

Paper I

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Cod in Faroese waters.

3.5 Cod in Faroese waters

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Background and physical environment

Commercially, cod is the most important demersal species in the catches from the Faroe area. Catches back to 1903 are shown in Figure 3.5.1. Since 1906, total catches have fluctuated between 6000 and 45 000 tonnes. With the exception of the World War periods, the proportion caught by the Faroese was rather low until 1970, but it then increased.

The habitat of cod, as well as the whole ecology of Faroese waters, is dominated by the location of the islands on the submarine ridge system between Scotland and Greenland, which separates the warm Atlantic waters from the cold waters of northern origin. In the northern part of the area, the Iceland-Faroe Ridge has a sill depth around 500 m while the southern part of the ridge system, the Wyville-Thomson Ridge, has a sill depth around 600 m (Figure 3.5.2). The Faroe-Shetland Channel separates the Faroe Plateau from the Scottish

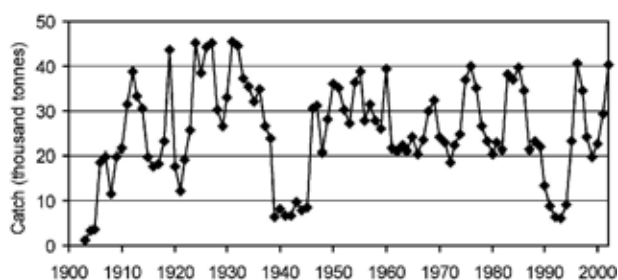


Figure 3.5.1. Annual catches of cod for the Faroe area (ICES Division 5).

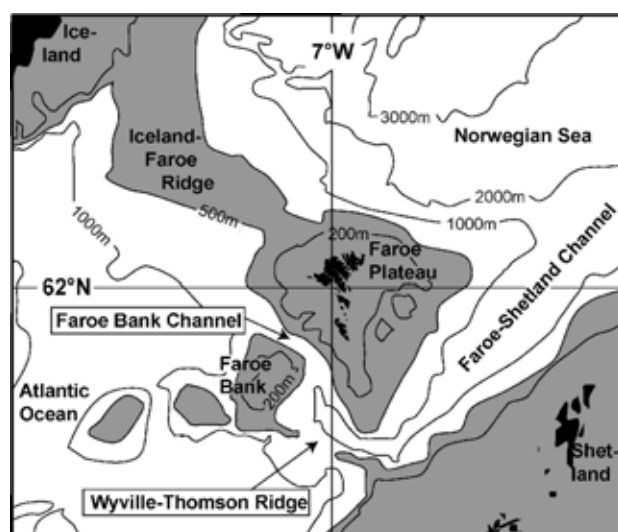


Figure 3.5.2. Bottom topography of Faroese waters (gray areas are shallower than 500 m).

continental shelf, whereas the Faroe Bank Channel, with sill depth around 840 m, separates the Faroe Plateau from the Faroe Bank.

The upper layers of the waters surrounding the Faroes are dominated by "Modified North Atlantic Water" (MNAW) which derives from the North Atlantic Current (Hansen and Østerhus, 2000). This water has typical temperatures of around 8°C and salinities of around 35.25. The general circulation pattern of the area (Figure 3.5.3) transports this water past the Faroes on all sides, but in the Norwegian Sea, north of the Faroes, the Iceland-Faroe Front separates it from the water carried by the East Icelandic Current. This water is much colder (temperature around or below 4°C) and fresher (salinity below 34.9). In the upper layers, it is only found north of the Iceland-Faroe Front, but at deeper levels to the north and east of the Faroes, this water may be found mixed into the MNAW in increasing amounts down to depths of 300 to 500 meters. Deeper than 500–600 m (Figure 3.5.3, bottom panel), the water northeast of the ridges is cold ($T < 0^\circ\text{C}$) with salinities close to 34.9. Only the region north of the Faroe Bank and west of the Iceland-Faroe Ridge is in the deeper parts dominated by Atlantic water, and even in that region, one finds colder water derived from overflow through the Faroe Bank Channel and across over the Iceland-Faroe Ridge.

