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Life History of the Davis Strait Greenland Halibut, with Reference to the Cumberland Sound Fishery

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1992

Canadian Manuscript Report of Fisheries and Aquatic Sciences 2130

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Canadian Manuscript Report of Fisheries and Aquatic Sciences

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This is the 24th Manuscript Report

from the Central and Arctic Region, Winnipeg

Cat. no. Fs 97-4/2130E ISSN 0706-6473

Correct citation for this publication is:

Crawford, R.E. 1992. Life history of the Davis Strait Greenland halibut, with reference to the Cumberland Sound fishery. Can. Manuscr. Rep. Fish. Aquat. Sci. 2130: iv + 19 p.

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ABSTRACT

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The Greenland halibut (Reinhardtius hippoglossoides Walbaum) is an amphiboreal, mesopelagic piscivorous predator. In Davis Strait, it is the object of an international fishery which uses bottom trawls, longlines, and gill nets. Young Greenland halibut inhabit nursery areas on the banks along both sides of the strait. As they approach sexual maturity, which they attain at about age 10-12, they seek deeper water. Mature females are larger than males. Greenland halibut spawn in spring primarily on the Continental slope and in deep basins (650-1000+ m). Currents distribute larvae along West Greenland and Baffin Island where they settle in the nursery grounds on the banks. In 1987, a winter fishery for this species began in Cumberland Sound (Baffin Island). Indigenous fishermen, operating from snow machines and sleds, set longlines through ice. They fish in depths between 600-1125 m. Their catch is predominantly female, aged 9-12. It is postulated that the fish in Cumberland Sound are a component of the larger population inhabiting Davis Strait.

Key words: Greenland halibut; Reinhardtius hippoglossoides; life history; migration; fishery management; longlining; Inuit fishery; Arctic ice.

RÉSUMÉ

Crawford, R.E. 1992. Life history of the Davis Strait Greenland halibut, with reference to the Cumberland Sound fishery. Can. Manuscr. Rep. Fish. Aquat. Sci. 2130: iv + 19 p.

Le flétan du Groenland (*Reinhardtius hippoglossoides* Walbaum) est un poisson piscivore mésopélagique à distribution amphiboréale. Dans le détroit de Davis, il fait l'objet d'une pêche internationale au chalut de fond, à la palangre et au filet maillant. Les jeunes flétans du Groenland vivent dans des zones d'alevinage le long des côtes bordant le détroit. À l'approche de la maturité sexuelle, qui se situe entre 10 et 12 ans, les poissons cherchent des eaux plus profondes. Les femelles matures sont plus grandes que les mâles. Le flétan du Groenland fraye au printemps, principalement sur le talus continental et dans des bassins profonds (650 à plus de 1 000 m). Les larves, dispersées par les courants le long des côtes de l'île de Baffin et de la côte ouest du Groenland, s'établissent dans les zones d'alevinage. En 1987, on a commencé la pêche hivernale de cette espèce dans la baie de Cumberland (Île de Baffin). Des pêcheurs indigènes ont installé des palangres à travers la glace en se servant de motoneiges et de traîneaux. Ils ont pêché à une profondeur se situant entre 600 et 1 125 m et ont capturé principalement des femelles âgées de 9 à 12 ans. On pense que les poissons présents dans la baie de Cumberland feraient partie de la population plus grande habitant le détroit de Davis.

Mots-clés: Flétan du Groenland; Reinhardtius hippoglossoides Walbaum ; cycle biologique; migration; gestion des pêches; pêche à la palangre; pêche inuite; glaces de l'Arctique.

INTRODUCTION

In 1986, the Department of Economic Development and Tourism (EDT) of the Government of the Northwest Territories (GNWT) sponsored a visit by West Greenlandic fishermen to Pangnirtung, Baffin Island. They were to teach local fishermen how to fish with longlines through landfast ice in Cumberland Sound. By the end of the several day demonstration, they caught 186 Greenland halibut, (Reinhardtius hippoglossoides Walbaum) or "turbot". The following winter (1987) Pangnirtung fishermen used these newly learned techniques to catch 4.1 tonnes (t) of Greenland halibut and the Cumberland Sound halibut fishery began (Table 1). Since then, this winter/spring fishery has progressed from a GNWT development project to a locally important commercial enterprise.

During the course of this development, the Arctic Fisheries Science Advisory Committee (AFSAC) was asked for guidelines regarding the establishment of quotas and the collection of data for fishery management purposes. During this process, the need for a summary of relevant biological information for the Greenland halibut was identified. This report constitutes a submission toward that end. It is a review of literature pertinent to this species, especially the population or stock that inhabits Davis Strait. This compilation is intended to provide AFSAC, fishery managers, and resource users with background descriptive information on the biology of Greenland halibut to facilitate the interpretation of data and to assist in the formulation of a Baffin Island fishery management strategy. A brief synopsis of the Greenland halibut fisheries in the Northwest Atlantic is included. This synopsis follows the convention of the Northwest Atlantic Fishery Organization's (NAFO) geographical division of the Northwest Atlantic into areas and sub-areas (Fig. 1).

COMMON NAMES

There is some disagreement regarding a common name for this species. In Europe, it is called "black halibut". In North America, its historical name has been "Greenland halibut". However, in 1968, the use of "halibut" in the name was protested by Pacific halibut producers and processors because they perceived it caused confusion among consumers in differentiating between products of the Atlantic and Pacific fisheries. An agreement was reached whereupon Greenland halibut exported from Canada to US markets must be labelled "Greenland turbot". But because "Greenland halibut" was firmly entrenched in scientific literature, the American Fisheries Society, NAFO, the Canadian Atlantic Fisheries Science Advisory Committee (CAFSAC), and the Department of Fisheries and Oceans (DFO) Newfoundland Region retained it as the common name for the species (Scott and Scott 1988).

However, DFO Central and Arctic Region, AFSAC, and DFO Economic Analysis and Statistics Division have continued to refer to this species as simply "turbot". Another flatfish (Scopthalmus maximus Linnaeus), a bothid that is the focus of an aquaculture industry in Europe, is referred to in the scientific literature as "turbot". Because of the unclear meaning of "turbot", the flatfish caught by the Cumberland Sound longline fishery is referred to in this report as "Greenland halibut".

DESCRIPTION

The Greenland halibut (Fig. 2) is a member of the Order Pleuronectiformes. These are laterally compressed fish that begin life as pelagic larvae with eyes on both sides of the head. During development they undergo a transformation; one eye migrates to the opposite side and the fish become horizontally oriented as a flatfish, lying on their side. Those that have both eyes on the left side are of the Family Bothidae ("left-eyed"). Those with the eyes on the right, such as the Greenland Halibut, belong to the Family Pleuronectidae ("right-eyed").

In flatfishes, this one-sided eye arrangement is advantageous for a benthic habit; both eyes have a full field of vision while the fish is lying on the bottom with its un-eyed side down. The Greenland halibut is unusual in this regard because its left eye remains on the border, rather than completing the migration to the right side. Thus, this species has vision on both sides of its head, a clue to its retention of pelagic habits by the adult form.

Another clue to its pelagic nature is the rather dark coloration of its left side. The blind side of demersal Pleuronectids is typically white; on the adult Greenland halibut, this side is grey to dark grey. The eyed side of an adult Greenland halibut is even darker (black or sometimes dark brown). The fish has a large head with large, strong jaws and its body is covered with cycloid scales. It grows to a maximum size of about 120 cm and 25 kg (Scott and Scott 1988), although more typically reaches 100 cm and 11.3 kg (25 lbs) (Robins and Ray 1986).

DISTRIBUTION

The Greenland halibut is an amphiboreal fish. Taxonomic studies, based on meristic and morphometric characteristics, indicate that the same species exists in both the Atlantic and Pacific oceans (Atkinson et al. 1982). It is not known to occur in the intervening Arctic Ocean. Biochemical genetic analysis has suggested the degree of divergence between Atlantic Ocean and Bering Sea stocks is at the subspecific level (Fairbairn 1981).

In the western Atlantic, its range extends from at least as far north as Smith Sound (78°N) (Fig. 3), southward to the southern edge of the Scotian Shelf and the southwest slope of Georges Bank (Scott and Scott 1988). It is also commonly found in the Gulf of St. Lawrence and Fortune Bay (Newfoundland). It occurs only rarely in the Gulf of Maine and the Bay of Fundy, but is known to stray as far south as New Jersey (Robins and Ray 1986).

