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Growth of Greenland cod, *Gadus ogac*, in the Nuuk area of West Greenland

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Abstract

A growth analysis of Greenland cod, *Gadus ogac* Richardson, caught by longline in the Nuuk / Godthåb area at West Greenland in 1987-89 is performed. A maximum length and weight of 77 cm and 7 kg, respectively, and a maximum age of 11 years are found. The Greenland cod has isometric growth and seems to follow a von Bertalanffy growth pattern with a slower growth rate than seen for Atlantic cod in Greenland waters. Differences in mean length per age group are found between sexes, years and between individuals infected with the gill worm, *Lernaeocera branchialis*, and those not infected. Further, there is found differential growth between fish from respectively offshore areas and inshore / archipelagic areas, while individuals caught at different bottom depth strata (0 to 300 m) show no considerable growth differences. No geographical differences in growth are found between individuals from two separate fjord systems in the survey area.

Introduction

Since 1973 Greenland cod has been commercially exploited in West Greenland and maximum landings occured in the period 1975-1987 with a peak of 6500 tonnes in 1985. With increasing fishery for Atlantic cod (*Gadus morhua*) through the late eigthies until 1990 the landings of Greenland cod decreased. (Nielsen, 1992). However, the recent (1991-92) collapse in Atlantic cod fishery in West Greenland waters and the low recruitment from the 1986-91 yearclasses to the Atlantic cod stocks in the area (Anon. 1992; Nielsen, 1991a) has created a demand for alternative resources and resulted in growing interest for extended exploitation of Greenland cod (Nielsen, 1992). Therefore improved knowledge of the fishery biology of the species is needed. No growth analyses exists for Greenland cod from Greenland waters and only very few growth estimates are published from its distribution area in Canada and Alaska (Nielsen, 1992). The purpose of the present study is to contribute to the knowledge of the growth of Greenland cod in West Greenland. This growth analysis is performed as a precursory study for estimation of Yield per Recruit and the Biomass of Greenland cod in the Nuuk area, West Greenland performed in Nielsen (1991b; 1992).

Materials and Methods

Growth analyses on Greenland cod from the Nuuk area (Fig. 1), West Greenland is performed based on catches from yearly longline surveys primary directed towards Atlantic cod at West Greenland in October-November 1987-1989. The survey area is situated on a subarctic latitude in NAFO subarea 1D covering the biggest demarcated fjord system in West Greenland. The survey area cover inshore, coastal and offshore localities and the stations are gathered in groups of 3-5 covering one days fishery. The groups are randomely distributed related to 100 m depth stratas in the bottom depth interval 20-300 m's. The fishing operations are mutually standardized: A demersal 7 mm (diameter) blue polypropylene longline with a lead anchor attached for every 200 m are used and the 50 cm long wisps, placed with a mutual distance of 2 m, were provided with Mustad no. 6 hooks baited with 11-17 cm pieces of recent thawet capelin. Mean fishing time was 4.5 h (3.7-7.8 h) with typically 400 hooks per fishing station. The growth analyses are supplemented with Greenland cod caught in yearly experimental gillnet surveys performed in July 1987-90 in inshore areas covering the same survey area (Fig. 1). The purpose of gillnet fishing is to cover shallow water areas (< 20 m bottom depth) and the growth of young fish (age group 2 and 3). The experimental gillnets are equipped with 10 equally sized panels with 5 equally represented stretched mesh sizes of respectively 16, 18, 24, 28 and 33 mm knot to knot placed with a mutual distance of 2 m in random order. This gear is further described in Hovgård (1988). The gillnets are set as sinking nets in 10 m depth strata parallel with the coastline covering the bottom depth interval 0-40 m and one station represents typically 3 sets each of 6 hours fishing time. The fishery with both gears are performed with R/V "Adolf Jensen" and R/V "Misiliisoq", Greenland Fisheries Research Institute.

Total length were recorded for each individual Greenland cod caught to the cm below. Otoliths were randomly sampled from the catch and from these individuals weight and sex were recorded. Age readings are performed in laboratory on sampled otoliths. Age-length keys based on the sampling are shown in appendix 3 for each gear used. Further, the intensity of parasitic infection with the gillworm (Lernaeocera branchialis) are registrated from randomely sampled individuals from the catch.

Both longlines and gillnets are size selective (Hamley, 1975; Løkkeborg and Bjordal, 1991) which is necessary to account for in estimation of growth parameters for the population. Appendix 1 and 2 show the calculation procedure of the selection coefficients used when accounting for the size selectivity of longline and experimental gillnet, respectively. The selection coefficients for each size class, S(L), of Greenland cod in the survey area are shown in Table 1 (longline) and Table 2 (gill net).

Table 1 Calculated size selection coefficients, S(L)l, for longline catches of Greenland cod per 3 cm length intervals.

LENGTH INTERVAL	INTERVAL MIDPOINT	S(L)l
29 - 31 cm	30 cm	0.0000
32 - 34 cm	33 cm	0.0425
35 - 37 cm	36 cm	0.0964
38 - 40 cm	39 cm	0.1650
41 - 43 cm	42 cm	0.2523
44 - 46 cm	45 cm	0.3631
47 - 49 cm	48 cm	0.5041
50 - 52 cm	51 cm	0.6833
53 - 55 cm	54 cm	0.9111
56 - 58 cm	57 cm	1.0000
59 - 60 cm		1.0000

Table 2 Calculated size selection coefficients, S(L)g, for Greenland cod catches in experimental gillnets per 3 cm length intervals.

LENGTH INTERVAL	INTERVAL MIDPOINT	S(L)g
14 - 16 cm	15 cm	0.7944
17 - 19 cm	18 cm	0.9501
20 - 22 cm	21 cm	0.9993
23 - 25 cm	24 cm	0.9807
26 - 28 cm	27 cm	0.9039
29 - 31 cm	30 cm	0.7514
32 - 34 cm	33 cm	0.5341
35 - 37 cm	36 cm	0.3095
38 - 40 cm	39 cm	0.1408
41 - 43 cm	42 cm	0.0489

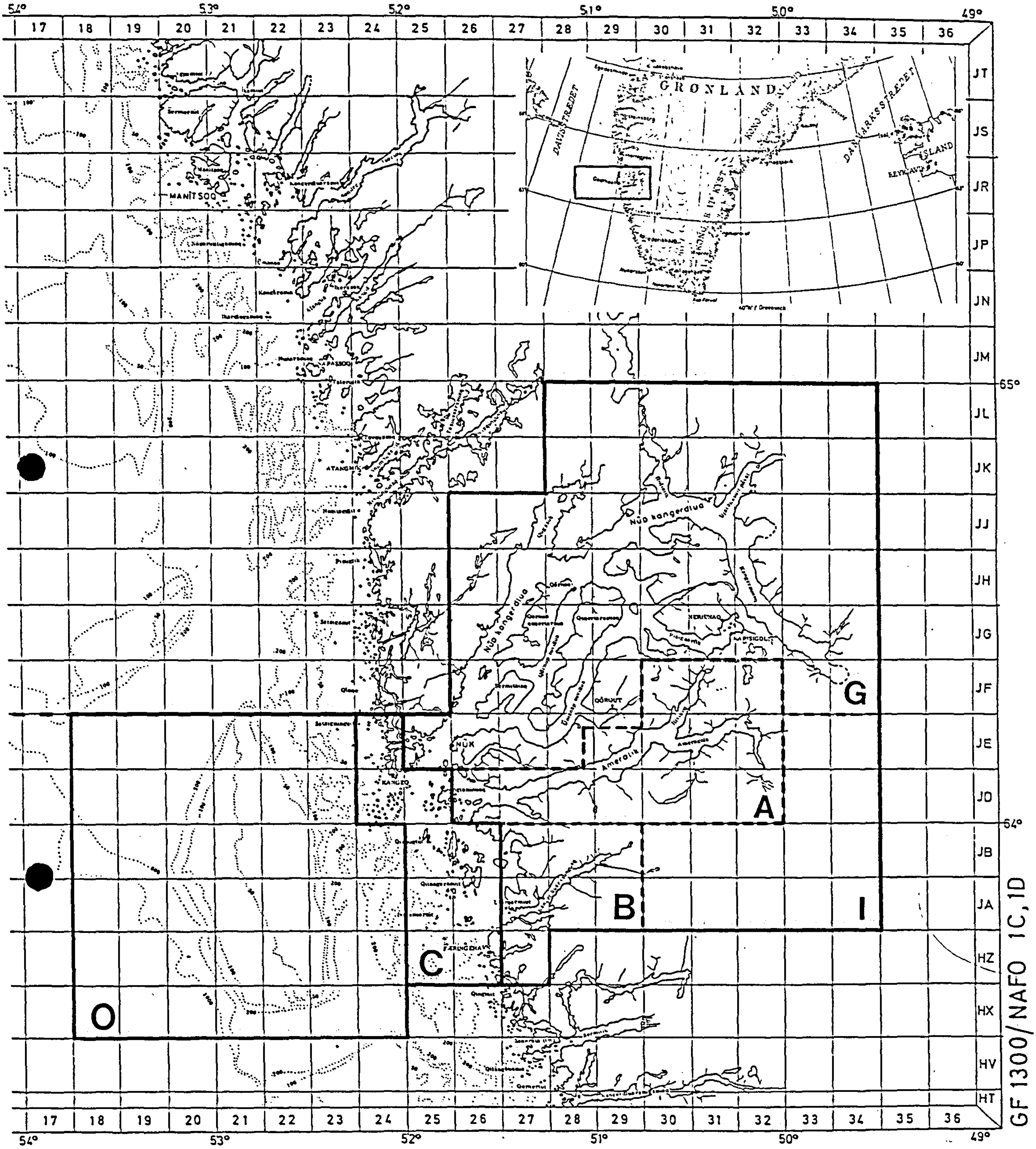

Figure 1. The survey area in the Godthaab / Nuuk area at West Greenland. The survey area is subdivided into the following areas: O: Offshore; C: Coastal; I: Inshore. The inshore area consist of: "Godthaabsfjorden" (G), Ameralik (A) and Buksefjorden (B).