All the hydrographic observations, that have been made during more than a century, have shown the Iceland-Faroe Front to be so far north of the Faroes, that the waters on the Plateau and on the banks have had comparatively small variations in temperature and salinity, although cold intrusions from the frontal region may occasionally reach the shelf region (Hansen and Meincke, 1979). Contributing to this stability are the almost closed anticyclonic circulation systems (Figure 3.5.3, top panel), which are known to dominate the shallower regions at least on the Faroe Bank (Hansen *et al.*, 1986) and on the Faroe Plateau (Hansen, 1992). The persistence of these flows results in long retention times for both the water and the planktonic organisms over the shallower regions; and the fact that the circulation over the Faroe Bank is separate from the circulation over the Plateau may explain how the two cod stocks can remain distinct. On the Faroe Plateau, there are indications that there may be more than one gyre, but detailed knowledge on this is lacking, as is knowledge on the vulnerability of the gyre systems to storms or abnormal weather conditions.

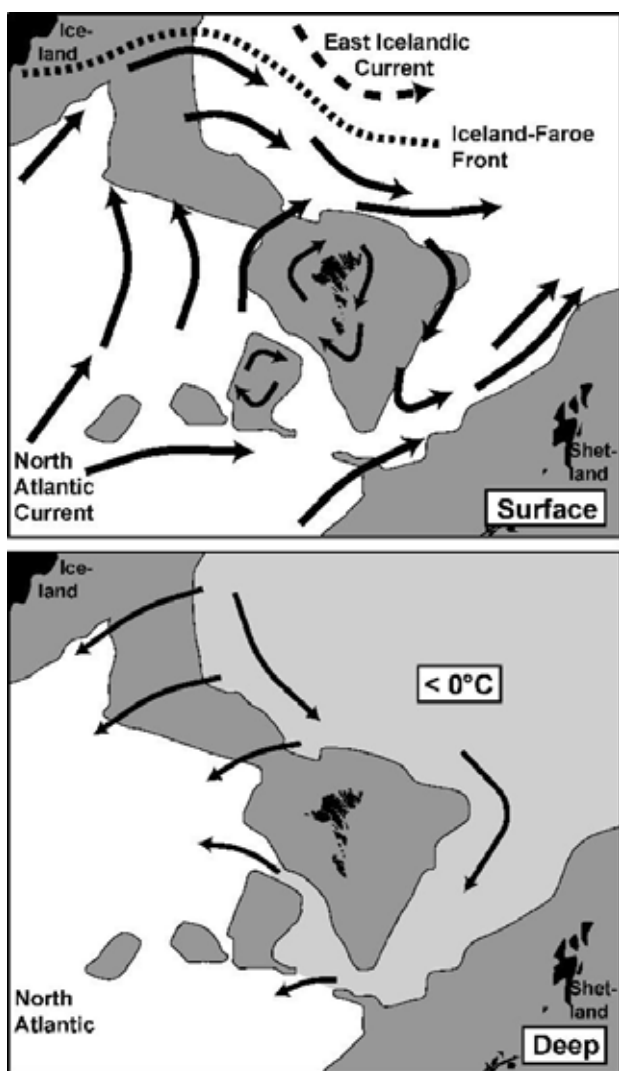


Figure 3.5.3. Circulation and water masses at the surface (top panel) and at depths greater than about 500 m (bottom panel). On top panel, thick continuous arrows indicate flow of Atlantic water. Thin continuous arrows indicate quasi-closed circulations on the shallow parts of the Faroe Plateau and Faroe Bank. On bottom panel, light grey areas indicate cold water flowing towards and across the ridges. Dark grey areas on both panels are shallower than 500 m.

In the shallow regions, there are strong tidal currents, which mix these waters very efficiently. This results in a difference between the vertically almost homogeneous shelf water and the offshore waters, which become stratified in the warmer seasons (Figure 3.5.4). On infrared satellite pictures the border between these two regimes is seen as a distinct front both on the Faroe Bank and on the Plateau. These three regimes (well-mixed, frontal, and stratified) give different conditions for primary production, but little is known about production cycles in Faroese waters, except for the shallow parts of the Faroe Plateau, and much more work is required to establish an understanding of these cycles and their dependence on the very variable weather conditions in the region.

