International Council for
the Exploration of the Sea

CM 2000/ Z:03
Theme session: General fisheries and
marine ecology (Z)

Some environmental factors that influence the growth of Arcto-Norwegian cod from the early juvenile to the adult stage

Kristin Helle[1], Bjarte Bogstad[1], Geir Ottersen[1,2] and Michael Pennington[1]

[1]Institute of Marine Research, P.O. Box 1870 Nordnes. N-58 17 BERGEN, NORWAY
[2]Department of Biology, Division of Zoology, University of Oslo, P.O Box 1050 Blindern, N-03 16 OSLO, NORWAY

Abstract

A high growth rate for Arcto-Norwegian cod (*Gadus morhua* L.) in the Barents Sea and adjacent areas from the larval stage to the O-group stage enhances survival and ultimately recruitment to the fishery. However, it appears that relatively high growth rates for a cohort through the O-group stage are not continued as the cohort ages. Based on survey data, there is a negative, though not significant, correlation between a cohort's average length at the O-group stage and its average length as 1 year olds and a significant negative correlation between the average length at the O-group stage and its average length at ages 2 through 9. It appears that the reason for this slowing of growth is that a strong inflow of warm, prey-rich Atlantic water into the Barents Sea from the Norwegian Sea provides favorable conditions for growth and hence survival of the cod larvae and juveniles. But this same strong inflow carries a proportion of the cohort farther to the east in the Barents Sea, where the bottom water is colder than in the west. Thus the young settled cod experience colder conditions, which slows their growth, than those cohorts that have a more westerly settlement, and this slow growth before age 2 appears to be the reason for the cohort's relatively smaller mean length at older ages.

Key words: Arcto-Norwegian cod; growth rates; larval and O-group stage

Introduction

Arcto-Norwegian cod (*Gadus morhua* L.) spawn along a 1200 km coastline from mid-Norway to north Norway. The main spawning areas are in Vestfjorden and on the continental shelf outside Lofoten and Vesterålen between 67" 30' N and 69° N. Approximately 70 percent of the spawning takes place in this region (Sundby and Bratland, 1987). The time of spawning is remarkably consistent from year to year. Spawning starts in early March, reaches maximum intensity during the first weeks of April and terminates by the first half of May (Ellertsen *et* al., 1987, 1989). The eggs, larvae and early juveniles drift north and northeastward carried by the Norwegian Coastal Current and the Atlantic Current (Ellertsen *et al.,* 198 1, Bergstad *et al.,* 1987).

In late August and September the juvenile cod have drifted for 4 to 5 months and their distribution extends from the coast of Spitsbergen to the central and eastern Barents Sea. The spatial extent of the distribution depends on the strength of the easterly and northerly currents (Muchina et *al.,* 1987). In particular, fur years when there is a strong inflow of Atlantic water into the Barents Sea, the spatial distribution of the juveniles will be more to the east than in years without strong inflows. A strong inflow of Atlantic water will also provide the juvenile cod with a relatively warm environment, and temperature is often understood to be the most important factor influencing the growth and abundance of young cod (Satersdal and Loeng, 1987; Campana and Hurley, 1989; Ellertsen *et al.,* 1989; Pedersen and Jobling, 1989; Sundby *et al.,* 1989; Suthers and Sundby, 1993; Brander, 1994).

Thus the yearly current patterns determine the temperature experienced by the drifting juveniles and their spatial distribution. For example, Fig. 1 shows the distribution and relative abundance of O-group cod for a cold year, caused by a weak inflow, and a warm year when the inflow was strong. In 1987 the average temperature for August and September in the Kola transect (Fig.2) between 0 and 200 m was 4.0°C, abundance was low, the average length of the 0-group cod was 5.52 cm and the spatial distribution was centered in the west (ICES, 1987). The opposite was observed in 1995, which was a warm year. The average temperature in the Kola transect was 5.6°C, abundance was high, the average length was 9.00 cm and the center of the distribution was more easterly (ICES, 1996a).