The growth curve for the population of Greenland cod in the study area is described by the von Bertalanffy growth equation.

The statistical analyses of differences in mean length are performed with multi variate ANOVA using the General Linear Models (GLM) procedure in SAS (Statistical Analysis System) version 6.03 described in SAS (1988). All first order interaction effects between the class variables has been included in the analysed linear models. The reduced end model is achieved from removing of all non-significant interaction effects and class variables on the 5 % level by successive analysing. The residuals of the resulting models are tested for normal distribution (SAS 1988, Univariate procedure) and plots of the residuals versus estimated model values are scrutinized for trends in respect of fulfilling the claim of equal variances when using ANOVA. Further, linear regression is performed connected to analysis of the condition factor for Greenland cod and the growth pattern in the analysed population of Greenland cod (SAS 1988, Reg. procedure).

Results

The maximum length and weight recorded for Greenland cod are 77 cm and 7 kg, respectively, and its maximum age is found to be 11 years in the Nuuk/Godthåb area of West Greenland.

1.1 Sexual difference in mean length per age gruop

A plot of mean length per age group by sex for Greenland cod from long line catches november 1989 in the inshore part (I) of the survey area is presented in Fig. 1.1.

Females is seen to be significantly larger than males for all age groups with a slightly increased difference with age. From 4 to 6 year old fish the difference in mean length are approximately 2 cm while the difference is nearly 7 cm for seven year old fish.

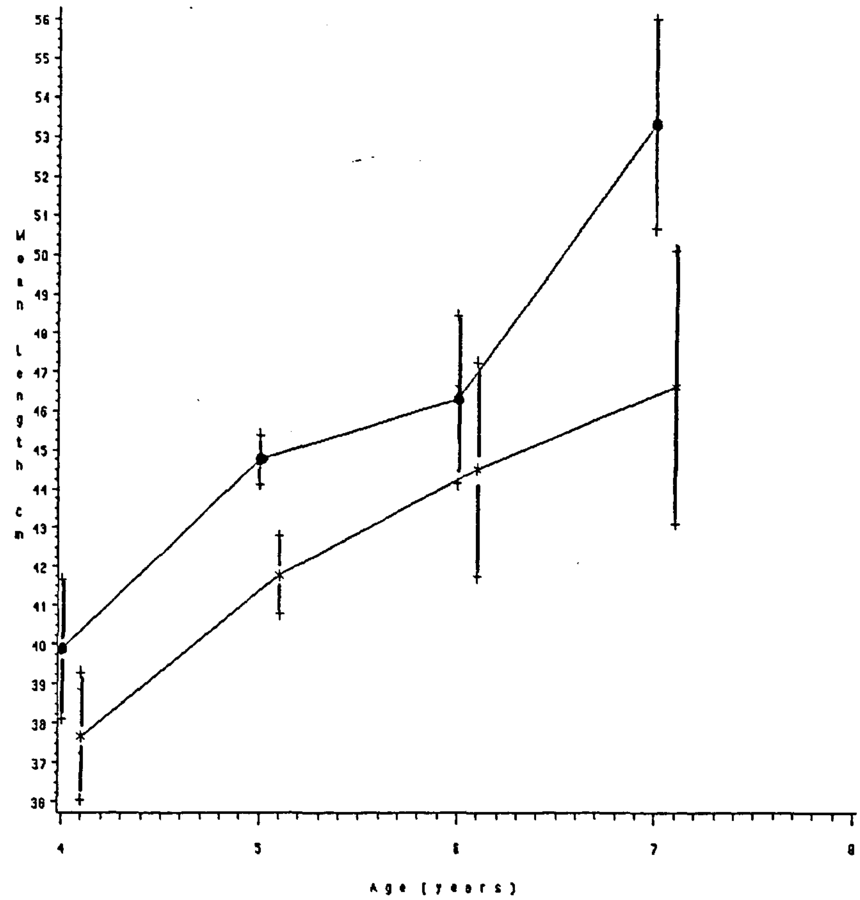

Figure 1.1 Mean length per age group divided by sex for Greenland cod from longline catches in inshore areas november 1989 in the Nuuk area. N = 254. Confidence levels: 2 * Standard Error. Star: Females; Black dot: Males. Only age groups containing more than 5 individuals are included.

1.2 Geographical differences in mean length per age group between two separate fjord systems.

Mean length per age group for male Greenland cod from longline catches november 1989 in inshore areas of "Godthaabsfjorden" (G) and "Buksefjorden" (B), respectively, is shown in Fig. 1.2. The two fjords are shown in Fig. 1 and they have a mutual distance of about 50 km. "Godthåbsfjorden" is a open fjord system while "Buksefjorden" is a treshhold fjord with no inflow of warm Atlantic bottom water giving the two fjord systems different environmental conditions (Hansen, 1935; Buch, 1990) and thereby possible different conditions of growth.

No consistent growth differences between individuals from the two fjord systems can be seen (Fig. 1.2), and analysing the mean lenght per age group of the females show no difference either (not shown). The absence of consequent and significant growth differences can be interpretated as presence of only one stock in the survey area.

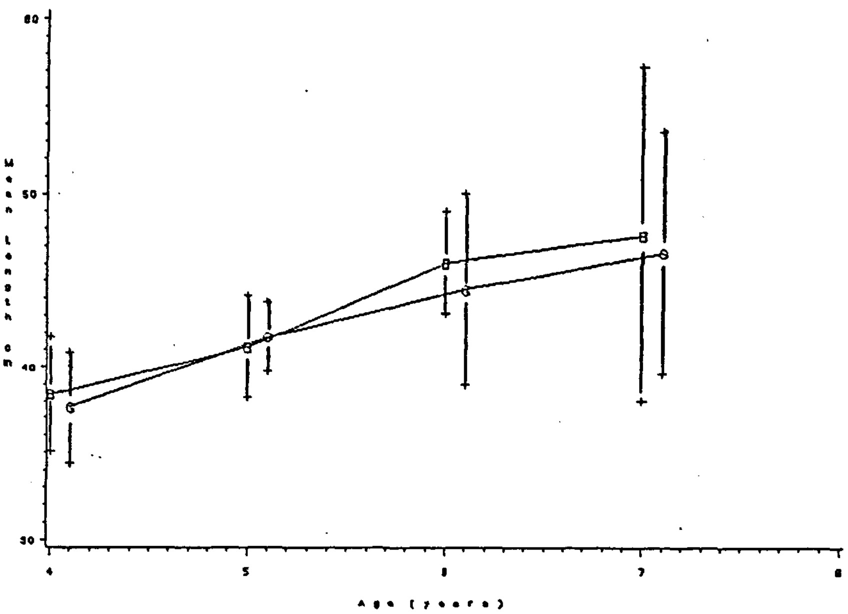

Fig. 1.2 Mean length per age group in "Godthåbsfjorden" (symbol G) and "Buksefjorden" (symbol B). Confidence limits (2 * Standard Error) is given. N ≥ 10 for each age group caught in each fjord.

Further, geographical growth differences in mean length at age are analysed between Greenland cod caugth in respectively inshore (I), archipelagic (C = Coastal) and offshore (O) areas. Only for the year 1988 fish from all three areatypes is represented, while respectively I / O and I / C is covered in 1987 and 1989. All data are from longline catches performed in October and November. Based on this unequal representation a multi variate ANOVA is performed using GLM analysis (SAS, 1988) with the class variables years, age, sex and areatype and all first order interaction effects. To ensure sufficient observation numbers in each group only age group 4 to 7 are included in the analyses. Successive tests show that none of the interaction effects are significant at the 5 % level. This reduces the GLM model to Eqn. 1.2 with the dependent variable length (L) in cm for Greenland cod of an given age and sex caught in an given year and areatype. Table 1.2 shows the results of the ANOVA.

