LONG-TERM VARIATIONS IN THE AGE COMPOSITION AND GROWTH RATES OF THE BARENTS SEA COD (*Gadus morhua morhua*)

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Cod (*Gadus morhua morhua*) is a valuable commercial fishery species in the North Atlantic and West Arctic. The species has a very spacious distribution area within which specialists identify several independent stocks. The Arctic-Norwegian (Lofoten-Barents) or the Northeast Arctic stock which inhabits the Barents Sea and adjacent waters is the northernmost and most abundant.

The Arctic-Norwegian cod fishery has been continuing since the early 20th century. The most intensive exploitation began after the Second World War and attained its maximum in 1951 - the 1960s (Fig.1).

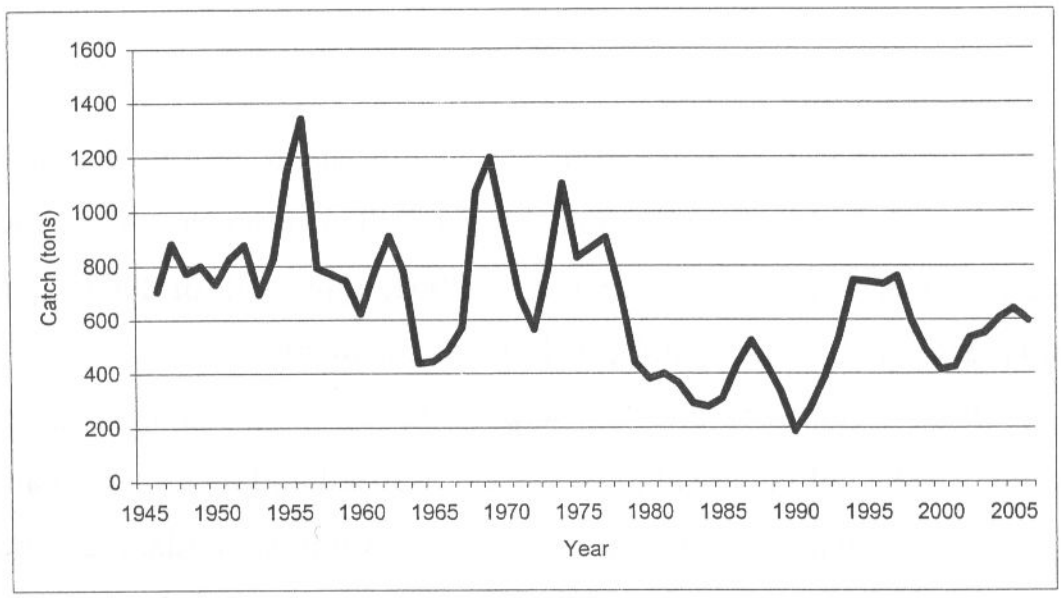

Fig.1. The Arctic-Norwegian cod landings in 1945-2005

In the 1970s, the total catch of cod stabilized at the mean long-term level. Poor year-classes emerged at the end of the 1970s and caused the cod stock diminishing in the 1980s. According to estimates of the ICES WG on Arctic Fisheries, current cod stocks are at the level close to the mean long-term one and demonstrate a slight tendency for increase. Meanwhile, commercial fishery data

indicate that cod stocks have considerably increased by now (Borisov & Kotenev, 2005).

This paper presents discussion of the current age composition and growth rates of the Arctic-Norwegian cod. The obtained results are compared with historical data to identify factors which could affect the cod growth rates.

MATERIALS AND METHODS

This work is based on observations collected during research/commercial cruises aboard the mid-sized fishing vessels within the framework of Research project on interannual dynamics of biomass, state, and distribution of demersal fish stocks in the North basin in 2002 - 2006. Catches were taken with commercial bottom trawls.

Cod age was determined by the otolith lateral section crossing the core which was baked with an alcohol lamp (Chilton, Bemish, 1982). Overall, the analyzed samples totaled 1,721 ind. in 2002; 1,446 ind. in 2003; 3,461 ind. in 2004; 3,807 ind. in 2005; and 1,904 ind. of cod in 2006.

Fishing grounds and, consequently, the sampling sites are presented in Fig.2. The collected samples were classified and analyzed in accordance with the following traditional division of fishing grounds: the South Barents Sea (68-74° N; 26-52° E), the Central Barents Sea (74-79° N; 26-52° E), and the Bear- Spitsbergen area (73-77° N; 12-26° E).

