May-July correspondingly, which is related to the transport of ichthyoplankton by the currents through the above mentioned sections.

Monthly mean atmospheric pressure datasets were acquired from Internet at the IRI/LDEO Climate Data Library (NOAA, http://ingrid.ldgo.columbia.edu), monthly mean sea water density datasets were calculated with Knudsen equation (Oceanographic tables, 1975) using temperature and salinity data acquired from the PINRO oceanographic database and currents velocity at open boundaries of the research area that was calculated using flows through corresponding sections and straits (Kudilo, 1961; Orlov, Poroshin, 1988; Midttun, 1985; Slagstag, 1987; Loeng, Ozhigin, Adlandsvik, 1997).

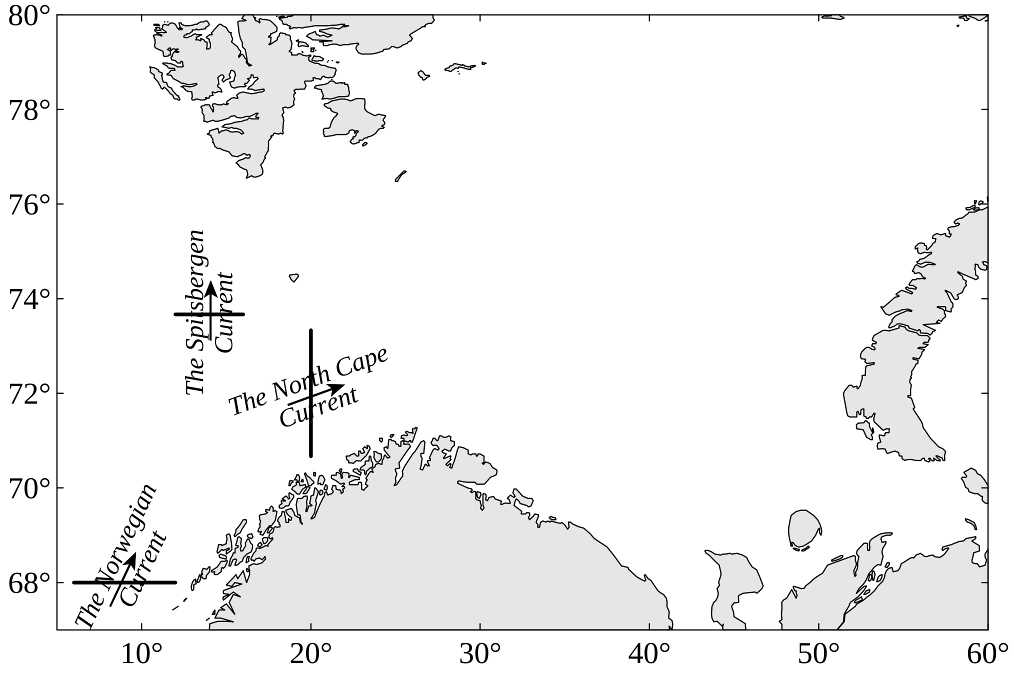

Figure 1. Model area and positions of sections for calculation of water fluxes.

The calculations results were compared with abundance of cod at age 3 years (Anon, 2003) and for doing this the year-classes of the period under study were divided in 3 categories:

- poor, less than 400 millions individuals;
- medium, from 400 to 700 millions individuals;
- rich, over 700 mullions individuals.

The estimates of eggs and larvae indices and the analysis of eggs and larvae distribution are based on the data from Russian ichthyoplankton surveys conducted by PINRO in April-July in 1959-1990 in the north-eastern Norwegian Sea and the south-western Barents Sea (Mukhina, 1992).

RESULTS

The results of the research work showed that oceanographic conditions of cod spawning in the Lofoten islands area differ significantly in the periods when different in abundance year-classes occur (Table 1).

Table 1. Characteristics of eggs ascent and oceanographic conditions in early April in the Lofoten islands area in the periods when different in abundance year-classes of cod occur

Cod year-classes	Characteristics of eggs ascent			Average in the 0-spawning layer			Gradient in 0-spawning layer		
	Spawning depth, m	Velocity, mm/sec	Time, hour	Tempe-rature	Sali-nity	Den-sity	Tempe-rature	Sali-nity	Den-sity
Poor	127.3	1.17	34.8	3.67	33.74	26.82	3.96	1.17	0.51
Medium	130.0	1.12	36.9	4.50	33.66	26.68	3.71	1.41	0.70
Rich	125.0	1.02	39.5	4.92	33.47	26.48	3.27	1.47	0.79

In the years with poor year-classes the average water temperature from the spawning depth to the surface is 1°C or more lower than in the years with rich year-classes and salinity and density have high values. Gradients of physical parameters of the water from the spawning depth to the surface have an opposite trend. In periods with low-abundant year-classes the difference between temperature at the spawning depth and in the surface is 0.5°C higher than in the years with rich year-classes. However, salinity and density in the years with poor year-classes is 0.3 lower than in the years with rich years-classes.