$L_{ijkl} = \mu + age_i + sex_j + year_k + areatype_l + \epsilon_{ijkl}$ (Eqn. 1.2), where μ is the grand mean, age = (4,5,6,7), sex = (males,females), year = (1987,1988,1989), areatype = (I,C,O) and ϵ is the residual of the model.

Table 1.2.1 Variance table for a reduced model of the catch. containing significant class variables only. The dependent variable is length in cm.

VARIABLE	SS	DF	MS	F	P > F	R^2
MODEL	13741.0	8	1717.6	126.9	0.0001	0.43
AGE	9511.0	3	3170.3	234.3	0.0001	-
SEX	1909.7	1	1909.7	141.1	0.0001	-
YEAR	914.1	2	457.1	33.8	0.0001	-
AREATYPE	618.5	2	309.3	22.9	0.0001	-
RESIDUALS	18498.2	1367	13.5	-	-	-
CORR. TOTAL	32239.2	1375	-	-	-	-

The model is statistically significant and accounts for 43 % of the total variation. The distribution of the residuals was not found to differ from normality (W:normal 0.9868, P<W 0.3882) and a plot of the residuals versus length shows no trends (not shown). All four class variables is highly significant at the 5 % level. Compared to the variables age and sex the variable areatype only accounts for a relatively small part of the variation in length. Estimates from the model in Tab. 1.2.2 shows no differences in mean length per age group between individuals from inshore and archipelagic areas, while Greenland cod from the offshore bank area were 3-4 cm longer in mean length per age group in the survey area. This conclusion is based on the difference (-3.72)-(-3.21)= -0.51 cm in mean length between I and C which is less than half value of the confidence limits (2*Standard Error).

Table 1.2.2 Estimates of the class variables areatype and years with standard error values estimated in the model.

PARAMETER	ESTIMATE (cm)	2* Std. Error (cm)
Grand Mean	53.91	1.41
Area type: I - O	- 3.72	1.14
Area type: C - O	- 3.21	1.19
Year: 1987 - 1989	3.65	1.16
Year: 1988 - 1989	1.60	0.51

1.3 Difference in mean length per age group between different years

From the results of the ANOVA it also appears (Tab. 1.2.1 and Tab. 1.2.2) that the class variable year is highly significant although it doesn't account for much of the variation in the model. Model estimates from Eqn. 1.2 shows that the mean length per age group varies between years and a continuous decrease of approximately 1.5-2.0 cm in mean length per year is observed for the period 1987-89 in the area (Tab. 1.2.2).

1.4 Difference in mean length per age group between different depth stata

It is tested whether there exist a specific depth effect on mean length per age group for Greenland cod in the survey area due to favorable conditions in some depths compared to others. Data from longline catch november 1989 in both coastal and inshore areas in different 100 m depth strata are used to test different growth conditions between depths. The depth is divided the strata 1: 20-100 m; 2: 101-200 m; 3: 201-300 m. The class variables used in the multivariate ANOVA is age, sex, depth stratum and parasitic infection with gill worms (see section 1.5). First order interaction effects is included in primary run. There were not found any significant interaction effects on the 5 % level which reduce the resulting GLM model to Eqn. 1.4.

$L_{ijkl} = \mu + age_i + sex_j + depth_k + parasites_l + \epsilon_{ijkl}$ (Eqn. 1.4),

where μ is the grand mean, age = (3,4,5,6,7,8,9), sex = (males, females), depth = (1,2,3), parasites = parasitic infection = (1: not infected, 2: infected) and ϵ is the residual of the model. Table 1.4 shows the ANOVA scheme.

Table 1.4.1 Variance table for a reduced model of the catch containing significant class variables only. The dependent variable is length in cm.

VARIABLE	SS	DF	MS	F	P > F	R^2
MODEL	10830.9	10	1083.1	83.4	0.0001	0.45
AGE	8781.7	6	1463.6	112.8	0.0001	-
SEX	1181.2	1	1181.2	91.0	0.0001	-
DEPTH STRATUM	138.4	2	69.2	5.3	0.0050	-
PARASITIC INF.	133.7	1	133.7	10.3	0.0014	-
RESIDUALS	13059.1	1006	13.0	-	-	-
CORR. TOTAL	23890.0	1016	-	-	-	-

It appears from Tab. 1.4.1 that the model is statistically significant (P<0.0001) and accounts for 45 % of the total variation. The distribution of the residuals are not differing from normality (W:normal 0.9870,P<W 0.5632) and a plot of the residuals versus length shows no trends. The analysis shows significant difference in mean length between the three depth strata on the 5 % level but the class variable depth explains only a minor part of the total variation in data (Tab. 1.4.1). In Tab. 1.4.2 estimates

of the GLM model is shown and it appears that the mean length in depth 20-100 m is 0.7-0.8 cm longer in average than fish caugth in the depths 101-200 m and 201-300 m. This difference is significant on the 5 % level (P<0.0289 and 2*Std.Err=0.66 cm) while the difference between 101-200 m 201-300 m is non-significant.

Table 1.4.2 Estimates of the class variables areatype and years with standard error values estimated in the model.

PARAMETER	ESTIMATE (cm)	P	2* Std. Error (cm)
GRAND MEAN	59.04	0.0001	3.64
Depth stratum: 1 - 3	0.72	0.0289	0.66
Depth stratum: 2 - 3	- 0.09	0.7778	0.66
Parasitic inf. : 1 - 2	0.81	0.0014	0.25

1.5 Differences in mean length per age group related to gill worm infection.

The functional effect of parasitic infection with the copepod gill worm on mean length per age group for Greenland cod in the survey area are analysed. The examined individuals of Greenland cod caught on longlines November 1989 are found to be infected with 0 to 11 gill worm individuals which are attached to the respiratory surfaces (both gills). However, there is not analysed for effects of the intensity of infection but only testet for the effect of presence or abscence of the parasite respectively. The prevalence of the parasite (relative number of Greenland cod infected) as an average for all age groups is for randomely sampled Greenland cod from longline catches in inshore and coastal areas found to be 71.7 % and 28.3 % respectively. Further sampling of data for parasitic infection from catch through gill net surveys in 1989 and 1990 shows that length groups less than 25 cm of Greenland cod are not infected with the copepod. In the mulivariate ANOVA giving the reduced GLM model in Eqn. 1.4 the class variable Parasites is seen to be significant on the 5 % level (P<0.0014) although the variable only accounts for less than 2 % of the variation in length in the model. It appears from the model estimates in Tab. 1.4.2 that infection with gill worms results in a lesser mean length at age for both sexes of about 0.81 cm in average (± 0.25 cm).

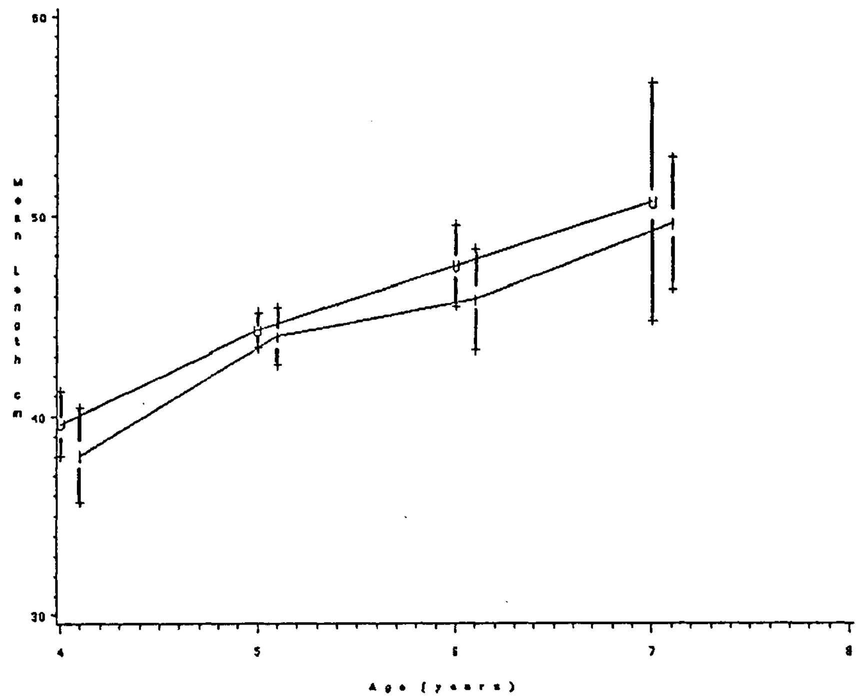

Fig. 1.5.1 Mean length per age group for infected (I) and non-infected (U) females of Greenland cod. Observation number: N = 607 and for all groups N ≥ 5. Confidence intervals as 2*Std. Error are shown for all mean val.