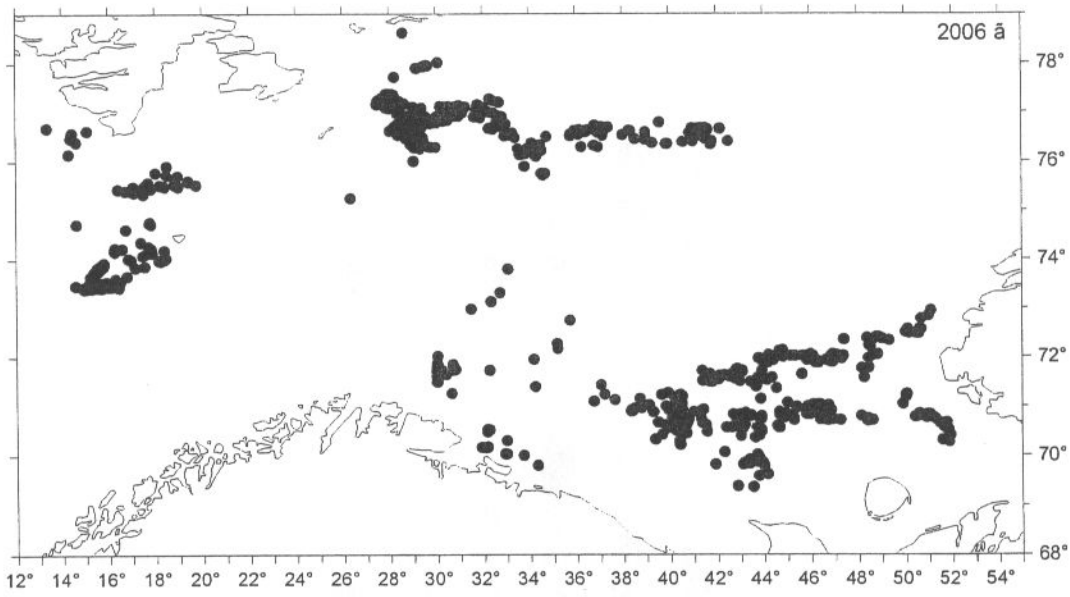

Fig.2. Cod sampling sites, 2002-2006

RESULTS AND DISCUSSION

Cod age composition

Catches included individuals at age 1 - 18. During the surveyed period, the bulk of samples were collected in the South Barents Sea. Cod aged between four and eight made the largest share in catches from this region (Fig.3). In 2002 and 2004, the modal group was made by five-year-old individuals, while in 2003 and 2005 it included individuals six years old. In 2006, the age group distribution in commercial catches differed from the usual one, which could possibly be associated with peculiarities of the cod vertical distribution in the second half of the year. According to researchers aboard commercial fishing vessels, that period was characterized by absence of dense aggregations of cod in the bottom layer; on the contrary, the species concentrated at the depth of 25-30 m above the bottom. Possible variations in bathymetric distribution of various generations could affect the size-at-age composition of the bottom trawl catches in 2006.

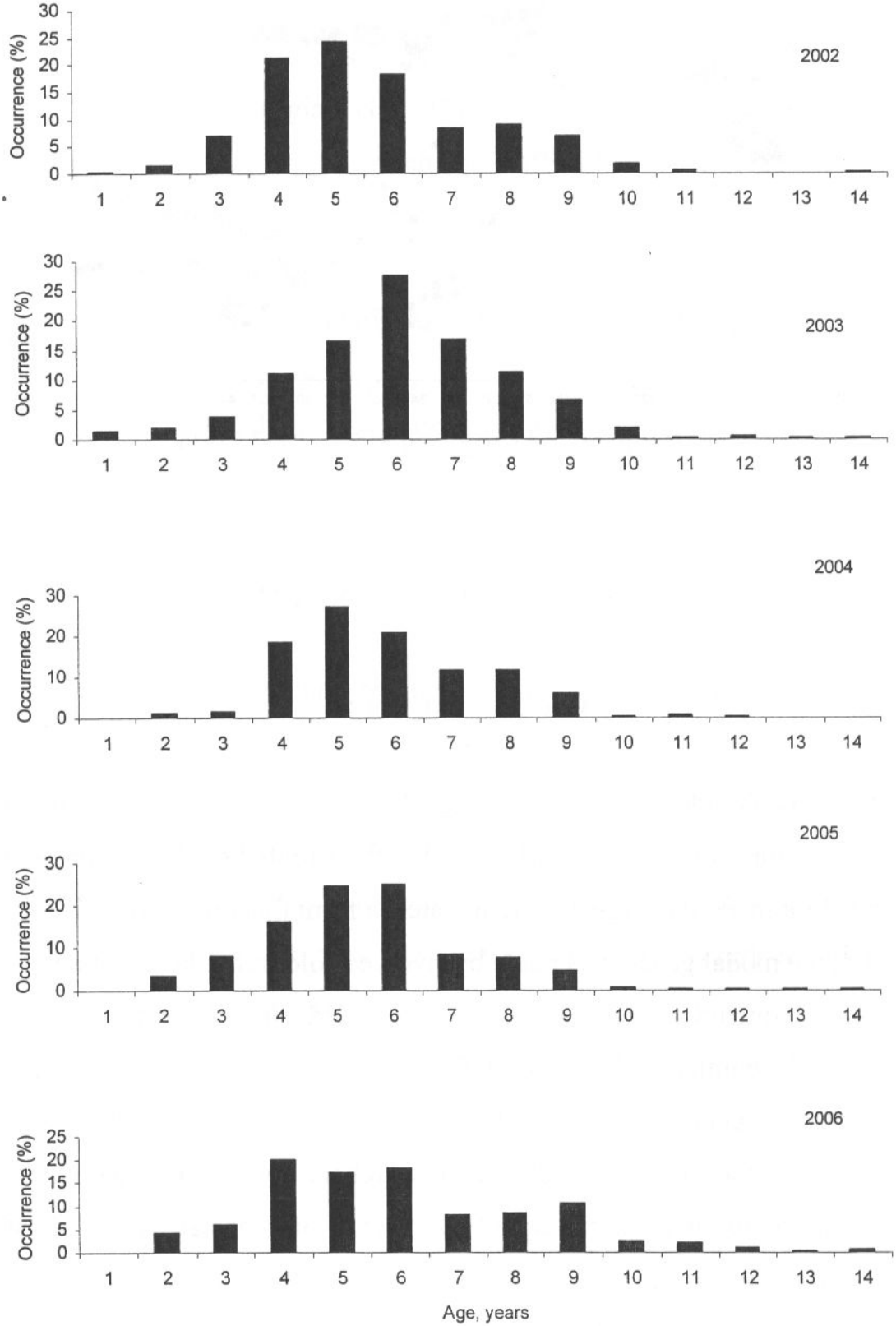

Fig.3. Age composition of cod in the South Barents Sea, 2002-2006.

During the surveyed period, the 1997 generation in the South Barents Sea was of particular interest as it was playing a significant role in the cod fishery for a number of years. In 2002, this year-class at age 5+ made 24% of the cod number in catches, in 2003 it attained 28%, while in 2004 this generation made 12%, with the further decline down to 7% in 2005 and then a slight increase up to 10% in 2006. In 2004-2005, the 1999 generation became prominent with its 27% of catches in 2004 and 25% in 2005. This generation of cod was also recorded in the Bear- Spitsbergen area, where it made 33% (2004) and 29% (2005) (Fig.4).

