AGE, GROWTH, AND SEXUAL MATURITY OF GREENLAND HALIBUT, *REINHARDTIUS HIPPOGLOSSOIDES* (WALBAUM), IN THE CANADIAN NORTHWEST ATLANTIC

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ABSTRACT

Age composition of Greenland halibut, *Reinhardtius hippoglossoides*, in the eastern area ranged up to 14 years for males and up to 18 years for females; most fish, however, were less than 10 years old, with a predominance of older fish in the more northerly areas. In the Gulf of St. Lawrence, males beyond age 9 and females beyond age 12 were completely absent from the catch. It is not fully clear if this is the result of emigration of older fish from the area or mortality due to early maturity. The empirical growth curves for all areas show females growing faster than the males, particularly in the older ages, while the mean size at age indicates little dlfference up to ages 8-12. Statistical treatment of back-calculated growth curves up to age 5 indicated no difference between males and females. No statistical difference was found in the growth rate of fish of the Labrador and eastern Newfoundland areas. Fish from the Gulf of St. Lawrence exhibited the fastest growth rate and fish from Baffin Bank the slowest throughout the range.

Onset of maturity of female Greenland halibut from the Gulf of St. Lawrence occurred at a much smaller size and over a more narrow range of sizes than in other more northerly areas. In the Labrador-eastern Newfoundland area the onset of maturity occurred at smaller sizes, moving progressively northward. Since the growth rates of fish throughout this area are similar, this shift of the maturity curves is believed to be a result of mature fish migrating towards the spawning ground. The Baffin Bank maturity curve, on the other hand, is similar to that of Nain Bank in the mid-Labrador area. However, since Baffin Bank is so near the presumed spawning ground and heavily influenced by the cold polar current, most maturing fish are likely to be in deep warmer water outside the fishable range; consequently, the curve may be biased to the right. These inferences are supported by other investigations, particularly migration studies.

Greenland halibut, *Reinhardtius hippoglossoides*, are found in both the North Atlantic and North Pacific Oceans but absent from intervening Arctic waters (Hubbs and Wilimovsky 1964; Atkinson et al. 1981). Based on meristic and morphometric characters, Hubbs and Wilimovsky (1964) concluded that there is one species found in both oceans, not two as previously suggested (Andriyashev 1954). In the northwest Atlantic, Greenland halibut are widely distributed along the west Greenland coast and in the Davis Strait and are reported as far north as Smith Sound (lat. 78°N) by Smidt (1969) and Templeman (1973). In the Canadian far north they are found in abundance in the Baffin Island area (Templeman 1973; Bowering 1978b, 1979a) and in the Hudson Strait to Ungava Bay (Dunbar and Hildebrand 1952). They are most prevalent in deeper waters from northern Labrador to the deeper waters of the northern Grand Bank (Templeman 1973; Bowering 1977, 1978c, 1979b, 1980b; Bowering and Brodie 1981) with small numbers recorded in the vicinity of the Flemish Cap (Bowering and Baird 1980). Greenland halibut are found incidentally on St. Pierre Bank with a small localized concentration located in Fortune Bay (Bowering 1978a). Recent investigations (Bowering 1979c, 1980a, 1981) have shown that Greenland halibut have now become commercially abundant in this area with very little occurrence on the Scotian Shelf. The most southerly occurrence is Georges Bank where 20 specimens were reported caught (Schroeder 1955).

According to Smidt (1969), the main spawning for Greenland halibut in the northwest Atlantic occurs during winter in the Davis Strait area (lat. 67°N) at depths of 600-1,000 m. From here the young are believed to be carried by currents to west Greenland and eastern Canada where they colonize the banks and slopes of the continental shelf. Spawning also occurs in the Gulf of St. Lawrence in the Laurentian Channel, southwest of St. Georges Bay, during wintertime (Templeman 1973).

The commercial fishery for Greenland halibut in the Canadian northwest Atlantic is one of the most important groundfish fisheries in the region with landings averaging over 60,000 t annually during the last few years. It is of prime importance to such countries

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as Canada, U.S.S.R., Poland, German Democratic Republic, and Federal Republic of Germany, who have prosecuted this fishery for over 25 yr from Davis Strait to the northern Grand Bank and, more recently, the Gulf of St. Lawrence.

The only published information on age and growth of Greenland halibut in the northwest Atlantic was by Bowering (1978a), who reported growth in terms of arithmetic linear least squares regressions for selected areas where data were available. Walsh and Bowering (1981) presented information on the validity of field observations on sexual maturity in female Greenland halibut using histological techniques; the data, however, were confined to one area of northern Labrador. To my knowledge, this is the only available information on sexual maturity of Greenland halibut in the northwest Atlantic.

This paper presents a detailed account of the age and growth of Greenland halibut in the Canadian northwest Atlantic from Baffin Bank to the northern Grand Bank and into the Gulf of St. Lawrence. An analysis of sexual maturity data on female Greenland halibut throughout the region (except the northern Grand Bank) is also discussed.

MATERIALS AND METHODS

Age and Growth

For examination, the data were organized according to seven geographical areas: 1) Baffin Bank; 2) Saglek Bank; 3) Nain Bank; 4) Hamilton Bank; 5) Northeast Newfoundland Shelf; 6) northern Grand Bank; and 7) the Gulf of St. Lawrence, since these are discrete fishing areas where data were available (Fig. 1). All data were collected during random-stratified research vessel surveys for groundfish (Pinhorn 1972) stratified by depth. The Baffin Bank data were collected by the French research vessel *Cryos* in October 1977. This vessel is a stern trawler, 46 m long, which uses a Lofoten bottom otter trawl with a 5 mm small mesh liner in the cod end. All sets were of 30-min duration during daylight hours at a towing speed of 3.5-4.0 kn. Data from sets in which the gear was badly damaged or other reasons considered to interfere with normal retention of the catch were not used. All other data were collected by the Canadian research vessel *Gadus Atlantica*. The *Gadus Atlantica* is a stern otter trawler, 85 m long, which uses an Engels high-rise bottom otter trawl with a 12 mm small mesh liner in the cod end. All sets were of 30-min duration at 3.5-kn towing speed, and fishing was carried out on a 24-h basis.

