SAITHE ON A SHELF

Two studies of *Pollachius virens* in Icelandic shelf waters

I. Food and feeding of saithe (*Pollachius virens*) at Iceland

and

II. On saithe (*Pollachius virens*) migrations to Iceland

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auð síða á
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bókarinnar

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Thesis submitted in partial fulfillment
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Sigurður Þór Jónsson

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SYNTHESIS

1. Introduction

The saithe is a resident of the North Atlantic. It occurs on both sides of the ocean, but is more abundant and widely distributed on the eastern side. The western Atlantic stock is found between the Gulf of St. Lawrence and Georges Bank and strays have been observed as far south as Chesapeake Bay and north to Davis Strait. On the eastern side of the Atlantic there are a number of stocks units, *i.e.* around Iceland, off the coast of Norway reaching north into the Barents Sea, in the northern part of the North Sea, and north and west of the British Isles. In the eastern Atlantic there are individual records of saithe in the Bay of Biscay or even farther south (Reinsch 1976; Anon. 1995a).

The saithe has been decribed as both pelagic and demersal, and also as a strong facultative schooler (Partridge *et al.* 1980). Observations have been made of saithe feeding on prey schooling close to the surface suggesting that the saithe may cooperate when foraging. Thus, Sæmundson (1926) observed that "in spring and summer [the saithe] often school at the surface in varying numbers, especially when preying on euphausiids, moving so swiftly and with such violent jumps, that the sea resmbles a boiling cauldron." And Misund (1993) states that "schools of large saithe hunted the schools of small herring, and occasionally forced them to the surface where a heavy predation, both by saithe and seabirds, was observed." Thus it is even possible that the saithe are capable of herding behaviour similar to that exhibited by some baleen whales when feeding on euphausiids.

In the literature saithe is generally described as a voracious predator, feeding to some degree on demersal, but mainly on pelagic prey species, such as euphausiids and various species of fish (*e.g.* Wagner 1959; Gislason 1983; Pálsson 1983; Sunnanå 1984; Daan 1991; Nicolajsen 1993).

The two most comprehensive recent studies of the feeding of commercially sized saithe were carried out in the northern North Sea. According to these studies there can be large variations in the diet of the saithe within a fairly small geographical area. Thus, to the west of Scotland fish completely dominated the diet with crustaceans contributing less than 10% of the estimated consumption, while east of Scotland crustaceans, mostly euphausiids, amounted to one third of the diet (Du Buit 1991). Off the southwest coast of Norway, Bergstad (1991) found the euphausiid contribution to be close to 80% for saithe smaller than 50-60 cm, while larger saithe consumed mostly fish prey.

For management purposes, the International Council for the Exploration of the Sea (ICES) has defined five separate saithe stock assessment units in the NE-Atlantic. These stock units, their average fishable and spawning stock biomass, and spawning stock as percentage of fishable stock in 1990-1994 are given in the text table below:

Stock	ICES subareas	Fishable stock (tonnes)	Spawning stock (tonnes)	SSB %
Northeast arctic saithe	I and II	540 000	127 000	24
North Sea saithe	III and IV	409 000	87 000	21
Saithe west of Scotland	VI	60 000	16 000	27
Faroese saithe	Vb	156 000	75 000	46
Icelandic saithe	Va	420 000	215 000	51

Sources: Anon. 1995, 1995b, 1996, 1996a

Average total annual landings of saithe from these stock units in the same period were 360 thousand tonnes. In addition, some landings have been reported from subarea VII, *i.e.* the waters surrounding Ireland, but these saithe have not been included in any assessment. The average fishable saithe biomass in ICES statistical areas I-VI has thus been approximately 1.5 million tonnes in the 1990s. This may be compared to the estimated cod biomass of 3 million tonnes in the same area, two thirds of which are the Northeast arctic cod (Anon. 1995, 1995b, 1996, 1996a). Northwest Atlantic saithe are regarded as one stock unit by Canada and the USA (Anon. 1995a).

Fisheries scientists are well aware of the limitations of such a division for migratory species like saithe. A number of studies have attempted to take account of migrations between different units when assessing the NE-Atlantic saithe stocks (*e.g.* Jakobsen 1981; Anon. 1983; Hastie 1995) and on one occasion a joint VPA was run for all the stocks (Anon. 1974).

The proportion of total stock biomass, estimated to be mature, is remarkably variable and twice as high at Iceland and the Faroes as in the other areas. On the other hand, the proportion removed annually by the fishery lies in the range of 20-30% of fishable biomass for all five stock units. The variability in the proportion of mature fish is probably for the most part due to the different harvesting strategies employed. The most recently recruited saithe year classes west of Scotland, in the North Sea and off the coast of Norway are subjected to intense fishing pressure. Thus, the easternmost saithe stocks can, to some extent, be characterized as growth overfished (Anon. 1995a). However, a possible supplementary explanation could be net immigration of adult saithe to Icelandic and Faroese waters from the eastern part of the distribution area. Such a migration would conform with the observation that the whereabouts of adult North Sea saithe are poorly known for large parts of the year (Reinsch 1994).