According to the long-term data, eggs ascent parameters (spawning depth, velocity, ascent time) also have specific features in the period when different in abundance year-classes occur. Spawning depth differs insignificantly from 125 to 130 m in the period with differently abundant year-classes. In the years with low abundance of cod juveniles the ascent velocity is higher (1.17 mm/sec), which effects the ascent time (34.8 hours).

A diagram was drawn based on the parameters of the water masses in the periods with different in abundance cod year-classes (Fig. 2). The areas (average values of physical parameter ± their standard deviations) for different in abundance year-classes are given in the coordinates system temperature-density. Poor year-classes occur when average temperature from the spawning depth to the surface is quite low and density in this area has values higher than average. In the years with rich year-classes the water masses have high heat content and density values are low.

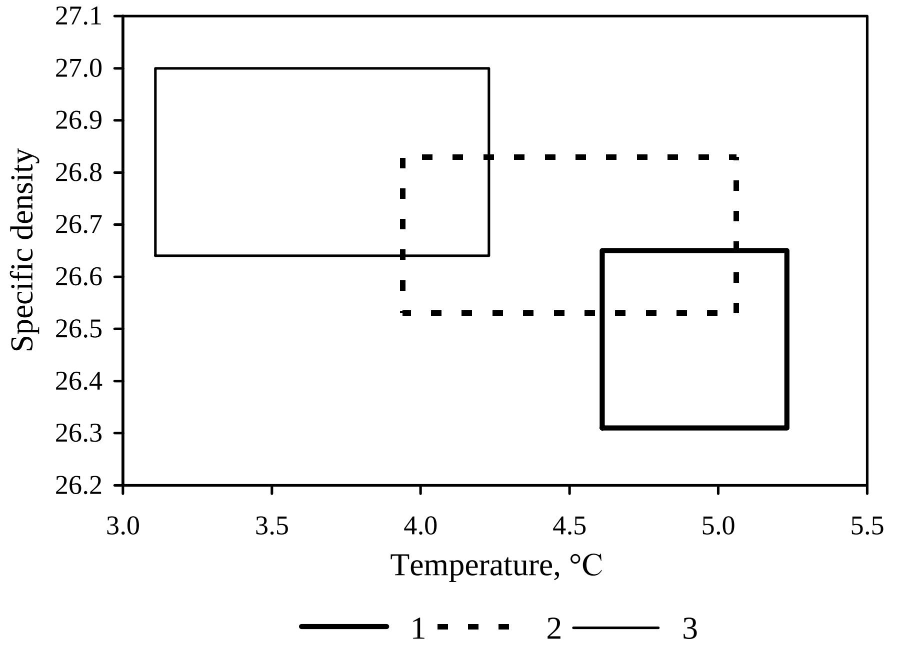

Figure 2. The characteristic of the water in the early April in the Lofoten islands area in the years with rich (1), medium (2) and poor (3) year-classes of cod.

The conditions under which fish spawn on the Malang bank have specific features, which differ from those in Vestfjod. In the years with different in abundance year-classes a quasi-permanent value of water density is observed (Table 2). However, in different years during spawning which usually occur at the same depth some insignificant differences in velocity and time of eggs ascent are observed. Water temperature is subject to the largest changes from year to year. In the years with rich year-classes the average water temperature in the interval from spawning depth to the surface is almost 1°C higher than in the years with poor year-classes.

Table 2. The characteristic of eggs ascent and oceanographic conditions in the last part of April on the Malang bank in the periods with different in abundance year-classes of cod.

Cod year-classes	Characteristics of eggs ascent			Average in the 0-spawning layer			Gradient in 0-spawning layer		
	Spawning depth, m	Velocity, mm/sec	Time, hour	Tempe-rature	Sali-nity	Den-sity	Tempe-rature	Sali-nity	Den-sity
Poor	100.1	1.53	23.2	4.82	34.54	27.35	0.92	0.38	0.20
Medium	96.1	1.52	22.2	5.31	34.54	27.30	0.89	0.36	0.18
Rich	92.8	1.53	21.2	5.94	34.61	27.27	0.59	0.35	0.20

Monthly drift (1961-1993) and total (1970, 1978-1993) circulation of water in the Barents Sea and adjacent areas were calculated to study the effect of the water dynamics on survival of cod juveniles. These estimates were further used for calculating of fluxes for main current brunches, which were mentioned above.

The results of the Norwegian current flux calculations in the upper 30 m layer in April based on total water circulation for poor (1978, 1979, 1981, 1985 and 1987) and rich (1970, 1989-1991) year-classes of cod are given in Fig. 3. It is clear that in poor years the flux was lower (0.191-

0.221 Sv (1 Sv = 10^6 m^3sec^{-1})) than in rich years (0.307-0.368 Sv), which means that intensity of the Norwegian current in the last case was higher.