This species has been reported to occupy a bathypelagic niche (Atkinson et al. 1982). Robins and Ray (1986) define this as living between about 1000-4000 m. Templeman (1973) reported its depth range extends from 50 m to about 1600 m, but commercial concentrations were most frequent in waters less than 1000 m deep. Likewise, Atkinson and Bowering (1987) found the majority of Davis Strait Greenland Halibut between 600-1000 m, although the preferred depth varied with the season (Bowering and Chumakov 1989). Because the mesopelagic zone extends from 200-1000 m, this fish is more appropriately classified as mesopelagic, with larger animals descending into the bathypelagic zone.

Greenland halibut are common in Cumberland Sound in the winter. Knowledge of summer distribution is inconclusive because of limited study. None have been caught there in the summer to date and it is assumed that they are less common during that time (D. Pike, DFO, Iqaluit, N.W.T.; personal communication). A similar pattern has been observed in the Gulf of St. Lawrence (Bowering 1982). During the winter, halibut were concentrated in the deep water of the Laurentian Channel off Southwest Newfoundland and easier to catch. In the summer, fish were more dispersed. The apparent low summer abundance of Greenland halibut in Cumberland Sound may be because the fish are similarly dispersed (and therefore more difficult to catch). It is also possible that they leave Cumberland Sound in the summer, migrating into Davis Strait where food might be more abundant. Further research is required to answer this question.

HABITS

Although a flatfish is usually associated with the bottom, Greenland halibut frequent the water column, as evidenced by their capture in pelagic drift-nets (Christensen and Lear (1977) as cited in Bowering and Parsons (1986)). However, their pelagic habits vary according to the time of day and with the size of the fish (Bowering and Parsons 1986). The mean number (and variance) caught by bottom trawl off Labrador was higher during daylight hours. The mean size caught was larger at night. This suggested Greenland halibut were nearer the bottom during the day, and smaller (younger) fish were more pelagic at night.

As noted later, halibut move to deeper water in the winter. They also move to deeper water as they grow, with the largest and oldest fish at the deepest depths.

REPRODUCTION AND RECRUITMENT

Details of the life cycle of the Greenland halibut are unknown. Our present understanding, summarized below, is based on a generalized description that has been constructed from observations collected during many different investigations.

SPAWNING AND LARVAL DEVELOPMENT

Templeman (1973) reported that North Atlantic Greenland halibut spawn in Davis Strait in winter or early spring, at depths between 650-1000 m. Bowering and Chumakov (1989) suggested spawning occurs deeper than 1000 m as well. Most literature notes that Greenland halibut spawn south of the Baffin-Greenland Rise (Fig. 4), a submarine ridge (depth to 675 m) between Greenland and Baffin Island at about 66°N. Spawning there probably occurs at temperatures of 3-4°C (Scott and Scott 1988). In general, water in these deep areas is warmer than at lesser depths (Atkinson and Bowering 1987). Fully sexually mature Greenland halibut are extremely uncommon in the colder waters on Canada's continental shelf and in the bays and fiords of Greenland. The relatively distinct shift in preponderance of sexually mature fish to the warmer, deeper waters suggests spawning occurs where higher temperatures aid ovarian and embryonic growth (Templeman 1973). Spawning may also occur in Baffin Bay north of the Rise, although this is not well documented. If this is so, spawning in that area would likely occur in depths greater than 1000 m at temperatures of 0°C or less (Scott and Scott 1988).

About 50% of the female Greenland halibut in Davis Strait reach sexual maturity by age 11+ (Atkinson et al. 1982). Males mature slightly earlier. Larger fish produce more eggs (about 30 000-300 000 each), and differences in fecundity by geographic region have been identified (D'yakov 1982). Fertilized eggs from the Northwest Atlantic are clear and about 4.0-4.5 mm in diameter (Scott and Scott 1988). Those collected from the Bering Sea were slightly smaller (3.7-4.1 mm) (Bulatov 1983). The neutrally buoyant eggs drift in the mesopelagic plankton (600-1000 m). The time required for embryonic development is unknown although Bulatov (1983) found yolk-sac larvae in the Bering Sea in May. He postulated that hatching occurred in April (spawning was thought to occur in December-January).

Young larvae are 10-18 mm in length. They are usually mesopelagic and are typified by a yolk-sac which is about 25% of body length (Fig. 5). At 16-24 mm in

length, the larvae become epipelagic. The body is symmetrical but the left eye is now slightly higher on the side of the head. By about 50 mm in length, the post-larvae resemble the adult form, although pectoral fin development and the migration of the left eye are still incomplete. When the larvae are about 70-85 mm in length, their transformation appears completed and the pelagic larvae have changed to the demersal form: teeth are present, fins are pigmented, scalature is complete and the left eye has migrated to the top of the head (Atkinson et al. 1982).

DISPERSION OF LARVAE BY CURRENTS

In Davis Strait, the larvae rise to the near-surface layer during June and July (Chumakov and Serebryakov 1982). They are dispersed during summer by currents which flow northward along West Greenland to the northern part of Davis Strait (Atkinson et al. 1982). The pattern of this dispersion is a reflection of the anti-clockwise movement of dominant currents in the area, driven by two principle inputs (Fig. 3). One, entering from the south, is actually a mixture of two currents that originate in the east Atlantic. One of these is the East Greenland current: cold, relatively low salinity polar water that has travelled southeastward toward the coast of Greenland. As it passes between Greenland and Iceland, it meets the warmer and more saline Irminger Current, a branch of the North Atlantic Current. The two flow southward until they pass Cape Farewell, at the southern tip of Greenland. Then, as the West Greenland Current, they flow northward into Davis Strait, along the coast of West Greenland (Riget and Boje 1989).

The northward flow of the West Greenland Current has distinct seasonal and interannual variations. In general, it reaches its maximum during two periods of the year: in June and July, East Greenland Current polar water dominates at the 50-250 m depth interval; in November and December, the component from the Irminger Current dominates at the 100-500 m depth interval. At maximum flow, the West Greenland current reaches the Baffin-Greenland Rise before it begins to split up. There the current begins to diffuse and the general flow is westward across Baffin Bay. At lesser flows, this diffusion begins further south (Riget and Boje 1989). Ultimately, these waters join the cold, southward flowing waters of the Polar current on the west side of Davis Strait. Then, the anti-clockwise pattern is complete.

Because the average velocities of these currents range from 16-22.5 km·day^{-1}, Greenland halibut eggs and larvae may be carried great distances (Chumakov and Serebykov 1982). It is believed that larvae within Davis Strait are dispersed by these currents to the west coast of Greenland and to the east coast of Canada (Templeman 1973). Near Canada, the main area of distribution of young is from about 68° N northward; the northern limit is unknown. In relation to the direction of current flow, this distribution correlates well with Jensen's (1935) assumption of a spawning area in Davis Strait south of 67° N. It also concurs with Smidt's (1969) findings indicating the densest occurrence of pelagic larvae between 62°30' N and 66°15' N. Parenthetically, it has been postulated that southwestern Greenland fiord populations are recruited from populations off East Greenland, rather than from Davis Strait (Riget and Boje 1989). There is little evidence to support this assumption. The distribution of ichthyoplankton off eastern Canada has been less well studied.

Templeman (1973) hypothesized that some larvae hatched in the Davis Strait spawning grounds are swept northward and eastward by the West Greenland Current, until they reach the influence of the Polar Current (Fig. 3). There the larvae would be carried southward, where they could settle on the banks off Baffin Island and grounds further south.

Specifically, there is no information on the distribution of eggs and larvae off the coast of Baffin Island. Sexually mature ("ripe") fish have been caught in Cumberland Sound (D. Pike, DFO, Iqaluit, N.W.T.; personal communication) so it is possible that spawning occurs there. As the sound is deeper than 1000 m, it is of adequate depth for this activity. South of the Baffin-Greenland Rise, there is no similar deep water on the Canadian side except for Davis Strait proper. As noted above, whether spawning occurs north of the Rise, is not known. It is also not known whether spawning there could be sufficient to support the halibut population on the western side of Davis Strait, without immigration of fish from the more southern spawning area(s).

NURSERY GROUNDS

Off western Greenland, it is assumed that there are several areas along the coast where the young settle to the bottom in the autumn. For example, the vast shallow-water (200-250 m) area near West Greenland's Disko Bay is considered a nursery area for the fisheries of Disko Bay, Umanak district and more northerly districts of West Greenland. Another nursery ground is located in the coastal waters (about 200 m) of Godthaab district (Atkinson et al. 1982). In addition, great numbers of juvenile Greenland halibut are caught as by-catch in the northern shrimp (Pandalus borealis Krøyer) fishery between 71° N and 73° N.