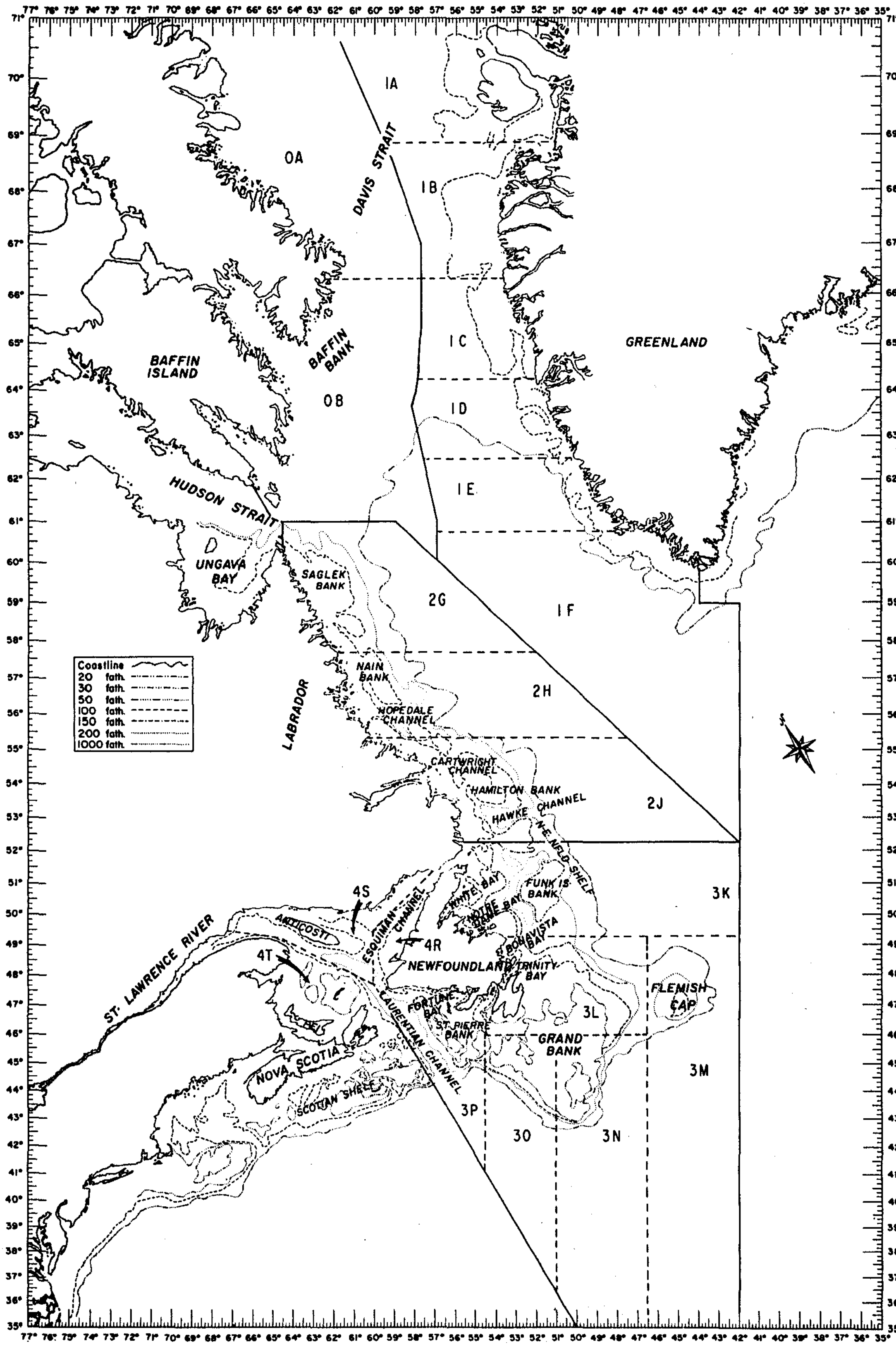
The fish ages were determined from the left sacculus otoliths which, in the case of Greenland halibut, were more suitable for age determination, since the annuli were spaced more evenly and were more distinct. Otoliths were ground on the convex surface exposing the center more clearly and were placed in a black watch glass containing ethanol in order to facilitate reading. Age frequencies were compiled for males and females separately using age-length keys for each area with the distributions calculated as numbers per thousand at age of the total catch.

For ease of statistical comparison, growth was expressed in terms of semilog curves (length $= a + b \ln$ age) similar to that used by Bowers (1960) for witch flounder and suggested in Roff (1980). Growth curves were computed separately by sex for each area. The growth curves were weighted by the number of observations at each age, since many of the older age groups were based upon as little as one observation, and the age reading of very large fish is often questionable (Lear and Pitt 1975).

Otoliths from 30 males and 30 females of the 1972 year class were selected from each area and examined to back-calculate length at age. Since the Baffin Bank data were collected in 1977 and the Gulf of St. Lawrence data were collected in 1980, only the 1972 year class was abundant enough in the samples for comparison. Subsequently, in order to standardize the number of ages for consideration, calculations could only be made up to age 5. Otoliths were measured by means of a drawing tube attached to a binocular microscope, using a technique similar to that described by Moores and Winters (1978). An annulus was considered to be the width described by an opaque (summer) zone and a translucent (winter) zone accounting for a growth increment in a particular year. The ratio of otolith length to total fish length was used to back-calculate the average length at each age, using the direct proportionality method described by Lea (1919). In order to validate the direct proportionality method as it applied to Greenland halibut, a linear least squares regression was performed on a random sample of 123 measurements of total fish length to total otolith length (3 measurements per 1 cm group from 10 to 50 cm).

A covariance analysis (Zar 1974) was performed on the back-calculated data for males versus females in order to determine if there were significant differences among the regression coefficients (slopes) or the adjusted means (y-intercepts). Where no differences between the sexes occurred the sexes were

FIGURE 1.—Map of study area with corresponding major names mentioned in text.


