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The Greenland Cod (*Gadus morhua*) at Iceland 1941–90 and Their Impact on Assessments

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Abstract

Studies have shown cod (*Gadus morhua* L.) in Icelandic waters form a unit stock with very little emigration, while cod from East and West Greenland migrate to Iceland and affect the stock abundance there. Such immigrations have through recent history resulted in the overestimating of the Iceland stock size while underestimating fishing mortality. Noting that for Icelandic cod the catch-at-age peaks at ages 4 or 5 years while immigrations from Greenland causes it to peak again at 7–9 years, Virtual Population Analysis was carried out on Icelandic stock analysis data from the period 1941–90 to determine years where fishing mortalities were higher for the older age groups. Immigrating year-classes through the period were thereby identified, particularly the outstanding 1945 year-class. On the other hand, it was observed that some year-classes emigrating from Greenland had in fact originated from spawning grounds at Iceland and drifted as egg/larvae to Greenland. This demonstrated the importance of information on larval drift.

Key words: Cod, *Gadus morhua*, exploitation pattern, fishing mortality, Iceland–Greenland, migrational rate, stock assessment

Introduction

Tagging experiments at Iceland show that cod (*Gadus morhua* L.) in Icelandic waters are more or less a unit stock (Jónsson, 1990). From more than 100 000 cod tagged since 1948, less than 30 recaptures have been recorded outside the Icelandic fishing grounds (J. Jónsson, pers. comm.). On the other hand, it is well known that cod from Greenland waters, both West and East Greenland stocks, do migrate in some years even on a large scale to Iceland (Hovgård *et al.*, MS 1989; Harden Jones, 1968). These immigrations affect the stock abundance at Iceland and hence the management of the stock. It is therefore important, in order to understand the fluctuations in the stock at Iceland, to be able to distinguish between the two cod stock components, i.e. the Icelandic and the Greenlandic components.

In general there is no exact solution available to the problem at present. Theoretically tagging experiments would solve this under the assumption that all recaptures were available for analysis and that tagging mortality, fishing mortality and natural mortality for both components are known. As these assumptions are never met, analysis of tagging experiments have only provided average estimates (Anon., MS 1981). Other parameters which are different for these stocks, such as otolith structure (Rätz, MS 1990), growth rate etc., have not yet answered this question sufficiently.

In this paper an attempt is made to analyze the immigration by studying the changes in the fishing mortalities for those year-classes at Iceland which are subject to such an immigration.

Materials and Methods

For this analysis, data on catch-in-numbers were available dating back to 1941. Data for the most recent years, i.e. 1971 and later, were basically the same as in Anon. (1991) with some modifications for cod older than 14 years. For the period 1955–70 basic data were the same as in Anon. (MS 1976) but data on the Icelandic fisheries were revised based on detailed information on how catches were distributed by gear and area. Also, mean weights-at-age have been revised to obtain more reliable SOP-figures than those which can be calculated from the data in Anon. (1976). The SOP-values between 1955 and 1970 give much higher landings than in reality. Therefore, mean lengths-at-age available for different fisheries were converted to mean weights-at-age and then weighted by the catch of each fishery to give the final figures of the total fisheries. The revised mean weights were then used for the stock biomass calculations in the above-mentioned period. Estimated catch-in-numbers for the period 1941–52 were entirely based on Icelandic age-length data available at MRI but in some cases never been published or worked up until recently (Schopka in preparation). Prior to 1953, only length composition data were available for the German fisheries but age-composition data were also available for the period 1953–54. By using the Icelandic age-length keys, the German length composition data were used to account for that fishery.

Another important cod fishery at Iceland in those years was that of the United Kingdom (UK). The only available information on that fishery prior to 1955 were catch and effort data by fishing grounds and by time of year. Icelandic age-composition data for the same time and grounds were then used to convert the UK landings into catch-in-numbers data.

