Paper IX

Steingrund, P., Ofstad, L.H., and Olsen, D. 2003:

Effect of recruitment, individual weights, fishing effort, and fluctuating longline catchability on the catch of the Faroe Plateau cod (*Gadus morhua* L.) in the period 1989-1999.

ICES Marine Science Symposia, 219: 418–420. 2003

Effect of recruitment, individual weights, fishing effort, and fluctuating longline catchability on the catch of Faroe Plateau cod (*Gadus morhua* L.) in the period 1989–1999

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The catch of Faroe Plateau cod fluctuated more in the 1990s than during almost any time in the previous 90 years, and one main aim of this study was to investigate whether the behaviour of cod was anomalous (e.g. large-scale migrations) during these years. It was found that the behaviour of cod was normal in the 1990s (except possibly in 1996) and that variations in recruitment, individual fish weights, fishing effort, and catchability (catch per unit effort divided by stock abundance) were the most important factors that determined the catch of cod. The fluctuating catchability especially applied to longlines where a negative relationship between catchability and individual growth rate of cod was found, indicating that cod preferred longline baits when the abundance of natural food organisms, was scarce. The study also shows that cod production was highly correlated with primary production. This indicates that primary production was the driving force behind recruitment and individual growth and hence the collapse of the cod stock in 1991 as well as its rapid recovery in 1995.

Keywords: catchability, cod production, *Gadus morhua*, growth, individual weights, primary production, recruitment.

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The catch of the Faroe Plateau cod has normally fluctuated between 20 and 40 thousand tonnes (Jákupsstovu and Reinert, 1994). During the period 1991–1994, however, catches were less than 10 thousand tonnes (ICES, 2001). The stock recovered rapidly thereafter (23 and 40 thousand tonnes landed in 1995 and 1996, respectively), and this study investigates the possible causes behind these large fluctuations.

An index of primary production was taken from Gaard *et al.* (2002). Fisheries data on fish weights, recruitment, and fishing mortality were taken from ICES (2001). Age disaggregated catch per unit effort for pair trawlers and longliners (taking the majority of the cod catches) was provided by the Faroese Fisheries Laboratory, Faroe Islands.

When illustrating why the annual catch of cod in a particular year was lower or higher than the average level, four scenarios were performed using different input values for recruitment, fish weights (W), and fishing mortalities (F). The resulting catch in each scenario was calculated and the change in catch between scenarios was taken as a measure of the factor that was changed. In Scenario 1, the input values were held on a constant (average) level, and gave, of course, a constant catch using the formula $W_tN_t(1-\exp(-M-F))(F/(M+F))$, and summing for all ages. The stock numbers were calculated according to $N_{t+1} = N_t\exp(-M-F)$, starting with the number of recruits. In Scenarios 2–4, the recruitment, fish weights, and fishing mortalities, respectively, were changed to the values obtained in the assessment in ICES (2001). The effect of fishing mortality (EF = Catch in Scenario 4 − Catch in Scenario 3) was split into four components.

1) The effect of fluctuating catchability of longlines (Q). First, adjusted longline catchabilities were calculated that corresponded to average fish growth: adjusted catchability = observed catchability − slope × (average growth − observed growth), where the slope was obtained from a simple linear regression of catchability at age versus growth. The effect on catch was calculated as individual weights × observed catch in numbers

for longliners × (adjusted catchability − observed catchability) / observed catchability, and summed for all ages.

2) The effect of unexplained catchability for longliners (UL). In the regression between longline catchability and growth, the difference between observed and predicted values was taken as a measure of unexplained error of catchabilities (probably indicating cod migrations). The catch corresponding to this error was calculated as individual weights × observed catch in numbers for longliners × (predicted catchability − observed catchability) / observed catchability, and summed for all ages.
3) The effect of unexplained catchability for pair trawlers (UP). Since there was no correlation between pair trawler catchabilities and growth, the regression lines had a slope of zero. The catch corresponding to the error was calculated as individual weights × observed catch in numbers for pair trawlers × (predicted catchability − observed catchability) / observed catchability, and summed for all ages.
4) The effect of fishing effort, which was quantified by EF − (Q + UL + UP).

Cod production, resulting from the primary production in year t, was defined as weight increase of the cod population (Pitcher and Hart, 1982): $P_t = N_{t+1} \times (W_{t+1} - W_t)$, where $W_{t+1} - W_t$ denotes the individual weight increase from summer in year t to the next year. N_{t+1} (stock population numbers at 1 January) was used as a proxy for the average number of cod in the time period. The contributions from the ages 2–6 were summed to give the total cod production.