In this paper we examined the relation between the temperature in the Barents Sea and the average length at the O-group stage and whether a high growth rate through the 0-group stage continues as the cohort ages. Unexpectedly, it was found that the average length of a cohort at the O-group stage was negatively correlated with its average length at ages 1 through 9. It is concluded that the likely cause for this slowing of growth after settlement to the bottom was that the inflow of Atlantic water that provided the juveniles with a good environment for growth and survival carried many of them to less favorable areas for growth after settlement.

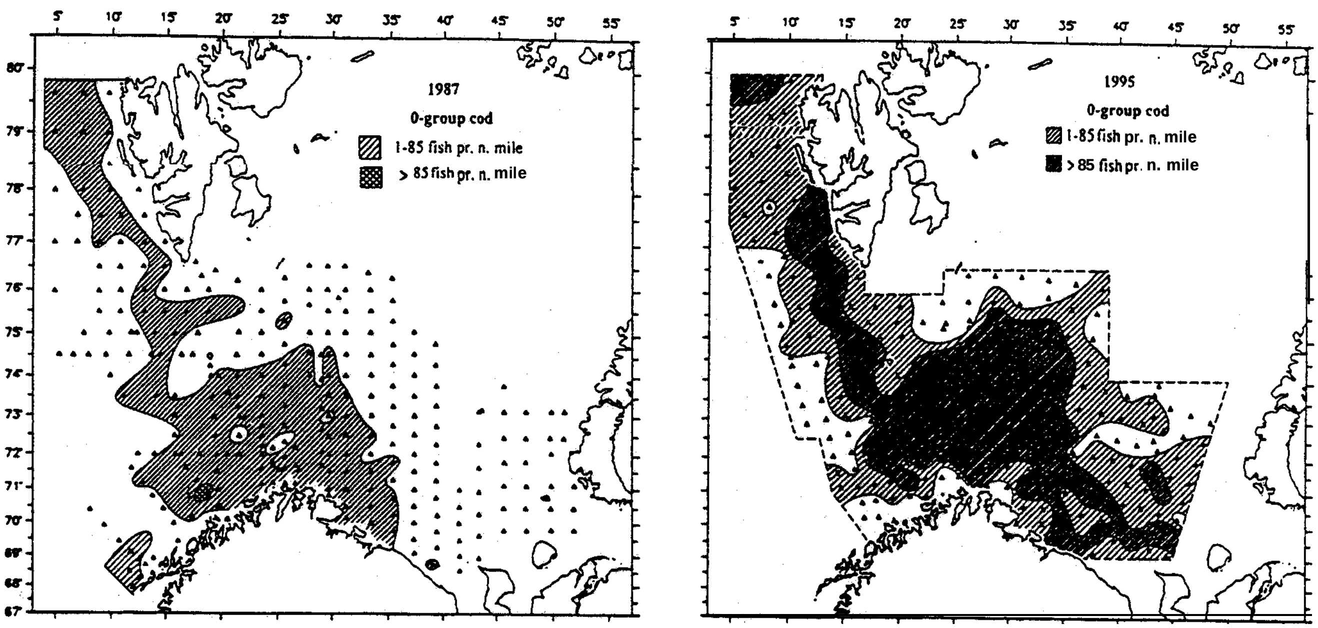

Figure 1. Distribution of O-group cod in 1987 and 1995 (adapted from ICES, 1987 and ICES, 1996a).