It is believed that some of the fish that develop on the banks of West Greenland cross Davis Strait to reside on the Canadian shelf. These would augment the numbers that might be carried there as larvae by the currents in the Strait. Whatever their source, an abundance of small Greenland halibut has been found off Baffin Island between 200-400 m during several surveys (Atkinson et al. 1982; Atkinson and Bowering 1987;

Bowering and Chumakov 1989) and in eastern Hudson Strait and Ungava Bay (Templeman 1973). In another series of surveys, small fish (<1 kg) were abundant between 48-229 m (Templeman 1973); only larger fish are found in deeper depths (Scott and Scott 1988).

SPAWNING MIGRATION

Details of the remaining sequence of events in the Greenland halibut life cycle are uncertain. The traditional view for the West Greenland fishery, derived from studies of the by-catch in the northern shrimp fishery, proposes that juveniles develop while on the banks, and later migrate into deeper water in fiords. In the fiords, they grow to a considerable size and constitute the main resource of the commercial fishery of West Greenland. As they approach sexual maturity, the fish are assumed to migrate from the fiords, down the continental slope, and into the deeper area of Davis Strait toward the Davis Strait spawning area. The fish are believed to return to the fiords after spawning (Riget and Boje 1989).

A recent interpretation presents an alternate series of events (Riget and Boje 1989). These authors determined that results of tagging experiments do not support the hypothesis of a spawning migration out of the fiords into Davis Strait. Instead, they found that halibut may migrate directly off the banks into the deeper part of Davis Strait, rather than go to the fiords first. These authors also reported that there were no data supporting the hypothesis that fish return to the fiords from the strait after spawning. They reported that tagging data indicated that Greenland halibut in West Greenland fiords remain there for several years. They found no evidence of an emigration from the fiords. Accordingly, these authors postulated that spawning may occur in the fiords as well, but perhaps sporadically. Although these authors found little supporting data for their hypotheses, they suggested this was a result of limited fishing effort on the western side of the banks off west Greenland. They noted that of the several studies of stock identification done to date, none have included adults from West Greenland fiords. They concluded that the simplest interpretation of available data suggested that stocks in the fiords remain stationary and do not participate in the spawning in the Davis Strait (i.e. are separate stocks).

As noted above, much of what is known about Greenland halibut migration off Greenland is derived from by-catch data of the northern shrimp fishery. There are few comparable data from the eastern Canadian coast. In general, mean size and age of Greenland halibut increases moving northward. For example, fish from the banks east of Newfoundland are small and sexually immature (Chumakov and Serebryakov 1982). Those tagged in this area were sexually maturing when recaptured off Baffin Island, presumably after migrating toward a spawning area (Chumakov and Serebryakov 1982; Bowering 1984a). Bowering and Chumakov (1989) also found a high abundance of large, sexually mature Greenland halibut off Baffin Island, between 1300-1500 m.

Fish in shallower waters near the island are much smaller and usually sexually immature. The mean weight of Greenland halibut (age unknown) caught in eastern Hudson Strait (200-300 m) in 1988 was only about 75 g (D.G. Parsons, NAFC, St. John's, Nfld.; unpublished data). Likewise, the mean size of Greenland halibut caught during an exploratory survey in western Hudson Strait was similar (Allard 1990). It is assumed that as these small fish grow, they gradually migrate to deeper waters off the Baffin Island banks, where fish ages 6+ to 10+ dominate (Chumakov and Serebryakov 1982). Eventually, as sexual maturity approaches, they migrate into deeper water and spawn. Unlike the fish from the fiords of Greenland, it is believed that spent Greenland halibut from the Canadian side of Davis Strait do not return to areas occupied before maturation (Chumakov and Serebryakov 1982).

FEEDING HABITS

DIET

The Greenland halibut is a voracious predator. In general, epi- and mesopelagic fishes are the dominant food items (Table 1). A low occurrence of benthic prey species reflects the weak association of the Greenland halibut with that habitat. Off the coast of Labrador, principal prey species were Greenland halibut and northern shrimp (Bowering et al. 1984). The remaining majority of the food was a variety of fish species (e.g. capelin, Mallotus villosus Müller and Arctic cod, Boreogadus saida Lepechin).

VARIATIONS

Studies have indicated that the food habits and apparent feeding intensity of Greenland halibut varies according to several factors, summarized below.

By size

The general trend in diet is toward increased piscivory with age. For example, Bowering and Lilly (1985) found that fish of 65-69 cm switched from smaller pelagic prey (e.g. pandalid shrimp and capelin) to larger groundfish (e.g. Atlantic cod, Gadus morhua Linnaeus). Yang and Livingston (1988) reported that Bering Sea Greenland halibut smaller than 20 cm fed primarily on euphausiids. Larger halibut were principally squid and fish eaters. Halibut larger than 70 cm ate fish almost exclusively.

By location and depth

Smidt (1969) found a predominance of crustaceans in fish taken from the banks and fiords of West Greenland. Shrimp was also an important prey on the Labrador banks (Bowering et al. 1984). Chumakov and Podrazhanskaya (1986) found the diet shifted to fish in halibut captured from Davis Strait proper. Off Labrador, Arctic cod, young Greenland halibut, and eelpouts (Lycodes spp.) were the most important food at depths less than 500 m; beaked redfish (Sebastes spp.) were the major prey in deeper waters. Also, the incidence of squid as prey increased with depth.

Feeding intensity may also vary by area and depth. Chumakov and Podrazhanskaya (1986) measured the highest mean index of stomach fullness on the continental slope (600-700 m). But in the Barents Sea, Nizovtsev (1977) as cited by Chumakov and Podrazhanskaya (1986) found the index of stomach fullness was highest in depths of 100-400 m. Food availability in the two regions was not evaluated in either study.

By season

Feeding activity also varies seasonally. Chumakov and Podrazhanskaya (1986) found it was higher during summer and autumn months and decreased to very low levels during winter and spring. They reported this pattern is typical of other species which live in the shelf and slope areas of the Northwest Atlantic (e.g. haddock, Melanogramus aeglefinus Linnaeus; Atlantic cod; beaked redfish; and roundnose grenadier, Coryphaeoides rupestris Günther).

Strict evaluation of all trends affecting Greenland halibut diet should consider seasonal abundance and distribution of prey species, aspects not routinely included in the literature.

GROWTH

SIZE AT AGE

Both sexes grow at the same rate for about the first 5-7 years, reaching a length of about 45 cm. After this, females grow faster and live longer than males. This divergence is probably the result of male precociousness; energy for growth is diverted from somatic growth to the formation of sexual products earlier than in females (Atkinson et al. 1982). Scott and Scott (1988) reported that the size of Greenland halibut from the northern Grand Bank were: 5 yr = 40 cm; 8 yr = 50 cm; and 10 yr females = 70 cm, 10 yr males = 60 cm. Males reached a maximum of 70-80 cm and age 12-14+. All northern Grand Bank Greenland halibut over 90 cm were females; they lived longer than 20 years.

These size/age relations are similar to those in data obtained from the 1987 Cumberland Sound halibut fishery (Fig. 6). However, Bowering and Stansbury (1984) reported that Greenland halibut from more southern Canadian waters (e.g. Gulf of St. Lawrence and waters off northeast Newfoundland) were significantly smaller at a given age than fish from more northern waters. A north-south gradient toward decreasing size at age was also reported by Bowering and Chumakov (1989).

DETERMINING AGE

Bowering (1982) described a method for estimating the age of Greenland halibut by counting checks (zones) on sagittal otoliths. The left otolith is ground on the convex surface to expose the nucleus. It is placed in ethanol against a dark background and checks are counted during examination under reflected light with a binocular microscope.

ANNUAL FOOD REQUIREMENT

Chumakov and Podrazhanskaya (1986) used Winberg's equation to estimate the food requirements of Davis Strait Greenland halibut. For the portion of the Northwest Atlantic population of age greater than 4+ (and assuming a six-month growing season), they estimated an annual food requirement of more than 750 000 t.

TEMPERATURE PREFERENCE

Scott and Scott (1988) reported that the Greenland halibut occurs in waters with temperatures between -0.5°C to about 6.0°C but is usually more abundant at temperatures between 0.0-4.5°C. Templeman (1973) reported that it was most common between -0.5°-3.0°C, except for spawning concentrations which were found at higher temperatures. Atkinson and Bowering (1987) found that maximum catches in Davis Strait occurred in waters of 1.0-1.9°C. Salinity in Davis Strait typically ranges between 34.4-34.9 $^{o}/_{oo}$ (Templeman 1973).