DAVIS STRAIT
BAFFIN ISLAND
BAFFIN BANK
HUDSON STRAIT
UNGAVA BAY
SAGLEK BANK
GREENLAND
LABRADOR
NAIN BANK
HOPEDALE CHANNEL
CARTWRIGHT CHANNEL
HAMILTON BANK
HAWKE CHANNEL
N.E. NFLD SHELF
FUNK IS. BANK
WHITE BAY
NOTRE DAME BAY
BONAVISTA BAY
TRINITY BAY
NEWFOUNDLAND
FORTUNE BAY
ST. PIERRE BANK
GRAND BANK
FLEMISH CAP
ESQUIMAN CHANNEL
ANTICOSTI
ST. LAWRENCE RIVER
LAURENTIAN CHANNEL
NOVA SCOTIA
SCOTIAN SHELF
0A
0B
1A
1B
1C
1D
1E
1F
2G
2H
2J
3K
3L
3M
3N
30
3P
4R
4S
4T
Coastline
20 fath.
30 fath.
50 fath.
100 fath.
150 fath.
200 fath.
1000 fath.

combined for each of the areas for further analysis. A covariance analysis was performed on these combined data to determine if there were any significant differences in the slopes of the fitted lines. Among the different areas, for areas where significant differences did not occur, the analysis was continued by using paired comparisons by t-tests to determine if differences occurred between the adjusted means (y-intercepts).

Sexual Maturity

Due to the difficulty and uncertainty connected with the determination of sexual maturity in male Greenland halibut, only sexual maturity data on female Greenland halibut were analyzed. Except for the Gulf of St. Lawrence data, only data collected during the same time of year were used to generate the maturity curves. Maturity conditions were determined by visual observations made at sea. Fish were considered mature if primary ova were visible in the ovary at any stage or if fish were in spawning or postspawning stages; otherwise, fish were considered immature.

The age or length when equal numbers of fish are mature and immature is known as the 50% maturity level or more commonly M_{50}. In assessing the effects of various dosages of poisons and vitamins on animals, Bliss (1952) devised a probit analysis method for calculating the 50% lethal dosage level (LD_{50}) which is the level where 50% of the animals are dead. Fleming (1960), Pitt (1966), and Bowering (1976) applied the same probit analysis method to determine the length at 50% maturity for cod, American plaice, and witch flounder, respectively. The only difference was that in fitting the provisional line (Bliss 1952), a closer fit was obtained by using log dosages which in the latter studies were the percentages of mature fish plotted against log length on probability paper. This modified probit analysis method was applied to the female Greenland halibut sexual maturity data from each of six areas where data were available. Since sexual maturity data for the northern Grand Bank area were so sparse, these were not included.

RESULTS

Age and Growth

Age Composition

Age composition of Greenland halibut from Baffin Bank in October 1977 showed a predominance of younger age-groups, particularly 3-5 yr olds, for both males and females (Fig. 2). Although fish were present in the catches up to age 14 for males and age 18 for females, very few fish were present beyond 8 yr old. In the Saglek Bank area, the opposite was the case with a strong predominance of fish beyond 5 yr old, although fish in the range of 3-5 yr olds were well represented (Fig. 2). Proportionally, there was a declining trend in the age-9+ groups of males from Saglek Bank to the northern Grand Bank with a marginal decline in the proportion of age-12+ females from Nain Bank to the northern Grand Bank. The most evident change in age composition over this range, however, is the abrupt change from the Northeast Newfoundland Shelf to the northern Grand Bank, particularly at ages 1 and 2. Age compositions for the Gulf of St. Lawrence data indicated very few fish less than age 4 for either sex (Fig. 2) with males absent beyond age 10 and females absent beyond age 12. The predominant age groups were 5-7 yr olds for males and 6-9 yr olds for females, all year classes of the early 1970's. It should be pointed out that since the Gulf of St. Lawrence data were collected in January and all other data collected late in the year, for comparison purposes, the Gulf of St. Lawrence data should be adjusted back by 1 yr.

Growth Curves from Observed Data

Female Greenland halibut have a longer life span than male Greenland halibut (Fig. 3). The difference in maximum age between males and females ranged from 2 yr in the Gulf of St. Lawrence to as much as 8 yr in the Saglek Bank area. It would appear from the curves (without considering mean size at age) that for all areas the overall growth rate of females is greater than that of the males. While the curves do not appear to fit the mean data points very well because of the weighting procedure, the correlation coefficients (r) were all greater than $r = 0.92$ and were all highly significant ($P > 0.001$). In almost all cases, however, the mean data points for the older ages are above the fitted lines (Fig. 3). This would suggest that if the observations were more numerous in the older ages, the computed growth rates would probably be higher than appear here, since more weight would be given to these points. As a consequence, the predicted size at age is probably only meaningful up to age 7 for males and age 10 for females. Beyond these ages, the mean size at age is increasingly higher than that determined from the fitted lines. In addition, the growth of males and females is identical up to age 7 for some areas and up to age 10 in others. It is clear that the weighting procedure underestimates relationships derived from the regression analyses compared with