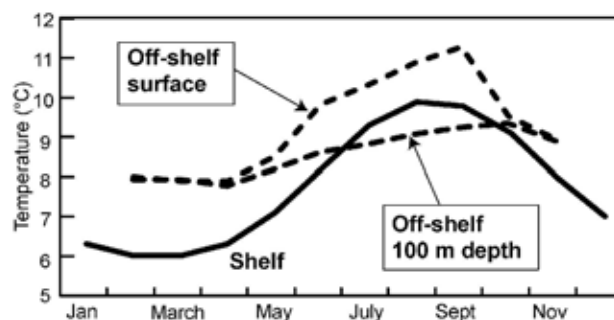


Figure 3.5.4. Seasonal temperature variation on the shallow parts of the Faroe shelf 1914–1969 (continuous curve) and at two depths on a station off-shelf (in the Faroe Bank Channel) 1982–1997.

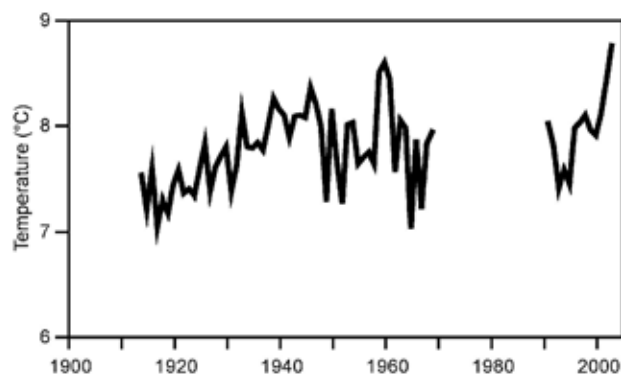


Figure 3.5.5. Annually averaged temperature on the shallow parts of the Faroe shelf based on measurements at two coastal stations.

From the beginning of the 20th century, hydrographic investigations have been made in Faroese waters, but irregularly. In the late 1980s three standard sections were established and one more was added in 1994. They are occupied at least four times a year. These sections were designed to coincide as closely as possible to the sections often occupied in the historical data set. Shore-based daily temperature measurements were initiated in 1875 in Tórshavn and moved in 1914 to Mykines, where they continued until 1969. A critical analysis (Hansen and Meincke, 1984) indicates that the Mykines series gives reliable annual averages for the shallow waters on the Faroe Plateau. These measurements were discontinued in 1969, but an automatic temperature recording station was established in 1989, close to the Mykines site. Together, these series give a long-term perspective on the temperature development on the Faroe shelf (Figure 3.5.5).

Stock and geographic distribution

Extensive tagging experiments have demonstrated the existence of two cod stocks in the Faroe area, one on the Faroe Plateau and one on Faroe Bank (Strubberg, 1916; Tåning, 1940; Joensen, 1954; Jones, 1966). Schmidt, (1930) has shown that cod on the Faroe Bank have a lower number of vertebrae than cod on the Plateau and concluded that the stock on Faroe Bank and that on the

Plateau are two different stocks. Analysis of serum protein by Jamieson and Jones, (1967) supports this thesis. In the assessment of cod in the Faroe area, the cod on the Faroe Bank and that on the Plateau are therefore treated as two different stocks.

The catch figures shown in Figure 3.5.1 are for the total Faroe area between 1903–1960 and for the Faroe Plateau between 1961–2002. Catches on the Faroe Bank since 1965 are shown in Figure 3.5.6. They reached a maximum of 5000 tonnes in 1973. The cod fishery in the Faroe area collapsed in 1990 and was historically low in 1991–1994. The cod stock recovered in the mid-1990s and the catch figures have shown the normal pattern since then.

