A comparison of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) fisheries and distribution in the Northwest and Northeast Atlantic

W. Raymond Bowering & Kjell H. Nedreaas[1]

SARSIA

Bowering WR, Nedreaas KH. 2000. A comparison of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) fisheries and distribution in the Northwest and Northeast Atlantic. *Sarsia* 85:61-76.

Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) are widely distributed over extensive geographic areas of both the Northwest and Northeast Atlantic Ocean with no break in the continuity of the respective distributions. Although the entire Greenland halibut resource in the North Atlantic is genetically homogeneous they mainly comprise a single interbreeding stock in each of the two regional areas investigated. Both stocks show similar distribution patterns over depth. Generally, larger fish become more abundant and smaller fish less abundant in progressively deeper water with peak abundance occurring over a depth range of 400-1000 m. Greenland halibut in the Northwest Atlantic were observed to be most abundant in bottom temperatures mainly between 2 °C and 6 °C compared to 0 °C to 4 °C in the Northeast Atlantic.

The fishery for Greenland halibut in the Northeast Atlantic was unregulated until 1992 although since 1995 catches substantially exceed those advised. The spawning stock size reached historically low levels during the 1990s and recruitment to the spawning stock remains uncertain based on the most recent assessment. In the Northwest Atlantic the Greenland halibut resource has been regulated by catch quota since 1974 although it was subjected to high-uncontrolled fishing pressure during the early 1990s. The spawning stock also reached historic low levels during this period but has recently showed improvement due to low fishing mortality since 1995 and better than average recruitment since 1990.

[1]authorship equal

W. Raymond Bowering, Northwest Atlantic Fisheries Center, P.O. Box 5667, St. John's, Newfoundland, A1C 5X1, Canada – Kjell H. Nedreaas, Institute of Marine Research, P.O. Box 1870 Nordnes, N-5817 Bergen, Norway.
E-mail: boweringr@dfo-mpo.gc.ca – kjell.nedreaas@imr.no

Keywords: Greenland halibut; Northwest Atlantic; Northeast Atlantic; fisheries; distribution; depth; temperature.

INTRODUCTION

The Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) is a deepwater flatfish distributed throughout the entire rim of the North Atlantic (Bowering & Brodie 1995; Godø & Haug 1987; Vis & al. 1997). Recent studies on stock structure of Greenland halibut using mitochondrial DNA have also indicated they are genetically homogeneous throughout the North Atlantic (Vis & al. 1997). This is not surprising given its highly migratory nature over extreme distances deduced from tagging experiments (Sigurdsson 1981; Boje 1994; Bowering 1984). Although it is now recognized that there is extensive gene flow occurring among populations of Greenland halibut in the North Atlantic, it was concluded that studies of the distribution of local spawning components remains essential for effective management (Vis & al. 1997).

The Greenland halibut has been studied rather extensively in the main areas of the Northwest Atlantic in recent years primarily as a result of its increased significance as a major groundfish fishery following the collapse of most cod and flatfish stocks in the area (see Bowering & Brodie 1995 for a more complete review). Some major aspects of recent biological study in the Northwest Atlantic are: 1) stock delineation (Vis & al. 1997), 2) sexual maturity and spawning (Junquera & Zamarro 1994; Morgan & Bowering 1997), 3) food and feeding (Bowering & Lilly 1992; Orr & Bowering 1997; Dawe & al. 1998) and 4) distribution and abundance (Bowering & Brodie 1995; Bowering & Power 1995; Jørgensen 1997a, 1997b). In addition, it has gained international notoriety following the infamous "turbot war" between Canada and the European Union during 1995 sparked by escalating, unregulated fishing effort for Greenland halibut in the Flemish Pass area east of the Newfoundland Grand Bank (Vis & al. 1997). Stock status of the major Greenland halibut resources is evaluated and scientific advice on fisheries management provided annually by the Scientific Council of the Northwest Atlantic Fisheries Organization (NAFO) (see Anon. 1998).

Greenland halibut in the Northeast Atlantic also has been the subject of considerable study regarding distribution, biological characteristics and fisheries. Godø & Haug (1987) reported on migration and recruitment patterns of Greenland halibut in the Spitsbergen area based on data available during the early 1980s. As well, Godø & Haug (1989) reviewed the available literature on natural history, fisheries and management of the species in the eastern Norwegian and Barents Seas to that time. More recently, Nedreaas & al. (1996) evaluated the biological implications of a multi-gear fishery for Greenland halibut in the Northeast Arctic while Michalsen & Nedreaas (1998) reported on a food and feeding study of Greenland halibut in the Barents Sea and East Greenland waters. A number of other studies on Greenland halibut in the Northeast Atlantic have been presented to recent NAFO or ICES symposia and are currently being reviewed for publication or are in press. For example, gear selection (Huse & al. 1999), fecundity (Gundersen & al. 1999), spawning (Albert & al. 1998; Stene & al. 1999) and recruitment studies (Albert & al. 1997).

For Greenland halibut in the Northeast Atlantic, stock status is determined and scientific advice on management is provided annually. This is the responsibility of the Arctic Fisheries Working Group and the Advisory Committee on Fisheries Management, respectively of the International Council for the Exploration of the Sea (ICES) (see Anon. 1999).

The purpose of the paper is to compare the fisheries as well as the current spatial distribution characteristics for major stocks of Greenland halibut in the Northwest and Northeast Atlantic Ocean. Implications for fisheries management within the respective areas will also be discussed.

MATERIAL AND METHODS

Geographic distribution is examined by depicting research vessel survey catches per set (all sets standardized to 0.8 nautical miles tow distance) as circles and subsequently plotting these circles on a map of the survey area according to the position of each catch. Circle diameters are chosen to represent proportionally increasing size groups of catch weights (kg) established from a cursory examination of the database. To allow for direct comparison of catch (kg) per set all geographic distribution maps use the same catch range scale and corresponding symbol size. All surveys were conducted using bottom trawls with small mesh liners in the codends. Survey details are outlined in Table 1.

For the northern management area of the Northwest Atlantic (NAFO Subareas 0 and 1), the geographic distribution is illustrated from a Canadian survey conducted in the summer of 1986 covering a depth range of 200-1250 m. Results are presented in Fig. 2. For the southern management area of the Northwest Atlantic (NAFO Subarea 2 and Divisions 3K, 3L, 3M, 3N and 3O) the geographic distribution is illustrated from a synoptic survey carried out by Canada in autumn 1997. In NAFO Divisions 2J, 3K, and 3L the survey covered all depths to 1500 m. For NAFO Divisions 2G, 2H and 3M the surveys covered a depth range of 200-1500 m whereas survey coverage in Divisions 3N and 3O included all depths to a maximum depth of 800 m. The results are shown in Fig. 3.

In order to present the most complete geographic distribution of Greenland halibut in the Northeast Atlantic a composite of survey catches from several sources were used. For the continental slope area in the Norwegian Sea and along the western edge of the Barents Sea from 62°N to 80°N, results are presented from Greenland halibut directed Norwegian surveys conducted in autumn 1995 (62°N to 68°N) and 1996 (68°N to 80°N) over a depth range of 500-1500 m. For the Svalbard and Barents Sea region, Greenland halibut catch results are shown from the standard Norwegian groundfish surveys which were carried out during autumn of 1996 to a maximum depth of 500 m. Data from a similar survey during the same time north and east of Spitsbergen directed for Greenland halibut are presented also but extended to a depth of approximately 800 m. The only available data to illustrate Greenland halibut areal distribution further east were from Russian exploratory surveys conducted in 1978-80 (from Borkin 1983). Many fishing stations were around Franz Josef Land (except on the north side due to ice) as far east as 73°E and covered depths to 1150 m. The results are presented in Fig. 4.

Distribution and relative abundance with depth are expressed as mean number and weight (kg) per standard set by 100 m depth intervals for depths to 500 m and 250 m intervals for depths greater than 500 m. A cursory examination of the data indicated that for the geographic areas investigated any trends with respect to time were similar. Therefore data for all years were combined in the analyses. The areas and survey time series that were evaluated are identified in Table 1. Results are shown in Figs 5 and 6 for the Northwest Atlantic and Figs 7 and 8 for the Northeast Atlantic.

Distribution and relative abundance of Greenland halibut with bottom temperature for the Northwest Atlantic data are expressed as mean number and weight (kg) per standard set by 1.0 °C intervals for bottom temperatures in the range of 0.0 °C to 7.0 °C. All catches in temperatures < 0.0 °C are grouped as well as those in temperatures > 7.0 °C. Most of the data for the Northeast Atlantic also are presented in 1.0 °C intervals although the scale is slightly different than that used for the Northwest Atlantic. For catch and temperature data analyzed from both regions, the areas and survey time series combinations examined were identical to those used in the analyses of distribution with depth (see Table 1). Results are shown in Figs 9 and 10 for the Northwest Atlantic and the Northeast Atlantic, respectively.