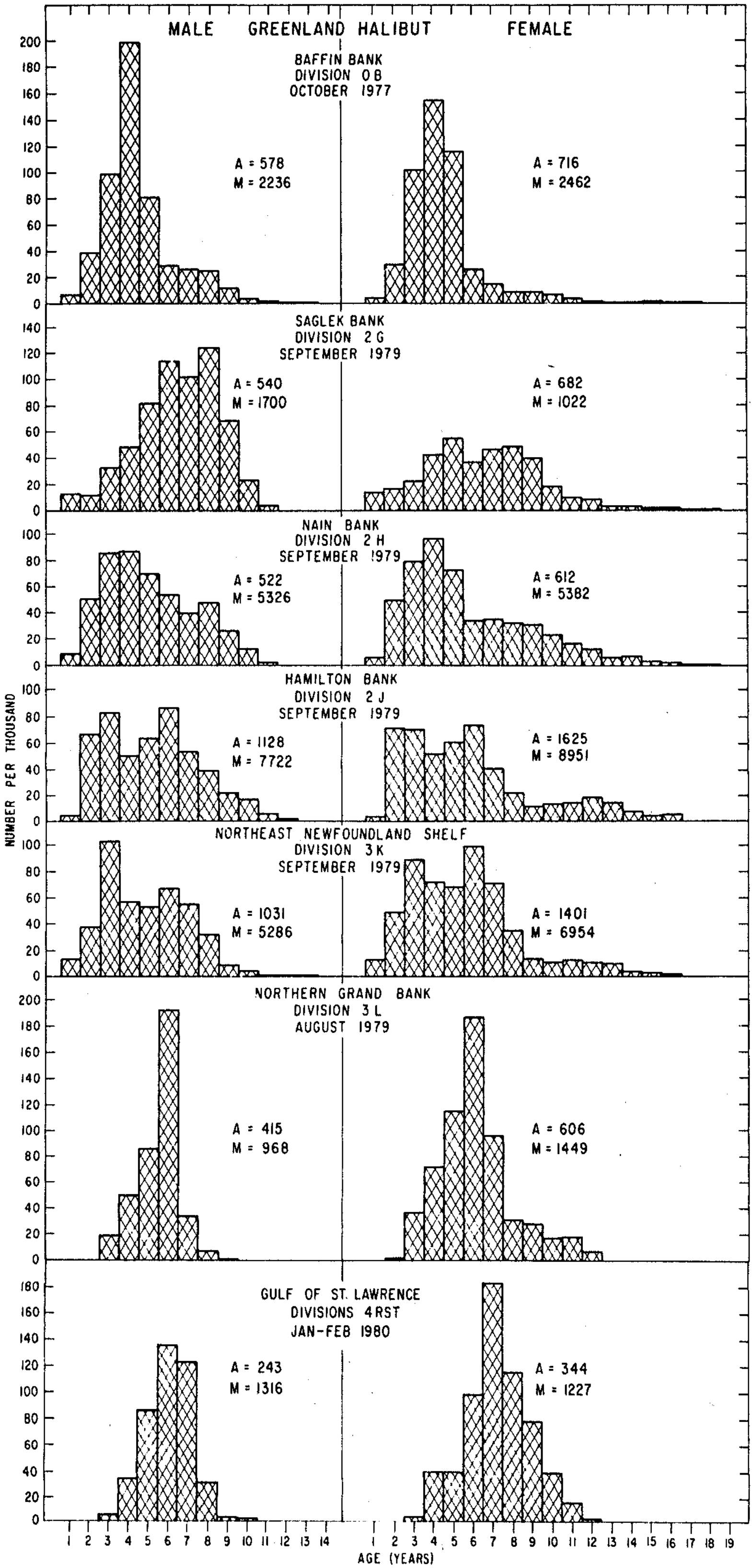


FIGURE 2.—Age composition of male and female Greenland halibut by area from Baffin Bank (NAFO Division 0B) southward to the northern Grand Bank (NAFO Division 3L) inclusive and the northern Gulf of St. Lawrence (NAFO Division 4RST).