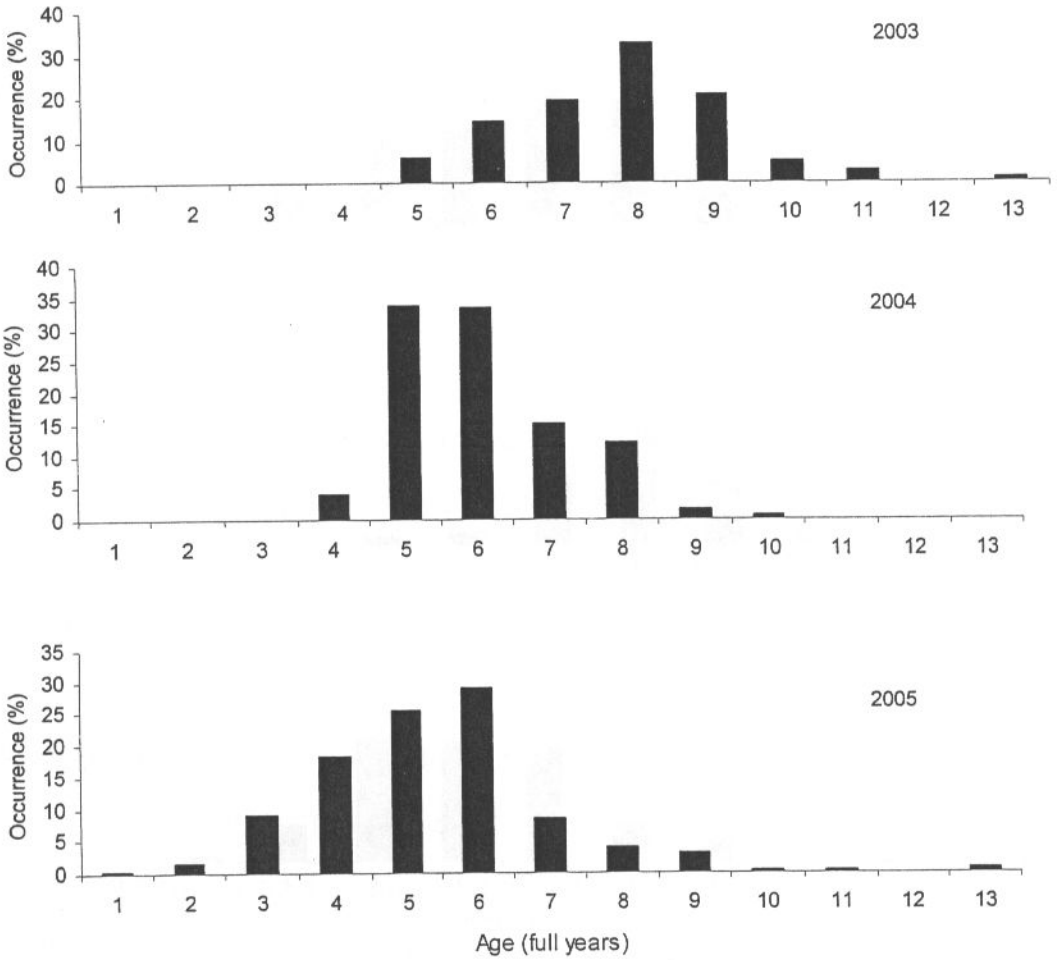

Fig.4. Age composition of cod in the Bear- Spitsbergen area, 2003-2005 гг.

As to the Central Barents Sea, in 2002, the trawl catches were dominated by cod at age 4-6. In 2004-2005, the largest percentage of catches was made by individuals at age 5-6, while in 2006, cod aged between 6 and 8 exceeded 70% of catches taken in this area (Fig.5).