RESULTS AND DISCUSSION

FISHERIES

Fishing for Greenland halibut in the Arctic regions of the Northwest Atlantic (NAFO Subareas 0 and 1) dates back to the early 1800s when local fishermen in the fjords of West Greenland caught them with baited longlines through the ice in wintertime. The catch was used primarily as food for sled dogs as well as local consumption (Rink 1852 as reported in Bowering & Brodie 1995). The Greenland halibut fishery was the most important local fishery in West Greenland until the 1920s when milder ocean climate brought cod in abundance to the area (Smidt 1969). The more lucrative cod fishing then largely replaced it.

Commercial exploitation of Greenland halibut did not begin in earnest until the 1960s as distant water trawling fleets of the former Soviet Union explored the potential fishery resources of Davis Strait particularly NAFO Division 0B (Fig. 1). Catches escalated from 2000-3000 tons in the 1960s and reached a peak of 25 000 tons by 1975 before declining again (Table 2; Fig. 1). The high catches experienced during the 1990s are related to the collapse of major groundfish resources in the Northwest Atlantic particularly cod and flatfish stocks in both West Greenland and in the Newfoundland-Labrador area. Effort from these fisheries has been redirected to Greenland halibut as a limited alternative (Bowering & Brodie 1995). In addition, the increases in both demand and price have made the fishery for Greenland halibut quite attractive. The fishery for Greenland halibut in the far north is prosecuted now primarily using trawlers and deepwater gillnets in the offshore areas of Davis Strait; longlines and gillnets in the fjords of West Greenland; and to a small degree by longlines in the inshore areas of Baffin Island.

Greenland halibut has been under quota control in the management area of NAFO Subareas 0 and 1 (managed jointly by Canada and Greenland) beginning in 1976 but until 1990 it has never been restrictive of the catch (Fig. 1). In 1995 the total allowable catch (TAC) was reduced by more than half from 25 000 tons to 11 000 tons and since then the inshore areas of NAFO Division 1A have been excluded from this management zone (see Anon. 1994 for details). The fishery for Greenland halibut here is currently unrestricted yet it comprises most of the catch in NAFO Subareas 0 and 1 in recent years (Jørgensen 1998; Simonsen 1998).

Historic catch records also show that a small Greenland halibut fishery using longlines existed off Labrador and eastern Newfoundland (NAFO Subareas 2 and 3 (except Division 3P) as early as mid 1800s. However, annual catches were very low, usually less than 1000 tons prior to the 1960s (Bowering & Brodie 1995). With the introduction of synthetic gillnets to the inshore domestic fishery during mid 1960s and the increased interest by large foreign otter trawlers catches rose quickly to peak at 37 000 tons in 1969 before declining again (Table 2; Fig. 1). In 1990, an intense unregulated fishery for Greenland halibut developed outside the Canadian 200-mile fishery zone (NAFO Regulatory Area or NRA) in NAFO Divisions 3L and 3M in the deep waters of Flemish Pass. Catches escalated rapidly to an average of 57 000 tons annually during 1990-94 (Ta-

Table 1. List of research vessel surveys by area, years and depth intervals used to investigate distribution and relative abundance of Greenland halibut in the Northwest and Northeast Atlantic.

Area	Combined survey years	Depth range (m)
Northwest Atlantic		
Davis Strait (NAFO Subareas 0 & 1)	1986	200-1250
N. Labrador (NAFO Divisions 2G, 2H)	1978-79, 1981, 1987-88	< 200-1500
S. Labrador to N. Grand Bank (NAFO Divisions 2J, 3K, 3L)	1977-97	< 200-1500
Flemish Pass and S. Grand Bank (NAFO Div. 3M, 3N, 3O)	1996-97	< 200-1500
Northeast Atlantic		
Continental Slope (62°N to 68°N)	1995	400-1500
Continental Slope (68°N to 80°N)	1994-97	200-1500
N. & E. of Spitsbergen	1996-97	<200-800
Franz Josef Land	1978-80	200-1150
Svalbard and Barents Sea	1986-88, 1995-97	<200-500

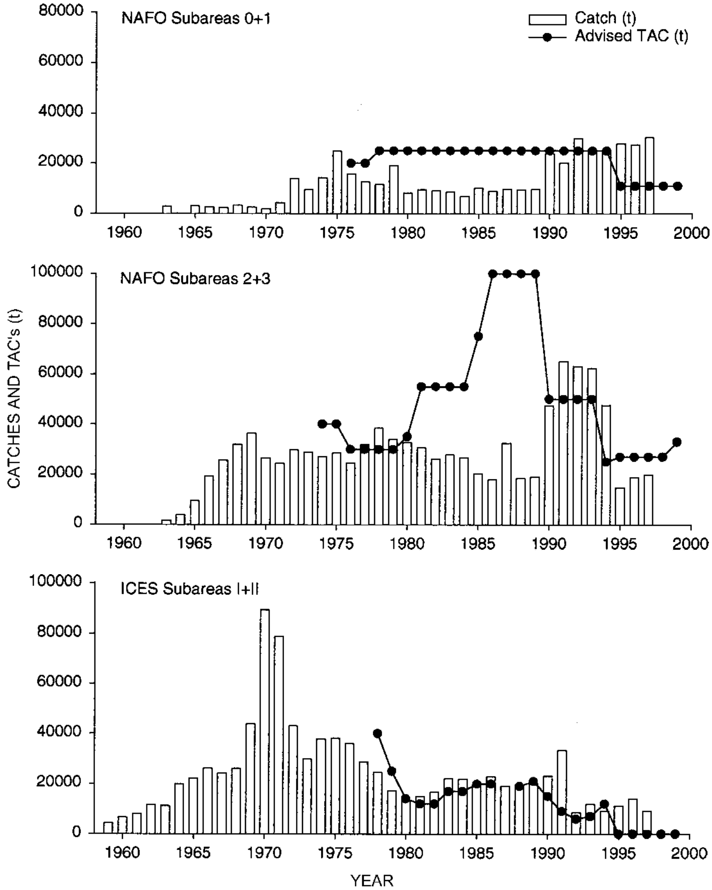

Fig. 1. Catches (tons) and scientifically advised total allowable catches (tons) (TACs) for Greenland halibut in the Northwest Atlantic (NAFO Subareas 0-3) and the Northeast Atlantic (ICES Subareas I & II). Data extracted from Anon. 1998a, 1998b.

ble 2; Fig. 1). With the introduction of catch restrictions and 100 % observer coverage in the NRA by the NAFO Fisheries Commission in 1995 catches declined to between 15 000 and 20 000 tons for the entire management area (NAFO Subareas 2 and 3 (except Division 3P)) during 1995-97 (Fig. 1). The fishery in this area now is comprised mainly of large freezer trawlers (mostly from Spain, Portugal, Russia, and Japan) fishing the NRA in depths of 1200-1800 m and by Canadian gillnet fishermen fishing the continental slope of NAFO Subarea 2 and Division 3K in depths of 800-1200 m (Brodie & al. 1998).

In 1974, the first TAC was introduced at a level of 40 000 tons for the Labrador-eastern Newfoundland management area (NAFO Subarea 2 and Divisions 3K and 3L) by the International Commission for the Northwest Atlantic Fisheries (ICNAF). TACs imposed by the coastal state (Canada) since the extension of jurisdiction to 200 miles in 1978 attained levels as high as 100 000 tons during 1986-89. This was based on survey biomass estimates as high as 400 000 tons and prospects for good recruitment (Bowering & Brodie 1995). The TAC was reduced to 25 000 tons by 1994 based on unexplained, rapid declines in survey biomass indices. In 1995, NAFO Divisions 3M, 3N and 3O were added to the management area and management responsibility given to the NAFO Fisheries Commission. With its new mandate the Fisheries Commission imposed a TAC of 27 000 tons for NAFO Subareas 2 and 3 (except Division 3P) during 1995 which remained in effect for 1996-98 (Brodie & al. 1998). Based on increases in stock size and better than average recruitment the TAC for 1999 was increased to 33 000 tons.