Data to assess the cod stock on the Faroe Plateau are available back to 1961 and limited attempts have been made to assess the Faroe Bank cod stock. Mean fishing mortalities for the age groups 3 to 7 of Faroe Plateau cod, estimated by virtual population analysis are shown in Figure 3.5.7. From 1961–1973 the fishing mortality decreased from 0.6 to 0.3 and fluctuated between 0.4 and 0.8 from the mid-1970s to 1990. After the collapse, the fishing mortalities were especially low (< 0.34) but they increased steeply after the recovery of the cod stock and have fluctuated between 0.36 and 0.9 since then. With the present exploitation pattern, F_{max} is estimated to be 0.41 and $F_{0.1}$ to be 0.25.

The estimated recruitment as two year old and the estimated spawning-stock biomass are shown in Figure 3.5.8. With the exception of the 1972, 1973, 1982, 1993, and 1999 year classes, the recruitment has fluctuated between 3 and 30 million. The long term recruitment is estimated at 18 million. A series of poor, or average, year classes during 1984–1991 was observed prior to the collapse of the fishery. The spawning-stock biomass increased from 1961 to 1976 when it reached the highest observed value (116 000 tonnes). It peaked again in the mid-1980s when the strong 1982 year class became sexually mature. During the collapse in 1990–1994, the spawning-stock reached the lowest observed value of 22 000 tonnes in 1992. The spawning-stock biomass then increased spectacularly and reached 86 000 tonnes in 1996 when the strong 1993 year class entered the fishery. At the beginning of 2002, the spawning-stock was estimated at 69 000 tonnes.

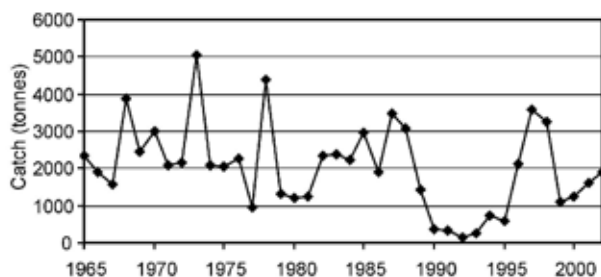


Figure 3.5.6. Annual catches of Faroe Bank cod.

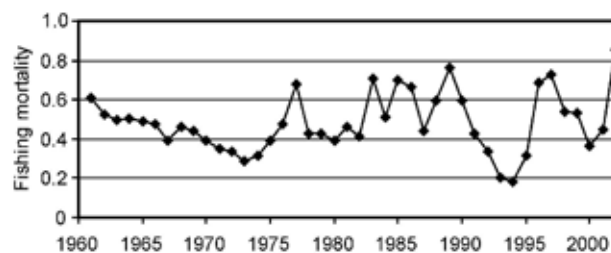


Figure 3.5.7. Mean fishing mortality for Faroe Plateau cod of age 3–7 years.



Figure 3.5.8. Spawning-stock biomass and recruitment as 2 year old for Faroe Plateau cod.

Time of spawning

Tåning (1943) and Joensen and Tåning, (1970) state that spawning takes place from February to May with April being the most important month. Analysis of roelandings (Hoydal and Reinert, 1978) and length distributions of pelagic larvae and juveniles (Reinert, 1979; Hansen *et al.*, 1990) verified this spawning period but indicated a mean spawning in the second half of March. Data from the Faroese Groundfish Surveys 1982–1989 have been used to estimate the timing of gonadal development and spawning. According to these data, spawning on the Plateau starts at a low level in February. In the second half of March, most of the sampled cod have been spawning. No data are available for the first half of February for the Faroe Bank but in the second half, the proportion spawning is at the same level as that on the Plateau. The lower proportion of spawning cod and higher proportion of maturing cod in March on the Faroe Bank compared to the Plateau indicates a prolonged spawning period on the Faroe Bank.

Location of spawning

Spawning takes place all around the Faroe Plateau at depths of about 80–180 m and at temperatures of 6–7°C. By far the most important spawning grounds are to the north and west of the islands (Figure 3.5.9). It should be mentioned that there seems to be a delay of about one month between the main spawning of the three main demersal gadoids in the area, with main spawning time of saithe in the second part of February, of cod in the second part of March and of haddock in mid-April (Joensen, 1954; Joensen and Tåning, 1970).