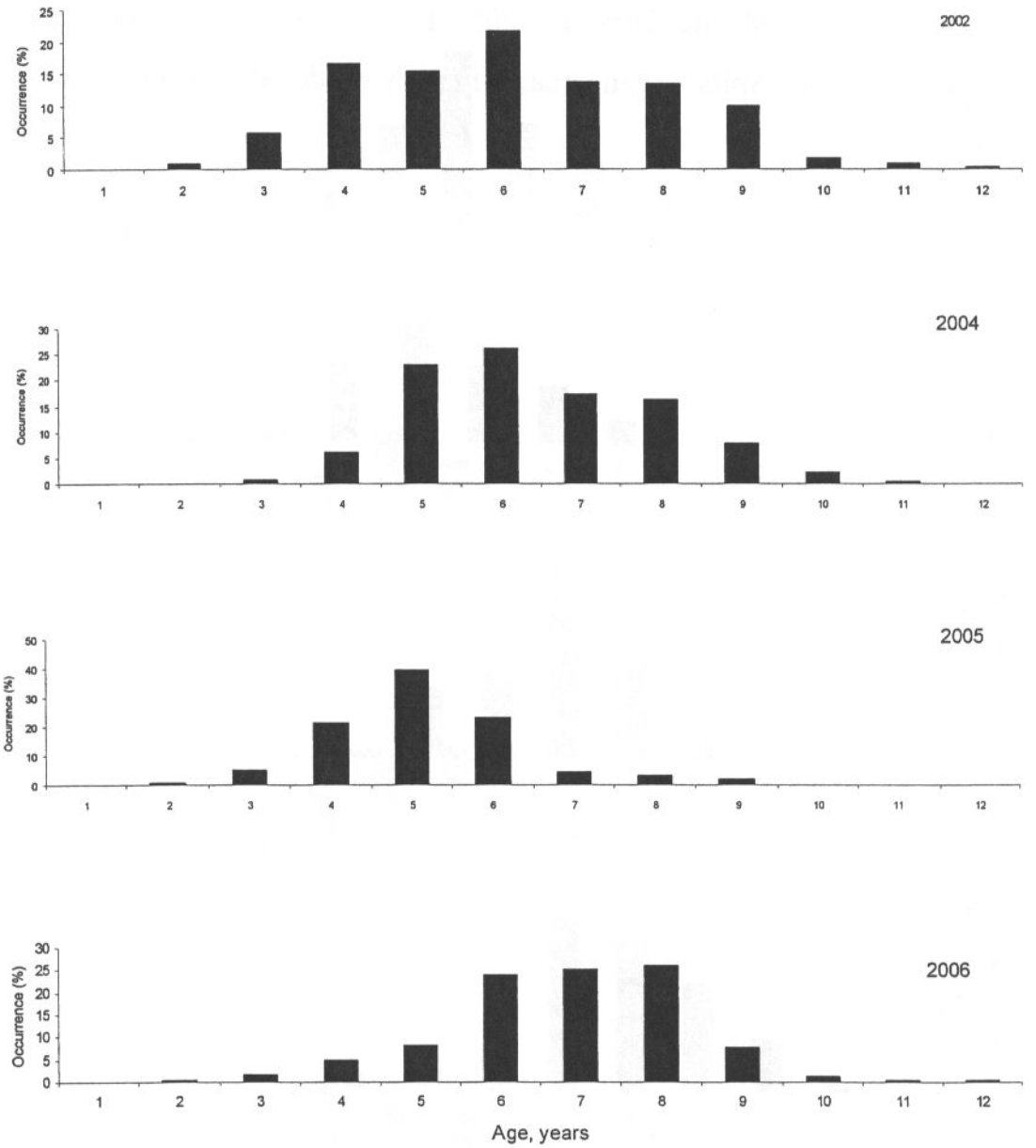

Fig.5. Age composition of cod in the Central Barents Sea, 2002, 2004-2006

In 1929 when the stock was underexploited, the bulk of cod catches from the South Barents Sea (83%) was made by individuals aged between 6 and 9, the

modal age was seven years (Esipov & Kuchina, 1932). In 1936-1946, cod at age 8-10 made 80% of catches with the modal age of nine years (Glebov, 1963). In the 1950s, the dominating age group was that of cod 8-10 years old, in the 1960s, the biggest percentage made fish 7-8 years old, in the 1970s – cod aged 8 - 9, in the 1980s catches were dominated by cod at age 6-7, in the 1990s, the seven-eight-year-old individuals were predominant (Yaragina, 2006).

Since the last century, the range of age groups has not changed, however, younger age groups have become predominant. While during the period since 1929 till the 1990s, the bulk of catches was made by cod at age 6-10 (the modal age varied from 7 - 9 years), in 2002-2006, the biggest percentage of catches from the southern part of the sea was the 4-8-year-old cod with the modal age of 5-6 years.

Size and weight growth of cod

Cod females from several age groups were somewhat larger than males from the same age groups, however, this difference was generally little. Therefore, the further analysis is proceeding with the mean data.

Neither did comparison of size of cod from the same age groups in different years of our surveys show considerable variations, though in 2005, individuals at age 1 - 4 were a bit larger.

Analysis of the cod size from different fishing grounds revealed that individuals at age 1 - 5 from the Bear- Spitsbergen area were larger than cod of the same age from other areas. Weight of female and male cod from the same age groups was similar to the age of nine inclusive, while in the age group of 10-12 years females were a bit superior in weight. Since the bulk of the fish stock is made by individuals younger than ten, we shall proceed using mean data without differentiation by sex.

The highest rates of size growth characterizes cod in its first two years. After two, cod demonstrates almost linear relationship between age and size (Fig.6).