Thus, at least two important aspects of saithe biology merit further study. On the one hand, the variability in the results from feeding studies suggests a certain degee of opportunism in the saithe's feeding behavior. This behaviour must therefore be carefully studied before the species can be properly placed in a multispecies modelling context. On the other hand, tagging studies have revealed movements of saithe between managment units. Indeed, such studies have shown that saithe are highly migratory, and methods must be developed to monitor their movements in order to improve stock assessment. The following two studies were carried out with the purpose of answering questions relating to these two aspects of the biology of saithe at Iceland.

In the food study, the diet of the saithe at Iceland is analysed in a descriptive sense, with the main emphasis on saithe predation on capelin and euphausiids. These prey categories are very abundant in Icelandic waters and make up the largest part of the diet. In the fashion of many diet studies, variability in the diet in relation to such factors as year, season, predator size and time of day is described.

In the migration study, indications of saithe migrations to Iceland are investigated, mainly on the basis of mean-length-at-age and catch-at-age data. The observed anomalies in mean-length-at-age might have alternative explanations, such as reduced growth or much delayed recruitment. However, when these indications are placed in the perspective of historical saithe data and tagging results, they seem to lend support to an hypothesis of immigration of saithe to Iceland from the 1984 year class in 1991. The magnitude of this migration is estimated.

Before the results of the two studies are summarized, a short introduction of the hydrobiological environment of the Icelandic shelf will be given, followed by a general description of the species, as well as results from various saithe studies and information extracted from the saithe data base at the Marine Reasearch Institute, Reykjavík (MRI).

2. The Icelandic shelf environment

Most of the saithe, which are the object of the following studies, were caught on the Icelandic shelf. A short description of this area, its bottom topography, circulation and water masses, and aspects of its temperature-salinity regime, primary and secondary production, will be given here based mainly on recent reviews (Vilhjálmsson 1994; Ástþórsson and Gíslason 1995).

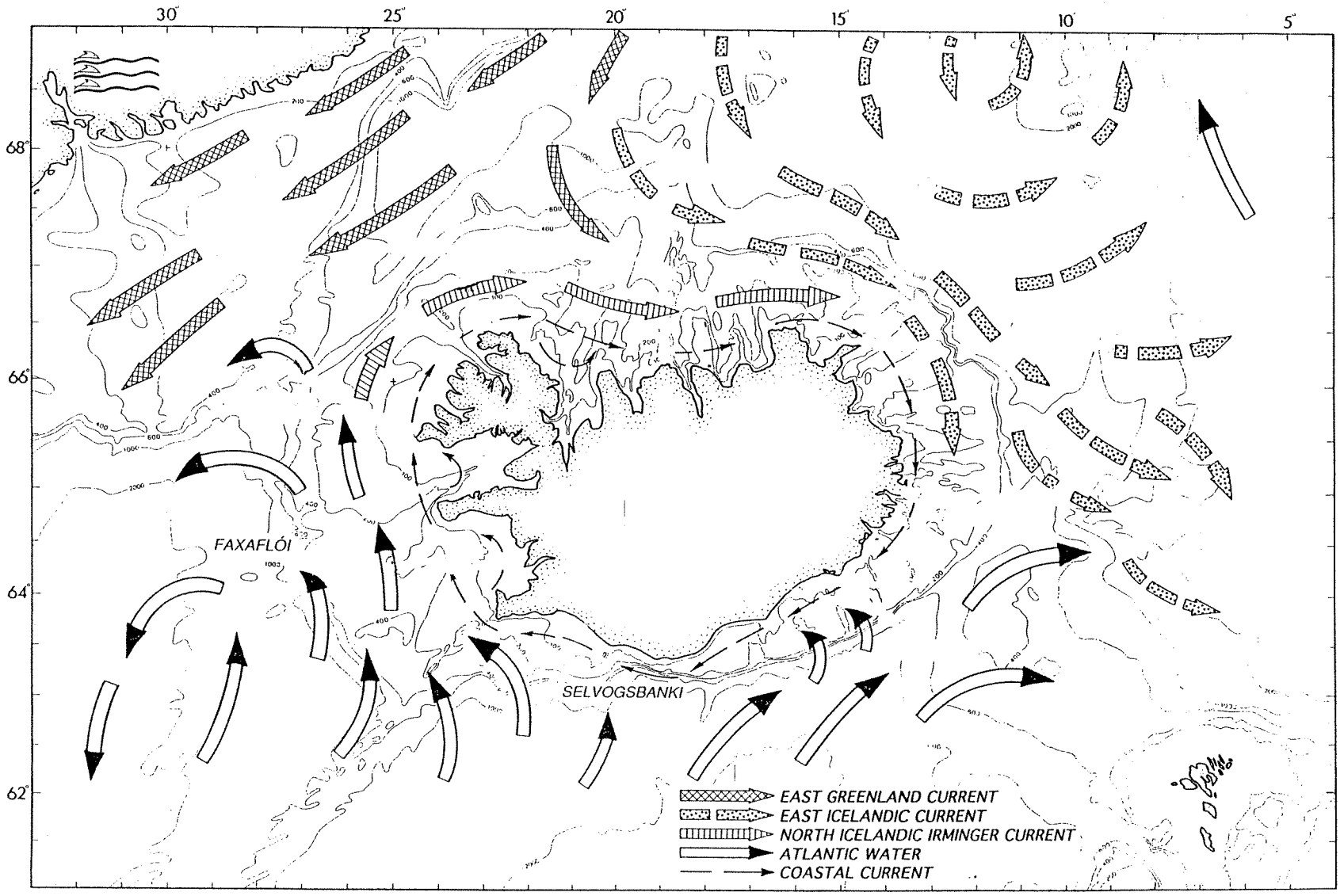


Figure 1. Ocean currents around Iceland (from Ástþórsson and Gíslason 1995).