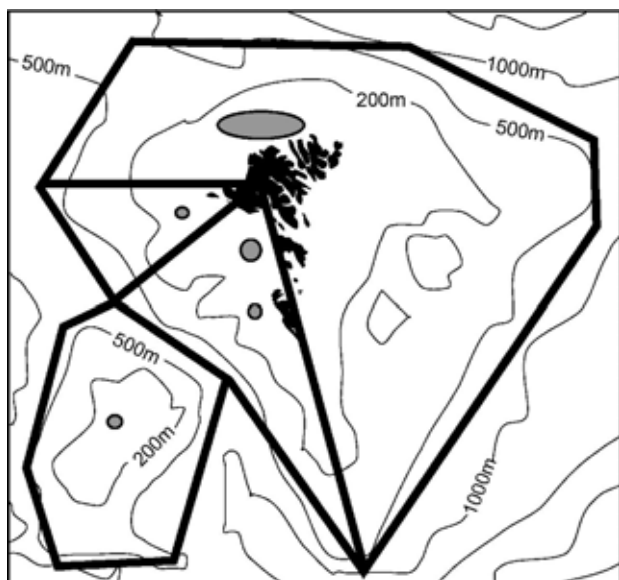


Figure 3.5.9. Spawning of Faroese cod. Thick lines roughly divide the waters shallower than 500 m into four regions. Mature cod in each of these regions, migrate to the spawning areas, indicated by gray ellipses within each region.

Biological details

After fertilization, the eggs ascend towards the upper layers. The eggs are advected by the clockwise circulation around the islands and are dispersed by the strong tidal currents (Reinert, 1979; Gaard, and Steingrund, 2001). On their way from the spawning grounds, the eggs hatch and the cod start feeding. The feeding seems to coincide fairly well with the onset of the spring bloom and the first-feeding larvae predate mainly on copepod eggs. As the larvae and pelagic juveniles grow, they consume progressively larger prey items, which may be copepod nauplii and small- to medium-sized copepods (Gaard and Steingrund, 2001). In mid-summer, having attained a length between 20 and 40 mm, the juveniles to a large extent predate on large-sized plankton, mainly the largest copepods and decapod larvae (Gaard, and Reinert, 2002).

In June and early July, the distribution of juveniles shows a characteristic picture on the Plateau, with heavy concentrations near the islands to the north and more scattered in other areas (Jákupsstovu, and Reinert, 1994). The Faroe Plateau seems to be a retention area for eggs and larvae, created by the anticyclonic current system, and a subdivision of this system into several minor gyres could be responsible for the characteristic distribution of the juveniles in June and early July. The current system around the Faroe Bank creates a retention area there as well.

The information on growth in the pelagic phase is scarce. Samples from Bongo, Gulf III and capelin trawl in the late 1970s (Reinert, 1979) indicated a logarithmic growth in agreement with Saville (1956). At lengths of about 3.5-40 cm, the juveniles leave the pelagic phase and most



Figure 3.5.10. Mean length-at-age for cod on Faroe Plateau (1994–2004) and Faroe Bank (1999–2003).

of them migrate into the littoral zone of the fjords. This usually happens after the first week of July. On the Faroe Bank, however, the juveniles settle on the Bank proper, i.e. in relatively deep water.

In late July, the demersal stages, now about 4.5 cm long, are found in the seaweed in the littoral zone. In the middle of August, the mean length is about 5 cm, and in mid-September, it is about 7 cm (Joensen and Tåning, 1970). The growth of cod from 1-year and onwards is shown in Figure 3.5.10.

After 1–2 years in the littoral zone of the fjords, the cod migrate towards deeper waters. Tagging experiments show, however, that the cod is rather stationary while sexually immature, i.e. up to about 3 years (Strubberg, 1916). The food in the littoral zone is mainly crustaceans and the young of other fish species, e.g. saithe and sandeel.