Historically, in the Northeast Atlantic there was little demand and poor price for Greenland halibut compared to other groundfish such as cod, therefore it received little attention from enterprising fishermen. It was not until a trade relationship developed (known as the Pomor Trade) between Russia and Norway during the 1760s that Norway began to fish this species commercially using longlines. Greenland halibut was more common in the Russian marketplace and the demand was sufficiently high to warrant the development of the fishery (Ytreberg 1942). The trade relationship eventually collapsed with the onset of the Russian Revolution in 1917 and the fishery declined. After 1935 the longline fishery again developed. Catches increased from about 1000 tons at the beginning to 10 000 tons by the 1960s (Table 2; Fig. 1). With the introduction of international trawling fleets to the fishery during mid 1960s, catches increased rapidly to peak at 90 000 tons in 1970 before declining (Anon. 1999). The fishery has been regulated

Table 2. Catches (tons) and scientifically advised total allowable catches (tons) (TACs) for Greenland halibut in the Northwest Atlantic (NAFO Subareas 0-3) and the Northeast Atlantic (ICES Subareas I & II). Data extracted from Anon. 1998, 1999.

	NAFO Subareas 0+1		NAFO Subareas 2+3		ICES Subareas I & II	
Year	Catch (t)	[1]TAC (t)	Catch (t)	[1]TAC (t)	Catch (t)	[1]TAC (t)
1959	-	-	-	-	4307	-
1960	-	-	-	-	6662	-
1961	-	-	-	-	7977	-
1962	-	-	-	-	11600	-
1963	2923	-	1602	-	11300	-
1964	180	-	3928	-	20000	-
1965	3069	-	9500	-	22300	-
1966	2696	-	19244	-	26245	-
1967	2327	-	25644	-	24267	-
1968	3323	-	31986	-	26168	-
1969	2510	-	36488	-	43789	-
1970	1884	-	26594	-	89484	-
1971	4336	-	24392	-	79034	-
1972	13905	-	29822	-	43055	-
1973	9558	-	28944	-	29938	-
1974	14258	-	27123	40000	37763	-
1975	24948	-	28681	40000	38172	-
1976	15788	20000	24598	30000	36074	-
1977	12649	20000	31946	30000	28827	-
1978	11653	25000	38541	30000	24617	40000
1979	19188	25000	34089	30000	17312	25000
1980	8272	25000	32688	35000	13284	14000
1981	9561	25000	30737	55000	15018	12000
1982	9211	25000	26275	55000	16789	12000
1983	8687	25000	27853	55000	22147	17000
1984	7031	25000	26711	55000	21883	17000
1985	10171	25000	20347	75000	19945	20000
1986	8977	25000	17976	100000	22875	20000
1987	9680	25000	32442	100000	19112	-
1988	9608	25000	18424	100000	19587	19000
1989	9699	25000	18920	100000	20138	21000
1990	23857	25000	47454	50000	23183	15000
1991	20226	25000	65008	50000	33320	9000
1992	30007	25000	63193	50000	8599	6000
1993	24161	25000	62455	50000	11933	7000
1994	24258	25000	47523	25000	9189	12000
1995	27862	11000	14699	27000	11043	0
1996	27427	11000	18840	27000	14073	0
1997	30339	11000	19858	27000	9264	0
1998	-	11000	-	27000	-	0
1999	-	11000	-	33000	-	0

[1]Advised TAC

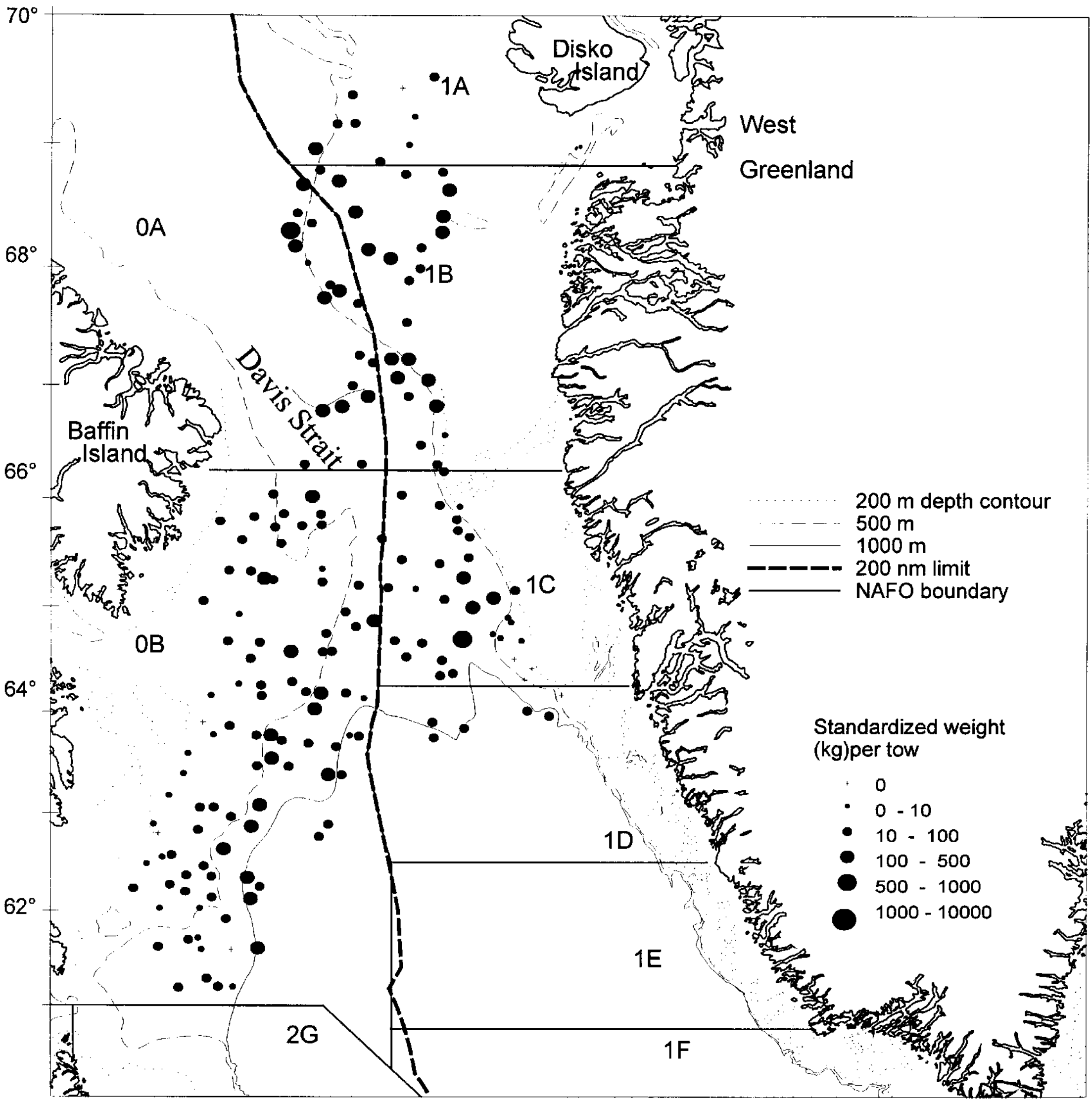

Fig. 2. Standardized weight (kg) per set of Greenland halibut from a Canadian research vessel bottom trawl survey in Davis Strait (NAFO Subareas 0 and 1) during summer 1986.

since 1992, and from 1992 until 1997 catches averaged around 10 000 tons annually, the lowest since the early 1960s (Table 2; Fig. 1). The fishery for Greenland halibut in the Northeast Atlantic has been conducted mainly along the continental slope of the Norwegian Sea between 68°N and 74°N in ICES Division IIa and along the continental slope of southern ICES Division IIb. High variability in catches is generally associated with proportions taken in ICES Division IIb and it was here that peak catches occurred in 1970-71 (Godø & Haug 1989). The Greenland halibut fishery in the Norwegian and Barents Seas has been prosecuted primarily by fishing fleets from the former Soviet Union, German Democratic Republic and Federal Republic of Germany as well as Poland and the United Kingdom (Anon. 1999). Since 1992, however, more than 80 % of the catches have been taken by Norway with Russia accounting for most of the remainder.