The shelf surrounding Iceland breaks roughly at a depth of 400-500 m. Thus, the Icelandic groundfish survey (IGFS) covers the area within the 500 m depth contour, amounting to some 61 500 square nautical miles or 210 000 km^2 (Pálsson *et al.* 1989). This may be compared to 1.4 million km^2 for the entire Barents Sea (Sakshaug *et al.* 1992). The shelf is narrowest in the south where the slope plunges to a depth of 1 500 m or more, only a few miles off the coast. It is broader east, north and west of Iceland, in most places reaching a width of 60-90 nautical miles. Several submarine ridges are connected to the shelf. These are the Reykjanes Ridge in the southwest, the Iceland-Greenland Ridge in the northwest, to the southeast lies the Faroe-Iceland Ridge, and, though less distinct, the Kolbeinsey Ridge extending due north from the central north coast and the Jan-Mayen Ridge which touches the northeastern part of the Icelandic continental shelf.

The ocean current system around Iceland is shown in Figure 1. As a result of this current pattern, the Icelandic shelf can be divided in two with regard to water masses. To the south and west, warm and saline Atlantic water predominates with a seasonally varying admixture of coastal runoff. To the north and east, on the other hand, conditions are more variable. A tongue of Atlantic water of varying extent mixes with water from the coastal current and arctic water from the East Icelandic Current. Thus, the strength of the East Greenland Current, the prevailing wind force and direction and variability in the coastal runoff are all factors known to have affected recruitment to the Icelandic cod stock (Vilhjálmsson and Magnússon 1984; Jakobsson 1992; Ólafsson *et al.* 1993) and, by analogy, although fewer analyses have been undertaken, other fish stocks at Iceland as well.

South of Iceland, runoff from the rivers has a direct effect on the establishment of stratification and thereby on the supply of nutrients, in particular, that of silicate. Wind pattern is a factor in determining the spread of the low salinity coastal water, southerly winds leading to increased stratification in the productive Faxaflói, while northerlies have the opposite and, on the plant production, negative effect. There have been large fluctuations in the inflow of Atlantic water onto the shelf area to the north and northeast of Iceland, with consequences for the nutrient supply to the otherwise nutrient poor and stratified arctic water there. At times, the strength of the East Greenland Current is such that it forms a barrier to the North Icelandic Irminger Current, causing much reduced productivity on the northern shelf, and on occasion directing the drift of larvae, from the spawning grounds off SW-Iceland, towards Greenland.

The primary production around Iceland is highest in areas where Atlantic waters predominate. There are two "hot spots" off the south coast, one in the southwest in the region of Selvogsbanki and another in the southeast, and a third in Faxaflói. In these

areas the average annual primary production exceeds 200 g C m^{-2} $year^{-1}$. The general area off the south and west coasts is more productive and stable with regard to primary production than the northern and eastern areas. Variations of one order of magnitude have been observed north of Iceland, depending on Atlantic influx to the northern shelf (Þórðardóttir 1984). Gíslason *et al.* (1994) timed the peak in the phytoplankton spring bloom to the southwest of Iceland in 1990-1992 and observed the highest concentrations in chlorophyll *a* in late May 1990, early May 1991 and early in June or even later in 1992. A close association between the spawning of *Calanus finmarchicus* and the spring bloom was observed, which is in agreement with findings from other areas.

Variations of zooplankton biomass in Icelandic waters in spring are described by Ástþórsson and Gíslason (1995). In summary, they found the spring biomass, in terms of volume measurements converted to dry weight per square meter of ocean surface, to range generally from 2 to 4 g m^{-2}, somewhat lower nearshore in the northeast and east, while some stations had persistently higher values, *i.e.* close to 10 g m^{-2}. The highest values were found in the southwest on Selvogsbanki, an important spawning ground for many fish species at Iceland, and in the arctic waters of the East Icelandic Current off the northeastern part of the shelf. *C. finmarchicus* is the dominant species, in particular to the south. The other main components of the plankton are cirrepede and euphausiid larvae close to shore while arctic species such as *C. hyperboreus*, *C. glacialis* and *Metrida longa* become abundant off the northeastern part of the shelf. Zooplankton biomass indices from stations in the Atlantic waters show a significant positive correlation with 0-group cod abundance.

3. General biology of the saithe

The saithe is one of the larger gadids. Lengths of up to 127 cm and weights close to 21 kg have been recorded at Iceland and the oldest saithe on record, among the year classes since 1959, belonged to age group 22. There are German records of a saithe 135 cm in length as well as of a 27 year old individual (Reinsch 1976). However, the bulk of the commercially caught saithe at Iceland are in the length range of 50-100 cm, weigh some 1,5-8 kg and the majority are less than 15 years old.