Temperature preference is reported to have resulted in a displacement of a portion of the Davis Strait Greenland halibut population to deeper waters during the early 1980's (Savvatimsky 1987). Waters off Labrador were cooler during the 1970's and early 80's than in either the late 60's or more recently. Catch data from the Davis Strait fishery suggested an apparent increase in halibut abundance during the colder years. Savvatimsky (1987) hypothesized that because of the cooler waters on the banks, Greenland halibut migrated to warmer deeper water along the continental slope (>1000 m). There they formed concentrations that were more vulnerable to fishing nets and there was an apparent increase in

abundance. During warmer years, the fish were more widely dispersed and catches were reduced.

Temperature preference may also result in seasonal changes in Greenland halibut distribution. Bowering and Chumakov (1989) presented data suggesting that Greenland halibut frequented warmer waters in the summer, but the disparity of sample sizes precluded testing for statistical significance. However, in the winter there was a marked absence of halibut in shallower waters. There had been an abundance of smaller animals there in the summer, when water temperatures were several degrees warmer.

MORTALITY

Ernst and Borrmann (1987) estimated the natural mortality rates (M) for Davis Strait Greenland halibut from 1977-1984. For males, M ranged from 0.230-0.245. Natural mortality of females was lower (M = 0.065-0.075). Total stock M (both sexes) was estimated to be also 0.065-0.075. The authors recommended a value of M = 0.10 for use in population dynamics calculations.

PREDATORS

The Greenland shark (Somniosus microcephalus Bloch and Schneider) is considered the most important predator of Greenland halibut, but narwhal (Monodon monoceros Linnaeus), beluga whales (Delphinapterus leucas Pallas), and hooded seals (Cystophors cristata Erxleben) are also prominent. Among fishes, Atlantic cod, Atlantic salmon (Salmo salar Linnaeus) and large Greenland halibut consume small Greenland halibut (Scott and Scott 1988).

STOCK IDENTIFICATION

In spite of the large geographical range of this species, a number of studies indicate that only a few genetically isolated stocks of Greenland halibut exist. In the Northwestern Atlantic, most evidence suggests that a relatively small stock spawns in the Laurentian Channel of the Gulf of St. Lawrence, and a much larger stock spawns in Davis Strait. Evidence supporting the existence of these stocks has been derived using meristics (Misra and Bowering 1984), biochemical genetics (Fairbairn 1981), blood protozoa as biological tags (Khan et al. 1982), and external tagging experiments (Bowering 1984a). In addition, studies of distribution patterns (Templeman 1973; Bowering 1984b), biological parameters (Bowering 1983), and spawning and nursery areas (Smidt 1969) have also supported this conclusion.

However, not all studies of Greenland halibut stock identity/fidelity suggest such homogeneity within Greenland halibut populations. For example, Bowering's 1988 statistical evaluation of the relationships between meristic characters of fish from the Northwest Atlantic identified separate stocks in each of the eight areas examined. That author rejected this conclusion because of the contradictory evidence cited above, and suggested the variation was caused by a genetic cline existing within the population. Khan et al. (1982) and Bowering (1984a) found evidence that there may also be a separate stock within Fortune Bay, off Southeastern Newfoundland. Riget and Boje (1989) more recently suggested there may be a stock that spawns in the fiords of south-west Greenland.

Likewise, during an examination of Greenland halibut meristics in the Pacific, D'yakov (1981) found significant differences between fish taken from four areas of the Okhotsk Sea. In another study, D'yakov et al. (1981) used biochemical genetics to separate halibut from the Bering and Okhotsk seas into six statistically different groups.

Because of the continued uncertainty regarding the number of stocks within Greenland halibut populations, the topic of stock identity in Davis Strait (and in the northwest Atlantic in general) continues to be examined by DFO scientists and others.

BIOMASS ESTIMATES

There have been no comprehensive analyses of the size of the Davis Strait Greenland halibut population. Due to (1) the remoteness of these waters, (2) the concentration of fishing effort in particular areas, and (3) the concomitant limited focus of most survey design objectives, biomass estimates have been restricted to only portions of the strait. For example, in 1977 there was an estimated 70 500 t of minimal trawlable biomass within about 30 300 square nautical miles along the Baffin Island banks off Cumberland Sound (Fig. 4). The greatest biomass was between 201-300 m (Atkinson et al. 1982), where smaller fish predominated. A 1986 survey (Atkinson and Bowering 1987) of a larger area, including parts of the east and west slopes and central basin (Fig. 4), was estimated to contain a minimum trawlable biomass of 282 000 t (311 million fish). There have been no studies of halibut abundance in Cumberland Sound.

FISHERY MANAGEMENT

NW ATLANTIC GREENLAND HALIBUT FISHERIES

The Davis Strait Greenland halibut fishery is one

of several broadly defined regional fisheries in the Northwest Atlantic. Originally, the longline was the preferred gear-type but a deepwater bottom trawl fishery developed along the Northwest Atlantic continental slopes in the late 1960's (Chumakov and Serebryakov 1982). Longline fisheries still take place in the fiords and coastal areas along the west coast of Greenland (Riget and Boje 1989) and in Cumberland Sound, Baffin Island.

In the trawl fisheries, vessels from Canada, Denmark (including Greenland and Faroe Islands), Germany, Norway, Poland, Portugal, United Kingdom, and USSR fish for halibut in the Northwest Atlantic. Historically, these fisheries have produced catches in the range of 30 000-63 000 t, averaging about 46 000 t during 1970-82 (Chumakov and Podrazhanskaya 1986).

FISHERY MANAGEMENT BY ICNAF AND NAFO

During the early 1970's, the Northwest Atlantic regional fisheries were monitored by the International Commission of the Northwest Atlantic Fisheries (ICNAF). The Greenland halibut stock in Davis Strait was considered distinct and was managed as a unit. With the establishment of 200 mile fisheries jurisdiction zones, NAFO was founded in 1979 to manage stocks outside the 200-mile zones of Canada, USA and European Economic Community (EEC) member states (including Greenland). Fishery boundaries were redrawn and the Davis Strait north-south dividing line coincided with the median line between Canada and Greenland (Fig. 1).

Within NAFO, the Scientific Council is charged with providing scientific advice for management of stocks partly or totally outside the 200-mile zones, and of stocks within those zones at the request of the coastal states concerned. Canada and the EEC have agreed to share control of the stocks overlapping the Davis Strait boundary line (e.g. Greenland halibut) on the basis of management advice provided by the NAFO Scientific Council (Atkinson et al. 1982). In 1976, in the absence of biomass estimates for the Davis Strait Greenland halibut population, a precautionary total allowable catch (TAC) of 20 000 t was established by ICNAF for the strait (Canadian and Greenland waters combined). This was increased to 25 000 t in 1978, as a result of a USSR study which indicated a large stock in the area (Atkinson et al. 1982). NAFO has kept the Davis Strait TAC at 25 000 t since then.

DAVIS STRAIT CANADIAN FISHERIES

The development of a Canadian strategy for managing its fisheries for Greenland halibut has resulted in a consideration of four fisheries (DFO 1990). Their location and corresponding NAFO fishing area identifications (Fig. 1) are as follows: the Gulf of St. Lawrence/West Newfoundland (areas 4RST), east of Newfoundland (areas 2J and 3KL), east of Labrador (areas 2GH), and the Canadian half of Davis Strait (areas 0AB). Only one of these fisheries, that in the Gulf of St. Lawrence, is known to be executed on a distinct stock of fish. The status of the others is under investigation, as noted previously.

The NAFO 25 000 t Davis Strait TAC is split evenly between Canadian waters (NAFO area 0), and the Greenland side (Fig. 1); NAFO area 0 quota is 12 500 t. For most of the 1980's, the Canadian allocation of this quota was 3000 t, with the remainder to foreign fleets (Table 2). Recently, this was increased and in 1991 was 5900 t. Foreign allocation was decreased accordingly. The TAC for the other three fishery units was also adjusted during this time, most notably decreasing for the fisheries east of Newfoundland and Labrador (Table 2).

Canadian catches of Greenland halibut in Davis Strait have remained negligible, however. Only the harvest of the Cumberland Sound longline fishery has been increasing (Table 3). Of the 5900 t allocated to the Canadian Davis Strait fisheries in 1991, 500 t were designated for development by Baffin Island inshore fisheries. Of this, 300 t were licensed to the Cumberland Sound experimental fishery. The success of this fishery has generated interest within other Baffin Island communities to develop similar Greenland halibut fisheries. Efforts to identify additional potential fishery resources beyond Cumberland Sound have been generally unsuccessful (D. Pike, DFO, Iqaluit, N.W.T.; personal communication).