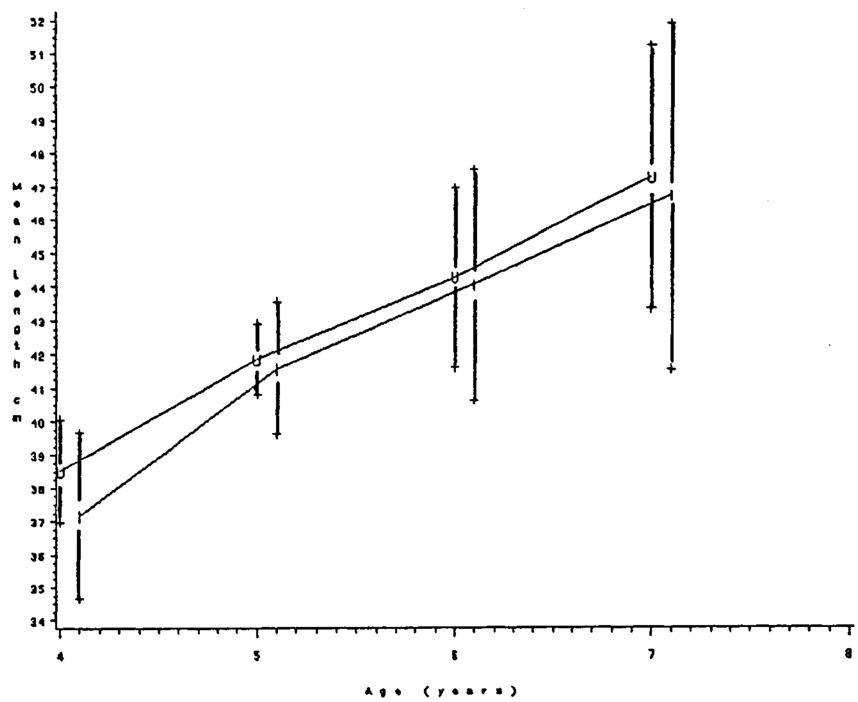

Fig. 1.5.1 Mean length per age group for infected (I) and non-infected (U) males of Greenland cod. Observation number: N = 380 and for all groups N ≥ 5. Confidence intervals as 2*Std. Error are shown for all mean val.

The difference in mean length between infected and non-infected Greenland cod is from Fig. 1.5.1 and Fig. 1.5.2 seen to be consequent for both sexes of all age groups.

1.6 Growth Pattern and Condition of Greenland cod

The purpose of the analyses in the next two sections is is to investigate the growth pattern of Greenland cod. By insertion of the equation for allometric growth ($W=a*L^b$) in the equation for isometric growht ($K=W*L^3$) we get:

$$1 = a/K * L^{(b-3)} \quad \Leftrightarrow$$

$$\ln K = \ln a + (b-3) * \ln L \qquad \text{(Eqn. 1.6.1)},$$

where K is the condition factor, W is fish weight and L is fish length, while a and b is real numbers. Eqn. 1.6.1 is a linear equation. A plot of ln K versus ln L (Fig. 1.6.1) for N = 3009 individuals of Greenland cod caught in the survey area in the period 1936 to 1990 is shown. It appars from the figure that the individuals show a even distribution around ln K=[-0.5;0.5] on a straight line where ln K not seems to differ for different length groups. Further, a linear regression is performed (GLM, SAS 1988) to test the linearity of the dependent variable ln K versus the independent variable ln L based on expectation of increasing variation in K with increasing length (Tab. 1.6).

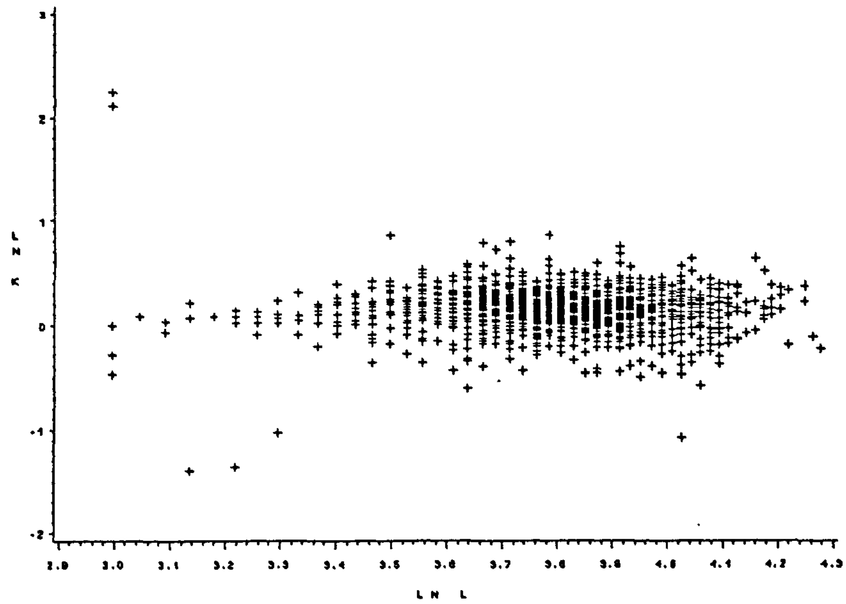

Fig. 1.6.1 Plot of ln K versus ln L (length in cm) for all Greenland cod caught in the survey area in the period 1936-1990 for which estimates of both length and weight exist. N = 3009 individuals.

The hypothesis that the slope (b-3) (Eqn. 1.6.1) not is significantly different form 0 for any groupings of data is tested with a Students T-test (Tab. 1.6).

Table 1.6 Results of the linear regression and on Students T-test for H0.

N	(b-3)	F	Pr > F	T for H0	Pr > T	2*Std.E.
3008	-0.0178	1.11	0.2929	-1.05	0.2929	0.0338

It appears that the slope is not significant different from 0 which suggests that the average condition is constant for all length groups. The intercept, ln a (Eqn. 1.6.1), is estimated in a two way ANOVA (GLM, SAS) and found significantly higher than zero with a mean value of ln a= -11.3537 (not shown). This gives a = exp(-11.3537) = $1.17 * 10^{-5}$. The analyses indicate that Greenland cod in the survey area has a isometric growth pattern over a 54 year period and the length-weight relationship can be expressed as follows in Eqn. 1.6.3:

$$W = 1.17*10^{-5} * L^3 \quad \text{(Eqn. 1.6.3)},$$

where W is in kg and L is in cm. This length-weight relationship is shown in Fig. 1.6.2.

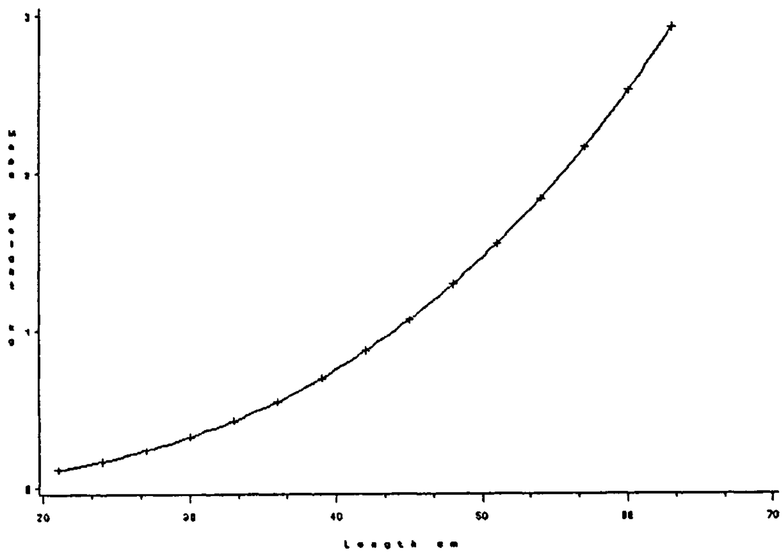

Fig. 1.6.2 Length-weight curve showing isometric growth for Greenland cod.

1.7 Mean length per age group in the population of Greenland cod in the Nuuk area, West Greenland.

Further, when the growth pattern for Greenland cod is examined correction for size selective effects of fishing gear is necessary to estimate the mean length per age group in the population of Greenland cod in the survey area. Data do not allow for estimation of growth by sex and the resulting pattern is therefore for the total population with assumption of equal sex ratios in the catch throughout the material. Mean length for age group 3-8 in the population is estimated on basis of longline catches in coastal and inshore areas from november 1989 (Tab. 1.7.1). Further, mean length in age group 2-4 is estimated from catch in experimentall gillnets as an average for the years 1987-1989 (Tab. 1.7.2). For each age group j the mean length in the population can be described as:

$$\bar{L}(j) = \Sigma\ (N(L)/S(L)) * F(L)j * L\ /\ \Sigma\ (N(L)/S(L)) * F(L)j\ ,$$

(Eqn. 1.7.1),

where F(L)j is the relative division of different age groups, j, in each length group, L. S(L) is the gear selection factor for each length group for a given type of gear.