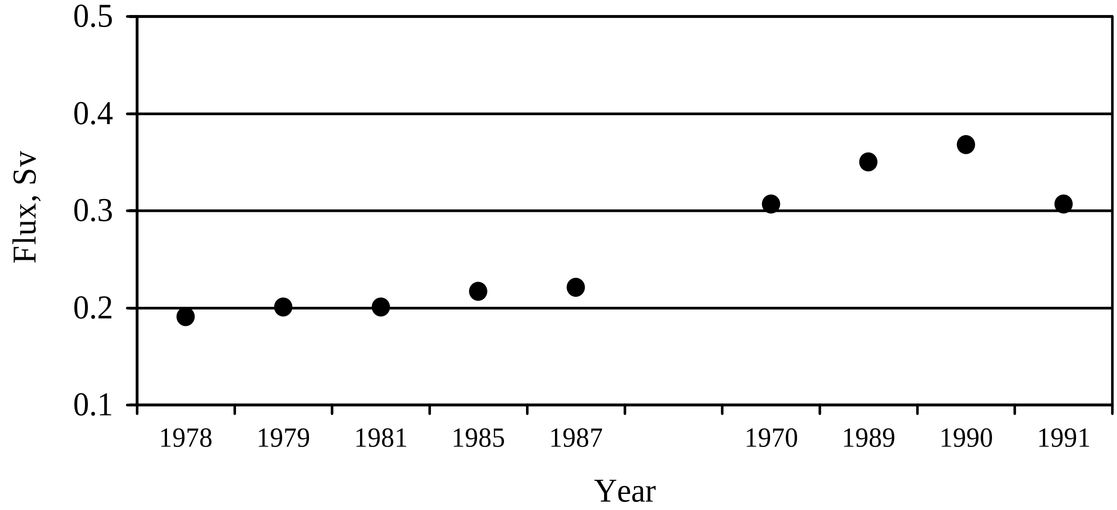

Figure 3. The Norwegian current flux based on total circulation.

The conditions during the transport of eggs and larvae of cod were the following (Fig. 4). For poor years ether strengthening of the Spitsbergen current in June-July (positive relative values of flux) and at the same time weakening of the North Cape current in May-July (1978 and 1985) or weakening of both currents in the same months (negative relative values of flux) (1979, 1981 and 1987) were observed. For rich years the situation was opposite; the Norwegian current was strong and the Spitsbergen current was weak in 1970 and 1991 but stronger (less than the North Cape current) in 1989 and 1990 (Fig. 4).

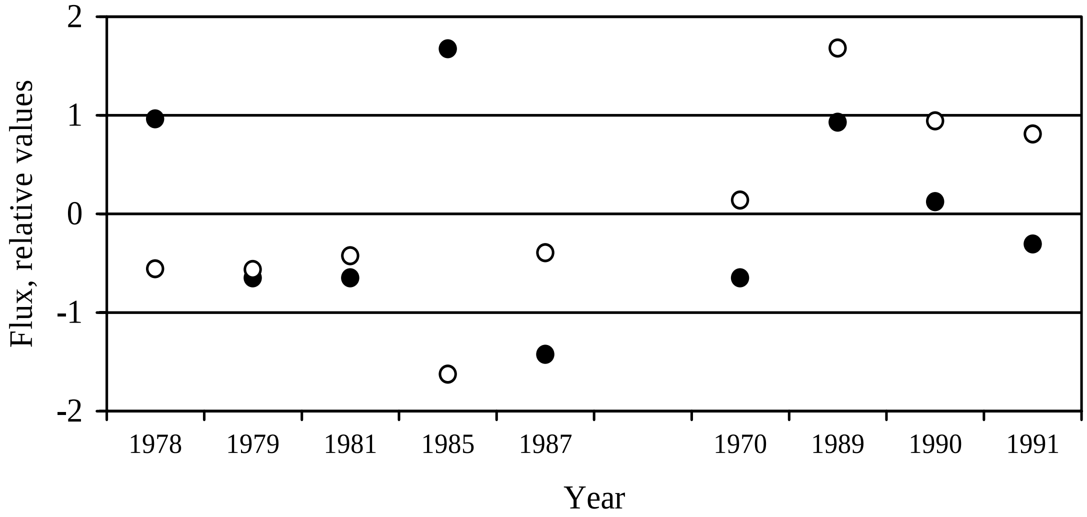

Figure 4. Fluxes in relative values for the Spitsbergen current (black spots) and the North Cape current (white spots) based on total circulation.

The results of the Norwegian current flux calculations in the upper 30 m layer based on the drift circulation in April in the same years with poor and rich year-classes are given in Fig. 5. However, 1961, 1966 and 1974 were added to the list of the poor years and 1964 was added to rich years due to the available data on atmospheric pressure, which allowed calculating of drift currents in a remote retrospective. Figure 5 shows that in poor years the flux was negative and had a value from –0.008 to –0.092 Sv, except 1966, 1979 and 1987 and in rich years the flux was positive (0.010-0.028 Sv). In case of a section with west-east orientation the negative values of flux will correspond to the drift flow turned northwards and positive values will correspond to the drift flow turned southwards. When the section is oriented from north to south negative and positive values of flux will point at the drift flows turned westwards and eastwards correspondingly.