The results show that the low catch at the beginning of the 1990s was caused by a combination of recruitment failure, low individual weights, and low fishing effort (Figure 1). The rapid increase in catch was caused by good recruitment combined with increased growth and fishing effort. In 1996 a substantial part of the catch was caused by high unexplained catchabilities, probably indicating anomalous cod behaviour that particular year. Poor growth in 1997 gave a high catchability with longlines, whereas the opposite occurred in 1995. Figure 1 should be interpreted in a qualitative way, since the results to some extent depended on the way of calculation, e.g. the sequence of the four scenarios, and which longline sets or pair trawler hauls were selected for the c.p.u.e. calculations.

Recruitment and individual weights often co-varied (good recruitment and large weights the same year; Figure 1), corresponding to periods of low and high cod production, respectively. Cod production was highly correlated with primary production (Figure 2), suggesting a direct relationship between primary production, production of food organisms, and cod production. The species composition of food organisms may vary considerably from year to year (unpublished data), making an opportunistic

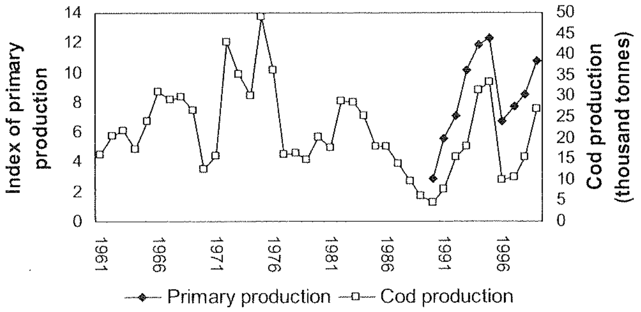

Figure 2. Index of potential new primary production on the Faroe Shelf and corresponding production of 2 to 6-year-old Faroe Plateau cod.

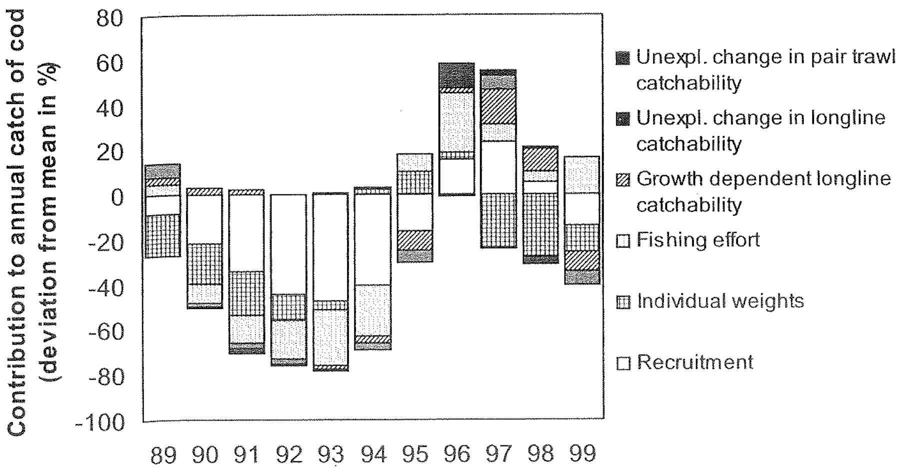

Figure 1. Illustration of the importance of recruitment, individual fish weights, fishing effort, and catchabilities on annual catch of Faroe Plateau cod (deviation from mean).

feeding behaviour necessary in order to capture the energy flow. Also the competition from other fish species, e.g. saithe and haddock, may be limited, since the diet is quite different (unpublished data).

Since the total cod production (production of recruiting cod and older cod) is fixed by the primary production, the recruitment is constrained to certain limits, as the recruiting cod and the older cod are competing for limited food resources. Even if the maximum possible recruitment in a given year is rather well defined (recruiting cod contributing 100% to the total cod production), the actual recruitment is hard to predict, since this depends on early life history of recruiting cod and the outcome of the competition with older cod. Thus both stochastic processes in early life, e.g. match-mismatch (Cushing, 1990), and deterministic processes (e.g. density-dependent mortality) seem to determine recruitment, as found for different cod populations in southern Norway (Fromentin *et al.*, 2001).

Acknowledgements

We thank Dr. Eilif Gaard for providing us with the data on primary production. We also greatly appreciate the comments from two anonymous referees on an earlier version of the manuscript.

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