Svetovidov (1948; in Patterson and Rosen 1989) is the classic work on gadiform systematics. However, later work, where cladistics have been applied to fish systematics, indicates that there is need for a revision of the Gadidae, and indeed of the order Gadiformes and the higher taxonomic grouping they belong to, the doubtfully monophyletic superorder Paracanthopterygii (Patterson and Rosen 1989; Nelson 1994). Thus, Dunn (1989) places the genus *Pollachius* in the new gadid subfamily Eleginae along with the genera *Merlangius*, *Melanogrammus*, *Trisopterus* and *Eleginus*, based on

a cladistic analysis of selected osteological characters. On the other hand, Nolf and Steurbaut (1989) place *Pollachius* in the tribe Gadini, along with *Eleginus*, *Gadus*, *Melanogrammus*, *Microgadus* and *Theragra* on the basis of similarities in sagittal otolith structure.

3.1 Spawning

Of all the gadids at Iceland, the saithe spawn earliest (Jónsson 1992). In the NE-Atlantic they spawn at temperatures of 5°-10°C and salinity close to 35‰. Spawning of saithe in the NE-Atlantic begins already in January and peaks in February, except at higher latitudes where it is delayed (Reinsch 1976). Their cousins on the western side of the Atlantic spawn at lower temperatures and salinities and can perhaps be characterized as mid-winter spawners, the spawning beginning already in October and continuing until March in this area (Svetovidov 1948; in Reinsch 1976).

At Iceland, ripe spawners are rare in January and February, but present in samples throughout March and April in substantial numbers. In comparison, the spawning of cod has just begun at the end of March and peaks in late April or early May (Marteinsdóttir and Pétursdóttir 1995). The main spawning areas are Selvogsbanki and Eldeyjarbanki, southwest of Iceland, with a secondary but substantial spawning taking place off the southeast coast.

3.2 Eggs and larvae

In a plankton study of the area off SW-Iceland, Gíslason and Ástþórsson (1991) observed eggs, judged to be saithe eggs from their diameter, in late March 1991. Magnússon (1966) observed saithe larvae at stations to the west of Iceland in May and June of 1961-1964 and saithe larvae have also been observed in Faxaflói and on Selvogsbanki at the same time of year (Anon. 1994; K. Þórisson, MRI, pers. comm.). On the other hand, saithe have only been observed sporadically in very low numbers in the MRI 0-group surveys, conducted in July and August since 1970 (*e.g.* Anon. 1972, 1973; Magnússon *et al.* 1987).

Saithe fry of unknown origin have been observed drifting towards Norwegian waters at 63°-64°N near the zero meridian, in late April and early May (Bjørke and Sætre 1994; Nedreaas and Smedstad 1995). If they stemmed from spawning at Iceland, the easternmost spawning ground would seem the most likely origin and the larvae would have drifted a distance of at least 500-600 nautical miles. To cover that distance in a period of 45-60 days, drift speeds of 20-30 cm s^{-1} are necessesary, or close to the maximum current speeds given for the North Atlantic Drift (Stefánsson 1994). Furthermore, the possibility of continued import to Norwegian waters at a later date can

not be ruled out, *i.e.* later in May or perhaps in early June. Although a survey in one year fails to detect saithe postlarvae, such results do not eliminate the possibility of their arrival at that time in a different year.

The diet of the 0-group saithe while in the plankton is mainly composed of calanoid copepods. During the first life-stages, the saithe diet is similar to that of other gadids which have been studied (Nagabhushanam 1965; Robb and Hislop 1980; Economou 1991).

3.3 Juveniles and nursery areas

During early and mid-summer, the first 0-group saithe can generally be observed settling in the littoral area (*e.g.* Nagabhushanam 1965; Lie 1961; Clay 1989; Godø *et al.* 1989). Throughout the distribution area of saithe, the 0-group has vanished from the plankton in July-August (*e.g.* Clay *et al.* 1989; Godø *et al.* 1989; Nedreaas and Smedstad 1995).

In general, the juvenile saithe reside in the littoral and sublittoral zones during the first 1-2 years of their life, but are often forced into deeper waters by the cooling of the surface layer in winter (Reinsch 1976; Clay *et al.* 1989). As they grow the saithe will gradually move away from the coast (Jakobsen 1981), but the juveniles often take up residence on nearshore reefs and shallow banks (*e.g.* Nedreaas 1987). Experiments conducted on acoustically tagged saithe at such locations have shown them to undertake short daytime feeding excursions from a home area where they spend the night (Smith *et al.* 1993; Sarno *et al.* 1994).

The importance of the kelp forest as a nursery for the juvenile saithe has recently been pointed out (Høisæter and Fosså 1993; Sarno *et al.* 1994a; E. Hjörleifsson, MRI, unpubl. mat.) and *Laminaria* is sometimes mentioned in descriptions of study areas where juvenile saithe have been studied (Ojeda and Dearborn 1991) These authors and others have also reported on the diet of juvenile saithe in their respective areas and generally found them to feed on a variety of littoral organisms and fish but, in some cases, mainly on planktonic prey (Nagabhushanam 1965; Salvanes and Noreide 1993).

Nedreaas (1987) found the diet of 2 year old saithe at two exposed locations on the west coast of Norway to be dominated by abundant planktonic organisms, such as copepods and euphausiids, but when these prey became scarce they were substituted by other available prey, either fish or benthic organisms, the latter probably least preferred.