CUMBERLAND SOUND FISHERY

Fishermen of Pangnirtung set longlines through the ice of Cumberland Sound from mid-January to June. They set in the deepest waters of the sound (between about 600-1125 m) for the best catches of the largest fish. As the line descends, a "kite" carries it away from the single fishing hole, spreading the string of about 100 baited hooks over the fishing grounds. After a "soak time" of about two hours, the catch is retrieved with a hand winch. Fish are headed, gutted, and bled immediately after capture. The fishermen then put the fish into seawater-filled tubs on a komatik (sled) for transport to the fish processing plant in Pangnirtung. This routine avoids freezing the fish prior to processing and yet ensures the maintenance of high quality product. At the plant, the fish are processed into steaks and fillets for consumption within the Northwest Territories or for export to Montreal and Ottawa (D. Pike, DFO, Iqaluit, N.W.T.; personal communication).

Since the fishery started in 1987, the preponderance of the catch has been females. Some have been sexually maturing but most of those have not been in spawning condition; only a few "ripe and running"

large females have been caught (D. Pike, DFO, Iqaluit, N.W.T.; personal communication). The size range of the 1987 catch was 45-105 cm, typical for the fishery. The age range was 7-16+ years (Fig. 7). The modal age for the fishery has been about 8-11+ years, similar to the age structure within the commercial catch off Labrador and eastern Newfoundland. This covers the sub-adult to adult sizes and is representative of a group that could have grown on Baffin Bank and then subsequently migrated down the slope to deeper water.

MODEL LIFE HISTORY OF CUMBERLAND SOUND GREENLAND HALIBUT

Fishery managers working with the Cumberland Sound Greenland halibut fishery are faced with many unknowns. The biology of Greenland halibut is not well understood, and much of our knowledge of this fish has been derived from research done throughout the northwest Atlantic. As with too many other Canadian Arctic fisheries, decisions regarding Cumberland Sound fishery quotas must be made without the benefit of basic knowledge of resource size or population dynamics. This document assembles background information regarding the biology of Davis Strait Greenland halibut for the benefit of this fishery and its managers.

From this compilation, the following model is presented for use as a basis for initial management or research decisions. The model is a conjectured scenario describing the life history of Greenland halibut in Cumberland Sound. It is assumed that these fish are a component of the Davis Strait Greenland halibut stock complex. It is also assumed that the biology of the fish in Davis Strait and Cumberland Sound follows a similar general pattern of life history. Subsequent investigation is required to verify or correct this conjecture.

CUMBERLAND SOUND LIFE HISTORY SCENARIO

Many Greenland halibut larvae that are hatched in central Davis Strait are swept westward toward the Baffin Island banks by the Greenland current. The fish grow as they drift and begin the metamorphosis into the flatfish form. Near Baffin Island, the postlarvae are convected southward by the Polar Current. That current follows the east coast of the island, carrying larvae to the Baffin banks, Cumberland Sound, Frobisher Bay, and Hudson Strait. There, they settle to the bottom, probably during the summer. The young fish remain on the shallow banks until the waters cool during winter. Then they descend into slightly deeper, warmer water. Some fish migrate eastward, down the continental slope into Davis Strait. Others, migrate into the deeper water in Cumberland Sound. The following spring, they return to the shallows when those waters begin to warm again.

As the Greenland halibut grow, this seasonal movement becomes more pronounced and develops into a spawning migration. This behaviour concentrates them in certain very deep areas and those which enter Cumberland Sound form the basis of the Cumberland Sound Greenland halibut fishery resource. Because the maximum depths of Cumberland Sound are similar to those for proposed Davis Strait spawning areas, it is possible that spawning occurs in the sound. Based on Cumberland Sound catches, it is also probable that some fish continue their spawning migration out of the sound and spawn elsewhere.

Eggs deposited in the Sound, and larvae that hatch there, encounter no barrier or retention mechanism that restricts their distribution. Juveniles hatched from Cumberland Sound eggs settle in the sound and on banks further south as well, mixing with young that hatched in other locations in Davis Strait. As they grow, these fish further disperse as they increase their feeding activity and seek pelagic prey.

Because Cumberland Sound fish can pass freely in and out of the sound through the deep channel at its mouth, it is unlikely that these fish constitute a reproductively isolated stock. Bowering (1988) interpreted the results of stock identification studies as indicative of a genetic cline within the Northwest Atlantic halibut population. In the absence of physical barriers, a cline could be maintained if many of the Davis Strait fish returned to a specific spawning ground, such as Cumberland Sound. This behaviour has been observed on a smaller scale in the winter flounder, Pseudopleuronectiformes americanus Walbaum (Crawford and Carey 1985; Crawford 1990), and has been attributed to Greenland halibut by Bowering (1984a). If there are certain "spawning grounds" for particular sub-populations of the North Atlantic Greenland halibut population, then the mechanism exists for the maintenance of genetic or physical characteristics that could differ in fish from different grounds. A tagging study would facilitate unravelling Greenland halibut migration patterns.

If this scenario is accurate, the deep (> 300 m) channel that connects Cumberland Sound with Davis Strait is fundamental. For example, water depths across the mouth of Frobisher Bay and Hudson Strait are less than 300 m. Given that few large halibut have been caught in these waters (Crawford 1989), the absence of deepwater access to these areas may diminish their prospects as adult Greenland halibut habitat. This constraint has been reported to limit halibut distribution near Newfoundland (Templeman 1973). Searches for new potential Greenland halibut fishing grounds near Baffin Island should include examination of local bathymetry for a deepwater connection to Davis Strait.

FUTURE RESEARCH

If the proposed scheme for the life history of Greenland halibut occupying Cumberland Sound is accurate, then the Inuit longline fishery is harvesting a portion of the spawning stock for the Davis Strait Greenland halibut population. There is evidence that the portion of the population exploited by the Labrador/East Newfoundland fishery is being overfished (hence the recent reduction in TAC for that fishery). If these events were related, they would be important considerations in decisions regarding the management of the Cumberland Sound Greenland halibut fishery.

This is one of several topics listed below as avenues for future research in Cumberland Sound pertinent to the Greenland halibut fishery. The list is by no means complete but contains items identified during the compilation of this review.

1. Study the life history of Cumberland Sound Greenland halibut and test the accuracy of the scenario proposed in this report.

2. Examine the potential consequences resulting from the Cumberland Sound fishery's exploitation of a component of the Davis Strait Greenland halibut spawning stock.

3. Determine seasonal population abundances of Greenland halibut in the sound.

4. Evaluate the stock identity question (e.g. through continued collaboration with Quebec and Newfoundland DFO Region scientists).

5. Examine Cumberland Sound as halibut habitat, including seasonal changes (e.g. near bottom water temperature, salinity, food abundance and diversity, etc.).

6. Examine seasonal population size structure and distribution of Greenland halibut in different areas and depths of the sound, using experimental fishing gear (e.g. longlines with hooks of various sizes).

7. Conduct ichthyoplankton studies in Cumberland Sound in late spring and summer for Greenland halibut early life history information.

8. Develop, in collaboration with Quebec and Newfoundland Region scientists, fishery management strategies that incorporate the results of the research suggested in this list.

ACKNOWLEDGMENTS

Sheila McRae contributed bibliographic research to this report. An earlier version of this paper was reviewed by D. Bodaly, J. Flannagan, A. Kristofferson, R. Moran, J. Reist and J. Babaluk. The final version benefitted from their comments.

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Table 1. Dominant prey species taken by large, mature Greenland halibut in several areas of the Northwest Atlantic. (from Chumakov and Podrazhanskaya 1986).

Location	NAFO Subarea	Prey species
Davis Strait	0,1	beaked redfish (Sebastes mentella) roundnose grenadier (Coryphanoides rupestris)
Labrador	2	lanternfishes (Myctophidae), roundnose grenadier, capelin (Mallotus villosus)
Eastern Newfoundland	3	capelin sand lace (Ammodytes sp.) crustaceans (primarily Pandalus borealis)

Table 2. Quotas for several years of the Canadian Greenland halibut fisheries. Quantities in metric tonnes. (Canada DFO 1990)

NAFO Area	1986 Total	1986 Canadian	1987 Total	1987 Canadian	1988 Total	1988 Canadian	1989 Total	1989 Canadian	1990 Total	1990 Canadian	1991 Total	1991 Canadian
OAB	12.5	3.0	12.5	3.0	12.5	3.1	12.5	5.7	12.5	5.9	12.5	5.9
2GH	35.0	15.0	35.0	15.0	35.0	20.2	35.0	15.0	17.5	10.0	17.5	10.0
2J, 3KL	65.0	58.2	65.0	57.3	65.0	59.3	65.0	59.3	32.5	29.5	32.5	29.5
4RST	5.0	5.0	8.7	8.7	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5

Table 3. Historical landings (tonnes) of Greenland halibut from Baffin Island waters (NAFO area 0) (Canada DFO 1990).