For the cod fisheries at Iceland catch-by-age normally reaches a peak at age groups 4 or 5 years. For a typical Greenland year-class entering Iceland grounds, catch in numbers peaks to fish at age 7 or 8 years, or even 9 years in the case of a strong year-class such as the 1945 year-class (Fig.1). From the available catch-in-numbers data an ordinary Virtual Population Analysis (VPA) was run. Input fishing mortality (F) for the oldest age group was chosen as 0.5 but terminal Fs in 1990 were the same as in Anon. (1991). It turned out that, as expected for some year-classes, Fs for the younger age groups were extremely low. Based on the assumption that the exploitation pattern had not changed, it was expected that Fs for these age groups should not be lower than for the surrounding year-classes at same age and the difference can be explained as an effect of an immigration. To account for this, F on these age groups can be increased. In the present paper, F was increased to a level of a similar order as that of the surrounding year-classes at the same age, or to a level representing the likely fishing pattern. An example of the method for the 1960–64 year-classes is shown in Tables 1 and 2. It should be noted that the underlined F-values in Table 2 were chosen as input values. If groundfish survey data or effort data are available, F values can be selected by tuning (Gunnar Stefánsson, Marine Research Institute, Iceland, pers. comm.). In the case of Icelandic cod, such data were only available for the most recent years. It can of course be argued that the F-values chosen here are not the right ones, but it is the author's opinion that they can be seen as fairly realistic.

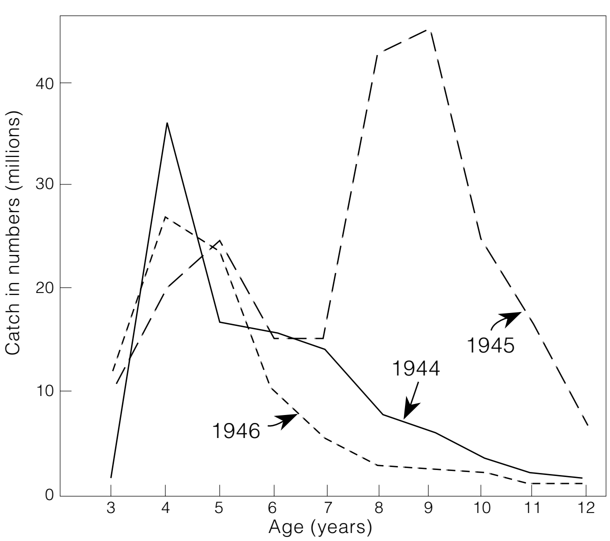

Fig. 1. Cod at Iceland: catch-at-age for the 1944–46 year-classes.

TABLE 1. Cod at Iceland: F-at-age from an ordinary VPA run for the 1960 to 1964 year-classes.

	Year-class				
Age	1960	1961	1962	1963	1964
3	0.12	0.08	0.10	0.08	0.09
4	0.28	0.17	0.20	0.16	0.25
5	0.41	0.16	0.24	0.19	0.40
6	0.42	0.13	0.25	0.22	0.40
7	0.52	0.27	0.31	0.30	0.52
8	1.08	0.44	0.57	0.38	0.60
9	0.76	1.05	0.60	0.70	0.68
10	0.69	1.11	1.03	1.11	1.04

TABLE 2. Cod at Iceland: F-at-age from a VPA run where F-values have been in- creased to account for the im-migration of 1961–63 year-classes.

	Year-class				
Age	1960	1961	1962	1963	1964
3	0.12	0.11	0.12	0.10	0.09
4	0.28	0.25	0.24	0.23	0.25
5	0.41	0.27	0.31	0.30	0.40
6	0.42	0.24	0.35	0.40	0.40
7	0.52	<u>0.60</u>	<u>0.50</u>	<u>0.50</u>	0.52
8	1.08	<u>0.70</u>	<u>0.70</u>	<u>0.70</u>	0.60
9	0.76	1.05	<u>0.80</u>	0.70	0.68
10	0.69	1.11	1.03	1.11	1.04

Results

Applying the revised fishery mortalities led to the identification of the following year-classes as having a high number of immigrants from Greenland: 1936, 1937, 1938, 1942, 1945, 1950, 1953, 1956, 1961, 1962, 1963, 1973 and 1984 (Fig. 2). It is quite possible that some cod from other year-classes might well have also migrated to Iceland, but if they existed those migrations would have been so small that they could not be detected from the usual noise in the data.