3.4 Recruitment

At Iceland, the saithe generally recruits to the fishery as age group 3 or 4 and is in most cases fully recruited at the age of 5. However, as will be shown in Paper II, the 1984 year class appeared not to have recruited fully until 1991, as age group 7, and other such anomalous examples can be found in older VPA tables (Anon. 1993). To the knowledge of this author, only one study has been carried out of saithe in the nearshore habitats (E. Hjörleifson, MRI, unpubl. mat.) and none of the transition from the juvenile coastal phase until the fish appear in the commercial catches in the Icelandic area.

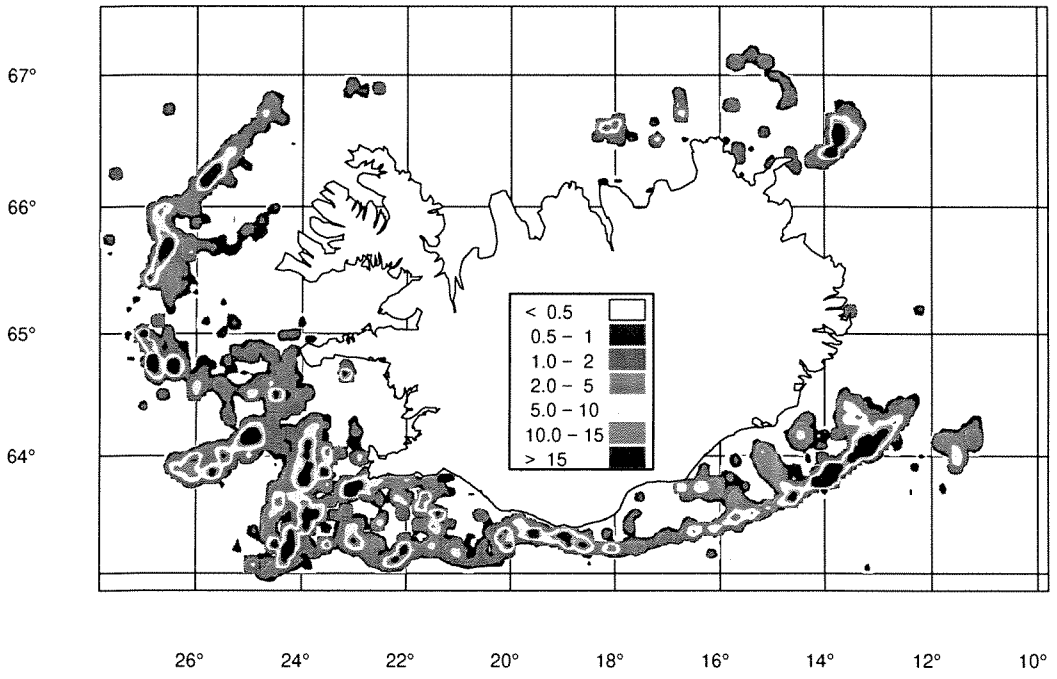
In Icelandic groundfish surveys, observations of age group 2 and 3 saithe are most frequent on the shelf area off Vestfirðir, the northwest peninsula of Iceland, indicating the importance of this area as a nursery ground. It is also clear that the saithe in this area prefer locations farther west and thereby in warmer waters than cod of the same age (Pálsson *et al.* 1993).

On the basis of data from the International Bottom Trawl Survey (IBTS), it has been observed that North Sea saithe of age groups 2 and 3 are to be found in highest concentrations on the western slopes of the Norwegian Deep (Reinsch 1994).

3.5 Adult saithe and the saithe fishery at Iceland

The distribution of adult saithe at Iceland, as reflected by the commercial catch in 1991-1994, is shown in Figure 2. The catches are summed over a fine grid and smoothed slightly for cosmetic purposes (H. Björnsson, MRI, pers. comm.). A decreasing trend is apparent, the total catch was reduced by approximately 50% in the period, and the saithe fishery at present is at a low level. The catches are distributed throughout the year and lie mainly in the relatively warm Atlantic waters to the south and southwest of Iceland. The predominant gear types are gill nets and bottom trawl. In the 1990s in the range of 10-40% of the annual landings were taken in gill nets, for the most part during the winter and spring fishery on spawning concentrations. For all intents and purposes, the remainder was caught by trawlers, their fishing effort more evenly distributed over the year. The size and age distributions in the Icelandic catches clearly show that younger and smaller saithe are caught in the bottom trawl than in gill nets. This is a reflection both of selection due to the difference in minimum mesh size between these two types of gear (155 mm for bottom trawl; 152-178 mm for gill nets) and the fundamental difference in fishing method.