Recruitment

The year-class strength seems to be determined rather late in life, i.e. during the second winter which coincides with the migration towards deeper waters (Steingrund and Gaard, 2005). The bottleneck seems to be food availability in the area, which is determined by the new phytoplankton production (about 6 months before) and the abundance of older cod, i.e. competition. The new primary production during spring and early summer may vary by a factor of five (Gaard, 2003) and the production of cod (numbers \times individual growth summed up for all age groups), which is highly correlated to phytoplankton production (Figure 3.5.11), may vary even more (Steingrund and Gaard, 2005). Thus, the collapse and rapid recovery of the cod stock in the 1990s seems to a large extent to be explained by variation in phytoplankton production.

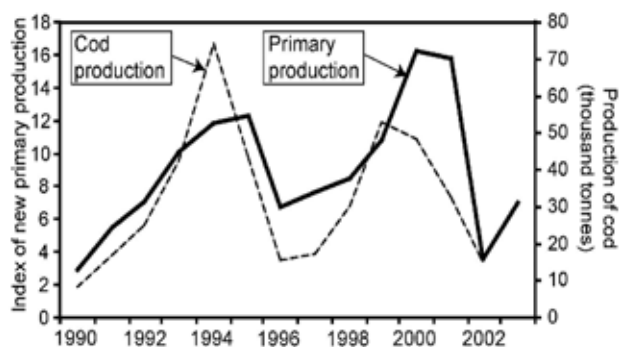


Figure 3.5.11. Index of new primary production on the Faroe shelf and corresponding production of Faroe Plateau cod older than 1.5 years. Updated from Steingrund *et al.*, 2003.

The mechanisms controlling the primary production on the shelf are not well understood. Earlier studies have shown no correlation between primary production (timing of spring bloom or production level) and light irradiance (Gaard *et al.*, 1998; Gaard, 2003). Also, modelling indicates that the spring bloom would have occurred earlier, than it does in nature, if light was the only controlling factor. Hence, other controlling mechanisms appear to be present. Gaard *et al.* (1998) and Gaard (2003) have shown a clear inverse relationship between new primary production and zooplankton biomass (variable influx of the copepod *Calanus finmarchicus* from offshore areas) and it has been hypothesized that the observed plankton variability could be due to variable grazing from *C. finmarchicus*. However, recent modelling studies indicate that the variable exchange rate between on-shelf and off-shelf waters may also be a main controlling factor for the timing and intensity of the spring bloom (Hansen *et al.*, 2004).

Migration

The geographical location of the stock depends on season. During spawning in March, the majority of the sexually mature part of the cod stock is located in two main spawning areas north and west of the Faroe Islands at 80–120 m depth, but other spawning areas also exist (Figure 3.5.9). Earlier tagging results showed that after spawning the fish disperse all over the Plateau (Joensen, and Tåning, 1970). An extensive tagging program, initiated in 1997, has confirmed that after spawning, the cod disperse all around the Faroe Plateau following the prespawning migration routes the opposite way, i.e. the cod move “back home”. The postspawning migration is considered to be a feeding migration. There is evidence of sub-populations, but no data on the genetic relationship between them are available. As cod grow larger, they gradually select deeper waters. Thus, the mean size increases with increasing depth. During summer, the cod have the maximum dispersion covering depths from 10–500 m, but the bulk are normally at depths of 60–150 m.

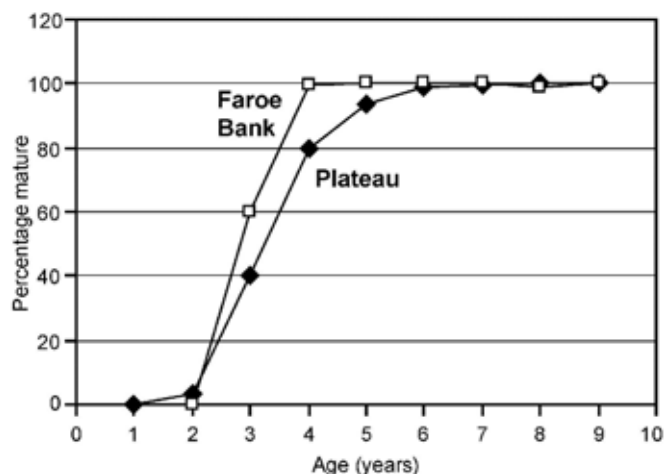


Figure 3.5.12. Average maturity ogives by age for Faroe cod during the period 1999–2003.