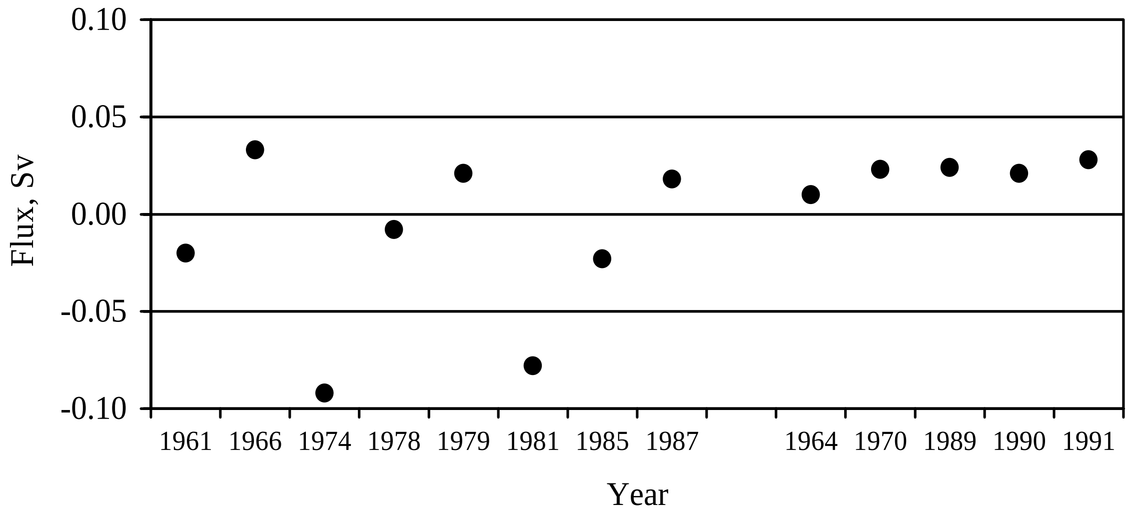

Figure 5. The Norwegian current flux based on drift circulation.

In the years with poor year-classes the Spitsbergen current flux based on drift circulation was positive (0.010-0.027 Sv) except 1987 and North Cape current flux was negative from –0.012 to –0.044 (Figure 6). In the years with rich year-classes North Cape current flux was positive (0.005-0.0035 Sv) and exceeded the Spitsbergen current flux, which varied from –0.017 to 0.012 Sv.

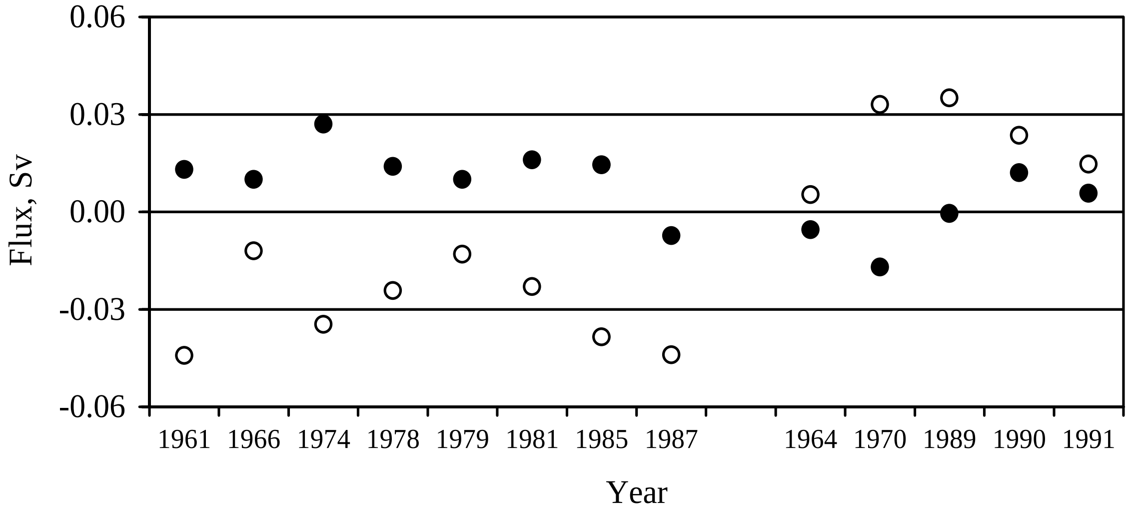

Figure 6. The Spitsbergen current flux (black spots) and the North Cape current flux (white spots) based on drift circulation.

The analysis of the Spitsbergen and North Cape currents fluxes allowed identifying the conditions under which poor, medium and rich year-classes of cod can occur (Fig. 7 and 8). Average values of corresponding fluxes and their standard deviations were used to diagram the datasets.

The areas given in Fig. 7 are drawn using fluxes based on total currents. Poor year-classes occurred when the North Cape current flux was low and in general made up to 0.234 Sv while the Spitsbergen current flux was about 0.152 Sv. In the years with rich year-classes the average North Cape current flux value was much higher (0.299 Sv) but the average Spitsbergen current flux value was almost the same (0.149 Sv). Even visually it is easy to notice that the area corresponded to poor year-classes is the largest.