1991



1992

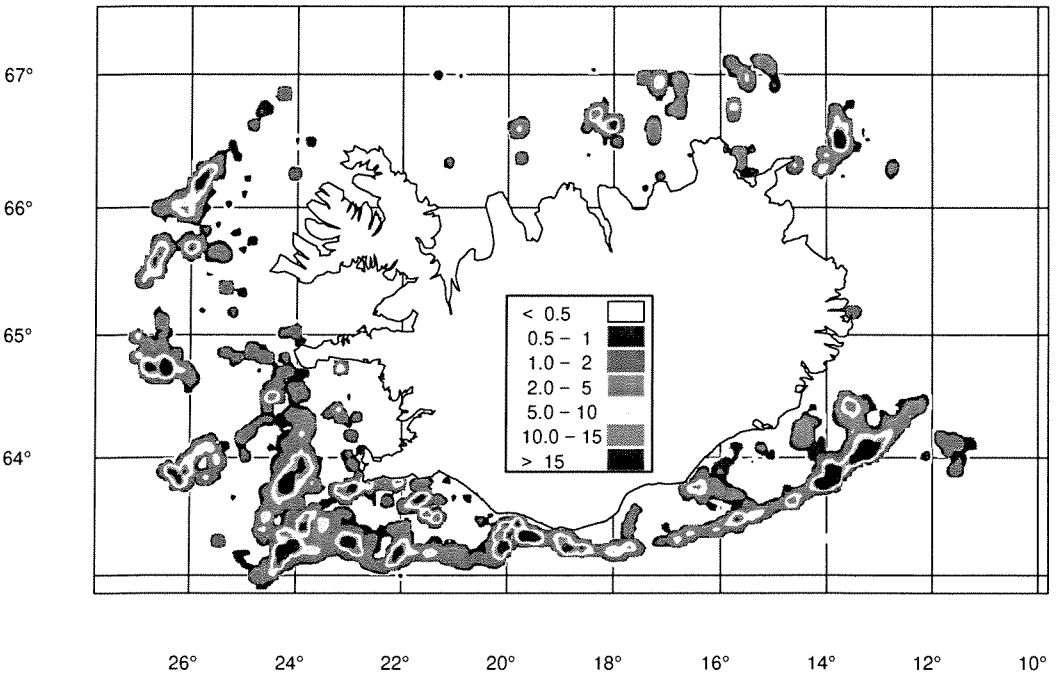
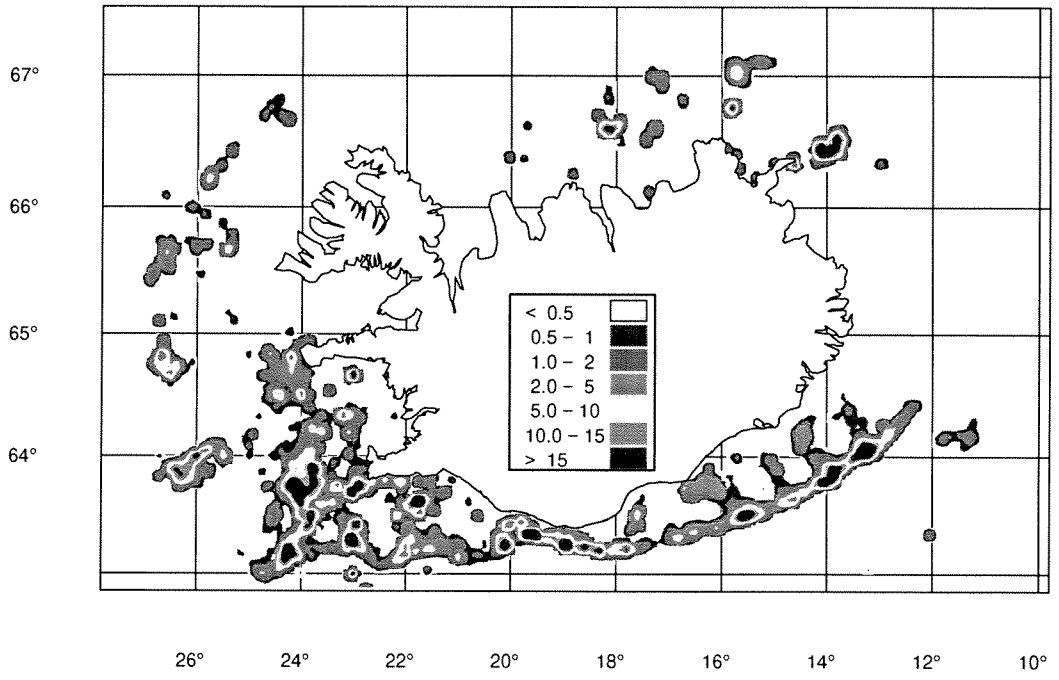


Figure 2. Saithe catches in bottom trawl and gill nets around Iceland in 1990–1994 in tonnes/square mile. Based on records from fishing vessel log-books.