ICES has provided annual scientific advice on catch levels for this stock since 1978, however, the fishery

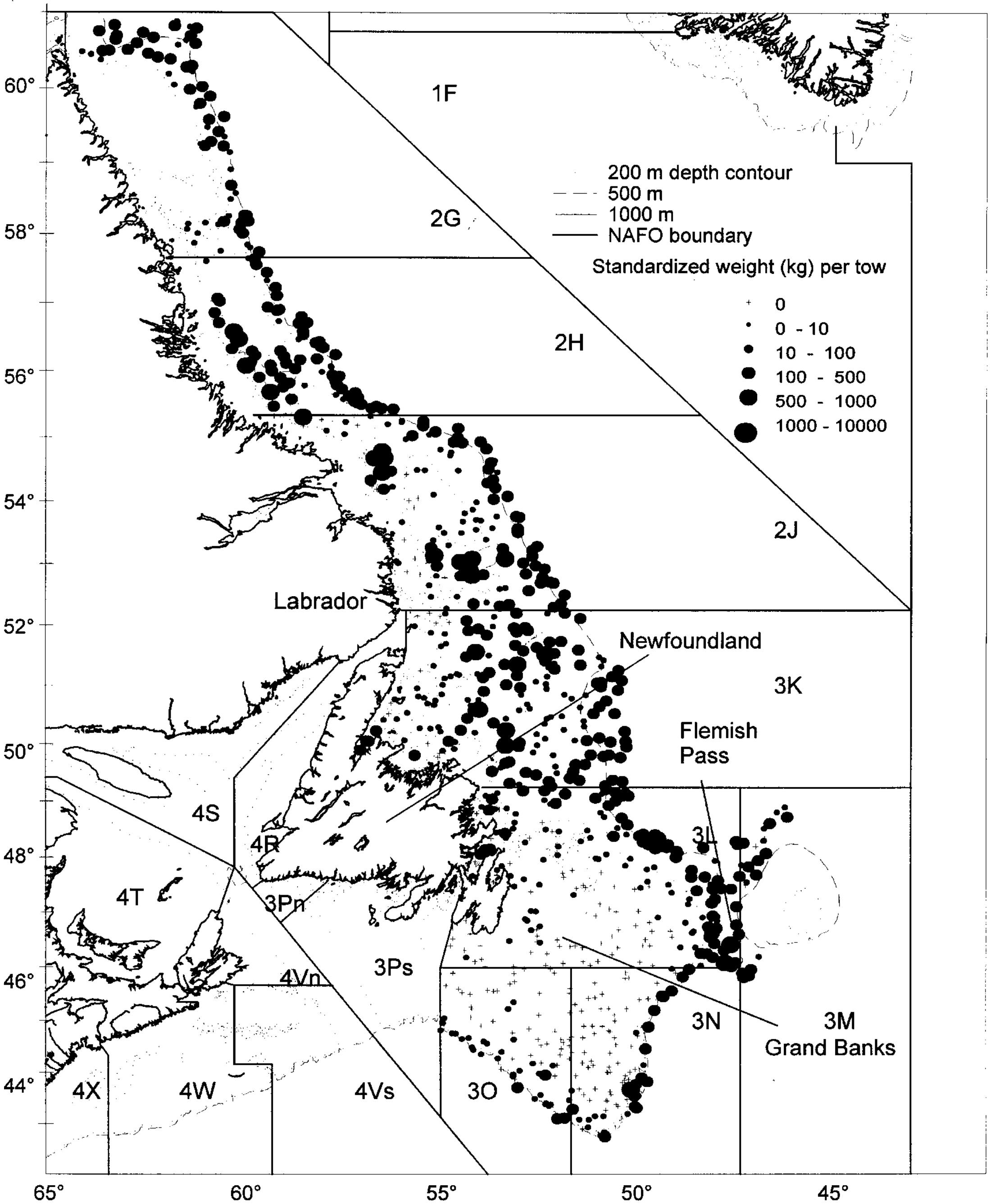

Fig. 3. Standardized weight (kg) per set of Greenland halibut from Canadian research vessel bottom trawl surveys from northern Labrador to the southern Newfoundland Grand Bank (NAFO Subareas 2 and 3) during autumn 1997.

remained unregulated until 1992. Since most of the Greenland halibut resource is located within the Norwegian fishery zone all regulations have been imposed and implemented by Norway. Considering the poor state of the stock, from 1992 the fishery has been regulated by permitting only vessels less than 28 m in length using longlines and gillnets to direct for Greenland halibut with a small assigned quota that can only be fished

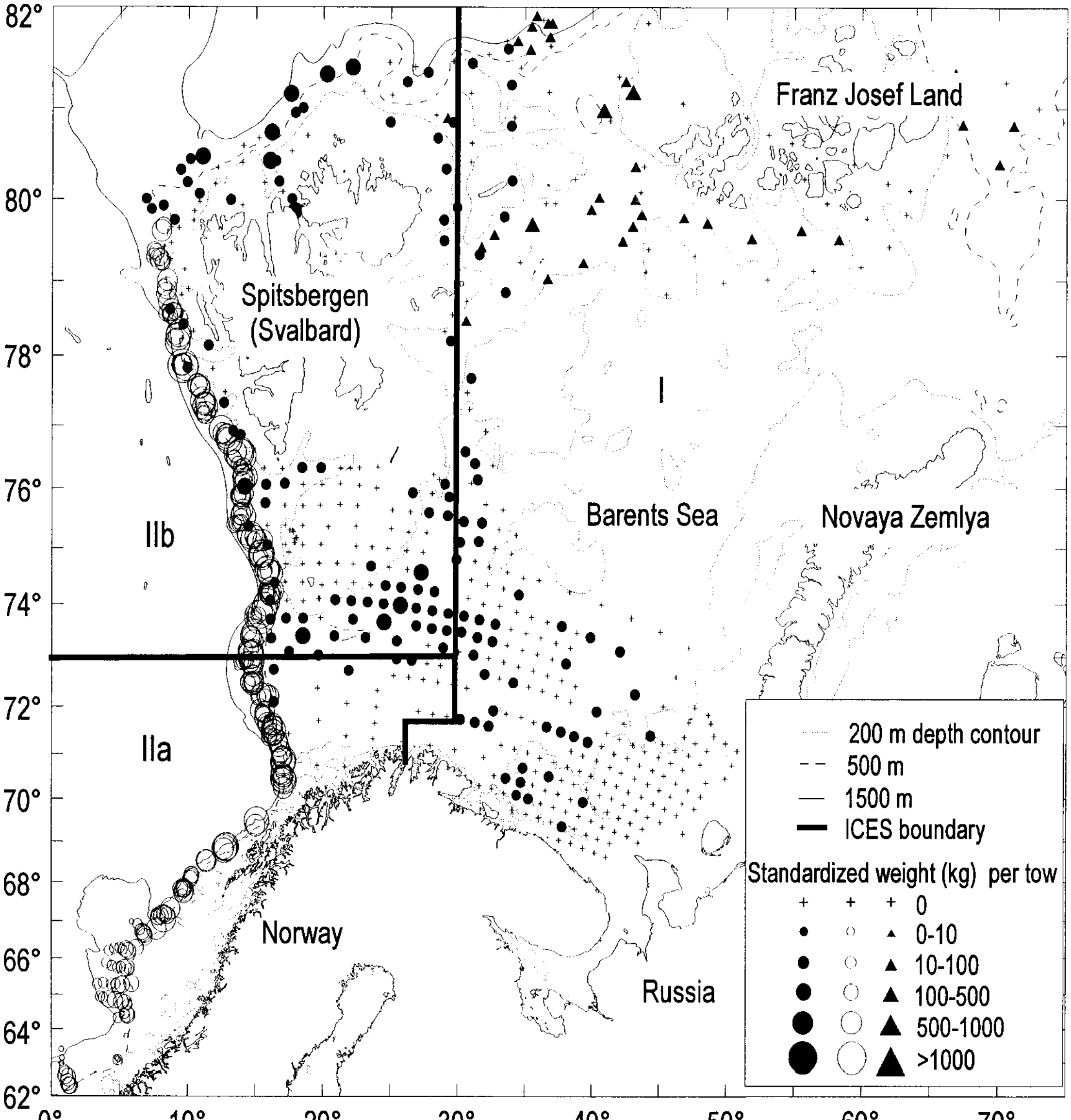

Fig. 4. Standardized weight (kg) per set of Greenland halibut from Norwegian bottom trawl surveys with the scientific *Campelen 1800* sampling trawl (filled circles) and the commercial *Alfredo* groundfish trawl (open circles) in the Northeast Arctic (ICES Subareas I and II) during 1995-96 and Russian exploratory surveys in ICES Subarea I during 1978-80 (filled triangles). All surveys were conducted in late summer and autumn.

during the month of June. In addition, catches by all other vessels and gears are restricted to by-catch only. The by-catch regulations also have become somewhat stringent. This included a by-catch limit restriction on Greenland halibut by weight for other fisheries prosecuted in the area, which has varied between 5 % and 10 % since 1992 (Anon. 1999). ICES has advised a zero catch for this stock since 1995 based on low spawning stock and the apparent failure of several pre-recruit year-classes. However, because Greenland halibut comprises an allowable by-catch in other major groundfish fisheries such as cod and haddock and a small directed fishery is permitted, the actual catch exceeds the advised TACs substantially (Anon. 1999; Fig. 1).