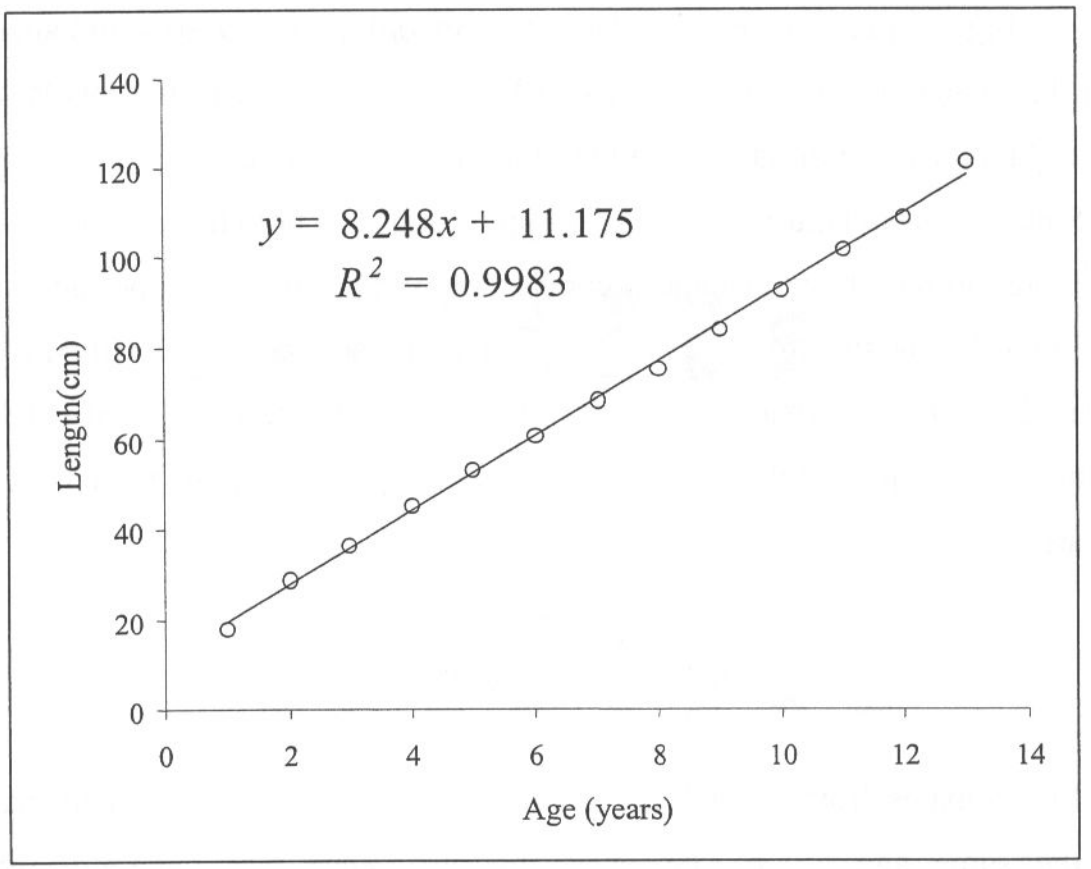

Fig.6. Size growth of cod.

Analysis of the cod weight did not show significant interannual variations between individuals from age groups below ten. In elder age groups the largest weight characterized individuals caught in 2006.

Comparison of weight of even-aged cod caught in different fishing grounds showed that cod under five from the Bear- Spitsbergen area had the largest weight, while after five it had the smallest one. However, these variations were insignificant, therefore, to compare our observations with historical data we united samples from all the areas.

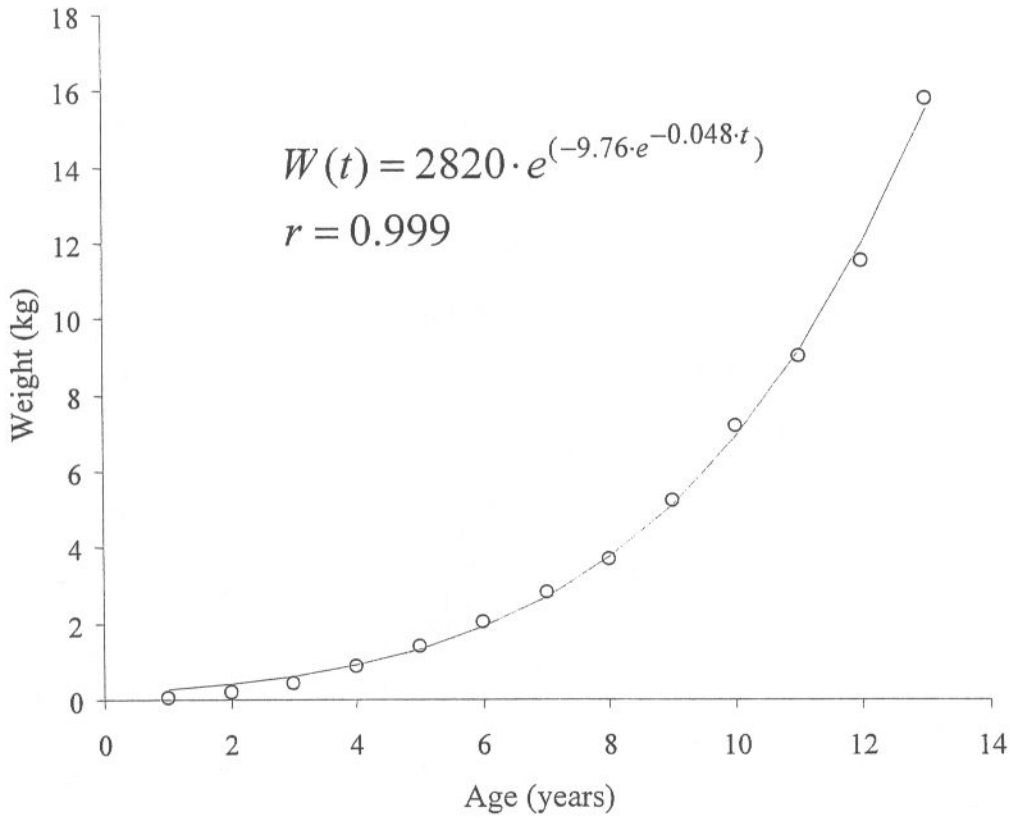

Fig.7. Weight growth of cod.

Growth rates of the cod weight increased gradually with age. The highest weight growth rates were recorded for cod older than eight. Weight growth of cod is well approximated with the Gomperts equation (Fig.7).

All the observed variations in the cod growth, both interannual and geographical, were small and only revealed some trends in the fish growth. Therefore, to compare our observations with historical data we united samples collected in different fishing grounds in 2002-2006 (Table 1).

Studies of long-term variability in the cod size growth were based on data on the cod growth in the 1st half of the last century from the miscellany of fishery studies in the Murman region (Esipov & Kuchina, 1932).

Table 1.

Length and weight of the Barents Sea cod, 2002-2006
(by age groups)