Most abundant of all the Greenland year-classes in the period in question was the outstanding 1945 year-class. According to landings from this year-class in the late-1940s and the beginning of the 1950s, this year-class turned out to be of an aver-

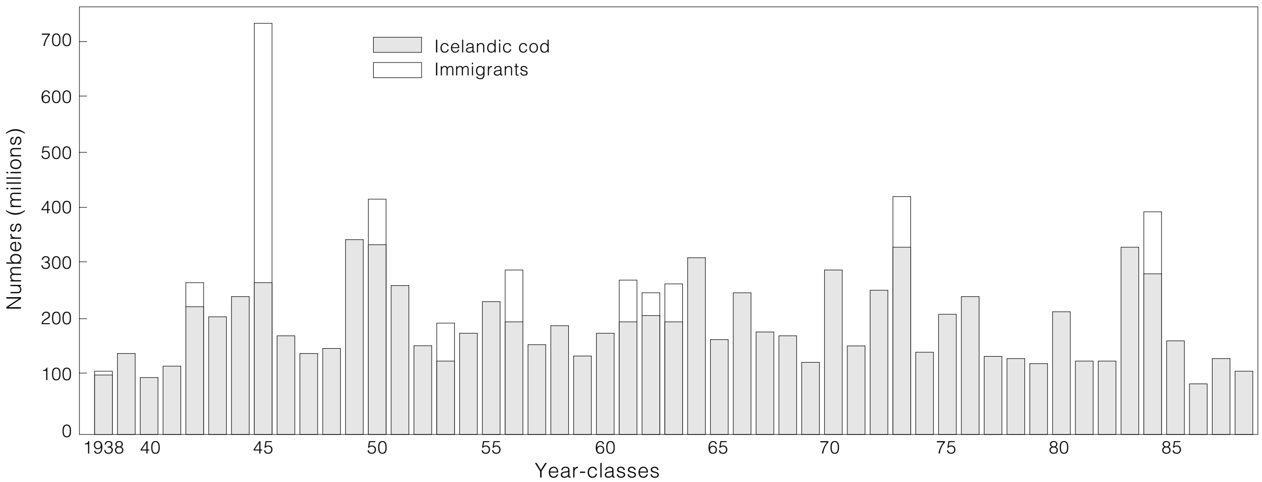

Fig. 2. Cod at Iceland: year-class size at age 3.

age size at Iceland. However, suddenly in 1953 and the following years, this year-class showed up in large quantities on the spawning grounds off the southwestern coast of Iceland (Fig. 1). According to the present analysis, two thirds of this year-class on Iceland grounds were immigrants from Greenland (Fig. 2). For other Greenland year-classes, around one third or less of the year-class size at Iceland were immigrants from Greenland.

In years prior to 1970 when Greenland year-classes were more frequent at Iceland, one or more Greenland year-classes could be found at the same time in the stock at Iceland every year. In such cases the VPA overestimates the stock size at Iceland considerably, as the VPA back-calculates the immigrants and Icelandic cod as one single stock and also includes the immature young cod component still at Greenland as a part of the Icelandic immature stock at Iceland (Fig. 3).

The impact of the immigrants on the assessment is greater than reflected by year-class strength only. This is due to the fact that the immigrants are almost entirely large mature cod, which have more impact on the biomass estimate of the stock than on the stock size in numbers. Thus, for example, let us look again on the 1945 year-class. If no fish of the 1945 year-class had immigrated in 1953, the expected biomass of 8-year-old fish would have been around 200 000 tons. The large scale immigration changed that figure to more than 900 000 tons of 8-year-old fish.

The migration of an immigrating year-class is normally spread over 2–3 years and therefore more than one immigrating year-class can be present at the same time in the stock at Iceland. This further increases the discrepancy in the back–calculations of the stock. The difference was greatest in the years around 1950 when the actual stock biomass at Iceland was overestimated by 40-60%. When the 1973 and 1984 year–classes immigrated to Iceland, the stock biomass was overestimated by 15-20% (Fig. 3).