Tab. 1.7.1 Estimates of mean length per age group, L(j), in the population as an average between sexes based on longline catch and corrected for gear selection effects.

L(j)=3	L(j)=4	L(j)=5	L(j)=6	L(j)=7	L(j)=8
33.91	36.63	40.33	42.73	45.26	50.37

The estimates of mean length for the 3-group and to a lesser degree the 4-group might be too high. The reason for this is existence of fish less than 30 cm in these age groups, which appears from the age-length key in Fig. 3.1 (App. 3). This shall be seen in light of the calculated selection coefficients for longline is estimated to zero (App. 1) for length groups less than 30 cm and therefore these length groups are excluded related to the mean length estimates.

Tab. 1.7.2 Estimates of mean length per age group, L(j), in the population as an average between sexes based on catches in experimental gillnet as an average of both sexes and the years 1987-1990. The mean lengths are corrected for gear selection effects.

L(j)=2	L(j)=3	L(j)=4
21.64	25.96	37.57

No age determined Greenland cod in the length interval 15-20 cm caught in experimental gillnet exists in the age data material which is presented in the age-length key Fig. 3.2 (App. 3). These length groups are possibly represented in age group 2 and to a lesser extend age group 3 based on scrutinization of the age-length key (Fig. 3.2). Therefore the estimates of mean length for these age groups might be too low.

Comparison of the estimated mean lengths per age group for the population of Greenland cod in the survey area with the corresponding mean lengths for Atlantic cod in West Greenland waters shows that the growth rate of Greenland cod is slower than for Atlantic cod (Tab. 1.7.3; Hansen, 1987). Further, Greenland cod does not reach the same maximum age and length as Atlantic cod in West Greenland waters which reach an age of more than 20 years and lengths above 120 cm (Hansen, 1949).

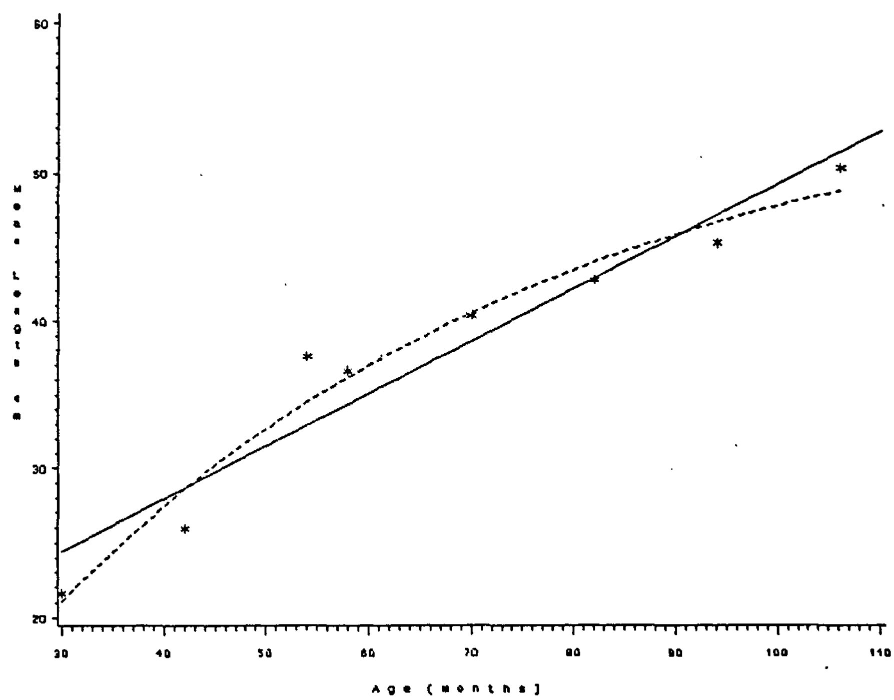

Fig. 1.7 Plot of estimated mean lengths (in cm) per age group (in months) for Greenland cod inshore in the Nuuk area, West Greenland. Further, two fitted growth curves for these estimates are shown. Symbols: Star = estimated mean lengths per age group; unbroken line = fit to linear growth; dotted line = non-linear fit to the von Bertalanffy growth equation. All values are corrected for gear selection effects.

Fig. 1.7 shows a plot of mean length at age from Tabs. 1.7.1 and 1.7.2 eccept for the estimate of mean length for age group 3 in

Tab. 1.7.1, which is omitted because of uncompletely estimation. A linear regression (REG procedure, SAS 1988) is performed for the plot (Fig. 1.7) and the regression line is shown in the figure. Further, the regression line of a non-linear regression (NLIN procedure, SAS 1988) to the von Bertalanffy growth equation is shown in the figure as a dotted line.

The von Bertalanffy growth equation seems to describe data best. This should be related to the uneven distribution of the mean lengths at age around the linear regression line which indicate that a linear growth equation doesn't give a optiamal description of data. The statistics for the non-linear regression is shown in Tab. 1.7.4 and it appears herefrom that the model describes data significantly and accounts for the variation in data up to a very high degree. A test for normal distribution of the residuals shows no trends (W:normal 0.9829, P<W 0.9722).

Table 1.7.4 Regression statistics of a non-linear regression for the estimates of mean length per age group in the population to the von Bertalanffy growth equation.

VARIABLE	SS	DF	MS
MODEL	11910.75	3	3970.25
RESIDUALS	22.69	5	4.54
TOTAL	11933.44	8	-

$L_T = L_{inf} *[1 - \exp(-K*(T-T_0))]$ (Eqn. 1.7.2).

L is the total length, T is the age, L_{inf} is the upper asymptotic growth, K is a proportionality constant for the growth rate and T_0 is the teoretical age of L = 0, i.e. where $L(T_0) = 0$. The estimates of the model gives an upper asymptotic length $L_{inf} = 57.07$ cm, a teoretical age of the fish at length = 0 cm of $T_0 = 6.25$ months and a growth rate of K = 0.0194 resulting in the following von Bertalanffy growth for Greenland cod (age in months):

$L_T = 57.07*[1 - \exp(-0.0194*(T-6.25))]$ (Eqn. 1.7.3).

This growth seems on that basis to fit the mean length estimates well which also immediately appears from Fig. 1.7. A problem is, however, that the values for L_{inf}, T_0 and K show intercorrelation in a correlation matrix analysis (SAS, 1988) connected to the non-linear regression in SAS (not shown). The parameters in the von Bertalanffy growth model is therefore not independently estimated, but only the products of the parameters are well estimated in the model. The reason for this is primarily lack of input estimates of mean length for the age groups 0, 1 and 9+ in the non-linear regression which lower the confidence of T_0 and L_{inf}.

Discussion and Conclusions

The estimation of mean length per age group for Greenland cod in the Nuuk area of West Greenland is performed with the assumption of only one stock component in the area. There has not been performed investigations on delimitation of stock components of Greenland cod in Greenland waters or investigations on migration patterns for the species. Therefore this basic assumption can´t be confirmed as fulfilled and the present growth analyses does consequently not take possible effects of size specific migrations related to physical and/or biological factors into account. However, no consistent differences in mean length per age group are found between two distantly located fjord systems with highly different environmental conditions inside the survey area. This can be interpretated as presence of only one stock in the survey area, although occurence of two or more stock components and/or migration between a stock unit in the area and surrounding stock components with similar growth pattern is possible.

Difference in growth of Greenland cod is neither found for fish caught in inshore and archipelagic areas. However, significant growth differences between offshore and inshore/archipelagic areas in West Greenland are found for the autumn periods 1987-88 where Greenland cod in average are found to be 3-4 cm longer in mean length on the former locality compared to the latter. This does not necessarily indicate existence of two isolated groups of Greenland cod. Size specific and season specific migrations cycles of Greenland cod for food from inshore / archipelagic localities to the offshore banks could exist related to occurence of abundant food sources of sandeel (Ammodytes dubius) in autumn on the West Greenland banks. This are to be seen in light of decrease in abundance of capelin (Mallotus villosus) in inshore/archipelagic areas after the spawning period for this species in the spring and summer period on these localities. (Andersen, 1985; Sørensen, 1985). Both of the above mentioned species are food species for larger size groups of Greenland cod at West Greenland for which fish is a major food source (Andersen, 1991). Greenland cod performing yearly migration to offshore areas might in that respect gain advance of better food and growth conditions compared to stationary individuals in inshore/archipelagic areas. Further, higher water temperatures (4.5°C) in the autumn period on the south-western offshore banks at West Greenland caused by the higher contribution from inflow of warm Atlantic water compared to the contribution of water inflow from southwards currents of Polar water to these areas in the autumn season (Buch, 1990) might result in better growth conditions for offshore Greenland cod.