1993



1994

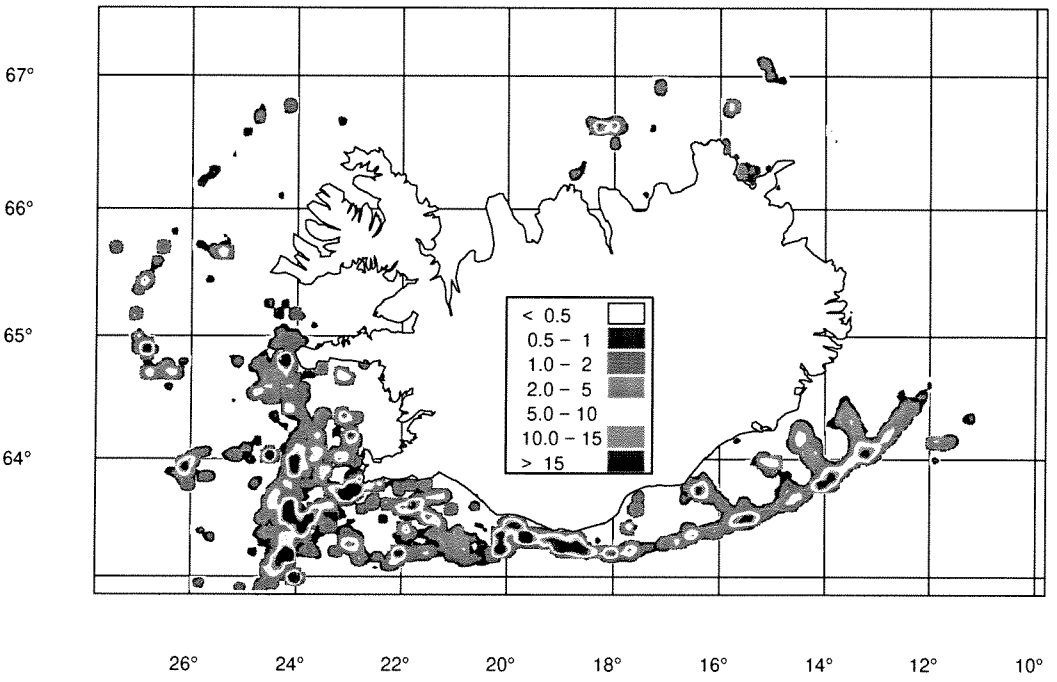


Figure 2 (continued).

A simple study of the catch per unit fishing effort (CPUE) of the Icelandic bottom trawlers reporting saithe, showed pronounced diel variation in the saithe catches throughout the year. The catch rates peaked at night and there was an early afternoon minimum corresponding to 50% of the CPUE at night. This phenomenon merits further study and a more complete analysis should be undertaken, especially of data from trawlers directing their effort at saithe and taking account of trawling depth and geographic location.

As stated earlier, tagging experiments have shown that saithe are highly mobile. As an example, saithe tagged at Iceland have been recaptured at the Faroe Islands and off the coast of Norway (Jones and Jónsson 1971), and Norwegian tags, have regularly shown up in catches taken at Iceland (Jakobsen and Olsen 1987).

Mean lengths of saithe in German trawl catches from the North Sea, calculated on a quarterly basis, show a fairly regular decrease from spring to summer and autumn as the saithe migrates out from the coast (Reinch 1994). No trend was apparent in quarterly mean lengths in saithe samples from Icelandic trawlers since 1980. This is probably a reflection, on the one hand of the schooling nature of the saithe, and on the other of variable fishing effort allocated to saithe by the Icelandic trawlers, depending *i.a.* on their cod quota status. Before making too much of Reinsch's observation, it must be noted that it is possible that outside of the spawning season, the largest saithe are more agile and better capable of avoiding the gear used by commercial trawlers. At a speed of 1.25 ms^{-1} or 2.5 knots, a 50 cm saithe has been shown to endure 30 minutes of swimming. Furthermore, extrapolating from the empirical relationship established for maximum sustained swimming speed, a 70 cm saithe can swim for prolonged periods at 2.5 knots (He and Wardle 1988). This indicates that saithe, 70 cm and larger, could endure swimming for some time at 4 knots, the common towing speed in the commercial fishery.

4. Main results and conclusions from the present investigations

4.1 Food and feeding

At Iceland, capelin was found to be the main constituent of the saithe diet in March 1990-1992. This is probably also true for February and April, *i.e.* the period when capelin are available in large amounts in the main distribution area of saithe, south and west of Iceland. The amount of capelin observed in the saithe stomachs varied in proportion to capelin stock abundance during the study period. Like in the case of capelin, the krill feeding level in summer seemed to be related to krill biomass in the area (Á. Gíslason, MRI, pers.comm.).

Euphausiids seem to be the staple diet of the saithe. The krill dominated in the summer stomach samples and were present in considerable quantities in spring and late autumn. These results conform well with previous studies of saithe feeding in other areas (*e.g.* Du Buit 1991; Bergstad 1991).

Seasonal and interannual variability in the saithe's feeding appeared to be considerable. The data indicate that feeding level is lowest in autumn, while inter-annual variations in spring and summer are large, and mainly a reflection of capelin and krill feeding level, respectively.

Diel variations in stomach fullness indices for capelin and krill in spring suggest nocturnal, or perhaps crepuscular, predatory activity by the saithe. Such variations conform with the general observation that both of these prey categories are more available in the pelagic layers during the hours of darkness than in the daytime.

4.2 Saithe migrations

Tagging experiments have demonstrated that saithe migrations across the NE-Atlantic are commonplace (Jones and Jónsson 1971; Jakobsen and Olsen 1987). Using a modification of the mixture model, for estimating the proportions of the components in a mixture of two distributions (James 1978; Shepherd and Pope 1993), it was estimated that in 1991 some 10-20% of age group 7 saithe at Iceland had immigrated from other areas. An approximation of the variance of the mixture proportion estimate is discussed.

A comparison was made of data used in virtual population analyses of the Icelandic saithe and the literature on saithe taggings. In some of the years, when it has been suggested that large migrations to Iceland have occurred, it was found that cach-at-age from certain year classes peaked later than normal. Thus, the well tagged Norwegian saithe year classes of 1962 and 1964 gave numerous returns from Icelandic waters (Reinsch 1976; Jakobsen and Olsen 1987) and had catch-at-age curves at Iceland similar to that of the 1984 year class.