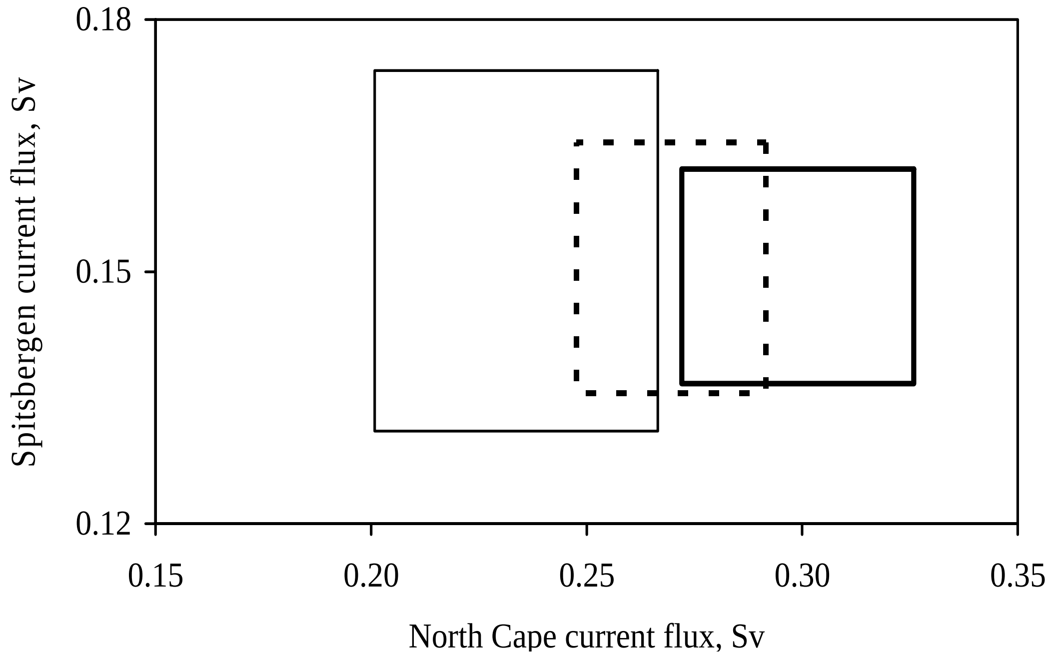

Figure 7. Conditions of occurrence of rich, medium and cod poor year-classes when the fluxes are based on total currents. Figure legend is given in Fig. 2.

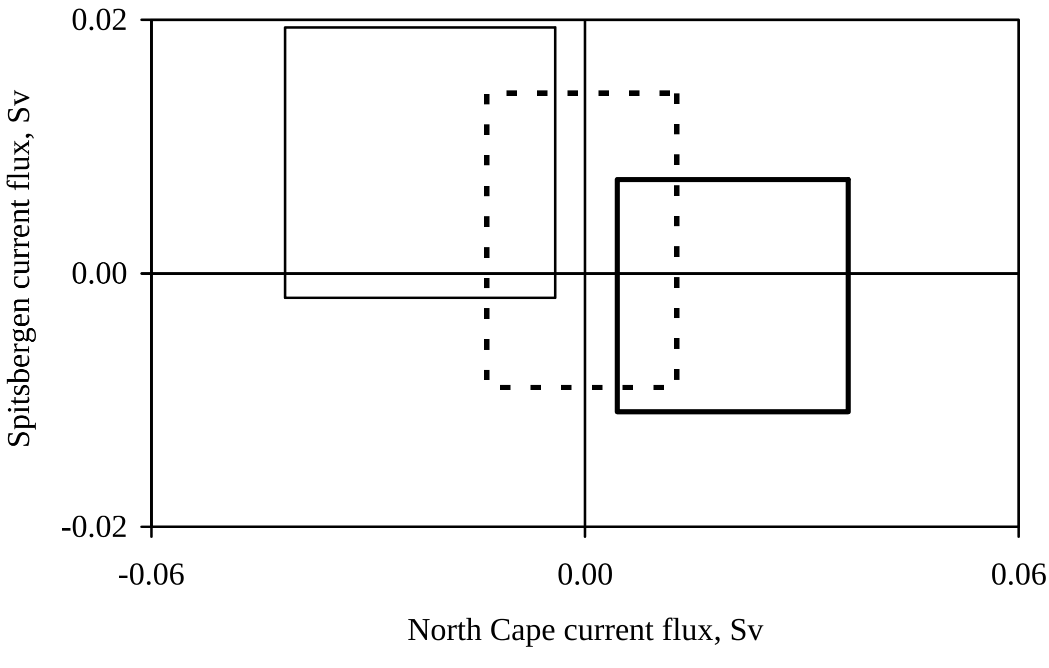

Figure 8. Conditions of occurrence of rich, medium and poor cod year-classes when the fluxes are based on drift currents. Figure legend is given in Fig. 2.

The diagram in Fig. 8 is similar to that in Fig. 7 but it differs from the latter in the sense that the calculations are based on modelled drift currents. In this case poor year-classes of cod occurred when the North Cape current flux was negative and its average value is –0.023 Sv while the Spitsbergen current flux was positive and its value was 0.009 Sv. In the years when rich year-classes occurred the average North Cape current flux was positive (0.020 Sv) and that of the Spitsbergen current was negative (–0.002 Sv). Besides, the area corresponded to the poor year-classes is only slightly larger than the area corresponded to rich year-classes.