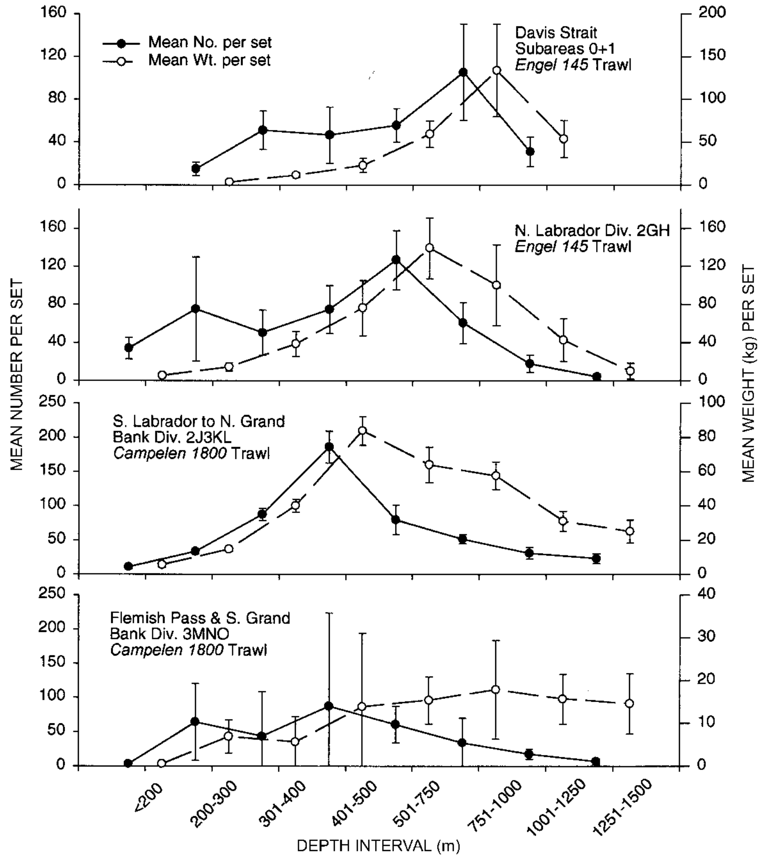

Fig. 5. Mean number and weight (kg) per standardized set (+/– 2 standard errors) by depth interval of Greenland halibut from Canadian surveys in the Northwest Atlantic during 1977-97.

Distribution and relative abundance

In the Northwest Atlantic Greenland halibut were caught with few exceptions throughout the entire survey area from 200-1500 m depths (Figs 2 & 3). The largest catches were observed along the slope of the continental shelf from southwest of Disko Island, Greenland (Fig. 2) to the southern extreme of the Newfoundland Grand Bank and Flemish Pass (Fig. 3). They are also abundant in the deepwater channels running between the shallower fishing banks especially in NAFO Divisions 2H, 2J and 3K. They are most widely dispersed in NAFO Division 3K where there is a predominance of deepwater channels running as far west as the east coast bays of Newfoundland but they are virtually absent over the Grand Bank (Fig. 3).

Greenland halibut in the Northeast Atlantic also were distributed extensively from as far south as 62°N along the continental slope near the European Union (EU)-Norway border, continuously to the northeast of Spitsbergen beyond 82°N (Fig. 4). They also were observed as far east as the eastern coast of Franz Josef Land at 73°E (Fig. 4). Catches are highest along the edge of continental slope although differences in fishing gear in the Northeast Atlantic surveys make it difficult to compare precisely. They are abundant in the deep channels running between the shallow fishing banks but are absent from the tops of the banks in the Barents Sea (Fig. 4). Relatively large catches were observed northeast of Spitsbergen and are widely distributed east of Svalbard towards Franz Josef Land. The central-eastern part of the Barents Sea towards Novaya Zemlya is not surveyed regularly but occasional bottom trawl sets in this area rarely caught Greenland halibut (Fig. 4).

Based on these findings Greenland halibut appear to be distributed with little or no break in the continuity of the distribution throughout both the Northwest and Northeast Atlantic Ocean. According to Godø & Haug

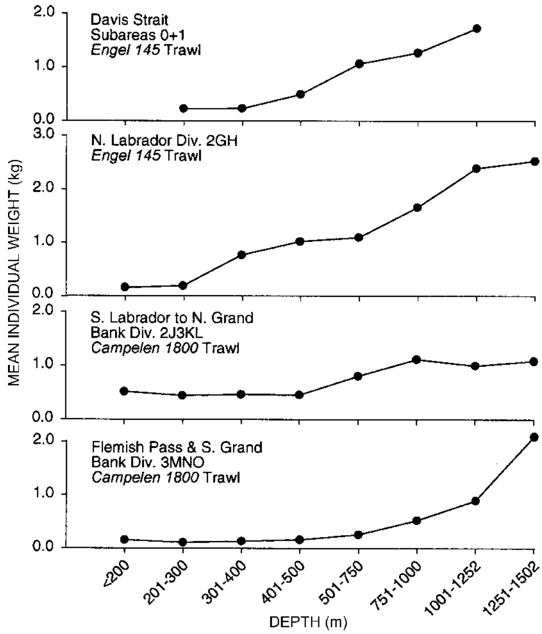

Fig. 6. Mean individual fish weight (kg) per standardized set by depth interval of Greenland halibut from Canadian surveys in the Northwest Atlantic during 1977-97.

(1989) Greenland halibut in the Northeast Arctic spawn along the continental slope primarily between 72°N and 74°N which is about mid latitude of the distribution range (see Fig. 4). Albert & al. (1998) also observed spawning Greenland halibut between 70°N and 75°N with peak spawning occurring in December. These authors noted, however, that some spawning occurred in adjacent areas more than 6 months later although how extensive it might be is unknown. According to Smidt (1969), Templeman (1973), Bowering & Chumakov (1989), and Bowering & Brodie (1995) Greenland halibut spawning in the western Atlantic has long been postulated to occur mainly in Davis Strait during late fall-early winter near the submarine ridge between Baffin Island and Greenland at about 67°N (see Fig. 2). More recently, spawning Greenland halibut have been sampled at various times of the year throughout the range of its observed offshore distribution along the continental slope from Davis Strait (70°N) to the Flemish Pass (47°N) (Morgan & Bowering 1997). Junquera & Zamarro (1994) studied Greenland halibut spawning in the Flemish Pass and observed a peak spawning period in winter and another in summer. These observed differences might be a result of a change in fish behavior associated with a shift in distribution pattern (Bowering & Power 1995; Bowering & Brodie 1995). On the other hand, it could represent normal behavior observed as a result of now obtaining samples from very deep water (1250-1800 m) compared to earlier years. Given the similarities reported above between the Northwest and Northeast Atlantic one could argue strongly for the latter.

Although very young Greenland halibut have been observed throughout the Northwest Atlantic (Templeman 1973; Bowering & Parsons 1986), the only recognized major nursery area is near the northern end of the distribution west of Disko Bay (69°N) (Smidt 1969; Jørgensen 1997a, 1997b). The main nursery area in the Northeast Atlantic is reported also to be more to the northern end of the distribution surrounding the island of Spitsbergen (Godø & Haug 1989). In fact, a recent study indicated that the areas north and east of Spitsbergen and eastwards to Franz Josef Land also might be important nursery areas. Since the northernmost areas are covered by ice during most of the year the northeastern border of the distribution could not be delineated (unpublished data at the Institute of Marine Research, Bergen, Norway).

Average catches of Greenland halibut in the Northwest Atlantic generally increase with increasing depth, peak and then decline (Fig. 5). The highest catches appear to peak at greater depths going northward. There is also a clear tendency for average individual fish size to increase with increasing depth (Fig. 6). This tendency is evident in all areas investigated in the Northwest Atlantic.

In the Northeast Atlantic Greenland halibut catches also exhibited a tendency to increase with increasing depth, peak and then decline (Fig. 7). However, no latitudinal trends in depth of peak abundance could be established. In the Northeast Atlantic there is no apparent change in individual mean size of Greenland halibut with depth along the continental slope area. However, in both the north and east of Spitsbergen surveys and the Svalbard and Barents Sea surveys indicate an increase in mean individual size in the catches in depths greater than 500 m (Fig. 8).