Mean length at age for female Greenland cod is significantly and consequently higher than for males which is in accordance with results from growth analysis performed on Greenland cod i James Bay, Canada (Nielsen and Whoriskey, 1992). However, no sexual growth differences are found for Greenland cod in Hudson Bay and connected Canadian waters by Mikhail and Welch (1989) and Morin (1990). The two latter growth studies does, however, use pooled growth data from catches with different fishing gears and pooled data from different years, season of years and different areas.

Further, Greenland cod show significant differential growth related to parasitic infection with the copepod gillworm Lernaeocera branchialis. The influence of the parasitic infection is a growth rate suppressing effect for both sexes and all age groups of Greenland cod. Infected individuals are in average for all age groups of both sexes found to be 0.81 cm smaller than not infected individuals. The infection with gill worms can on that basis not be consideret as an important restraining factor on growth for Greenland cod which is to be seen in light of the relatively low prevalence of 30 % for infection with gill worms of Greenland cod. Greenland cod in length groups less than 25 cm was not infected with gill worms. The only known host of gill worms in Greenland is the lumpsucker (Cyklopterus lumpenus) and Greenland cod predates not on fish prey before they reach a certain length.

No considerable differences in mean length per age group of Greenland cod are found between cod caught in separate 100 m strata of sea bottom depths from 20-300 m, although there seems to be a tendency towards greater mean length per age group in the depths of 0-100 m compared to the depth intervals from 101-200 m and 201-300 m between which no growth differences are found. This probably indicate size specific distribution rather than depth dependent growth differences.

The found average decrease of 2-3 cm per year in mean length through the period October-November 1987-89 suggest occurence of less favorable growth conditions in average year for year in that period for Greenland cod in the survey area. Also mean length at age for Atlantic cod has decreased during that period (Riget and Hovgård, 1990). On that basis it can be concluded that differences in growth between different years / year classes of Greenland cod in the same area occurs. However, these results related to potential growth differences between different depths and years (yearclasses) does not take possible size specific migrations related to season, year and depth into consideration.

The Greenland cod seems from the present study to show an isometric growth pattern and following a von Bertalanffy growth curve in general. However, the present estimates of mean length per age group in the population might be influenced on growth differences between years and seasons. Further, unequal sex ratios and migratory effects may bias the estimates. It should also be emphasized that the correction for gear selection in these estimates is based on a very small observation number for both longline and gillnet and finally the gear selection coefficients for longline is based on great dispersion in time of fishing with risk of introducing effects of time dependent difference in catchability of the used gears. Whether the assumption of the shrimptrawl to be non-selective for size classes larger than 10 cm is fulfilled can neither be established for the performed fishing operations. Therefore the estimates of mean length per age group in the population of Greenland cod in "Godthaabsfjorden" can only be regarded as indications of the order of magnitude of the growth.

The tendency towards a non-linear growth pattern with an upper asymptotic length also appears from earlier studies of mean length per age group for Greenland cod in Hudson Bay, Canada (Morin and Dodson, 1986; Mikhail and Welch, 1989). Comparison of the growth estimates in these studies and the present study indicate higher mean length at age for Greenland cod in Greenland waters than in Canadian waters. Further, Hansen (1961) found decreasing growth rate for Greenland cod after the age of 3 years in West Greenland waters. These studies therefore confirm the found trend in growth pattern of Greenland cod in the present study. However, none of these earlier investigations take potential size selective effects of several used fishing gears into consideration which might bias the results. Greenland cod does not reach the same age and size as Atlantic cod and has a slower growth rate than the Atlantic cod.

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Appendix 1:

Selection coefficients are calculated (Tab. 1 and 2) based on earlier parallel fishing in the survey area with longline of same type as used in 1987-89 and a demersal "Fjordtoft-Sputnik" shrimptrawl with 1200 meshes of meshsize 20 mm produced by "Hirtshals Vod- og Trawlbinderi", Hirtshals, Denmark. The swept area (SA) is calculated as the product of the wing spread of approximately 8 m and the fishing speed of 2 knots. The trawl is assumed non-selective for Greenland cod longer than 10 cm.

Tabel 1.1 5 overlapping fishing operations with shrimptrawl and longline in the survey area. The number of hooks (Ho.) and trawling time (Tr.H) in minutes are given.

No	DATE	GEAR	POSITION	DEPTH	Ho./Tr.H.
Ns1	06-04-61	Shrimptr.	63°53N-51°28W	240 m	55
Nl1	11-04-61	Longline	64°15N-50°33W	270 m	1500
Ns2	23-10-62	Shrimptr.	63°53N-51°28W	260 m	60
Nl2	05-12-62	Longline	64°07N-50°00W	250 m	1500
Ns3	15-01-64	Shrimptr.	63°53N-51°28W	260 m	270
Nl3	08-01-64	Longline	64°13N-50°36W	250 m	1850
Ns4	02-02-73	Shrimptr.	63°53N-51°28W	255 m	50
Nl4	17-01-73	Longline	64°04N-52°21W	230 m	1100
Ns5	25-03-80	Shrimptr.	64°14N-51°02W	147 m	80
Nl5	25-03-80	Longline	64°14N-51°02W	140 m	400

Table 1.2 Frequensies of Greenland cod caught per 5 cm length group (L) in the 5 paired fishing operations.

L (cm)	Ns1	Nl1	Ns2	Nl2	Ns3	Nl3	Ns4	Nl4	Ns5	Nl5
6-10	5	0	0	0	0	0	0	0	0	0
11-15	11	0	0	0	0	0	0	0	0	0
16-20	1	0	6	0	5	0	23	0	0	0
21-25	0	0	3	0	5	0	6	0	0	0
26-30	0	0	2	0	13	0	2	0	1	2
31-35	0	2	8	0	16	0	1	0	5	7
36-40	4	7	2	6	15	2	8	0	4	6
41-45	4	18	10	12	8	8	4	0	0	13
46-50	2	23	6	24	8	16	7	2	3	17
51-55	1	17	3	37	2	13	1	7	2	10
56-60	0	17	0	13	1	6	1	8	0	0
61-65	0	0	0	1	1	1	0	1	0	0
66-70	0	0	0	0	0	0	0	1	0	0
TOTAL	28	84	40	93	74	46	53	19	15	15

The size selection for a fishing gear can be described as

$$N(L)catch = C(L) = q * E * S * N(L)population \quad \text{(Eqn. 1.1)},$$

where $N(L)$ is the length frequency in the population, $C(L)$ the length frequency in the catch, q is the catchability, E is the fishing effort and S is the gear selection coefficient for length group L (Sparre et al., 1989).

The relation between number of fish caught in shrimptrawl, Ns, and longline, Nl, per length group is derived from Eqn. 1.1 based on the assumption that the shrimptrawl is non-selective for individuals in the length interval 70 cm $\geq L \geq$ 10 cm, [S=1] giving:

$$C(L)l/C(L)s = ql/qs * El/Es * S(L)l/S(L)s * N(L)pop/N(L)pop \quad \Leftrightarrow$$

$$C(L)l/C(L)s = ql/qs * El/Es * S(L)l \text{ , when } S(L)s \text{ is set to } 1 \quad \Leftrightarrow$$

$$C(L)l/C(L)s * Es/El = ql/qs * S(L)l \quad \Leftrightarrow$$

$$CPUE(L)l/CPUE(L)s = ql/qs * S(L)l \quad \text{(Eqn. 1.2)},$$

where CPUE is Catch per Unit of Effort (per 1000 hooks for longline and per trawl hour for shrimptrawl).

When setting $A = ql/qs$ and

$Y = C(L)l/C(L)s * Es/El = CPUEl/CPUEs$ we have:

$$Y = A * S(L)l \quad \text{(Eqn. 1.3)}$$

for each paired fishing operation. A expres the relation between the catchability of the two gears dependent of trawl time and number of hooks and is expected constant for each pair of fishing operations.

For each paired fishing operation where the catch is different from 0 the relation between number of fish caugth in respectively trawl and longline is calculated for each 5 cm length group in the length interval 10-70 cm weightet by the respective fishing effort of each gear. The longline catch is 0 for $L < 30$ cm and therefore $S(L)l$ is set to 0 for these length groups. Further, the low observation number for catch in length groups higher than 60 cm is regarded too low for selection calculations. Non-linear regression (NLIN procedure, SAS 1988) of plots of Y against the length interval midpoints for each overlapping fishing operation shows five curves fitting a exponential function with the expression $Y = a * (\exp(b * X) - 1)$, not shown. The upper asymptote of these curves is estimated to be approximately $L > 55$ cm. Therefore $S(L)l = 1$ for $55 \leq L \leq 60$ and $S(L)l = 0$ for $L \leq 30$ cm. By insertion of the exponential function in Eqn. 1.3 we get:

$$Y = A * (\exp(\Omega*(L-30))-1) / (\exp(\Omega*(55-30))-1) \quad \text{(Eqn. 1.4)},$$

where Ω is a constant and $L \in [30;55]$ and

$$S(L)l = (\exp(\Omega*(L - 30)) - 1) / (\exp(\Omega*25) - 1) \quad \text{(Eqn. 1.5)}.$$

where the denominator makes $S(L)l = 1$ for $L = 55$ cm. By a further non-linear regression the five overlapping fishing operations are fitted to common A- and Ω- values. In Table 1.3 the estimates of the regression with standard deviation on the 95 % level are given together with model, residual and total sum of squares. The model describes to a high degree the variation in data (81.35 %) and a plot of the residuals against the length interval midpoints showed even distribution around the model value without trends (not shown).