Age	Length, cm (M±m)		Weight, Kg (M±m)		Number		Total	
	Males	Females	Males	Females	Males	Female	Length	Weight
1	19,8±0,63	18,6±0,37	0,057±0,005	0,048±0,003	23	34	19,1±0,35	0,052±0,003
2	30,8±0,26	31,3±0,26	0,237±0,007	0,255±0,007	98	105	31,0±0,18	0,245±0,005
3	37,8±0,16	38,1±0,16	0,467±0,007	0,477±0,007	278	281	37,9±0,12	0,472±0,005
4	45,9±0,11	46,5±0,10	0,849±0,007	0,882±0,006	905	923	46,2±0,07	0,866±0,005
5	53,6±0,07	53,9±0,07	1,344±0,006	1,357±0,006	1413	1418	53,7±0,05	1,351±0,004
6	61,2±0,07	61,6±0,07	1,956±0,009	1,990±0,009	1465	1425	61,4±0,05	1,972±0,006
7	67,9±0,07	68,5±0,07	2,655±0,015	2,705±0,013	729	777	68,2±0,05	2,681±0,010
8	74,1±0,10	75,1±0,11	3,462±0,021	3,577±0,021	699	705	74,6±0,08	3,520±0,015
9	83,1±0,20	84,0±0,16	5,003±0,055	5,142±0,039	292	451	83,6±0,13	5,087±0,032
10	92,8±0,44	93,8±0,28	7,097±0,157	7,498±0,103	49	102	93,5±0,24	7,368±0,088
11	101,8±0,53	102,2±0,27	9,416±0,430	9,952±0,0198	21	50	102,1±0,25	9,793±0,191
12	109±0,67	109,1±0,32	10,567±0,738	12,213±0,358	7	29	109,1±0,29	11,893±0,340
13	114,8±0,33	113,0±0,29	13,524±1,198	12,889±0,432	5	12	113,5±0,30	13,076±0,471
14	123,5±1,06	119,7±0,51	16,015±0,0202	16,107±0,704	2	23	120±0,52	16,099±0,648
15		128,0±1,94		21,816±1,714		5	128±1,94	21,816±1,714
16		138,0±2,12		27,693±3,799		2	138±2,12	27,693±3,799
17		142,0		32,800		1	142,0	32,800
18		148,0		28,700		1	148,0	28,700

Data on the cod growth in 1949 - 1993 were taken from article "The Arctic-Norwegian Cod Growth" (Ozhigin et al., 1996), which analyzed possible impact of various types of the survey trawls on age composition in cod catches and divided the surveyed period into three intervals: 1949-1966, 1967-1980, and 1981-1993. From one interval to another, there was an increase in mean size of cod from the most abundant age groups (three-nine-year-old cod); the authors suggested that this was associated with increase in the mesh size in trawls. It is noteworthy, however, that increase in size characterized not only young fish (this could be explained by selective catch of high growth cod), but also elder cod (aged 8-9), which size growth was the highest. Theoretically, the selective catch of high growth cod from younger age groups would cause decrease (not increase!) in size of elder fish. The selective catch of high growth cod from younger age groups results in decrease in size of elder fish in consecutive years, in accordance with positive relationship between the fish size at younger and

elder age. Given the genetic component in the cod growth rate determination, the selective catch of high growth cod contributes to the general decrease in the cod growth rates. Hence we could well consider these data on the surveyed periods objective population characteristics, particularly for cod from mid- and elder age groups. It this context, it is especially interesting to compare our data on the current cod growth rates with historical ones.

The highest size growth rates of the cod aged between 3 and 9 were recorded in 1981-1993 (Fig.8). Cod at age 3 - 5 had similar size in all surveyed periods, except the first one, i.e. in 1981-1993. The smallest fish aged 6 - 9 was recorded in 1908 and 1914 when the stock was underexploited.

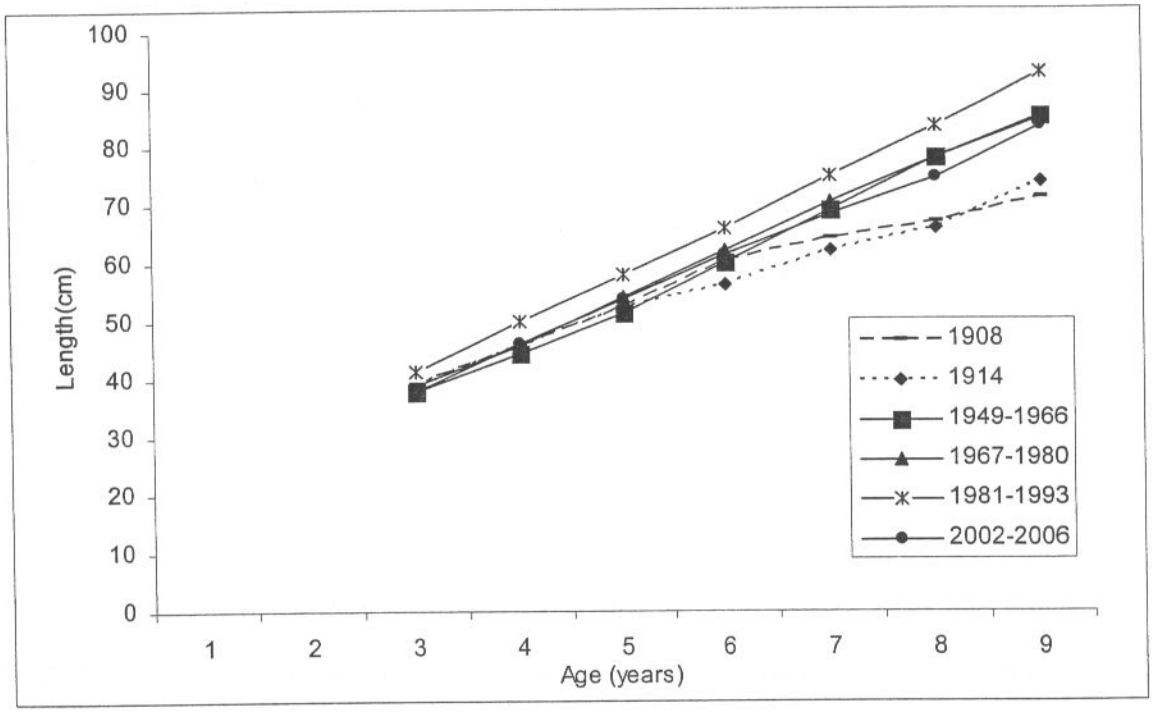

Fig.8. Size growth of cod in various periods

Comparison of data on the cod growth in 2002-2006 with earlier periods revealed correspondence in the size-at-age values between current cod catches and those taken in 1949-1980 and a significant decrease in size, compared to 1981-1993.

Similar results were yielded by comparison of the cod mean weight in 2002-2006 with respective data on 1949-1993. There is correspondence between the current cod size-at-age values and those from 1949-1980, and decrease in weight compared to the period of 1981-1993 (Fig.9).