DISCUSSION

Environmental conditions in spawning period play an important role for abundance of year-classes. The results of the calculations showed quite significant year-to-year variations of oceanographic parameters in Vestfjord, where cod spawns most active. The main factor, which affects the velocity of eggs ascent from the spawning depths to the surface, is distribution of water density. The higher density of water, the higher velocity of eggs ascent, which makes eggs move faster from the warmer depth waters to the colder surface waters and affects development of eggs. Besides, in the years when poor year-classes occurred on the way of eggs movement the average value of water temperature was 1°C lower and temperature gradient was 0.5°C higher than in the years with rich year-classes (Table 1). The effect of temperature on eggs during one day can be compared to temperature variations on the surface of the Barents Sea in several months. So, poor year-classes of cod occur under conditions of high water density and low temperature (Fig. 2). The classification of cod year-classes abundance (rich, medium and poor) in accordance with temperature and density of the water allows us to estimate the degree to which the conditions of spawning are favourable and give a hypothetical estimate of the new year-class.

Spawning areas on the Malang bank are of minor importance and do not have any significant influence on the abundance of new year-class. Therefore, the comparison of the results on eggs ascent dynamics with the number of cod recruits does not show any clear relationship. Oceanographic conditions during spawning on the Malang bank have a number of specific features comparing with the waters near the Lofoten islands. Average salinity of water in the northern spawning areas is higher by 1 than in Vestfjord. High salinity value leads to a higher water density, which in its tern causes increase of eggs ascent. For instance, on the Malang bank the velocity of eggs ascent is 36 % higher than near the Lofoten islands and spawning depth is 20 meters less. In the northern spawning areas the characteristics of the water and conditions of eggs ascent are quite stable in the years when different in abundance cod year-classes occur (Table 2). Anyway, rich year-classes are observed in the periods with high water temperature.

The analysis of water dynamics shows that poor cod year-classes occur when Norwegian current is weak in April, North Cape current is weak in May-July and Spitsbergen is weak in June-July (Fig. 3 and 4). Spitsbergen current in this case can also be strengthened. This situation leads to a weak transport of cod juveniles to the Barents Sea with either weak or strong transport of eggs northwards to Spitsbergen.

Rich year-classes of cod occur when intensity of the Norwegian and North Cape currents is higher and that of the Spitsbergen current is lower (Fig. 3 and 4). It leads to fast transport of cod eggs and juveniles from spawning, and further is favourable for transport to the southern Barents Sea, where survival of cod larvae is higher than in the northern area (Ponomarenko, 1982, 1984).

The calculation of fluxes based on drift current was made due to good availability of data on atmospheric pressure, which are necessary for calculating drift currents. These fluxes were calculated in order to found out the extent to which a drift current can affect the transport and distribution of cod juveniles. The results showed that rich year-classes occurred in the years when drift component of the Norwegian current or to be precise the drift flow going through the section and cross-cutting the current was turned northwards it strengthened the general current expressed in density component (Fig. 5). Poor year-classes occurred in the years when fluxes affected by the drift circulation had negative values except 1966, 1979 and 1987. However, despite these exceptions a clear relationship was observed in further transport of cod juveniles (Fig. 6). In the years when poor year-classed occurred the drift flow strengthened the Spitsbergen current and weakened the North Cape current except 1987, when both currents were directed opposite general current system. In the years when rich year-classes occurred the North Cape currant was strengthened by drift component and the Spitsbergen current was weakened or strengthened like in 1990 and 1991 but less than the North Cape current. These results prove the earlier statement that poor year-classes of cod is caused by strengthened transport of cod juveniles northwards to Spitsbergen while transport to the Barents Sea is weakened. The opposite situation when transport of ichthyoplankton to the Barents Sea prevails over the transport northwards is favourable for rich year-classes.

The conclusions are shown in Fig. 7 and 8, where conditions under which different in abundance year-classes occur are clearly differentiated. It should be noted that if fluxes are based on drift currents the distinguishing of areas by flux not only for the North Cape current but also for the Spitsbergen current is clearly observed (Fig. 8). It was found that when water dynamics favoured rich year-classes the average survival rate for this period was 0.82 and when it inclined towards poor year-classes the survival rate was 0.51, in case of medium it was 0.65.

CONCLUSION

In this work the conditions and characteristics of eggs ascent of North-East Arctic cod from the spawning depths to the surface in the Lofoten islands area and on the Malang bank in the years when different in abundance year-classes occurred were discussed. Rich year-classes occur when temperature is high and water density is low during spawning. These conditions cause a longer eggs ascent due to slower ascent velocity. When poor year-classes occur, the water masses have low temperature and high density; therefore eggs rise faster under a larger thermal press.

Oceanographic water conditions on the Malang bank create conditions under which eggs ascent velocity is 36 % higher than in the Lofoten islands. Low variations of water density from year to year on the Malang bank cause no significant changes in the velocity and time of eggs ascent in the years when different in abundance year-classes occur. The most abundant year-classes of cod occurred, when thermal background of the water on the Malang bank was high.