Tabel 1.3 Regression statistics for the fitted regression curve.

SS-mod	SS-res	SS-tot	Ω	A	SSmod/SSres
725.94 DF=2	166.44 DF=24	892.38 DF=26	0.08 ± 0.03	9.66 ± 1.00	81.35 %

The regression curve is shown in Figure 1.1 below. The variation in the A- and Ω- values is probably due to the low observation number, season effects and that the fisheries were directed towards cod and shrimps giving an effect on catchability. The latter indicate, however, random fishery for Greenland cod. On that basis and no trends in residuals the selection model is accepted.

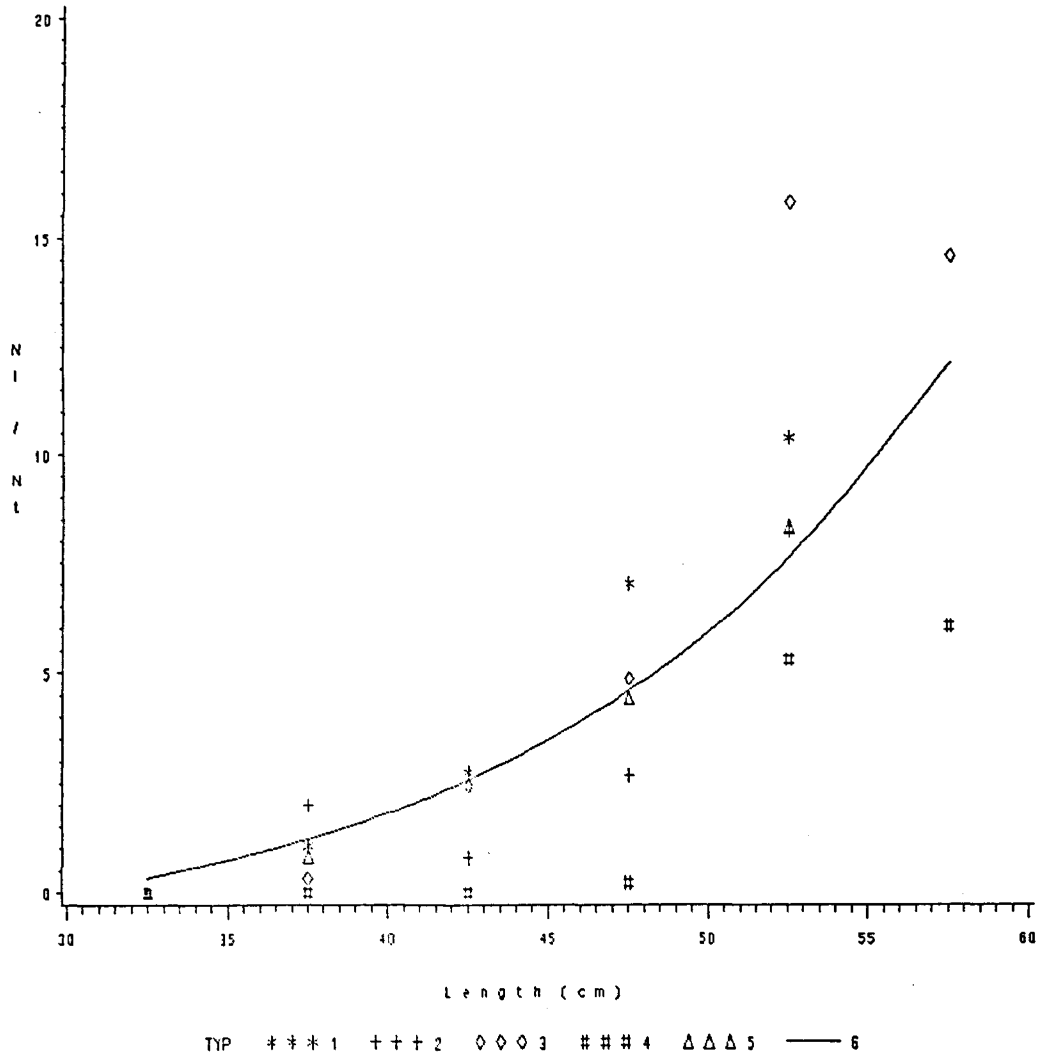

Fig. 1.3 Plot of N(L)1 / N(L)t against length interval midpoints in an overall fittet exponential curve for the five overlapping fishing operations. Further, the observed values of N(L)1 / N(L)t for each fishing operation are shown. Type 6 is the overall regression curve.

Appendix 2:

Gill net are highly selective (Hamley 1975) and the mesh sizes used in the experimental fisheries will influence the estimates of size at age. Based on Holt's (1963) theory dealing with simoultaneously fishing of multiple nets with different mesh sizes, which are further developed in Sparre et al. (1989), the selective effect on estimates of mean size at age are studied. It is assumed that the selection ogive is bell shaped around an optimum length proportional to the mesh size and that the selection curve have the same standard deviation independent of the mesh size. All meshsizes occupies equal areas in the gear and it is assumed that each section represents the same fishing power. A further assumption of isometric growth of Greenland cod is made which probably is fulfilled according to the present growth analyses. (Baranov, 1948; Holt, 1963; Hamley, 1975).

$$S(L) = \exp\left[-\tfrac{1}{2}\left(\left(L - K*m\right) / w\right)^2\right] \qquad \text{(Eqn. 2.1)}$$

where $S(L)$ $[0<S(L)g\geq 1]$ is the proportion of fish retained in the length interval with interval midpoint L, $[L-1;L+1]$. 2w is the selection range for the normal distribution of the bell shaped selection ogive and K is the selectivity coefficient. The combined size selection for the experimental gill net with contributions from multiple panels with separate mesh sizes can be estimated through calculation of an overall K - and w - value using the principle in Eqn. 2.1. The method is based on calculation of K and w for each successive pair of mesh sizes separately including the assumption of overlapping selection ogives for these mesh sizes e.g. overlapping selection intervals. This assumption is fulfilled which appears from the overlapping catch per length group for successive mesh sizes shown in Table 2.1. The used data are number of fish caught per length group, C(L), in the successive mesh sizes 1 and 2.

Tabel 2.1 Grouping of selection data in 2 cm length intervals for each mesh size m(i) in mm from knot to knot.

LGT.INTERVAL (cm)	INT. MIDPOINT (cm)	m(1) 16 mm	m(2) 18 mm	m(3) 21 mm	m(4) 28 mm	m(5) 33 mm
13 - 14.9	14	1	-	-	-	-
15 - 16.9	16	3	4	-	-	-
17 - 18.9	18	2	11	1	-	-
19 - 20.9	20	3	9	5	1	-
21 - 22.9	22	1	11	15	2	-
23 - 24.9	24	-	4	2	13	2
25 - 26.9	26	1	4	2	5	2
27 - 28.9	28	-	-	1	7	9
29 - 30.9	30	-	-	4	5	19
31 - 32.9	32	-	-	-	-	11
33 - 34.9	34	-	1	1	4	7
35 - 36.9	36	1	1	-	5	9
37 - 38.9	38	-	1	3	1	22
39 - 40.9	40	-	-	2	2	15
41 - 42.9	42	-	1	-	3	13
43 - 44.9	44	-	-	-	-	4
45 +	-	2	3	-	2	25

Following theory (Holt, 1963; Sparre et al., 1989) C(L)1 and C(L)2 can be described as normal distributions (symbolized by Φ) which are derived from the general equation for size selection of fishing gears given in Eqn. 1.1, App. 1:

$$C(L)1 = q1 * \Phi(L, K*m1, w^2) * N(L) * E1 \qquad \text{(Eqn. 2.2),}$$
$$C(L)2 = q2 * \Phi(L, K*m2, w^2) * N(L) * E2 \qquad \text{(Eqn. 2.3),}$$

where q is catchability and E is fishing effort. N(L) is number of fish per length group in the population. By performing linear regression on the equation below with intercept = a and slope = b for each pair of mesh sizes E and N(L), which are assumed to be equal for all panels, are omitted.