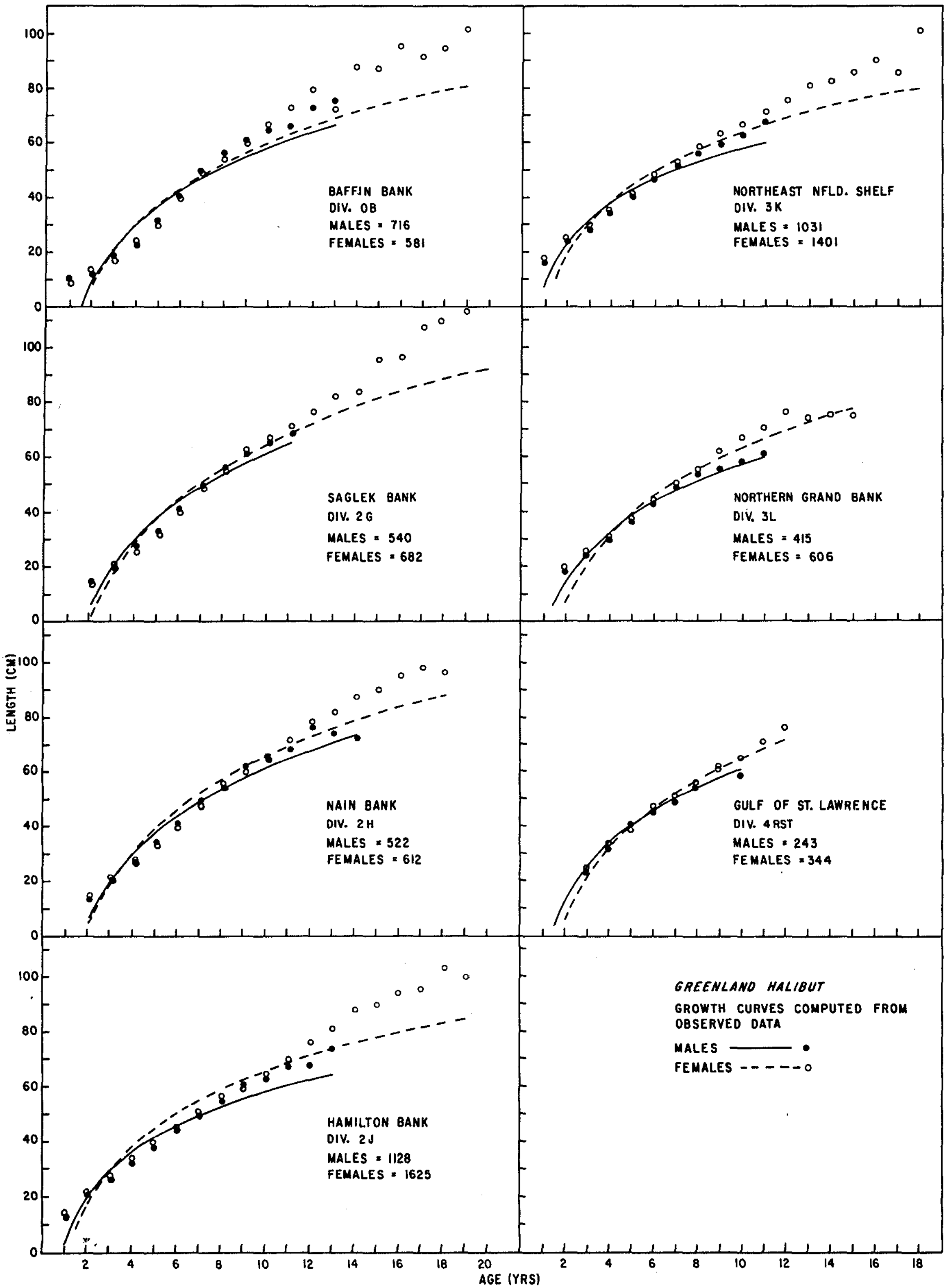


FIGURE 3.—Empirical growth curves of male and female Greenland halibut from seven areas of the Canadian northwest Atlantic.

the mean sizes at age, however, giving equal weight to each age may overestimate if given the lower numbers and questionable age readings in the very large fish.

Back-Calculated Growth Curves

The direct proportionality method (Lea 1919) for back-calculating size at age from otoliths appears valid for Greenland halibut (Fig. 4). The linear least squares regression for total fish length on total otolith length based on 123 observations yielded a correlation coefficient (r) of 0.98 and a t-value for r of 48.59 which is highly significant.

Back-calculated growth curves up to age 5 of the 1972 year class show very close agreement (Fig. 5) between males and females, particularly for the more southerly areas where the curves essentially coincide (Fig. 5). A covariance analysis of males versus females, however, indicated no significant difference in the males and females for both the regression coefficients (slopes) or adjusted means (y-intercepts) throughout the range under consideration ($P = 0.44$). The sexes, therefore, were combined. A covariance analysis on the slopes of the fitted lines for the sexes combined was performed and indicated that, with the exception of the Baffin Bank data, the regression coefficients (slopes) were not significantly different ($P > 0.05$). This would indicate that the growth rates in these areas were similar. Paired comparisons using t-tests to test for differences between the adjusted means indicated that both the Gulf of St. Lawrence data and the Nain Bank data were significantly different from those of all other areas. The Saglek Bank data differed from those of the Northeast Newfoundland Shelf but did not differ from either the Hamilton Bank data or the northern Grand Bank data. There were no significant differences amongst the adjusted means of the Hamilton Bank, Northeast Newfoundland Shelf, and the northern Grand Bank data. The combined back-calculated growth curves (Fig. 6) show the Baffin Bank growth rate to be the slowest with a considerably smaller size at age. The largest size at age is found in the Gulf of St. Lawrence with all other areas in the midrange.

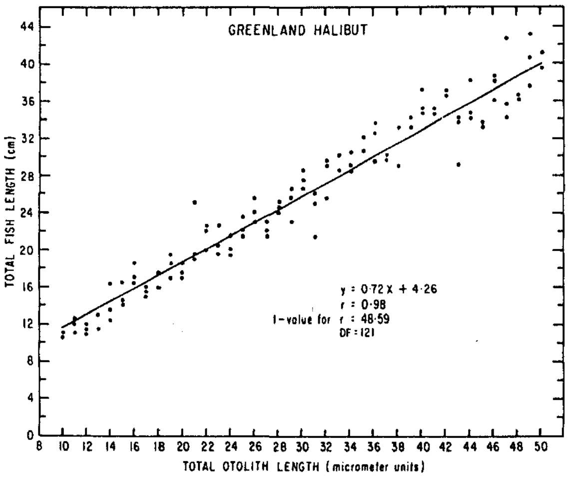


FIGURE 4.—Linear least squares regression of fish length against total otolith length of Greenland halibut.

Sexual Maturity

The sexual maturity curves (Fig. 7) indicate a clear shift to the right in the curves going from northern Labrador to southern Labrador with the Northeast Newfoundland Shelf and southern Labrador curves approximately the same. The curve for the Baffin Bank area falls near the middle (Fig. 7), close to that of the Nain Bank area. The Gulf of St. Lawrence curve, however, is well to the left and appears nearly isolated from all others.

The results of the probit transformation analysis of sexual maturity data, by area are shown in Table 1. All chi-square tests indicate acceptance of the fitted lines to the observed data at the 5% significance level. The length at the 50% maturity level, or M_{50},

TABLE 1.— Results of probit analyses of sexual maturity data for the Greenland halibut, by area, with results of χ^2 tests for acceptability of the fitted lines to the observed data.

Statistical parameter	Baffin Bank	Saglek Bank	Nain Bank	Hamilton Bank	Northeast Newfoundland Shelf	Gulf of St. Lawrence
Slope	0.1574	0.0733	0.0864	0.1118	0.1016	0.1574
y-intercept	−6.297	0.250	−1.312	−4.043	−3.086	−4.101
Length at M_{50}	71.76	64.80	73.05	80.86	79.58	57.83
χ^2 (Res. SS)	3.830	19.565	11.460	11.806	5.141	9.906
$\bar{x}$	70.57	60.70	69.82	78.85	72.52	56.07
SE M_{50}	0.2048	0.0613	0.0681	0.1237	1.7904	0.0684
SE M	0.0267	0.0058	0.0053	0.0208	0.0127	0.0127
No. fish	583	682	612	517	736	513
Age at M_{50}	10.6	9.6	10.8	12.0	12.0	7.8