Even though the fishing mortality at younger ages of an immigrating year-class is lower than for the surrounding year-classes, the average unweighted fishing mortality for the most exploited age groups does not differ much when comparing the Icelandic stock component to the combined estimates (Fig. 4). On the other hand, if fishing mortality is weighted by the year-class strength, a much larger difference appears compared to unweighted fishing mortality depending on the magnitude of the immigration and the relative year-class strength at Greenland and Iceland. This was especially pronounced in early-1950s.

Discussion

According to the analysis presented here, immigrations took place more often prior to 1970 than during the last two decades. This might be connected to a much poorer state of the stock at Greenland especially West Greenland after 1970. On the other hand, the last three year-classes which emigrated from Greenland, i.e. 1963, 1973 and 1984 year-classes, were all known to be of Icelandic origin to some extent. They were described to have drifted as eggs/larvae from the spawning grounds at Iceland (Anon. 1976, Vilhjálmsson and Magnússon 1984). Due to lack of research information prior to 1963, no observation have been reported on larval drift from Iceland. However, it may be concluded that since the three above-mentioned year-classes were of Icelandic origin, the other previous immi-

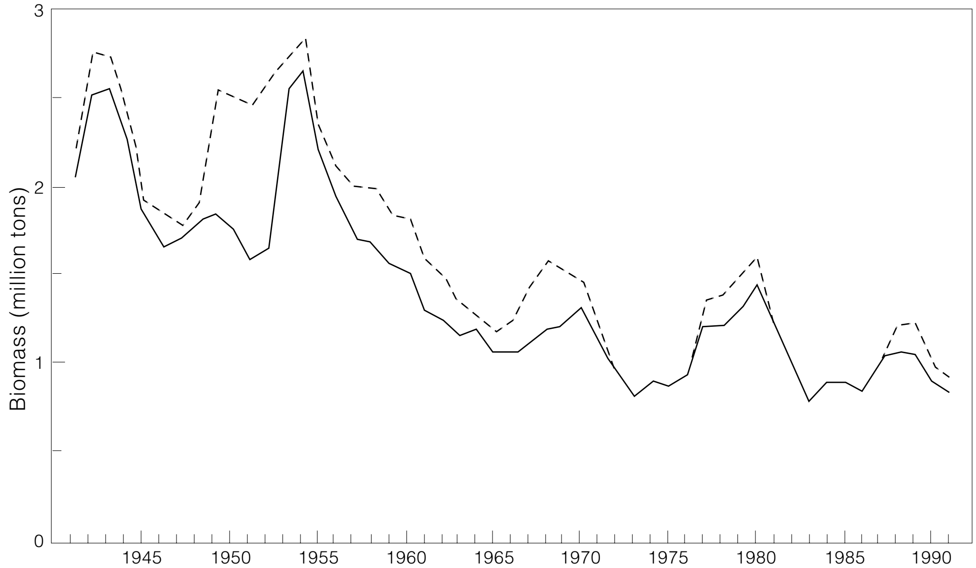

Fig. 3. Cod at Iceland: stock biomass estimates. Broken line: ordinary VPA run; solid line: VPA run based on expected or likely fishing mortality at Iceland. This line should reflect the stock biomass at Iceland each year.