Fishery	1985	1986	1987	1988	1989	1990[a]
Cumberland Sound	0	0	4.1	10.6	180	255
Canadian Offshore fleet	0	0	0	2	0	0
Foreign Offshore fleet	1039	272	388	59	7	N/A

[a] Catch as of November 28, 1990

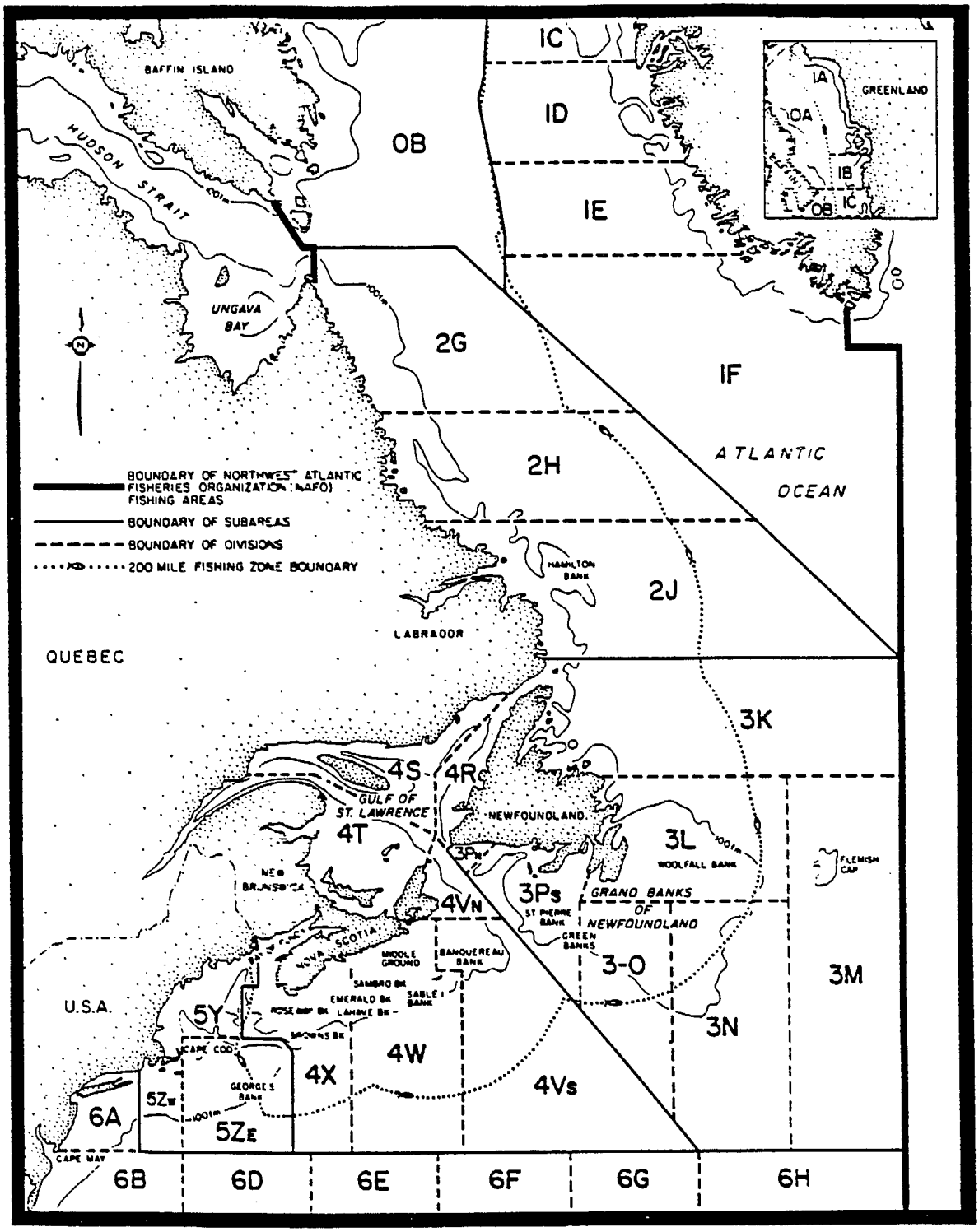

Fig. 1. Subareas and Divisions of the NAFO Convention Area.

Reinhardtius hippoglossoides (Walbaum 1792)

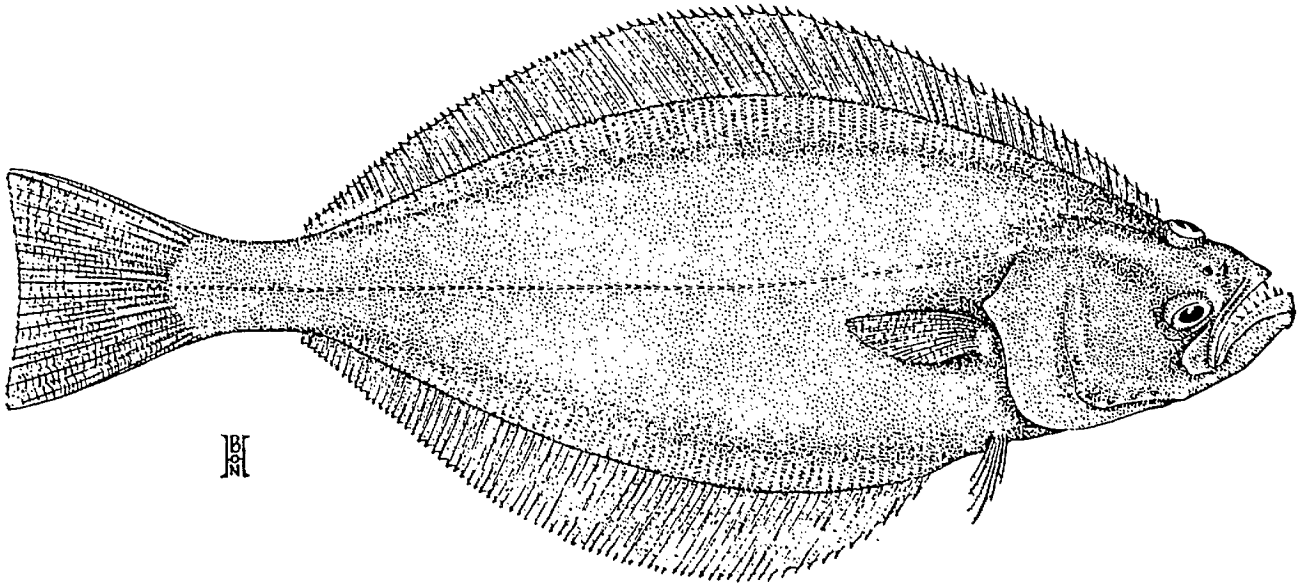

Fig. 2. An adult Greenland halibut, *Reinhardtius hippoglossoides* Walbaum (from Hart 1973).