The affinity for young juvenile Greenland halibut to nursery areas in the north and larger fish to be in deep water along the continental slopes of the Northeast Atlantic might explain some of the variability apparent in preferred depth range. For example, the distribution data from surveys along the slope of the Norwegian Sea did not demonstrate any change in mean individual fish size over the range of depths fished. Since this survey series includes the spawning area (Albert & al. 1998), young fish would have a tendency to be less abundant here; therefore a change in mean individual size with depth likely would be less apparent. Age compositions from these surveys reported in Anon. (1999), in fact, indicated very few Greenland halibut less than age 5 were

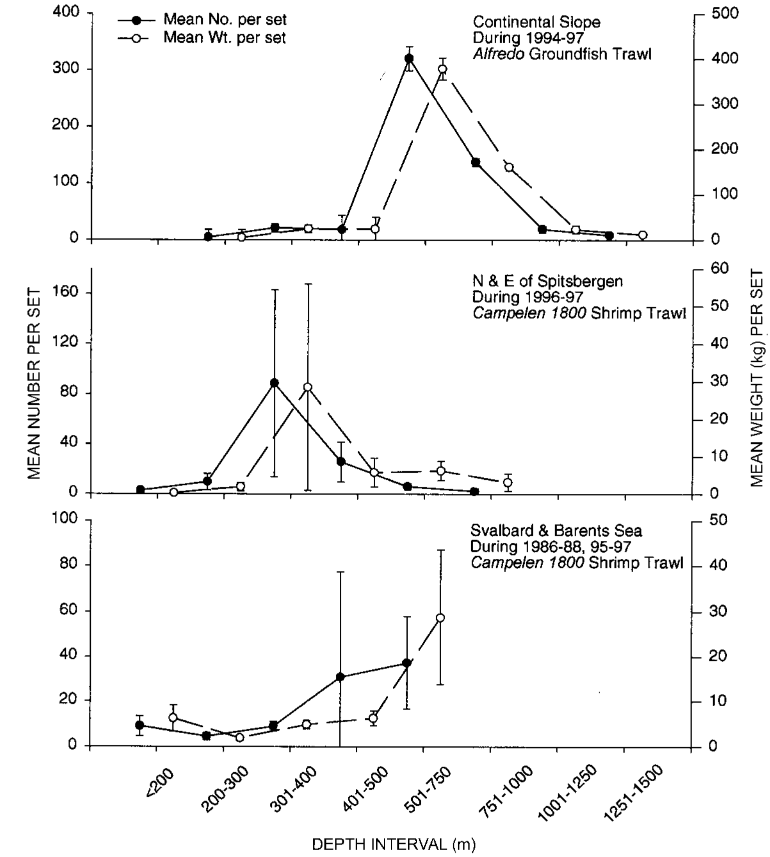

Fig. 7. Mean number and weight (kg) per standardized set (+/– 2 standard errors) by depth interval of Greenland halibut from Norwegian surveys in the Northeast Atlantic during 1986-97.

caught. On the other hand, unpublished survey and commercial catch rate data from the Institute of Marine Research, Bergen, Norway show that from September onwards there seems to be a clear trend in mean individual size with depth. Larger mature fish appear to migrate to shallower depths and to some extent into the Barents Sea even into 200-meter depths. This would indicate some seasonality in the distribution pattern. Although it might be likely associated with spawning behavior, Albert & al. (1998) reported that peak spawning of Greenland halibut in the Northeast Atlantic occurs in much deeper water in depths of 500-800 m. Therefore, these opposing observations warrant further investigation. Bowering & Chumakov (1989) also observed a seasonality effect on mean individual size with depth in Northwest Atlantic although in the opposite direction. Here larger fish move progressively to deeper water late in the year presumably also related to spawning. Based on recent investigations in the Northwest Atlantic, spawning is believed to occur at considerably deeper water than previously believed and much deeper than indicated for the Northeast Atlantic (Albert & al. 1998). Jørgensen (1997a) identified the main spawning area in Davis Strait in depths greater than 1200 m while Junquera & Zamarro (1994) observed peak spawning in Flemish Pass in depths greater than 900 m. These observations are similar to east Iceland Greenland halibut, which are reported to spawn in depths greater than 1 000 m (Sigurdsson 1979).

The shift in size with depth observed in the Northwest Atlantic where the mean size at depth increases going northward and peak catch rates occur at progressively deeper water going northward may be explained by spawning migrations. Bowering & Brodie (1991) hypothesized from the data examined that as maturing fish migrate northwards and deeper towards Davis Strait for spawning one would expect a preponderance of larger fish in more northerly areas and deeper water. This could

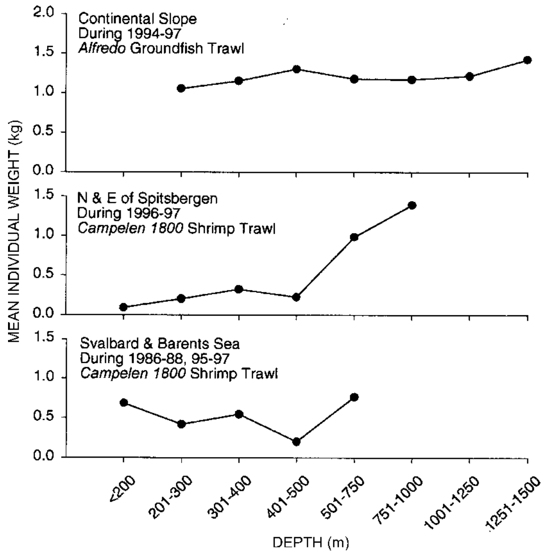

Fig. 8. Mean individual fish weight (kg) per standardized set by depth interval of Greenland halibut from Norwegian surveys in the Northeast Atlantic during 1986-97.

enhance the north-south effect although the spawning area may extend much further south of Davis Strait than previously thought (Junquera & Zamarro 1994; Morgan & Bowering 1997).

Any trends in distribution and relative abundance of Greenland halibut with respect to bottom temperature in the Northwest Atlantic surveys were not especially clear (Fig. 9). In the Davis Strait survey, catch rates were relatively high and stable within a bottom temperature range 0.0 °C to 5.0 °C and lowest below 0.0 °C. The northern Labrador surveys exhibited little in the way of trend although the mean weight (kg) per set appeared to increase as bottom temperatures surpassed 3.0 °C (Fig. 9). The catch rates from the remaining areas to the south showed improvement as bottom temperatures increased beyond 2.0 °C. Catch rates declined beyond bottom temperatures of 4.0 °C for the most southerly surveys and beyond 3.0 °C and 5.0 °C for mean number per set and mean weight (kg) per set, respectively for the adjacent survey series to the north (Fig. 9).

Trends in distribution and relative abundance of Greenland halibut with respect to bottom temperature in the Northeast Atlantic surveys are more evident than for the Northwest Atlantic described above (Fig. 10). For all three survey series, the average weight (kg) per set increases to peak within a bottom temperature range of 1.1 °C to 2.0 °C beyond which the average weight (kg) per set declines. The trend is similar for average number per set from the continental slope surveys. However, the peak occurs within a bottom temperature range of 2.1 °C to 3.0 °C for the north and east of Spitsbergen data and below 0.0 °C for the Barents Sea and Svalbard data (Fig. 10).

Evidently, bottom temperatures associated with the distribution of Greenland halibut are not greatly different between the two regions of the Atlantic. It is rather surprising, nonetheless, that Greenland halibut in the Northeast Atlantic tend to be more widely distributed at colder bottom temperatures compared to those of the Northwest Atlantic given the apparent slower growth rate of the latter (Anon. 1997). However, this will be the subject of a later comparative investigation and will not be pursued further here (Bowering & Nedreaas in press). Peak spawning in the Northeast Atlantic is reported to occur at bottom temperatures of 2.0 °C (Albert & al. 1998) compared to 3.0 °C to 3.5 °C for Davis Strait (Jørgensen 1997a).

Resource assessments of Greenland halibut in the Northwest Atlantic during recent years have shown that there was a shift in distribution from the eastern Newfoundland-Labrador area to the deep southern area of the Flemish Pass during the late 1980s (Bowering & al. 1993). This was complemented by a substantial decline in stock size (especially the spawning stock), which by the early 1990s was at the lowest level observed since 1977 (Brodie & al. 1998). The concentration of the resource in this area resulted in the development of the large unregulated fishery of the early 1990s. Similar shifts in distribution were observed for many other stocks in this region during the same period except that most were accompanied by stock collapse. For examples of these stock collapses, see Taggart & al. (1994) for cod (*Gadus morhua*) in NAFO Divisions 2J, 3K and 3L; Bowering & al. (1997) for American plaice (*Hippoglossoides platessoides*) in NAFO Subarea 2 and Division 3K; Bowering & al. (1996) for American plaice in NAFO Subdivision 3Ps and Bowering (1998) for witch flounder (*Glyptocephalus cynoglossus*) in NAFO Divisions 2J, 3K and 3L). As fishing pressure was reduced considerably by 1995, the stock began to recover. Nearly all year-classes of the 1990s appear to be average to above average abundance, which should result in an increase in stock size provided fishing pressure remains low (Brodie & al. 1998; Anon. 1998). There is also some indication that geographic distribution patterns may be returning to those of earlier years, however, this will become more apparent as these strong year-classes develop and presumably contribute to the spawning stock (Brodie & al. 1998).