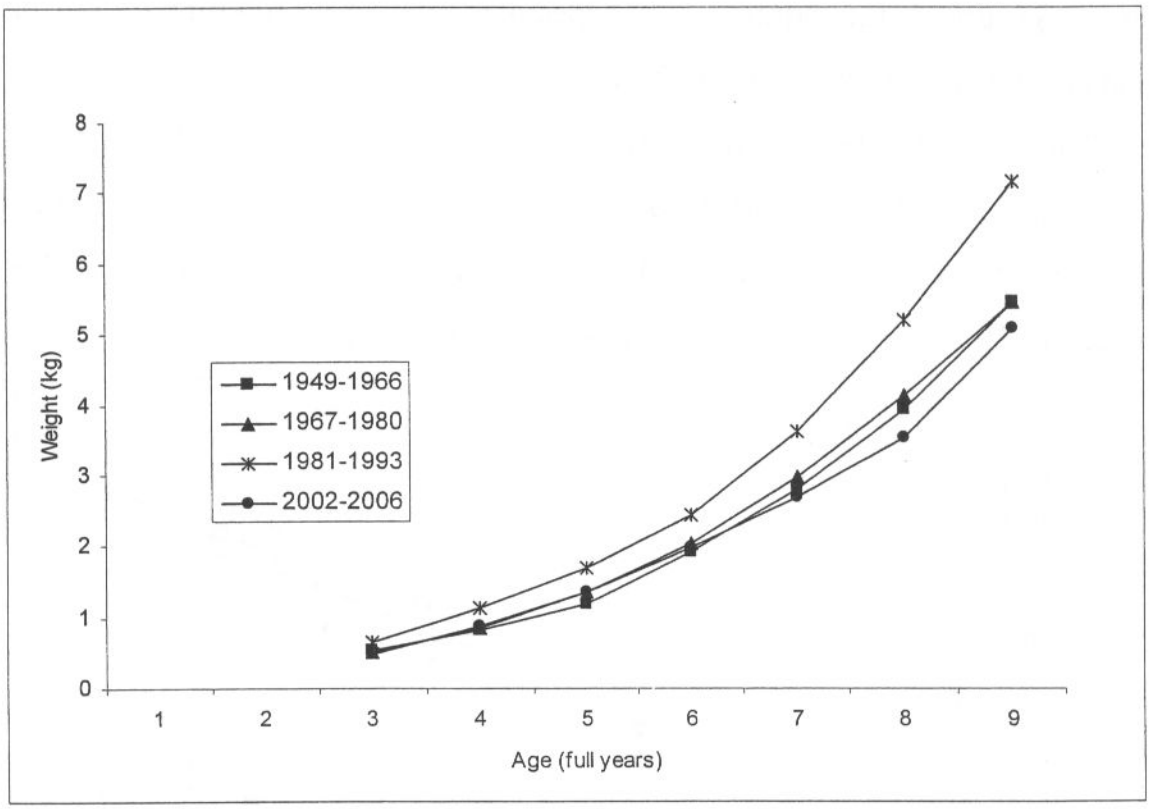

Fig.9. Weight growth of cod in various periods

Since the late 1930s till the mid-1950s, there was an increase in the cod growth rates resulted from intensification of metabolic processes which was associated with the North Atlantic warming up (Dement'eva & Mankevich, 1966). In consecutive years the cod growth rates continued to increase despite a persistent cooling of the Barents Sea (Boitsov et al., 2003). Therefore, many specialists consider that the principal cause of the cod growth speedup was lower concentrations of stocks and, consequently, better food supplies (Ponomarenko, 1968; Ponomarenko et al., 1985).

Current slowdown in the cod growth, compared to 1981-1993, could not be explained by climatic variations. Mean annual SST along the Kola meridian

is considerably higher than both the mean long-term value (Sostoyanie syr'evyh biologicheskih resursov ..., 2006) and the SST recorded in 1981-1993 r. (Fig.10). Generally, when the water temperature varies in a wide range the fish growth accelerates along with the temperature growth. We should note, however, that it is very difficult to determine in situ relationship between the water temperature and the cod growth rates (Ozhigin et al., 1995).