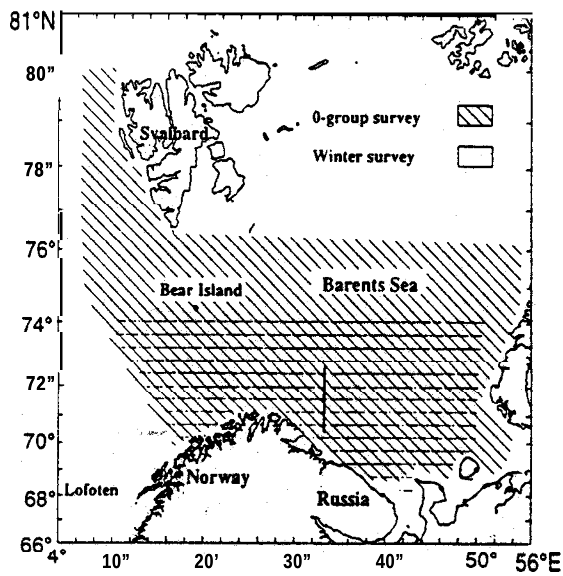

Figure 2. The general areas covered by the International O-group survey and the winter bottom trawl survey. The straight line denotes the location of the Kola transect.

Materials and methods

Estimates of a cod cohort's relative abundance and its mean length at the O-group stage were generated by the yearly International O-group Survey, which began in 1965 and is conducted in late August through early September. The objectives of this survey are to determine the spatial distribution and to estimate abundance indices for commercially important species in the Barents Sea during their pelagic stage. The survey procedure is described in Anonymous (1983). The estimates of mean (total) length of the O-group cod juveniles used in this paper are from the International O-group Reports (see for example

ICES, 1996b) and the indices of relative abundance are from Nakken and Raknes (1996) and ICES (2000). The methods used for calculating the index of abundance are described in Haug and Nakken (1977) and Randa (1982, 1984).

The estimates of a cohort's mean length at ages 1 through 9 are based on data from the Institute of Marine Research winter bottom trawl surveys in the Barents Sea. These surveys started in 1981 and are conducted yearly from January to March. For a detailed description of the survey and its history, see Jakobsen *et al.* (1997) and ICES (2000). The estimates of the mean length used in this paper are taken from ICES (2000).

Estimates of the mean water temperature from 0 - 200 m in August and September along the Kola transect were used as an indicator of the temperature regime experienced by a cohort at the O-group stage. The Kola transect is at 33°30'E and extends from 70°30' to 72°30'N (see Fig. I). The temperature estimates are taken from Tereshchenko (1996) and ICES (1998).

Standard regression techniques were used to relate the variables of interest (see, e.g., Draper and Smith, 1981).

Results

The estimated mean length of a cod cohort at the O-group stage in late August to early September was positively correlated (r = 0.73, p = 0.0003) with the average temperature from the surface to a depth of 200m along the Kola transect in August and September during the period 1974 through 1998 (Fig. 3). The cohort's relative abundance at O-group stage was also positively correlated- with average length during this same period (r = 0.66, p = 0.0003).

In Table 1 are the estimated correlations between the average length attained by a cohort at the O-group stage and their subsequent estimated average length, based on the 1981 to 1998 winter surveys in the Barents Sea, at ages 1 to 9. The correlation was negative but not significant at age 1 and significantly negative for ages 2 through 9 (Table 1, Fig. 4).

Table 1. Estimated correlation, r, and its probability level, p, between a cohort's average length at the O-group stage and its subsequent average length at ages 1 through 9.

Age	1	2	3	4	5	6	7	8	9
r	-0.32	-0.66	-0.60	-0.71	-0.76	-0.64	-0.58	-0.53	-0.63
P	(0.2)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.01)	(0.02)	(0.02)