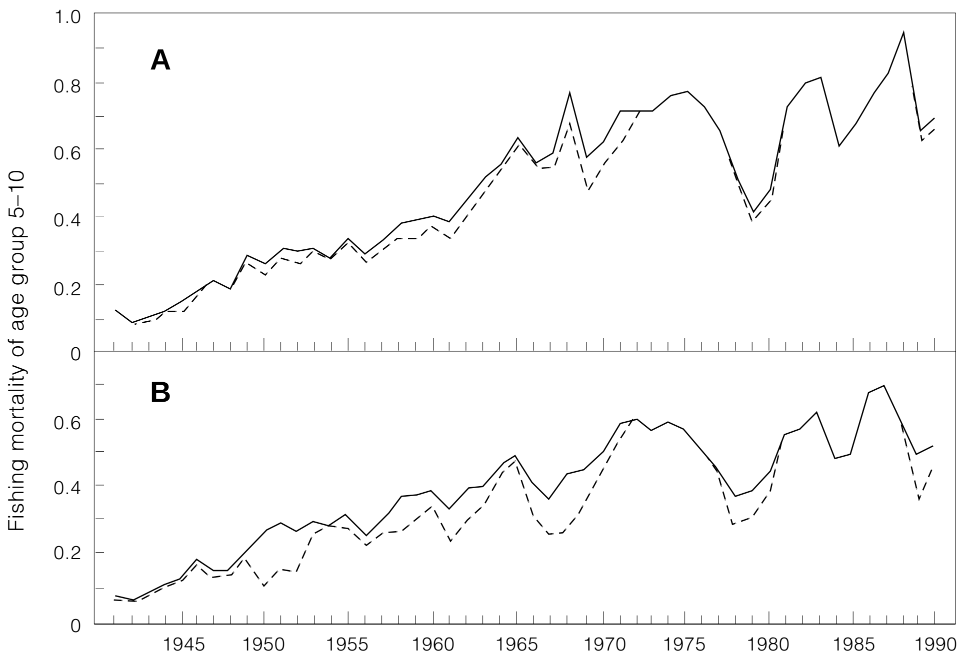

Fig. 4. Cod at Iceland: (**A**) unweighted mean fishing mortality for the age groups 5–10; (**B**) weighted mean fishing mortality for the age groups 5–10. Broken lines: ordinary VPA run; solid lines: VPA run based on expected or likely fishing mortalities at Iceland.

grating year-classes could also have originated from the spawning at Iceland. If this is the case, the decline in frequency of larval drift towards Greenland may be caused by changes in the environment and/ or be connected with the reduction of the stock at Iceland.

From the year-class strength shown in Fig. 2, the size of the year-class at age 3 has fluctuated by a factor of 7. It should, however, be noted that the year-class strength in Fig. 2 only reflects the numbers in the stock at Iceland. A part of the year-classes which drifted to Greenland were exploited there and therefore the actual size of these year-classes are underestimated. If data are available for the Greenland fisheries, it might be possible to shed some light on the actual size of these year-classes. When studying the stock recruitment relationship for the cod stock at Iceland or fluctuations in the recruitment in relation to the environment, such information is important.

Even though calculation from tagging experiments at Greenland indicate an average emigration rate of 0.5 at West Greenland and a value of 0.29 at East Greenland (Anon., MS 1981), the emigration fluctuates considerably between years depending on year-class strength, age-at-maturity, etc. Other year-classes than those defined here as immigrating year-classes might also have included some migrants, but in comparison to the stock size at Iceland, two or three million immigrants are hardly detectable and do not affect the assessment at all.

More serious consequences for the stock assessment at Iceland could happen when a strong immigrating year-class does show up on the Icelandic grounds. This was not a problem earlier when fishing was unlimited and VPA was unknown. At that time everybody, including the fishery scientists, was happy if more fish were seen on the fishing grounds. After the stock declined and the fishery needed to be restricted, immigrants posed an extra problem for the assessment of the stocks and hence the management. In 1980 and 1981, the 1973 year-class showed up in large quantities on the spawning grounds off the southwest coast of Iceland. Back-calculations by VPA showed an increase in the stock size of the younger ages of the year-class, and hence the fishing mortality in the years 1977–79 decreased in the new analysis compared to the assessment made the year before.

As this was shortly after the extension of Icelandic fisheries jurisdiction which led to the sharp reduction of non-Icelandic fishing effort in 1977 and 1978, this decline in fishing mortality (weighted Fs was used at that time) was consequently interpreted as a part of the overall reduction of the fishing effort, and the impact of the immigration which could not be quantified very well at that time was underestimated. The cod stock at Iceland was therefore thought to be in a better state, i.e. larger biomass and lower fishing mortality, especially on the younger age-groups. Total allowable catch (TAC) recommendations for 1982 of 450 000 tons was based on that assessment. Even though cod catches were somewhat restricted at that time (effort limitations), the stock was in such bad shape that the total catch (388 000 tons in 1982) did not reach the recommended TAC.

It is important both for the assessment and management of the Icelandic cod fisheries, that information on larval drift and the size of the stock components is collected. This can be done by carrying out more extensive 0-group and groundfish surveys in the Iceland-Greenland areas.

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