Stock evaluations of the Greenland halibut resource in the Northeast Atlantic also indicate that the stock has been declining steadily since the 1970s and by the early 1990s the spawning stock here also had reached the lowest level observed (Anon. 1999). This was mainly a re-

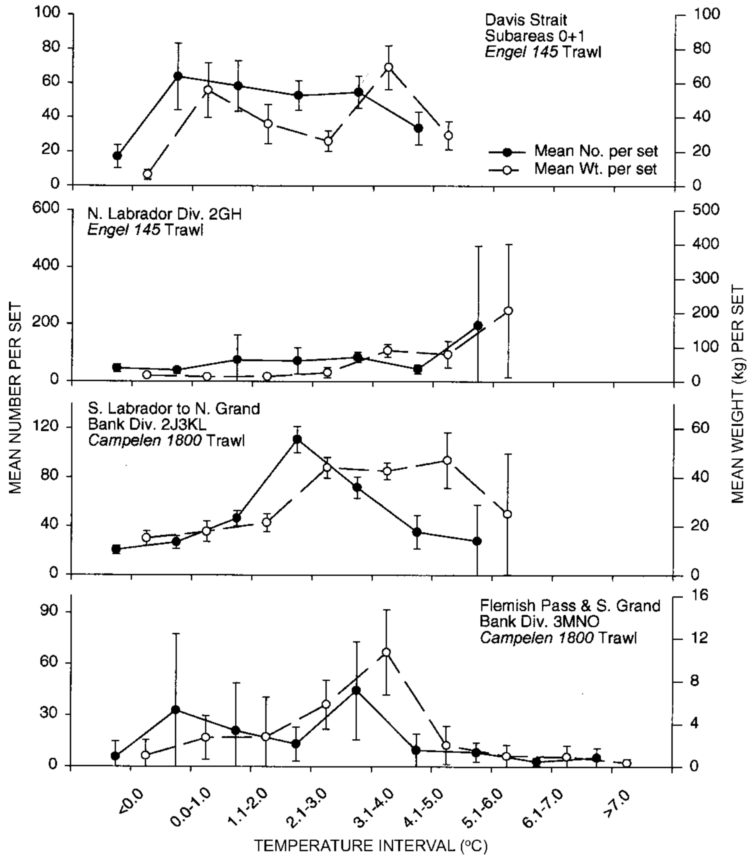

Fig. 9. Mean number and weight (kg) per standardized set (+/– 2 standard errors) by bottom temperature interval (°C) of Greenland halibut from Canadian surveys in the Northwest Atlantic during 1977-97.

sult of excessive exploitation over the period, given the fishery was totally unregulated until 1992. Even since then landings far exceed advised catch levels. Based on a historically low spawning stock size and apparent recruitment failure of several consecutive year-classes (mainly 1989-94), ICES has advised a zero catch for this resource from 1995-1999. Recruitment failures were deduced from extremely low survey abundance indices of Greenland halibut at ages 0-4. Estimates of the abundance of these same year-classes at ages 5 and older, on the other hand, suggest that these year-classes may not be nearly as weak as indicated at the earlier ages (Anon. 1999). It seems clear from recent studies and the data presented here that important areas for young Greenland halibut may be found further north and east of Svalbard than previously considered. This area would have been outside the former surveyed areas on which the pre-recruit abundance indices were derived (unpublished data at the Institute of Marine Research, Bergen, Norway). Albert & al. (1997) also showed that the southwestern end of the distribution area of age 1 fish was gradually displaced northwards along west and north Spitsbergen in the period 1989-92 (partly outside the former surveyed areas) and southwards in the period 1994-96. These displacements seem to have corresponded to changes in hydrography, i.e., a more northern distribution when the temperature in the Barents Sea is high and a more southern distribution when the temperature is low. It is hypothesized that this may have caused the main concentrations of at least the 1989-1992 year-classes at early ages to move outside the areas formerly covered by the surveys. If this is correct, the implications for evaluating stock status are particularly worrisome for this resource considering the fishery independent database used in the assessments and advised TACs of recent years. Nevertheless, these year-classes as yet would have little effect on current estimates of the very low spawning stock size, which alone

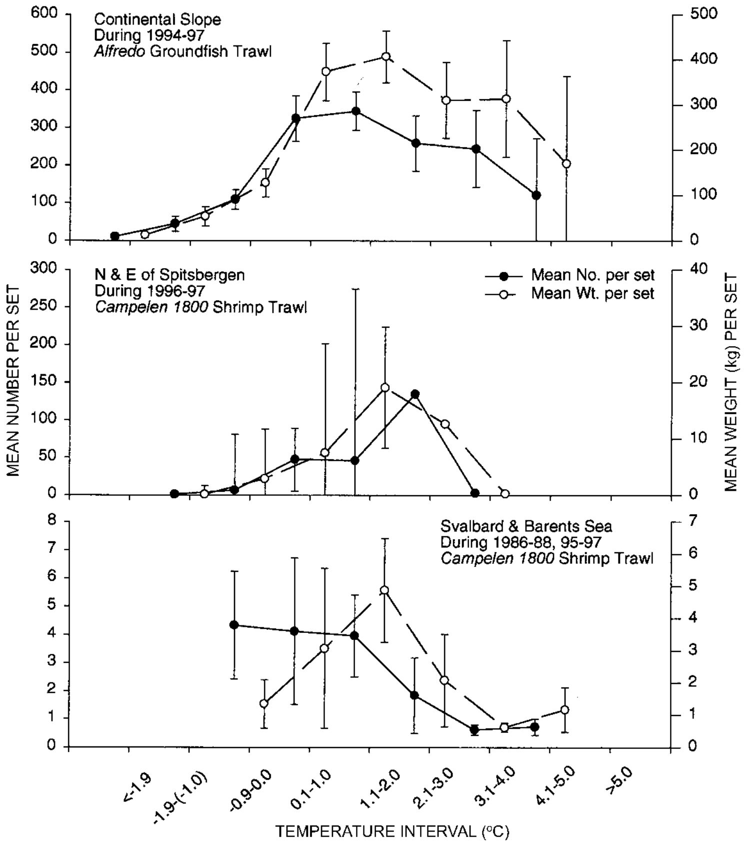

Fig. 10. Mean number and weight (kg) per standardized set (+/– 2 standard errors) by bottom temperature interval (°C) of Greenland halibut from Norwegian surveys in the Northeast Atlantic during 1986-97.

would warrant the very strict scientific advice. On the other hand, if the estimates of the 1989-94 yearclasses at older ages are confirmed to be more representative of year-class size, then improvements to the spawning stock could occur earlier than previously anticipated provided that catches are kept low.

ACKNOWLEDGMENTS

The authors would like to gratefully acknowledge the assistance of David C. Orr, Northwest Atlantic Fisheries Center, St. John's, Canada and Lisbet Solbakken, Institute of Marine Research, Bergen, Norway. Both were instrumental in the developing compatibility in the distribution maps that made the comparisons between the distant regions more easily understood.

REFERENCES

Albert OT, Nilssen EM, Nedreaas KH, Gundersen AC. 1997. Recent variations in recruitment of Northeast Atlantic Greenland halibut (*Reinhardtius hippoglossoides*) in relation to physical factors. *ICES Council Meeting* 1997/ EE:06. 22 p.

Albert OT, Nilssen EM, Stene A, Gundersen AC, Nedreaas KH. 1998. Spawning of the Barents Sea/Norwegian Sea Greenland halibut (*Reinhardtius hippoglossoides*). *ICES Council Meeting* 1998/O:22.

Anon. 1994. *Northwest Atlantic Fisheries Organization Scientific Council Report, June 1994*. 234 p.

Anon. 1997. Report of the ICES/NAFO workshop on Greenland halibut age determination. *ICES Council Meeting* 1997/G:1. 53p.

Anon. 1998. *Northwest Atlantic Fisheries Organization Scientific Council Report, June 1998*. 257 p.

Anon. 1999. Report of the Arctic Fisheries Working Group. *ICES Council Meeting* 1999/ *Advisory Committee on Fisheries Management*: 3. 276p.

Boje J. 1994. Migrations of Greenland halibut in the Northwest Atlantic based on tagging experiments in Greenland waters 1986-1992. *Northwest Atlantic Fisheries Organization Scientific Council Research Document* 94/18, Ser. No. N2383. 13p.