In the years when rich year-classes of cod occurred it was observed that the Norwegian current was strengthened (flux was 0.307-0.368 Sv) in April and the North Cape current was strengthened (average flux was 0.299 Sv) in May-July while the Spitsbergen current was weakened in June-July and though in some years it was strengthened but less than the North Cape current.

In the years when poor year-classes occurred it was typical that the Norwegian current was weakened (flux was 0.191-0.221 Sv) in April and the North Cape current was weakened (average flux was 0.234 Sv) in May-July while the Spitsbergen current was either strengthened or weakened in June-July.

The results of flux calculations based on drift currents showed that in the years when rich year-classes occurred, the drift circulation favoured strengthening of the Norwegian current in April and the North Cape current (average flux due to drift currents was 0.02. Sv) in May-July and normally inclined towards weakening of the Spitsbergen current (average flux was –0.002 Sv) in June-July. In the poor years drift circulation weakened the Norwegian and the North Cape currents (average flux was –0.023 Sv) in the corresponding months and strengthened the Spitsbergen current (average flux was 0.009 Sv).

REFERENCES

Averkiev A.S., and V.Yu. Chats.v 1995. Calculations of cod eggs distribution in the upper layer on the divide between the Norwegian and Barents Seas based on hydrodynamic model. Issues of fisheries oceanology in the Northern basin: Collection of scientific works. PINRO – Murmansk: PINRO publish, p. 131-138.

Dvinina E.A., and N.V.Mukhina. 1984. Horizontal circulation of waters and distribution of cod eggs and larvae on the divide between the Norwegian and Barents Seas in 1978, 1980-1982. Issues of fisheries oceanology in the Northern basin. – Murmansk: PINRO, p. 30-35.

Kudlo B.P. 1961. Some data on water exchange between the Barents and Norwegian Seas. Works of GOIN. – No. 64. p. 33-39.

Kuhlin Kh. 1985. Reference book on physics. –M: “Mir”, 520 pp.

Mukhina N.V., 1992. Results of ichthyoplankton surveys conducted in the Norwegian and Barents Seas in 1959-1990. Ecological problems of the Barents Seas: Collection of scientific works. PINRO. –Murmansk. PINRO Press, p. 62-102.

Mukhina N.V., Mukhin A.I., and E.A. Dvinina. 1987. Oceanological conditions and reproduction of Norwegian Arctic cod in the Barents Seas. Effect of oceanological conditions on distribution and dynamics of target fish populations in the Barents Sea/ Proceedings of 3rd Soviet-Norwegian symposium: PINRO, p. 199-215.

Ozhigin V.K., Tretyak V.L., Yaragina N.A., and V.A. Ivshin. 1999. Oceanographic conditions of the Barents Sea and their effect on survival and development of juveniles of North-East Arctic cod. – Murmansk: PINRO Press, 88 pp.

Oceanographic tables. 1975. L.: Gidrometeoizdat,. 478 pp.

Orlov N.F., and V.V. Poroshin. 1988. Flux of water and heat in the North Cape current in 1961-1980. Nature and Economy of the North. – Murmansk, No. 16, p. 31-34.

Ponomarenko I.Ya., 1982. Estimation of registrations of juveniles of cod and haddock in the Barents Sea in fisheries. Ecology and fisheries of demersal fish species in the North European basin: Collection of scientific works. PINRO. – Murmansk, p. 10-23.

Ponomarenko I.Ya. Survival of “demersal” juveniles of cod in the Barents Sea and factors conditioning it. Reproduction and recruitment of cod: Proceedings of first Soviet-Norwegian symposium. – M., 1984. 301-316 pp.

Rass T.S. 1949. Materials on cod *Gadus morhua morhua* L. reproduction and on distribution of cod eggs, larvae and juveniles in the Barents Sea. Trudy VNIRO. Vol. 17, p. 67-138.

Tereschenko V.V. 1980. Specific features of hydrometeorological drift conditions of eggs and larvae of Lofoten cod. Physical and chemical conditions of production formation in the Barents Sea. – Apatity. Kola branch Academy of Science of the USSR, p. 34-40.

Trofimov A.G. 2000. Numeric modelling of water circulation in the Barents Sea. – Murmansk: PINRO Press, 42 pp.

Yavorskiy B.M., and A.A. Detlaf. 1971. Reference book on physics. –M.: “Nauka”, 944 pp.

Aadlandsvik B. 1989. Wind-driven variations in the Atlantic inflow to the Barents Sea. ICES CM - 1989/C:18. - 13 pp.

Aadlandsvik B., Gundersen A.C., Nedreaas K.H., Stene A., and O.T. Albert.1999. Modelling the advection and diffusion of eggs and larvae of northeast Arctic Greenland halibut. ICES CM - 1999/K:03. - 20 pp.

Anderson J.T. 1988. A review of size dependent survival during pre-recruit stages of fishes in relation to recruitment. Journal of Northwest Atlantic Fishery Science. No.8, p 55-66.

Anon. 2003. Report of the Arctic Fisheries Working Group. ICES CM 2003/ACFM:22, 404 pp.

Bartsch J., Brander K., Heath M., Munk P., Richardson K. and E. Svedsen. 1989. Modelling the advection of herring larvae in the North Sea. Nature. No.340, p.632-636.