Data on feeding and predation are scarce. Joensen and Tåning (1970) describe the cod as feeding on nearly everything they come across and mention fish, crustaceans, worms, mussels, echinoderms, ascidians and hydroids. The most favoured fish species in the food are probably sandeel and herring, but also Norway pout. The abundance of these fish species and their migrations may at times be decisive for the cod migration. Cod stomachs have regularly been collected during March and August since 1997. The results are not published, but they show that cod prey on Crustaceans (Portunidae, Pandalidae, Crangonidae, *Hyas coarctatus*, *Pagurus bernhardus* and *Pagurus pubescens*) as well as fish (Ammodytidae, *Trisopterus esmarkii* and juvenile *Melanogrammus aeglefinus*).

Adult growth

In Figure 3.5.10, the mean lengths-at-age for the two cod stocks in the Faroe area are shown. The figure is based on ages determined from otoliths collected over the period 1994–2004 (Faroe Plateau) or 1999–2003 (Faroe Bank). The Faroe Bank cod grow more rapidly than the Plateau cod. At an age of 3 years, the average length of cod on the Faroe Bank is around 72 cm, while on the Faroe Plateau it is around 53 cm. Cod on the Faroe Bank is one of the cod populations with the fastest growth.

The individual growth of Faroe Plateau cod is density-dependent, but not in the typical sense of the word (many fish – slow growth). The phytoplankton production sets the limits for overall cod production (number of fish \times individual growth summed up for all age groups). Within those limits, individual growth depends on the abundance of cod and may be regarded as density-dependent. Since the annual variation in phytoplankton production is so great, no relationship is found between stock size and individual growth.

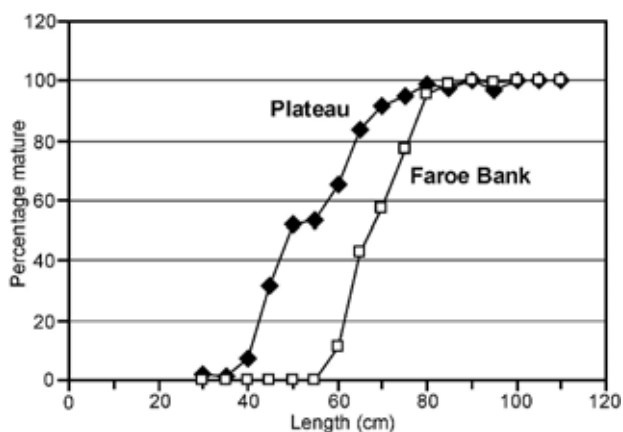


Figure 3.5.13. Average maturity ogives by length (5 cm groups) for Faroe cod during the period 1999–2003.

Very little data have been published on the maturation of cod at the Faroes. Tåning (1943) and Joensen and Tåning (1970) state that, on average, the cod on the Faroe Plateau becomes mature at an age of 4 years while the Faroe Bank cod reaches maturity at 3 years old. Since 1982, samples have been collected during the Faroese groundfish surveys in February and March to estimate maturity ogives. Some of the results are shown in Figure 3.5.12. According to these investigations, there is no large difference in the maturity ogives by ages for cod on the Plateau and the Faroe Bank cod. In both cases, 50% of the cod became mature at an age of 3 years, i.e. one year younger than stated by Tåning (1943) and Joensen and Tåning (1970). The rapid growth of cod on the Faroe Bank and the similar maturity ogives by ages must imply that cod on the Faroe Bank become mature at a larger length as compared to cod on the Plateau, and this is demonstrated in Figure 3.5.13. The 50% maturation length of the Faroe Bank cod was around 65–70 cm while for the Plateau cod it was around 50–55 cm.

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