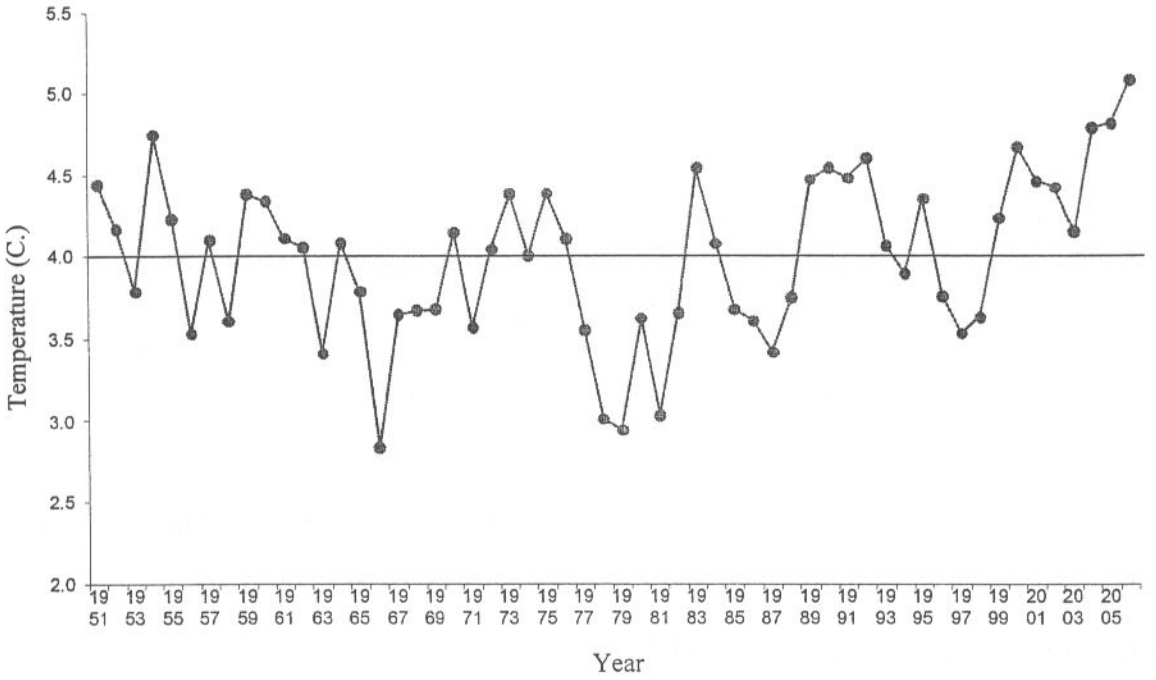

Fig.10. Mean annual water temperature in the layer of 0-200 m, the Kola meridian (PINRO).

Comparison of data on the cod growth rates with available information about the food supplies (biomass of capelin and zooplankton, Fig.11) failed to reveal any clear relationship. Low rates of the cod growth in 1908 and 1914 could be associated with a high density of the cod population which was only exploited to a limited extent.

Consequently, from among the discussed factors we could single out density as being particularly important. It is likely that the current increase in cod catches is associated with increase in the stock abundance which has badly affected the cod growth rates.

Another possible cause of the cod growth slowdown is selectivity of the trawl fishery. Increase in the trawl mesh size from 90 mm (before 1961) to 125 mm (since 1981) primarily contributes to the high growth cod capture. Though we have reasonable grounds to think that intensive non-selective fishery could accelerate the cod growth and maturity (Borisov, 1978), in the course of time such measures controlling selectivity could have a contrary impact on the fish stock composition.

CONCLUSION

In 2002-2006, trawl catches of cod included individuals at age 1 - 18. The core of the fish stock in all the areas was formed by four-eight-year-old cod. Taking into consideration the age composition of the cod catches, we could note that the year-class of 1997 continued to be the most prominent in commercial catches for four years. The age composition of the cod catches together with a stable high output of fishing vessels indicate good recruitment to the fish stock during the surveyed period of 2001-2006.

The range of age groups has not changed since the last century, however, younger age groups have become predominant. While during the period since 1929 till the 1990s, the bulk of catches was made by cod at age 6-10 (the modal age varied from 7 - 9 years), in 2002-2006, the biggest percentage of catches from the southern part of the sea was the four-eight-year-old cod with the modal age of 5-6.

Comparison of data on the cod size growth in 2002-2006 with earlier periods revealed correspondence in the size-at-age values between current cod catches and those taken in 1949-1980 and a significant decrease in size, compared to 1981-1993. Cod aged between six and nine was only small-sized in 1908 and 1914 when the stock was underexploited. Comparison of data on the cod weight growth yielded similar results. Current slowdown in the cod growth

has occurred despite the ongoing warming up which should have contributed to increase in the growth rates.

Available data on food ssupplies (biomass of capelin and zooplankton) failed to explain the observed changes.

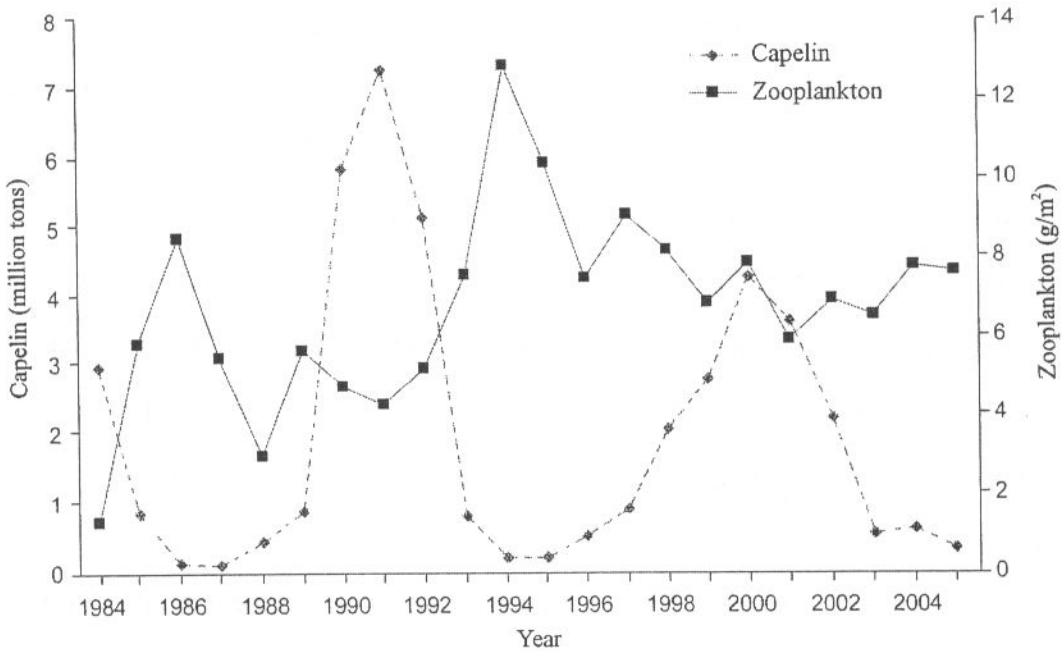

Fig.11. Biomass of capelin and zooplankton in the Barents Sea, 1984-2004 (IMR/PINRO, 2006).

Obviously, from among the discussed factors we could single out density as being particularly important. It is likely that the current increase in cod catches is associated with increase in the stock abundance which has badly affected the cod growth rates. Another possible cause of the cod growth slowdown is selectivity of the trawl fishery which primarily captures high growth cod.

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