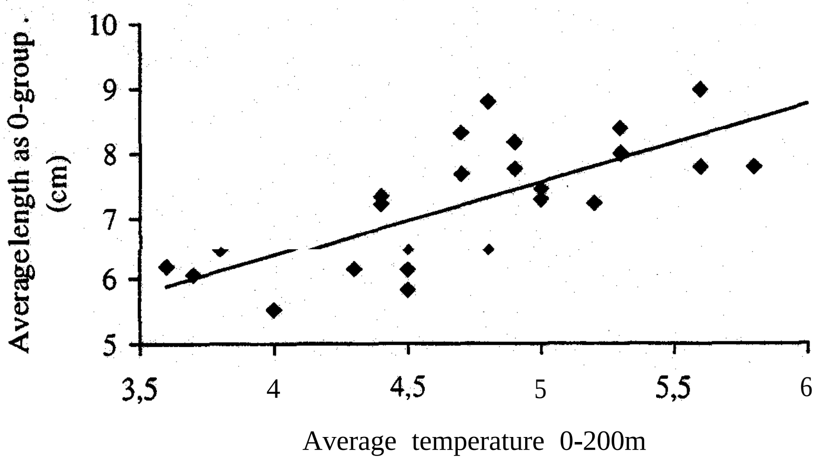

Figure 3. Average length of O-group cod versus average temperature in the **Kola** section between 0 and 200m during August and September for the period 1974 through 1998. The straight line denotes the regression line ($y = 1.53 + 1.21x$. $r^2 = 53\%$).

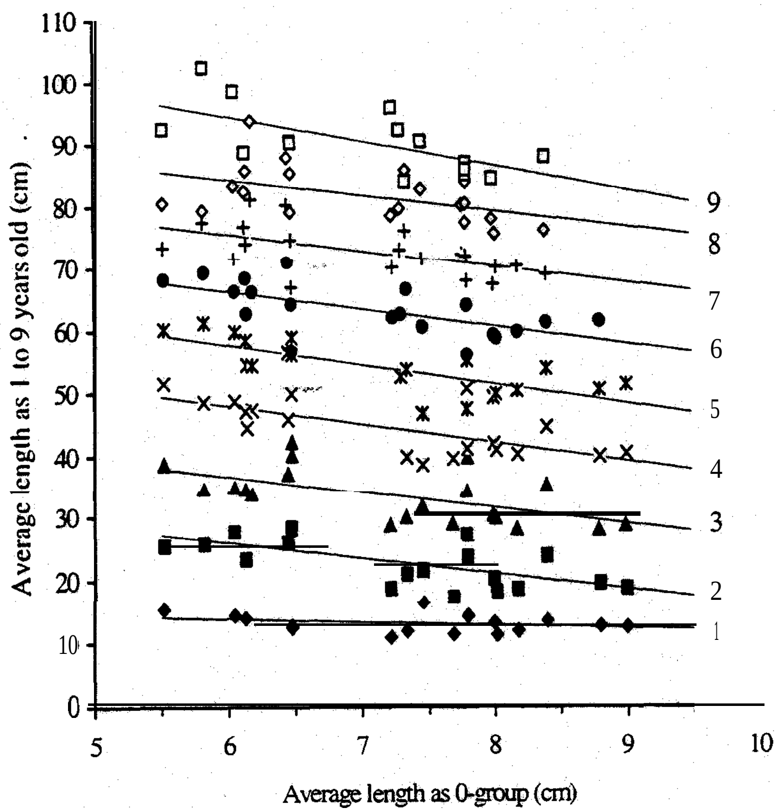

Figure 4. Average length of a cohort at ages 1 to 9 years versus its average length at the O-group stage.

Discussion

Temperature is one of the most important factors influencing the growth and survival of young cod (Sætersdal and Loeng, 1987; Campana and Hurley, 1989, Ellertsen *et al.,* 1989, Suthers and Sundby, 1993; Brander, 1994; Nakken, 1994; Sundby, 2000). The water temperature in the Barents Sea is closely related to the amount of inflow of relatively warm Atlantic water (Adlandsvik and Loeng, 1991). This inflow is sporadic and variable because changing atmospheric conditions over the North Atlantic affect the wind patterns and hence modify the current system (Loeng *et* al., 1997). During periods when there is a strong inflow of water into the Barents Sea, the developing larvae and juveniles experience relatively warm temperatures.

A strong inflow of Atlantic water not only warms the Barents Sea but also transports large quantities of prey from the Norwegian Sea into the Barents Sea (Ozhigin and Ushakov. 1985; Nesterova, 1990; Helle and Pennington, 1999: Helle 2000a). The resulting increase in zooplankton abundance in the Barents Sea during periods of large inflows appears to enhance the growth rates of early juvenile cod (Helle and Pennington, 1999; Helle, 2000b).