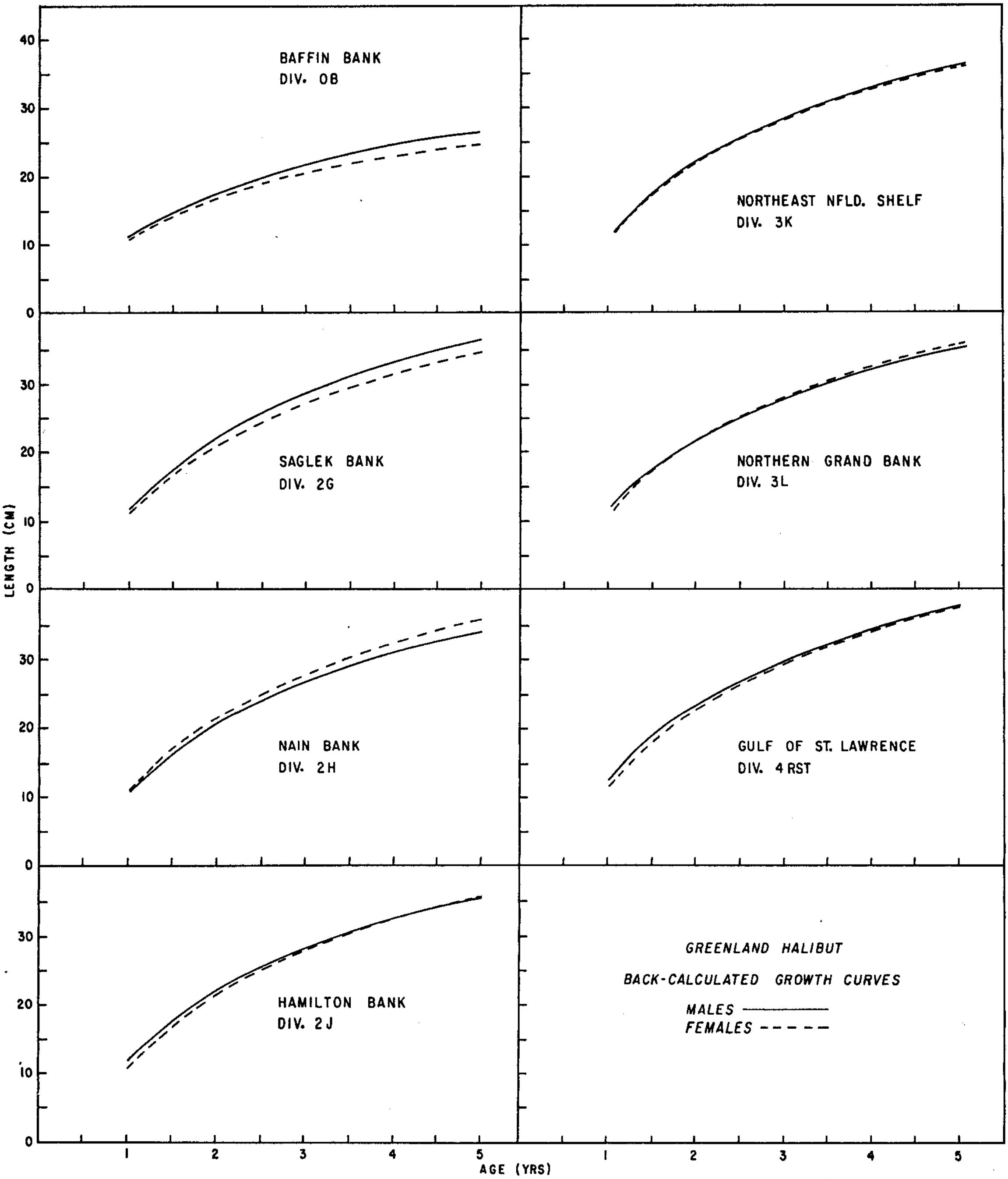


FIGURE 5.—Back-calculated growth curves (ages 1-5) of male and female Greenland halibut from seven areas of the Canadian northwest Atlantic.

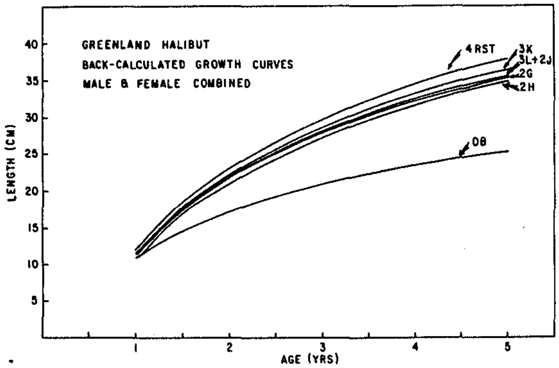


FIGURE 6.—Comparisons of back-calculated growth curves (ages 1-5) of Greenland halibut, sexes combined from seven areas of the Canadian northwest Atlantic.

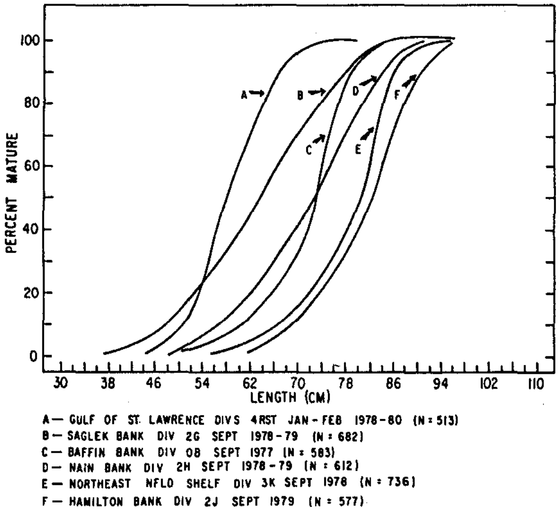


FIGURE 7.—A comparison of sexual maturity ogives of female Greenland halibut from six areas of the Canadian northwest Atlantic.

decreased from 71.8 cm in the Baffin Bank area to 64.8 in the Saglek Bank area; however, the length at M_{50} increased to 73.1 cm in the Nain Bank area and then to 80.9 cm in the Hamilton Bank area. The length at M_{50} for Northeast Newfoundland Shelf area was 79.6 cm, very similar to the Hamilton Bank value. The lowest length at M_{50} was 57.8 cm for the Gulf of St. Lawrence.