A comparison of a re-analysis of the only saithe tagging experiment conducted at Iceland with saithe taggings on the eastern side of the Atlantic, does not indicate any difference in saithe traffic east or west across the Norwegian Sea. In other words, on the basis of the available information, emigration from and immigration to the Icelandic area are just as likely.

In view of previous evidence as well as that presented in these studies it would seem that the boundaries, used in the present management of NE-Atlantic saithe stocks, are, at least at times, by no means clear.

4.3 Coupling of the two papers

The feeding study does not lend any obvious support to the migration hypothesis. On the contrary, it seems likely that low capelin biomass in 1990 and the apparently poor feeding conditions in that year could have resulted in retarded growth, thereby casting doubt on the validity of the mixture model results. However, cod at Iceland, which are notorius capelin eaters, do not seem to have suffered any reduction in growth in 1990 and 1991 (Anon. 1995).

A necessary prerequisite for the application of the mixture model for estimating migrations is an approximate size distribution for the resident fish. In this study that variable had to be roughly estimated by ANOVA methods. This approximation could be improved by growth modelling, where one key component naturally is the abundance of the main prey groups. The present feeding study indicates that capelin and krill should be included in a growth model for the Icelandic saithe, at least for age groups 3 and older.

Due to low number of stations and different vessels used, the material collected in the summer and autumn stomach sampling surveys was much less complete than the spring material. This, together with the semi-pelagic behavior of saithe, makes it difficult to draw any firm conclusions from the feeding study in support of a migration hypothesis. However, the summer diet was dominated by euphausiids, with a significant contribution of both mesopelagic fish and blue whiting. A common characteristic of all these prey species is their wide distribution throughout the N-Atlantic. Low saithe occurrence in the samples taken on the Icelandic shelf in summer could be a reflection of the saithe's foraging expeditions off the shelf, *e.g.* in pursuit of blue whiting. Such a feeding strategy would be comparable to that of the Atlantic salmon.

5. Future research

5.1 Recruitment studies

Although outside of the main scope of these studies, it is clear that further recruitment studies of saithe are called for. For the North Sea saithe, a recruitment index is established from the IBTS and used in stock assesments. In all other VPA assessments of saithe in the NE-Atlantic an average recruitment is assumed. At Iceland, no studies of juvenile saithe have been attempted, with the exception of their ecological position in the kelp forest (E. Hjörleifsson, MRI, unpubl. mat.).

A survey of the distribution of postlarvae off the coasts of Norway was conducted in the period 1985-1992. The predictive value of the results was found to be low, and the programme is under reconsideration (Nedreaas and Smedstad 1995). In light of the

coastal distribution of juvenile saithe, it seems reasonable to attempt some sort of monitoring of the strength of incoming saithe year classes while still in the nearshore habitat. In Norway, the development of a recruitment monitoring programme for predicting the development of the adult stock is still at the experimental stage (Aglen 1995; Smedstad 1995). At Iceland, a simple first step could be to single out some key locations, and study the development of a few successive year classes, using different sampling methods.

5.2 Incorporating the saithe into multispecies models

The comparison of the biomass of saithe and cod in ICES statistical areas I-VI makes one thing clear. Assuming similar energetic demands, as ecosystem components the two species are, at present, on an almost equal footing except in the Barents Sea. The distribution and predatory behaviour of cod is such that they are probably more serious competitors to man for commercially utilized species, *e.g.* cod, redfish, capelin and northern shrimp. However, saithe at Iceland are obviously important predators on capelin in winter and spring. Consequently, they compete for that resource with cod and man and must be taken account of. Although saithe prey on euphausiids for most of the year, also when feeding heavily on capelin, the state of knowledge of euphausiid distribution and abundance at Iceland must be improved to allow further speculation. It has been suggested that saithe, along with other zooplanktivorous fish, could exert a controlling effect on euphausiid populations in the North Sea area (Bergstad 1991a)

5.3 Monitoring saithe migrations

In light of the indications of saithe migrations, it seems reasonable ask for more frequent sampling, although the samples need not necessarily be as large as those presently collected from the saithe landings. It has been shown that such a sampling strategy can improve precision of survey abundance estimates, the estimation of biological parameters of fish being surveyed (Pennington and Vølstad 1991, 1994; Bogstad *et al.* 1995) and also improve the estimation of age and length stucture of fish populations from trawl catches (Horppila and Peltonen 1992).

In attempting to estimate the size of a saithe migration, a more direct approach than that possible with a joint VPA and related methods, should be taken. It seem reasonable to ask for better tagging evidence, especially with respect to a possible emigration from Iceland. Morphological and genetic characters should be studied in order to determine whether such characters can testify to the origin of a saithe.

Fish otoliths and scales have been used to differentiate stock units of marine species (*e.g.* Easey 1978; Rätz 1990; de Barros and Holst 1996). No observations have been made of different types of otoliths in Icelandic saithe samples since the suspected immigration in

1991 (Þ. Viðarsson, MRI, pers. comm.), but it is possible that differences unnoticed by the a human age reader might be detected by modern image analysis systems applied to fish age determination. Observations of otolith type differences between saithe stocks that might merit further study have been made (Olsen 1959). Methods and systems for this type of image analysis are under development but have not yet reached the stage of routine application (*e.g.* Troadec 1991).

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