The strength and timing of the inflow determines how far east the distribution of the cod larvae and juveniles extends (Helle and Pennington, 1999). Right before settling to the bottom in September through November, the O-group cod reach their maximum spatial extension (Sundby et al., 1989). The time of settlement. which varies from year to year and by location. depends on plankton settlement and the cooling of the surface water layers (N. A. Yaragina, PINRO, Murmansk, Russia. pers. comm.). The bottom temperatures that the juveniles with an easterly settlement experience are considerably colder than those for juveniles who settle in the west. Michalsen er al. (1998) observed that the bottom temperature decreased from west to east by about 5-6 °C regardless of whether it is a cold or a warm year. Thus the strong inflow that provided the larvae and juveniles with conditions favorable for growth also transported a large number of them to areas where after settlement, lower bottom temperatures would tend to impede growth.

Cod juveniles generally remain in the area where they settled (Maslow, 1944, 1960; Baraenkova, 1957) and young cod up to age 2 undergo little or no seasonal migrations (Ottersen et al., 1998: Anderson and Gregory, 2000). Based on laboratory experiments, Jobling (1988) observed that the growth rate of cod decreased about 8- 10% for each °C decrease in temperature. Hence the lack of correlation at age one and the negative correlation at age 2 between a cohort's average length as juveniles and its average length at ages 1 and 2, respectively, may be caused by east-west differences in temperature regimes. Jorgensen (1992) found that the growth trajectories for cohorts of Arcto-Norwegian cod are approximately linear and parallel from age 2 to age 8, which implies, as Jorgensen points out, that a cohort that grows more slowly until age 2 will attain a lower average length as adults than a cohort that grew more quickly before age 2.

Since the abundance of O-group cod is positively correlated with its average length (Ottersen, 1996; Ottersen and Loeng, 2000), an alternate hypothesis for the negative correlation between a cohort's average length at the O-group stage and its average length at older ages may be density-dependent growth after settlement. Jorgensen (1992) was not able detect (or reject) density-dependent growth for ages 1 through 8 Arcto-Norwegian cod. Therefore, unless density affects growth during the short period between settlement and age one, the likely reason for the slowing of growth after settlement by a cohort consisting of large, on average, juveniles is the relatively cold temperatures that many in the cohort experience after settling in the eastern Barents Sea.

References

Adlandsvik, B., and Loeng, H. 199 1. A study of the climatic system in the Barents Sea. Polar Research, 10(1): 45-49.

Anderson, J. T., and Gregory, R. S. 2000. Factors regulating survival of northern cod (NAFO 2J3KL) during their first 3 years of life. Journal of Marine Science, 57: 349-359.

Anonymous. 1983. Preliminary report of the International O-group fish survey in the Barents Sea and adjacent waters in August-September 1980. Ann. Biol. 37: 259-266.

Baraenkova, A. S. 1957. Comparative abundance of year classes of cod and. haddock in the Barents Sea according to the quantitative estimation of the young fish and the data on fisheries. Trudy PINRO, 10: 54-77 (in Russian).

Bergstad, 0. A., Jorgensen, T., and Dragesund, 0. 1987. Life history and ecology of the gadoid resources of the Barents Sea. Fisheries Research, 5: 119-161.

Brander, K. M. 1994. Patterns of distribution, spawning, and growth in North Atlantic cod: the utility of inter-regional comparisons. ICES Marine Science Symposia, 198: 406-413.

Campana, S. E., and Hurley, P. C. F. 1989. An age- and temperature-mediated growth model for cod (*Gadus morhua)* and haddock (*Melanogrammus aeglefinus*) larvae in the Gulf of Maine. Canadian Journal of Fisheries and Aquatic Sciences, 46: 603-613.

Draper, N. R., and Smith, H. 1981. Applied Regression Analysis. Second edition. Wiley and Sons. New York. 709 pp.