The ages at M_{50} calculated from the growth equations of Bowering (1978a) showed the same trends as did the lengths at M_{50}. The lowest age at M_{50} was 7.8 yr for the Gulf of St. Lawrence data to a maximum of 12 yr for both Hamilton Bank and Northeast Newfoundland Shelf. The results of the covariance analyses for testing the regression coefficients (slopes) and elevations (y-intercepts) of the fitted lines are shown in Table 2. The slope of the Baffin Bank data differed from that of Saglek Bank and Nain Bank but not from those of any other areas. The slope of the fitted lines for Saglek Bank, Nain Bank, Hamilton Bank, and Northeast Newfoundland Shelf did not differ significantly. Biologically, this means that the proportional increase of mature fish from one size group to the next were the same for these areas. The slope of the Gulf of St. Lawrence data differed significantly from those of all areas except Hamilton Bank and Baffin Bank. For paired comparisons which did not yield significant differences between the slopes of the fitted lines, statistical treatment of the elevations (y-intercepts) indicated highly significant differences between the intercepts for all pairs at the 1% significance level (Table 2). This means that although the proportional increase of mature fish from

TABLE 2.—Matrix of t-values for paired comparisons of sexual maturity data for Greenland halibut.

	Saglek Bank		Nain Bank		Hamilton Bank		Northeast Newfoundland Shelf		Gulf of St. Lawrence	
	0.0733 Slope	0.250 Int.	0.0864 Slope	−1.312 Int.	0.118 Slope	−4.043 Int.	0.1016 Slope	−3.086 Int.	0.1574 Slope	−4.101 Int.
Baffin Bank										
t	[1]2.404	N/A	[1]2.455	N/A	1.154	[2]−2.977	1.959	[2]−10.748	−0.0001	[2]−11.484
df	28	27	18	19	20	21	19	20		
Saglek Bank										
t			1.634	[2]8.311	1.877	[2]14.947	1.586	[2]13.824	[2]5.905	N/A
df			39	40	30	31	32	33	31	
Nain Bank										
t					1.394	[2]10.775	1.008	[2]7.958	[2]5.604	N/A
df					29	30	31	32	30	
Hamilton Bank										
t							0.426	[2]−4.619	1.918	[2]−6.643
df							22	23	21	22
NE Nfld. Shelf										
t									[2]2.923	N/A
df									23	

[1]Indicates rejection of H_0 at $\alpha = 0.05$.
[2]Indicates rejection of H_0 at $\alpha = 0.01$.

one size group to the next was the same, the range of the size groups themselves was different. In biological terms, this means that there is a significant difference in the size at M_{50} for all areas tested. Subsequently, the ages at which Greenland halibut reach the 50% maturity level are also different for these areas.

DISCUSSION

Age and Growth

Age composition of Greenland halibut varied throughout the range under consideration. It was apparent (although not greatly pronounced) from the age distribution that the older fish were proportionately more abundant in the more northerly areas and, according to Bowering (1978c), are more abundant in deeper waters. The large numbers of young fish in the Baffin Bank area suggest that this area may be a nursery area as indicated by Atkinson et al. (1981). However, the lower numbers of large Greenland halibut in the Baffin Bank survey may also be due to the ineffectiveness of the fishing gear at great depths (>500-700 m), since the vessel is comparatively small for fishing such depths. Chumakov (1975) found that the oldest individuals throughout the range studied here are located in waters >800 m deep in the northern region of Baffin Island (which he considered to be on or near the spawning grounds). Berth et al. (1979), in reporting results of a survey for Greenland halibut throughout the same area in December 1978, also found that young Greenland halibut increased in abundance with increased distance from the more northerly areas. Berth[2] also found that mature individuals are more abundant in the more northerly areas, suggesting a northward migration of maturing Greenland halibut for spawning. Subsequently, Templeman (1973) indicated that pelagic larvae are carried from there by the polar currents to the banks of west Greenland and eastern Canada.

The absence of Greenland halibut less than age 4 from the Gulf of St. Lawrence is difficult to explain. It may be that the young fish move to a different area than that surveyed in winter or, for some unknown reason, they are inaccessible to the fishing gear. It may be possible that if there is immigration into the Gulf of St. Lawrence from outside as suggested by Bowering (1980a, 1981), it may not include Greenland halibut in the very young age groups. The reporting of numerous 1-group Greenland halibut in summer of 1980 by Tremblay and Axelsen (1981) may in fact simply be the result of a very strong anomalous year class produced by a resident population of Greenland halibut within the Gulf of St. Lawrence. Furthermore, Bowering (in press) indicated that recruitment to the Gulf of St. Lawrence fishery was higher than that which could be expected from the stock of mature fish in the gulf. Therefore, most recruitment would have to come from elsewhere. Evidence from electrophoretic studies (Fairbairn 1981) also supports this hypothesis. Fairbairn (1981) concluded that Greenland halibut in the Gulf of St. Lawrence support a separate breeding stock with some gene flow (migration) between the Gulf of St. Lawrence area and the Northeast Newfoundland Shelf area, probably through the Strait of Belle Isle. It would appear then that the Gulf of St. Lawrence Greenland halibut population is composed of a small stock that spawns there and immigrants from the Labrador area that may emigrate to the north for spawning.

Growth Patterns

Differences in growth rate between males and females are generally the result of genetics which determine the physiology and behavior of the fish rather than the result of the environment (Alm 1959), since the males and females presumably are subjected to the same set of environmental conditions. These differences are generally the result of a diversion of energy towards the formation of the sex products with less energy available for growth, according to Alm (1959). Bowering (1978a) expressed growth of Greenland halibut in terms of linear least squares regression, since most fish in the study were immature and showed little or no diversion in growth patterns of males and females. Because of this, it was considered that the study only dealt with that section of the growth curve below the inflection point, and consequently estimates of L_∞ for the traditional von Bertalanffy growth equation were not realistic and could not be used. Results of back-calculated growth curves up to age 5 in this study resulted in no statistical difference between males and females, which in essence would support Alm (1959) and Bowering (1978a). Furthermore, the mean size-at-age points from the empirical data suggest that the difference in growth patterns between males and females would not be readily observed until in the range of 8-12 yr olds. These data suggest that, with the possible exception of the Gulf of St. Lawrence, the influence of sexual maturity on growth patterns in these areas was

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negligible. Statistical comparisons could not be made with Bowering (1978a), since the data could not be standardized.