Bjorke H., and S. Sundby. 1984. Distribution and abundance of post larval northeast Arctic cod and haddock.Reproduction and recruitment of Arctic cod: Proceed. of the Sov.-Norw. Symp. Norway: IMP. P.72-98.

Checkley D.M., Raman S., Maillet G.L. and K.M. Mason. 1988. Winter storm effects on the spawning and larval drift of a pelagic fish. Nature. No.335, p.346-348.

Coombs S.H. 1981. A density gradient column for determining the specific gravity of fish eggs, with particular reference to eggs of mackerel (*Scomber scombrus*). Marine Biology. No. 63, p.101-106.

Ellertsen B., Fossum P., Solemdal P., Sundby S., and S. Tilseth. 1987. The effect of biological and physical factors on the survival of Arcto-Norwegian cod and the influence on recruitment variability. The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea: Proceed. of the 3rd Sov.-Norw. Symp. Murmansk: IMR. - - P.101-126.

Ellertsen B., Furnes G.K., Solemdal P., and S. Sundby. 1981. Influence of wind induced currents on the distribution of cod eggs and zooplankton in Vest-Fjorden. Proceedings from the Norwegian Coastal Current Symposium. Geilo. Norway, 9-12 Sept. 1980. -University of Bergen. P.604-628.

Fortier L. and W.C. Leggett. 1983. Vertical migrations and transport of larval fish in a partially mixed estuary. Canadian Journal of Fisheries and Aquatic Sciences. No.40, p.1543-1555.

Houde E.D. 1987. Early life dynamics and recruitment variability. American Fisheries Society Symposium. No.2, p.17-29.

Koutsikopoulos C., Fortier L. and J.A. Gagne. 1991. Cross-shelf dispersal of Dover sole eggs and larvae (Solea solea) in Biscay Bay and recruitment to inshore nurseries. Journal of Plankton Research. No.13, p.923-946.

Loeng H., Ozhigin V., and B Aadlandsvik. 1997. Water fluxes through the Barents Sea. ICES J. Mar. Sci. Vol. 54. P.310-317.

Midttun L. 1985. Formation of dense bottom water in the Barents Sea.Deep-Sea Research. Vol. 32, No. 10. P.1233-1241.

Mukhina N., Marshall T., and N. Yaragina. 2002. Tracking the signal in year-class strength of northeast arctic cod through multiple survey estimates of egg, larval and juvenile abundance. 26^{th} Annual Larval Fish Conference, 22-26 July 2002 Solstrand Fjord Hotel Bergen, Norway, 82 pp.

Neilson J.D. and Perry R.I. 1990. Diel vertical migrations of marine fishes: an obligate or facultative process? Advances in Marine biology.No.26, p.115-168.

Ocubo A. 1962. Horizontal diffusion from an instantaneous point source due to oceanic turbulence. Technical Report of the Chesapeake Bay Institute. No.32, p.1-123.

Pedersen T. 1984. Variation of peak spawning of Arcto-Norwegian cod (*Gadus morhua* L.) during the time period 1929-1982 based on indices estimated from fishery statistics. The Propagation of Cod *Gadus morhua* L. Part 1. Arendal. Norway. P.301-316.

Serebryakov V.P., and V.K. Aldonov. 1984. Spawning grounds of the Arcto-Norwegian cod outside Vestfjorden. The Propagationof Cod *Gadus morhua* L. Part 2. Arendal. Norway. P.479-500.

Slagstad D. 1987. A 4-Dimensional Physical Model of the Barents Sea. SINTEF Report. - Trondheim, - No. STF48 F87013, 34 pp.

Solemdal P., and S. Sundby. 1981. Vertical distribution of pelagic fish eggs in relation to species, spawning behaviour and wind conditions. ICES CM 1981/G:77, 26 pp.

Spawning and Life History Information for North Atlantic Cod Stocks. ICES Cooperative Research Report. 1994. No. 205, 150 pp.

Sundby S., and P. Bartland. 1987. Kartlegging av gytefeltene for norsk-arktisk torsk i Nord-Norge of beregning av eggproduksjonen I arene 1983-1985 (Spatial distribution and production of eggs from Northeast Arctic cod at the coast of Northern Norway 1983-1985). Fisken og havet. № 1. P. 1-58.

Svendsen E., Fossum P., Skogen M., Eriksod G., Bjorke H., Nedraas K., and A. Johannessen. 1995. Variability of the drift patterns of Spring Spawned herring larvae and the transport of water along the Norwegian shelf. ICES CM 1995/Q:25, 29 pp.

Trofimov A.G., Ivshin V.A., and N.V Mukhina. 2003. The impact of eggs vertical ascent speed and water dynamics on abundance and survival of the north-east arctic cod (*Gadus morhua morhua L.*) in the Barents Sea at early life stages. ICES C.M. 2003/O:04.

Van der Lingen C.D. and J.A. Huggett. 2002. The role of ichthyoplankton surveys in recruitment research and management of south African anchovy and sardine. 26^{th} Annual Larval Fish Conference 22-26 July 2002, Solstrand Fjord Hotel Bergen, Norway. p.109.