Ellertsen, B., Solemdal, P., Strømme, T., Sundby, S., Tilseth, S., Westgård, T., and Øiestad, V. 1981. Spawning period, transport and dispersal of eggs from the spawning area of Arcto-Norwegian cod (*Gadus morhua* L.). Rapports et Procès-verbaux des Réunions du Conseil International pour l'Exploration de la Mer. 178: 260-267.

Ellertsen, B., Fossum, P., Solemdal, P., Sundby, S., and Tilseth, S. 1987. The effect of biological and physical factors on the survival of Arcto-Norwegian cod and the influence on recruitment variability. *In* The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea. Proceedings of the third Soviet-Norwegian symposium, Ed by Loeng, H. Murmansk, 26-28 May 1986, Institute of Marine Research, Bergen, Norway, pp 101-126.

Ellertsen, B., Fossum, P., Solemdal, P., and Sundby, S. 1989. Relation between temperature and survival of eggs and first-feeding larvae of Northeast Arctic cod (*Gadus morhua* L.). Rapports et Prods-verbaux des Reunions du Conseil International pour l'Exploration de la Mer, 191: 209-219.

Haug, A., and Nakken, 0. 1977. Echo abundance indices of O-group fish in the Barents Sea. 1965-1972. Rapports et Procès-verbaux des Reunions du Conseil International pour l'Exploration de la Mer. 170: 259-264.

Helle, K. 2000a. Distribution of the copepodite stages of *Calanus finmarchicus* from Lofoten to the Barents Sea in July 1989. ICES Journal of Marine Science (in press).

Helle, K. 2000b. The influence of biological and Physical processes on early juvenile Arcto-Norwegian cod (*Gadus morhua* L.) with special emphasis on zooplankton abundance. Dr. Scient. thesis. University of Bergen, Norway, 113 pp.

Helle, K., and Pennington, M. 1999. The relation of the spatial distribution of early juvenile cod (*Gadus morhua* L.) in the Barents Sea to zooplankton density and water flux during the period 1978 - 1984. ICES Journal of Marine Science, 56: 15-27.

ICES, 1987. Preliminary report of the International O-group fish survey in the Barents Sea and adjacent waters in August-September 1996. ICES CM 1987/G: 38, 31pp.

ICES, 1996a. Preliminary report of the International O-group fish survey in the Barents Sea and adjacent waters in August-September 1995. ICES CM 1996/G: 30, Ref H, 37 pp.

ICES, 1996b. Preliminary report of the International O-group fish survey in the Barents Sea and adjacent waters in August-September 1996. ICES CM 1996/G: 31, Ref. H. 37 pp.

ICES, 1998. Preliminary report of the International O-group fish survey in the Barents Sea and adjacent waters in August-September 1998. 26pp.

ICES, 2000. Report of the Arctic Fisheries Working Group. ICES CM 2000/ ACFM: 3, 312 pp.

Jakobsen, T., Korsbrekke. K., Mehl, S. and Nakken, O. 1997. Norwegian acoustic and bottom trawl surveys for demersal fish in the Barents Sea during winter. ICES CM. 1997/Y: 17.26 pp.

Jobling, M. 1988. A review of the physiological and nutritional enefgetics of cod, *Gadus morhua* L., with particular reference to growth under farmed conditions. Aquaculture, 70: 1 - 19.

Jorgensen, T. 1992. Long-term changes in growth of North-east Arctic cod (*Gadus morhua*) and some environmental influences. ICES Journal of marine Science, 49: 263-277.

Loeng, H., Ozhigin, V., and Adlandsvik, B. 1997. Water fluxes through the Barents Sea. ICES Journal of Marine Science, 54: 3 10-3 17.

Maslow, N. A. 1944. The bottom fishes in the Barents Sea and their fisheries. Trudy PINRO, 8: 3-186 (In Russian).

Maslow, N. A. 1960. Soviet fisheries investigations. North European seas, Moscow, pp 185-231.

Michalsen, K., Ottersen, G., and Nakken, 0. 1998. Growth of North-eastern Arctic cod (*Gadus morhua* L.) in relation to ambient temperature. ICES Journal of Marine Science, 55: 863-877.