Covariance analyses on the back-calculated growth data indicated that the growth rate throughout the entire area, with the exception of the most northerly Baffin Bank area, was the same. The growth rate from the Baffin Bank data was considerably lower than all other areas. Analysis of the adjusted means (intercepts) indicated that the average size at age for the Gulf of St. Lawrence data was significantly higher than all other areas. Since the overall growth rate was the same as other areas, this would imply that the growth rate of the Gulf of St. Lawrence fish was substantially higher in the first year of life compared with other areas. While the size at age from Nain Bank was significantly different from all areas, it did not appear to vary greatly from the adjacent Labrador and eastern Newfoundland areas. Since differences between growth patterns from Saglek Bank and other areas are not totally variable, they may be a result of the location and behavior of the fish in the first year of life throughout the range.

Because there appears to be a general increase in average size at age from north to south, temperature would appear to be a contributing factor. Templeman (1964) indicated that the volume of warmer waters increased from north to south because of the direction of the Labrador Current so that temperature may have an influence on growth pattern. Any influence would have to be particularly related to the first year of life, since older Greenland halibut are known to migrate over long distances (Nizovtsev 1970; Chumakov 1970; Sigurdsson 1977), as well as vertically in the water column (Lear 1970; de Groot 1970), making them subject to a wide variety of temperatures. This may explain the high growth rate in the first year for the Gulf of St. Lawrence fish where temperatures are considerably higher than the eastern areas. It should be pointed out, however, that these growth patterns are based mostly upon immature individuals, and the difference in growth patterns of the immature individuals alone may simply be a result of conditions where they grew prior to maturity. Upon approaching maturity they could all still return to a common breeding area and be part of the same original stock.

Sexual Maturity

The commercial fisheries for Greenland halibut on the banks and slopes in the northwest Atlantic are mainly composed of immature fish (Chumakov 1975; Zilanov et al. 1976; Templeman 1973; Berth et al. 1979; Bowering 1977-81). The scarcity of mature fish in the commercial, as well as research, catches led to consideration of the possible misinterpretation of maturity condition of the ovaries, particularly by visual observation. Walsh and Bowering (1981) studied the problem histologically and concluded that while the accuracy of visual observations of sexual maturity of female Greenland halibut may be enhanced by histological analysis, for practical purposes, field observations on the onset of first maturity are adequate. Maturity of male Greenland halibut was not included in the analysis here, since it was extremely difficult to determine whether males with growing gonads were maturing for the upcoming spawning season or later. This uncertainty was probably a result of the timing of the surveys when milt was not present in the testes and previously spawned fish may have been fully recovered.

The results of probit transformation analysis indicated that the 50% maturity level (M_{50}) was reached at a much smaller size for the Gulf of St. Lawrence fish, whereas there was a trend of increasing size at M_{50} for fish from northern Labrador to the southern Labrador-Northeast Newfoundland Shelf area. Covariance analysis indicated that for the Labrador-eastern Newfoundland areas the rate of increase in the proportion of mature fish from one size group to the next was the same. The Baffin Bank and Gulf of St. Lawrence data differed from some areas but not from others. More importantly, however, were the significant differences in the intercepts of the fitted lines for all areas. In biological terms this indicates a significant difference in the sizes and ages of M_{50} for all areas.

Molander (1925), in studying European plaice and flounder in the Baltic, found that with increased growth rate, maturity occurred at a lower age but at a greater length. Bowering (1976) found similar results for witch flounder in the northwest Atlantic. Pitt (1975) indicated for American plaice that faster growing fish matured at an earlier age but all matured at approximately the same size, suggesting that sexual maturity is probably dependent on size, and indirectly on growth rate, rather than on age. From experimental research on sexual maturity of fishes, Alm (1959) concluded that "with an initially good growth rate maturity is reached at an earlier age than an initially poor growth rate. The metabolic processes are probably relatively fast with good growth rate. Consequently, differentiation processes in gonads and maturity apparently occur much earlier, the opposite being the result of poor growth rate."

The results reported here support in part the conclusions of Alm (1959). Greenland halibut from the

Gulf of St. Lawrence exhibit the highest growth rate and mature much earlier than fish from other areas. Conversely, the population of Greenland halibut from Baffin Bank exhibits the slowest growth rate, and maturity is reached at a later age than those from the Gulf of St. Lawrence. The initial growth rate of the Labrador-eastern Newfoundland areas has been shown to be very similar, occurring somewhere between those of the Baffin Bank and the Gulf of St. Lawrence. However, the size and age at maturity decrease significantly from south to north, contrary to the above theory. The reason for this may be explained if a northward spawning migration occurs. If this is the case, then it would be expected that the proportion of maturing individuals in catches at any particular size up to 100% mature would be greater, moving progressively northward. This would result in a shifting of the maturity curve to the left going north and subsequently producing lower values of M_{50}. This would further suggest that in the Labrador area the value of M_{50} for Saglek Bank may be in fact more representative of the entire Labrador-eastern Newfoundland area. The value of M_{50} for Saglek Bank falls between that of the Gulf of St. Lawrence and Baffin Bank data as does the initial growth rate. This would then be in agreement with Alm's (1959) theory of the relationship of maturity and initial growth rate.

Recent investigations by Chumakov (1982) also found that the abundance of larger mature fish increased moving northward. From tagging studies in eastern Newfoundland, Chumakov (1982) found that Greenland halibut migrated northward over long distances, from the southernmost parts of the area to the spawning grounds located in Davis Strait. He also indicated that having reached the spawning grounds, mature fish would not return to the areas where they had been dwelling before maturation. The proportions of mature fish in the more southerly areas would therefore be expected to be slowly moving southward, as shown in the data presented here. Furthermore, Bowering (1982) also studied migrations of Greenland halibut in the same area. For Greenland halibut tagged in White Bay, Newfoundland, (Fig. 1) the returns mostly came from deep waters along the continental slope of Labrador to as far north as the waters off Baffin Island near the known spawning grounds. This further suggests a northward migration of prespawning Greenland halibut.

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