Borkin IV. 1983. Results of investigation of ichthyofauna in Franz Josef Lands region and to the North of Spitsbergen. *Investigations of biology, morphology and physiology of hydrobionts. Apatiti. Science Academy of USSR.*:34-42. (In Russian)

Bowering WR. 1984. Migrations of Greenland halibut (*Reinhardtius hippoglossoides*) in the Northwest Atlantic from tagging in the Labrador-Newfoundland region. *Journal of Northwest Atlantic Fishery Science* 5: 85-91.

Bowering WR. 1998. Changes in distribution and trends in stock size of the witch flounder resource in Divisions 2J, 3K and 3L. *Northwest Atlantic Fisheries Organization Scientific Council Research Document* 98/64, Ser. No. N3056. 16 p.

Bowering WR, Brodie WB. 1991. Distribution of commercial flatfishes in the Newfoundland-Labrador region of the Canadian Northwest Atlantic and changes in certain biological parameters since exploitation. *Netherlands Journal of Sea Research* 27:407-422.

Bowering WR, Brodie WB. 1995. Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)). A review of the dynamics of its distribution and fisheries off Canada and West Greenland. In: Hopper AG, editor. *Deep-Water Fisheries of the North Atlantic Oceanic Slope. Northwest Atlantic Treaty Organization Advanced Science Institutes Series*. Boston: Kluwer Academic Publishers. p 113-160.

Bowering WR, Brodie WB, Morgan MJ. 1996. Changes in abundance and certain population parameters of American plaice (*Hippoglossoides platessoides* (Fabricius)) off Newfoundland during 1972-94 with implications for fisheries management. *North American Journal of Fisheries Management* 16:747-769.

Bowering WR, Brodie WB, Power D. 1993. An evaluation of the status of the Greenland halibut resource in NAFO Subarea 2 and Divisions 3KLM. *Northwest Atlantic Fisheries Organization Scientific Council Research Document* 93/75, Ser. No. N2260. 29 p.

Bowering WR, Chumakov AK. 1989. Distribution and relative abundance of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) in the Canadian Northwest Atlantic from Davis Strait to the northern Grand Bank. *Fisheries Research* 7:301-327.

Bowering WR, Lilly GR. 1992. Greenland halibut (*Reinhardtius hippoglossoides*) off southern Labrador and northeastern Newfoundland (Northwest Atlantic) feed primarily on capelin (*Mallotus villosus*). *Netherlands Journal of Sea Research* 29:211-222.

Bowering WR, Morgan MJ, Brodie WB. 1997. Changes in the population of American plaice (*Hippoglossoides platessoides* (Fabricius)) off Labrador and Northeastern Newfoundland: A collapsing stock with low exploitation. *Fisheries Research* 30:199-216.

Bowering WR, Nedreaas KH. (In press.). Age validation and of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)): A comparison of populations in the Northwest and Northeast Atlantic. *Sarsia.*

Bowering WR, Parsons DG. 1986. Diel variability in catches of Greenland halibut (*Reinhardtius hippoglossoides*) from the channels off coastal Labrador. *North American Journal Fisheries Management* 6(2):149-155.

Bowering WR, Power D. 1995. Spatial distribution of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) in the Labrador-Eastern Newfoundland area of the Canadian Northwest Atlantic. *Northwest Atlantic Fisheries Organization Scientific Council Studies* 22:51-62.

Brodie WB, Bowering WR, Power D, Orr D. 1998. An Assessment of Greenland halibut in NAFO Subarea 2 and Divisions 3KLMNO. *Northwest Atlantic Fisheries Organization Scientific Council Research Document* 98/47, Ser. No. N3038. 38p.

Dawe EG, Bowering WR, Joy JB. 1998. Predominance of Arctic squid (*Gonatus* spp.) in the diet of Greenland halibut (*Reinhardtius hippoglossoides*) on the deep slope of the Northeast Newfoundland continental shelf. *Fisheries Research* 36:267-273.

Godø OR, Haug T. 1987. Migration and recruitment to the commercial stock of Greenland Halibut (*Reinhardtius hippoglossoides* (Walbaum)), in the Svalbard area. *Fiskeridirektoratets Skrifter serie Havundersøkelser* 18:311-328.

Godø OR, Haug T. 1989. A Review of the natural history, fisheries, and management of Greenland Halibut (*Reinhardtius hippoglossoides*) in the Eastern Norwegian and Barents Seas. *Journal du Conseil International pour de l'Exploration de la Mer* 46:62-75.

Gundersen AC, Kjesbu OS, Nedreaas KH, Stene A. 1999. Fecundity of Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*). *Journal of Northwest Atlantic Fisheries Science* 25:29-36.

Huse I, Gundersen AC, Nedreaas KH. 1999. Relative selectivity of Greenland halibut (*Reinhardtius hippoglossoides*, Walbaum) by trawls, longline and gillnets. *Fisheries Research* 44:75-93.

Jørgensen OA. 1997a. Movement patterns of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)), at West Greenland, as inferred from trawl survey distribution and size data. *Journal of Northwest Atlantic Fishery Science* 21:23-37.

Jørgensen OA. 1997b. Pelagic occurrence of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)), in West Greenland waters. *Journal of Northwest Atlantic Fishery Science* 21:39-50.

Jørgensen OA. 1998. Assessment of the Greenland halibut stock component in NAFO Subarea 0 + Div. 1A offshore + Div. 1B-1F. *Northwest Atlantic Fisheries Organization Scientific Council Research Document* 98/56, Ser. No. N3047. 20p.

Junquera S, Zamarro J. 1994. Sexual maturity and spawning of Greenland Halibut (*Reinhardtius hippoglossoides*) from Flemish Pass area. *Northwest Atlantic Fisheries Organization Scientific Council Studies* 20:47-52.

Michalsen K, Nedreaas KH. 1998. Food and feeding of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) in the Barents Sea and East Greenland waters. *Sarsia* 83:401-407.

Morgan MJ, Bowering WR. 1997. Temporal and geographic variation in maturity at length and age of Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) from the Canadian Northwest Atlantic with implications for fisheries management. *ICES Journal of Marine Science* 54:875-885.

Nedreaas K, Soldal AV, Bjordal Å. 1996. Performance and biological implications of a multi-gear fishery for Greenland halibut (*Reinhardtius hippoglossoides*). *Journal of Northwest Atlantic Fishery Science* 19:59-72.

Orr DC, Bowering WR. 1997. A multivariate analysis of food and feeding trends among Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) sampled in Davis Strait, during 1986. *ICES Journal of Marine Science* 54:819-829.

Rink H. 1852. De Danske Handelsdistrikter i Nordgrønland, deres geografiske Beskaffenhed og produktive Erhverskilder. Første Deel. In: *Grønland geografisk og statistisk beskrevet* 1. (1857).

Sigurdsson A. 1979. The Greenland halibut (*Reinhardtius hippoglossoides* (Walb.)) at Iceland. *Hafrannsoknir* 16:23-29.

Sigurdsson A. 1981. Migrations of Greenland halibut (*Reinhardtius hippoglossoides* (Walb.))from Iceland to Norway. *Rit Fiskideidar* 6:3-6.

Simonsen CS. 1998. An Assessment of the Greenland Halibut stock component in NAFO Division 1A inshore. *Northwest Atlantic Fisheries Organization Scientific Council Research Document* 98/44, Ser. No. N3035. 18 p.

Smidt E. 1969. The Greenland halibut *(Reinhardtius hippoglossoides),* biology and exploitation in Greenland waters. *Meddelelser fra Danmarks Fiskeri- og Havundersøgelser* 6:79-148.

Stene A, Gundersen A, Albert OT, Nedreaas KH, Solemdal P. 1999. Early development of Northeast Arctic Greenland halibut (*Reinhardtius hippoglossoides*). *Journal of Northwest Atlantic Fisheries Science* 25:171-177.

Taggart CT, Anderson J, Bishop C, Colbourne E, Hutchings J, Lilly G, Morgan J, Murphy E, Myers R, Rose G, Shelton P. 1994. Overview of cod stocks, biology, and environment in the Northwest Atlantic region of Newfoundland, with emphasis on northern cod. *ICES Marine Science Symposium* 198:140-157.

Templeman W. 1973. Distribution and abundance of the Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)), in the Northwest Atlantic. *International Commission for the Northwest Atlantic Fisheries Research Bulletin* 10:83-98.

Vis ML, Carr SM, Bowering WR, Davidson WS. 1997. Greenland halibut (*Reinhardtius hippoglossoides* (Walbaum)) in the North Atlantic are genetically homogeneous. *Canadian Journal of Fisheries and Aquatic Sciences* 54:1813-1821.

Ytreberg NA. 1942. Handelssteder i Finnmark. p 178-192. *Trondheim*. (In Norwegian)

Accepted 19 May 1999 – Printed 24 March 2000
Editorial responsibility: Jarl Giske