Muchina, N. V., Muchin, A. I., and Dvinina, E. A. 1987. Oceanographic conditions and reproduction of Arcto-Norwegian cod of the Barents Sea in 1980-1985. *In* The effect of oceanographic conditions on distribution and population dynamics of commercial fish stocks in the Barents Sea. Proc. 3rd Soviet-Norwegian Symposium, Murmansk, 26-28 May 1986, p. 145-158. Ed. by H. Loeng. Institute of Marine Research, Bergen, Norway. 250 pp.

Nakken, 0. 1994. Causes of trends and fluctuations in the Arcto-Norwegian cod stock. ICES Marine Science Symposia. 198: 212-228.

Nakken, O., and Raknes, A. 1996. Corrections of indices of abundance of O-group fish in the Barents Sea for varying capture efficiency. ICES C.M. 1996/G: 12.

Nesterova, V.N. 1990. Plankton biomass along the drift route of cod larvae (reference material). Murmansk: PINRO 64 pp. (In Russian).

Ottersen, G. 1996. Environmental impact on variability in recruitment, larval growth and distribution of Arcto-Norwegian cod. Dr. scient. Thesis, Geophysical Institute, University of Bergen, November 1996, 136 pp.

Ottersen, G., and Loeng, H. 2000. Covariability in early growth and year-class strength of Barents Sea cod, haddock and herring: the environmental link. ICES Journal of Marine Science, 57(2): 339-348.

Ottersen, G., Michalsen, K., and Nakken, 0. 1998. Ambient temperature and distribution of north-east Arctic cod. ICES Journal of Marine Science, 55: 67-85.

Ozhigin, V. K.. and Ushakov, N. G. 1985 The effect of the thermal conditions of the sea and atmospheric circulation on the distribution of the Barents Sea capelin feeding areas. In Proceedings of the-Soviet-Norwegian Symposium on the Barents Sea capelin, pp 149- 156. Ed. by H. Gjøsæter. Institute of Marine Research, Bergen, Norway.

Pedersen. T.. and Jobling, M. 1989. Growth rates of large. sexually mature cod, ***Gadus marhua,*** in relation to condition and temperature during an annual cycle. Aquaculture, 81: 161-168.

Randa, K. 1982. Recruitment indices for the Arcto-Norwegian Cod for the period 1965-1979 based on the international O-group fishery. ICES CM 1982/G:53. 22pp.

Randa, K. 1984. Abundance and distribution of O-group Arcto-Norwegian cod and haddock 1965- 1982. *In* Proceedings of the Soviet-Norwegian Symposium on Reproduction and recruitment of Arctic Cod. Leningrad, 25-30 September 1983, pp. 192-2 12. Ed. by 0. R. Godø and S. Tilseth. Institute of Marine Research, Bergen.

Sætersdal, G., and Loeng, H. 1987. Ecological adaptation of reproduction in Northeast Arctic cod. Fisheries Research, 5: 253-270.

Sundby, S. 2000. Recruitment of Atlantic cod stocks in relation to temperature and advection of copepode populations. Sarsia, in press.

Sundby, S., Bjørke, H., Soldal, A. V., and Olsen, S. 1989. Mortality rates during the early life stages and year-class strength of Northeast Arctic cod (*Gadus morhua* L.). Rapports et Prods-verbaux des Reunions du Conseil International pour l'Exploration de la Mer, 19 1: 35 I-358.

Sundby, S. and Bratland, P. 1987. Spatial distribution and production of eggs from Northeast-arctic cod at the coast of Northern Norway 1983-1985. Fisken og Havet, (1): l-58. (English abstract).

Suthers, I. M., and Sundby, S. 1993. Dispersal and growth of pelagic juvenile Arcto-Norwegian cod (*Gadus morhua*), inferred from otolith microstructure and water temperature. ICES Journal of Marine Science, 50: 261-270.

Tereshchenko, V. V. 1996. Seasonal and year-to-year variations of temperature and salinity along the Kola meridian transect. CM 1996/ C: 11, 24 pp.