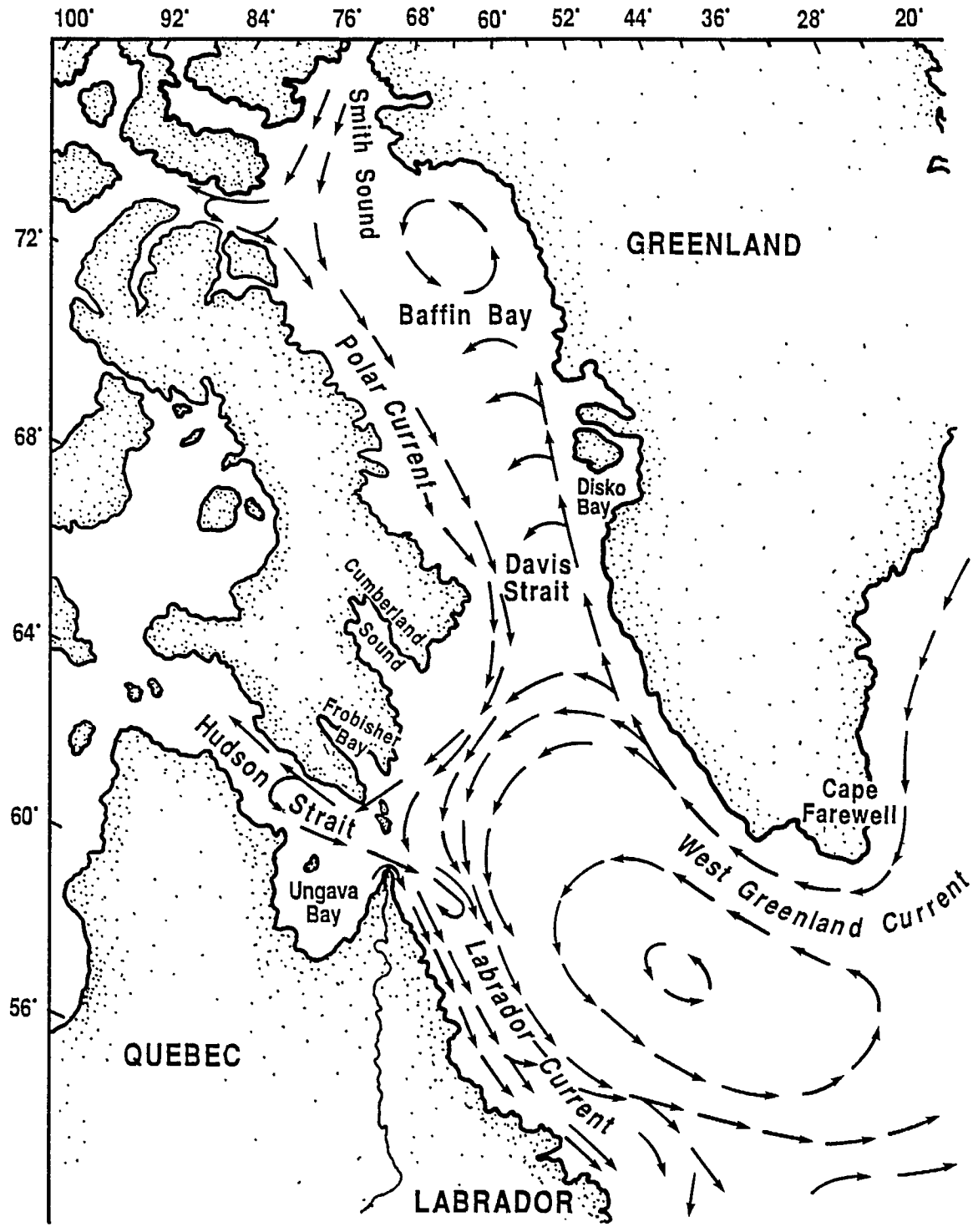

Fig. 3. Land masses, locations, and water currents mentioned in the text.

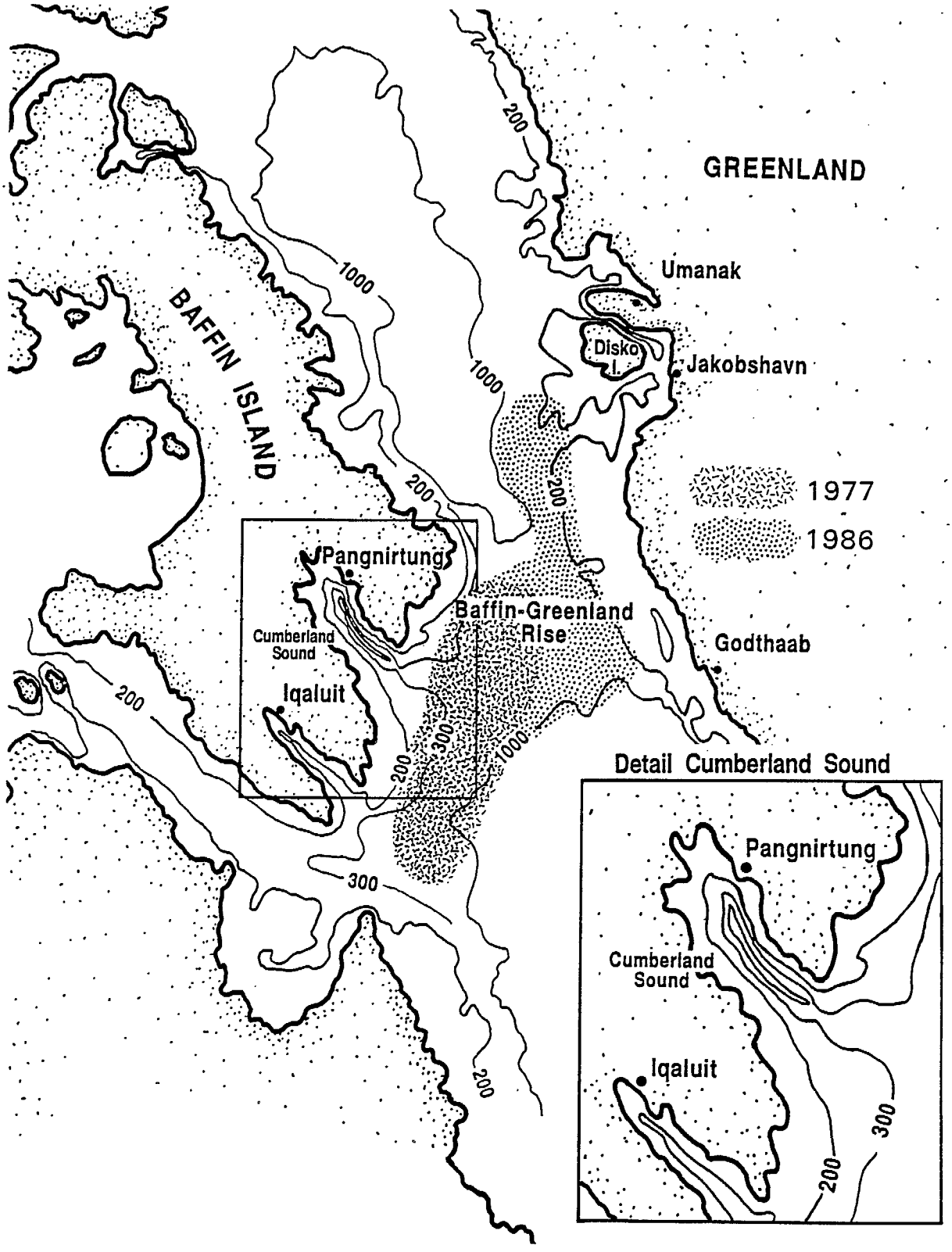

Fig. 4. Details of Davis Strait, showing areas of significance to the Greenland halibut fishery, and the areas covered during 1977 and 1986 assessments of Greenland halibut abundance.