$$C(L)1 / C(L)2 = a + b * L \qquad \text{(Eqn. 2.4)}$$

For n mesh sizes it gives n-1 estimates of a and b: [a1,b1], [a2,b2], .., [a(n-1),b(n-1)] corresponding to [m1,m2], [m2,m3], .., [m(n-1),m(n)]. According to Holt (1963) and Sparre et al. (1989) K, a, b, and w^2 can be expressed as:

$$K = (-2 * a) / (b * (m1 + m2)) \qquad \text{(Eqn. 2.5),}$$
$$a = (K^2 / (2 * w^2)) * [m2^2 - m1^2] \qquad \text{(Eqn. 2.6),}$$
$$b = (- K / w^2) * [m2 - m1] \qquad \text{(Eqn. 2.7),}$$
$$w^2 = 2 * a * ((m1 + m2) / (m2 - m1)) \qquad \text{(Eqn. 2.8).}$$

The overall selectivity coefficient will then be:

$$K = - 2 * \sum_{i=1}^{n-1} [a(i)/b(i)] * [m(i)+m(i+1)] \Big/ \sum_{i=1}^{n-1} [m(i)+m(i+1)]^2 ,$$

$$i = \{1, 2, 3, 4, 5\}. \qquad \text{(Eqn. 2.9).}$$

The corresponding width of the overall selection ogive is:

$$w = (1/n-1) * \sum_{i=1}^{n-1} [(2*a(i)*(m(i+1)-m(i)))/(b(i)^2*(m(i)+m(i+1)))]$$

$$i = \{1, 2, 3, 4, 5\}. \qquad \text{(Eqn. 2.10).}$$

Table 2.2 Estimates of the selection parameters a, b, w^2, w and the size selective interval for each mesh size pair.

PAIRS OF MESH SIZES (mm)	16-18	18-24	24-28	28-33	MEAN VAL.
m(i) + m(i+1)	3.4 cm	4.2 cm	5.2 cm	6.1 cm	-
m(i) - m(i+1)	0.2 cm	0.6 cm	0.4 cm	0.5 cm	-
SELECTION INTERVAL (cm)	15-22	17-26	19-33	23-[illegible]	-
a	[illegible]	1.2385	3.1[illegible]	3.8[illegible]	-
b	-0.3262	-0.1561	-0.1355	-0.1364	-
K	8.31	12.93	9.60	8.54	9.70
w^2	157.25	59.31	82.14	86.66	96.42
w	12.5	7.70	9.08	9.31	9.82

The values in table 2.2 gives an overall K value of 9.48 using equation 2.9. It appears that K and w not are equal for each pair of mesh sizes. They are, however, in the same order of magnitude. Especially for the mesh sizes 16-18 mm and 18-24 mm there seems to be discrepancies. A problem is that K and w seems to be intercorrelated. On that basis a multi variate ANOVA test (GLM analysis) of the gillnet catch is performed using the catch equation (Eqn 2.11) to test trends in the data material related to the used selection model:

$$C(L) = q * N(L)pop * S(L) * \epsilon \qquad \text{(Eqn. 2.11)},$$

The effort is omitted assuming equal effort for each mesh size. Eqn. 2.1 is inserted for S(L) in the catch equation giving the following GLM model:

$$\ln C(L)m = \ln q + \ln C(L) - \tfrac{1}{2}*[(L^2 - 2*K*L*m + K^2*m^2)/(w^2)] + \epsilon$$

$$\text{where } K = -2 * (m*m) / (L*m) \qquad \text{(Eqn. 2.12)}.$$

The residuals ϵ of the model are assumed to show normal distribution around 0 and Θ^2 (Θ = the variance of the distribution of the residual): $\ln \epsilon = \Phi(0,\Theta^2)$. The test shows that the model describes the data in Table 2.1 significantly (P>0.0001) and explains 89 % of the variation in data. A SAS Univariate procedure performed on the residuals showed normal distribution around the model values on the 5 % level (W:normal 0.9791, [illegible] 0.7592) without trends (not shown). Based on the estimates of first order interaction effects m*m and L*m in the GLM analysis a selectivity coefficient of 9.84 are calculated from Eqn. 2.12. On that basis the selection model is accepted despite variations in K and w and the limited observation number. The overall K = 9.48 is used to calculate S(L)g from Eqn. 2.1:

$$S(L)g = \Sigma \exp [-\tfrac{1}{2} ((L - K * m(i)) / w)^2] \qquad \text{(Eqn. 2.13)}.$$

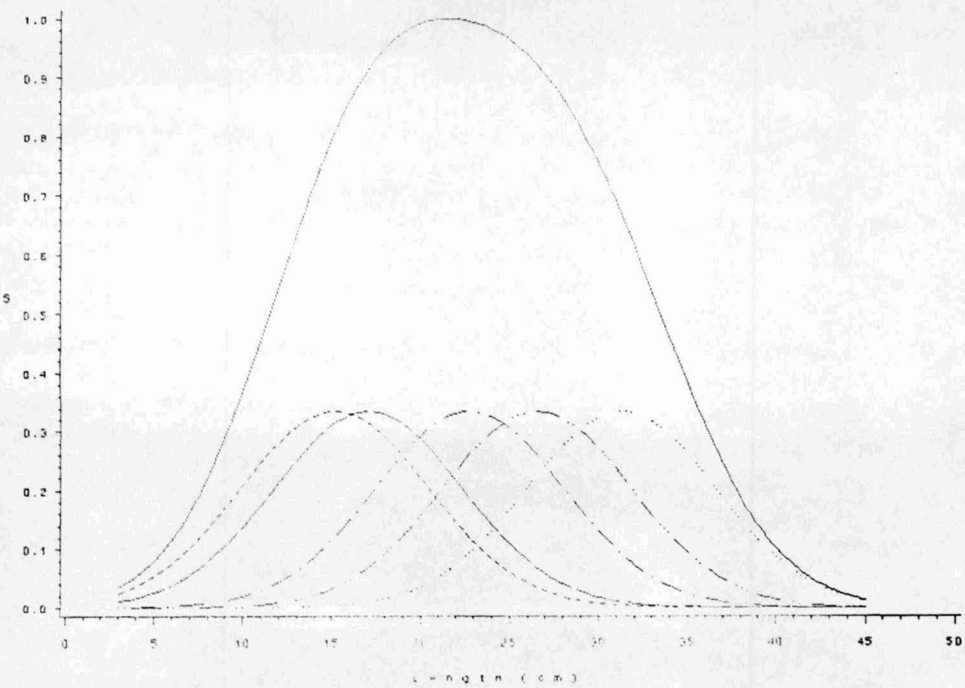

Fig. 2.1 The overall gear selection ogive for experimental gillnet as the sum of all selection ogives for all mesh sizes shown. The selection ogives is based on the above estimates of K and w used in Eqn. 2.13. Symbols: = overall selection ogive, = 16 mm, = 18 mm, = 24 mm, = 28 mm and = 33 mm.

Appendix 3:

Table 3.1 Age-length key for both sexes of Greenland cod based on longline catch of 1032 aged individuals in inshore and coastal areas of the survey area November 1989. Length are given in cm.

L	N(L)	S(L)	N(L)/S(L)	F(L)3 %	F(L)4 %	F(L)5 %	F(L)6 %	F(L)7 %	F(L)8 %
30	30	0.0000	0.0	60.00	40.00				
33	89	0.0425	2094.1	23.08	50.00	26.92			
36	231	0.0964	2396.3	2.44	52.44	35.37	8.54	1.22	
39	465	0.1650	2818.2	2.22	40.56	50.00	6.67	0.56	
42	476	0.2523	1886.6		12.80	75.20	9.60	2.00	0.40
45	431	0.3631	1187.0		4.62	73.11	19.75	2.10	0.42
48	271	0.5041	537.6		1.92	59.62	29.49	7.69	1.28
51	120	0.6833	175.6			33.85	38.46	26.15	1.54
54	44	0.9111	48.3			25.00	35.00	20.00	15.00
57	16	1.0000	16.0				40.00	20.00	40.00
60	11	1.0000	11.0						33.33

Table 3.2 Age-length key for both sexes of Greenland cod based on longline catch of 91 aged individuals in inshore areas of the survey area July 1987-89. Length are given in cm.

L	N(L)	S(L)	N(L)/S(L)	F(L)2 %	F(L)3 %	F(L)4 %	F(L)5 %	F(L)6 %
21	32	0.9993	32.0	40.00	60.00			
24	24	0.9807	24.5	14.29	85.71			
27	27	0.9039	29.9		100.0			
30	31	0.7514	41.3		50.00	33.33	16.67	
33	18	0.5341	33.7		9.09	63.64	27.27	
36	27	0.3095	87.2			54.55	36.36	9.09
39	32	0.1408	227.3			50.00	43.75	6.25
42	19	0.0489	388.6			6.67	73.33	20.00
45	12	-	-				71.43	28.57