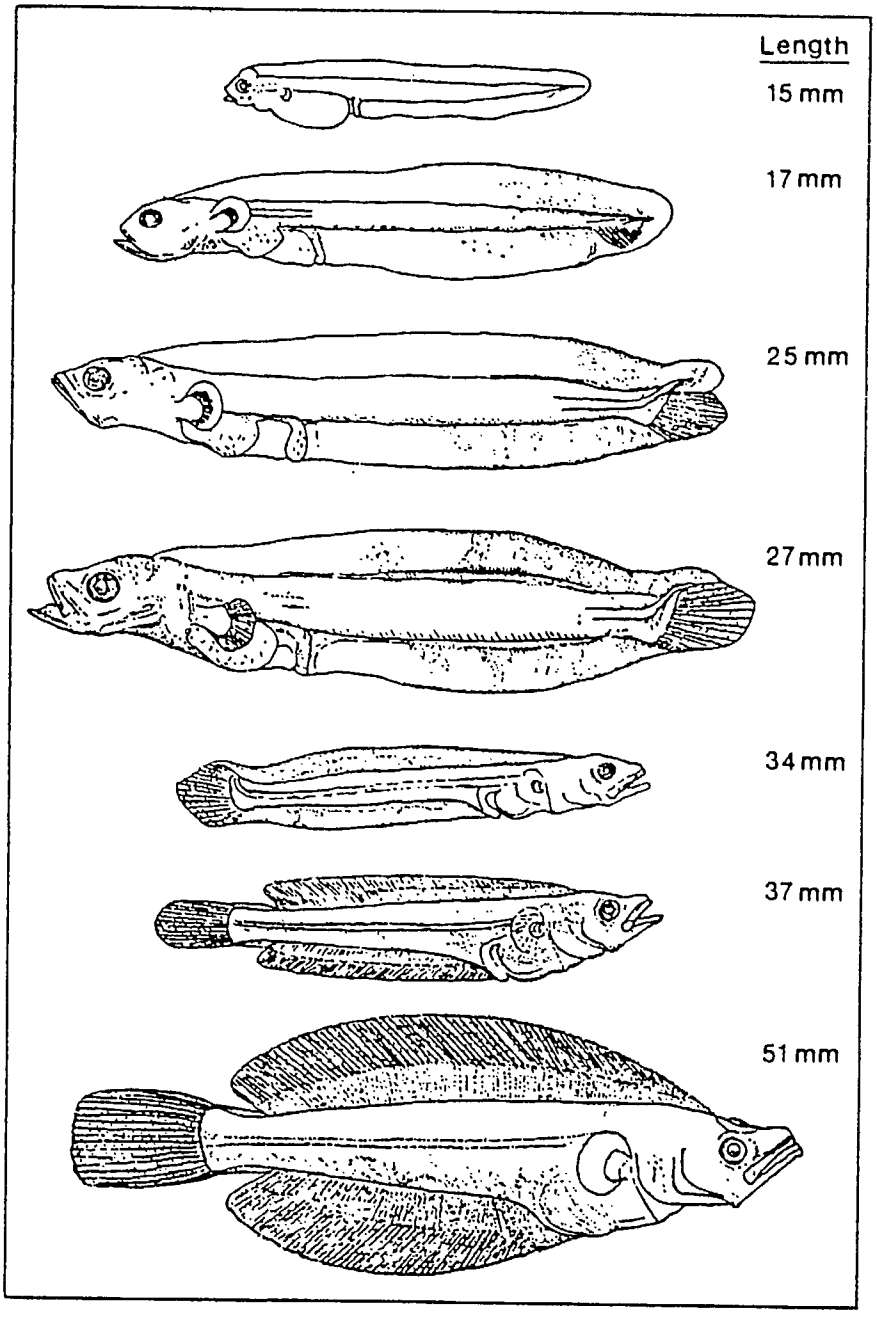

Fig. 5. Drawings of various sizes of Greenland halibut larvae collected from Davis Strait (from Schmidt 1904).

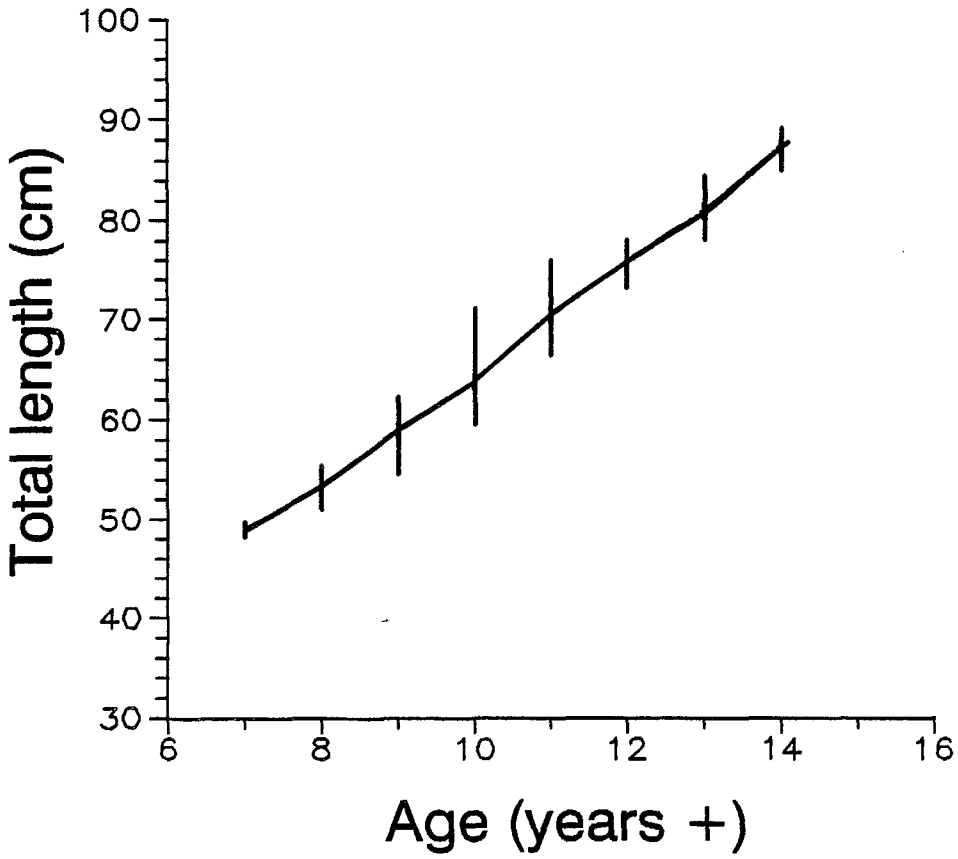

Fig. 6. Length-at-age (and data ranges) of Greenland halibut caught during the 1988 Cumberland Sound Greenland halibut fishery.

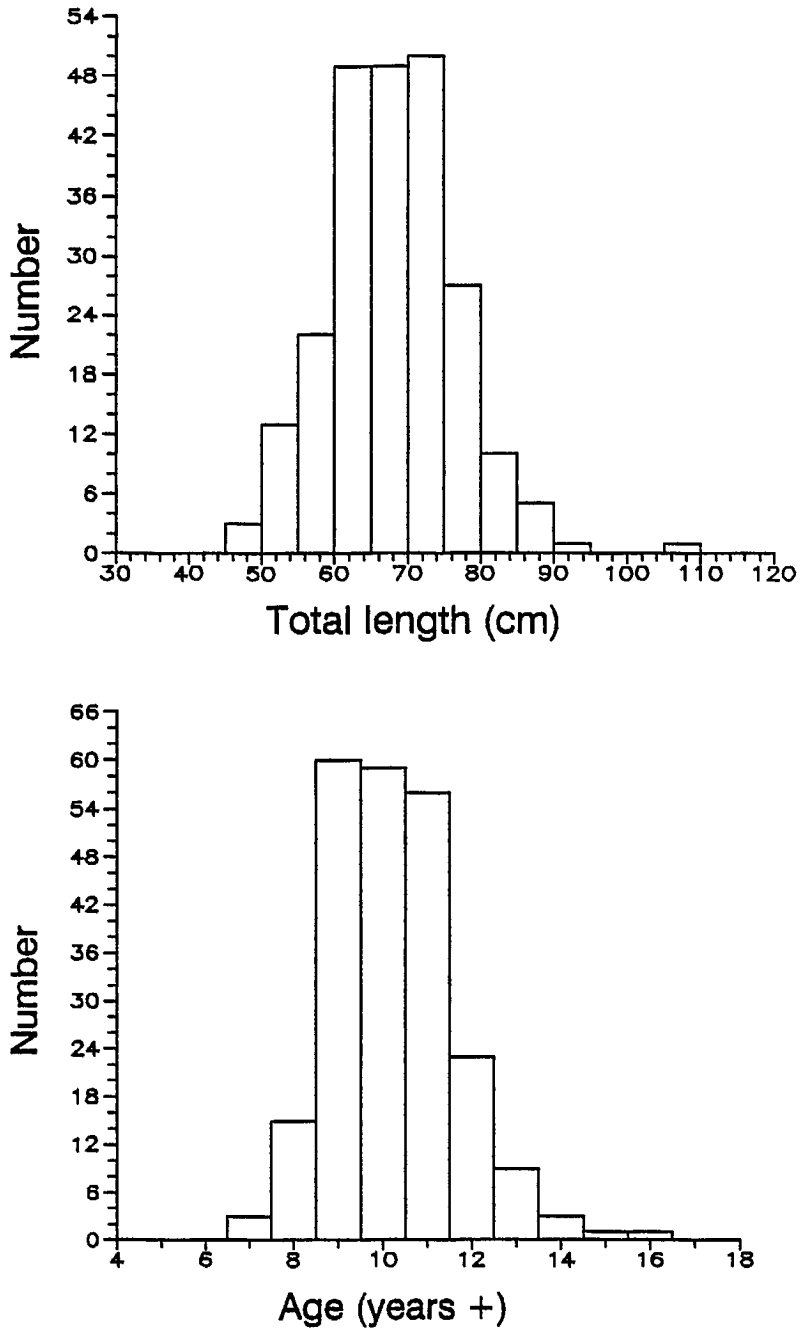

Fig. 7. Length (total) and age frequency within the catch of the 1987 Cumberland Sound Greenland halibut fishery (from Crawford and Dahlke 1989).