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Population Parameters of the Iceland Scallop (*Chlamys islandica* (Müller)) from West Greenland

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Abstract

New information is presented on the distribution, size composition, sex ratio, maturity and growth of the Icelandic scallop (*Chlamys islandica*) along West Greenland. In West Greenland, populations of *C. islandica* are mainly distributed in the outer regions of fjords at depths between 20–60 m. They are distributed in areas characterized by strong tidal currents and populations are generally composed of large scallops in the range of 60–110 mm shell height with the majority being 75–100 mm. There is minor morphometric variation between areas. The sex ratio is generally 1:1 and they become sexually mature from 30 to 55 mm shell height at ages 4–9 years. There are small differences in shell height-at-age between males and females, but between area means vary from 58 to 68 mm at age 10 years. Seasonal and areal variations in both the muscle and gonad weights were also observed.

Key words: Distribution, Greenland, growth, Iceland scallops, *Chlamys islandica*, maturity, sex ratio, size composition

Introduction

The Iceland scallop (*Chlamys islandica* (Müller)), the northernmost species of the family Pectinidae of commercial interest, is a predominantly subarctic (low-arctic and high-boreal) species distributed in the subarctic transition zone (Ekman, 1953). Fisheries for *C. islandica* occur in Iceland, Norway, West Greenland, Canada and to a lesser extent the United States of America (Parsons *et al*., 1991; Naidu *et al*., MS 1982; Naidu, 1988). *Chlamys islandica* has been described as circumpolar in its distribution (Parsons *et al*., 1991), although this has recently been questioned by Waller (1991). At East Greenland the species is apparently prevented from becoming established by the cold southward flowing Arctic current except in the inner parts of Kejser Franz Josephs Fjord (Kong Oscars Fjord) and in the southernmost part of the Kong Frederik VI coast (Fig. 1) (Ockelmann, 1958). Their isolated occurrence in the inner parts of Kejser Franz Josephs Fjord suggests this is a relict population from postglacial times when milder conditions prevailed at Northeast Greenland (Ockelmann, 1958).

In West Greenland, commercial fishing began in 1983. The fishery has remained small with catches ranging from 410 tons (round weight) in 1984 to 1 966 tons in 1991 (Table 1). The main fishing area is around Nuuk where the fishery has yielded an average annual harvest of about 800 tons. Except for the Nuuk area, nearly all scallop beds at West Greenland are ice covered during winter and spring which confines exploitation to summer and autumn. From its inception, the fishery has been regulated by licensing (limited entry), a minimum landing size of 65 mm shell height and annual catch quotas.

Biological studies were initiated by the Greenland Home Rule Authorities in spring 1984 to evaluate resource levels and fishery developments (Pedersen, MS 1988a and MS 1988b). In the years 1984–88 inshore surveys (within the 3-mile boundary) located several populations (Fig. 1). Two offshore surveys (outside the 3-mile line) were carried out in summer 1986 covering banks off West Greenland from Nuuk to the Disko Island, but no beds of commercial interest were found.

The occurrence of *C. islandica* in West Greenland waters has been known for many years (Posselt, 1899; Jensen, 1912), but until recently little information on the biological characteristics of the species from this area has been available. This paper presents new information on the distribution, size composition, sex ratio, maturity and growth parameters of populations in West Greenland waters.

Materials and Methods

The areas surveyed during 1984–88 were selected from sea charts based on information about the most probable localities for scallops at West Greenland (H. Eiriksson, Marine Research Institute, Reykjavík, pers. comm.). The surveys were performed using different fishing vessels and two different scallop dredges: (1) an Icelandic made –

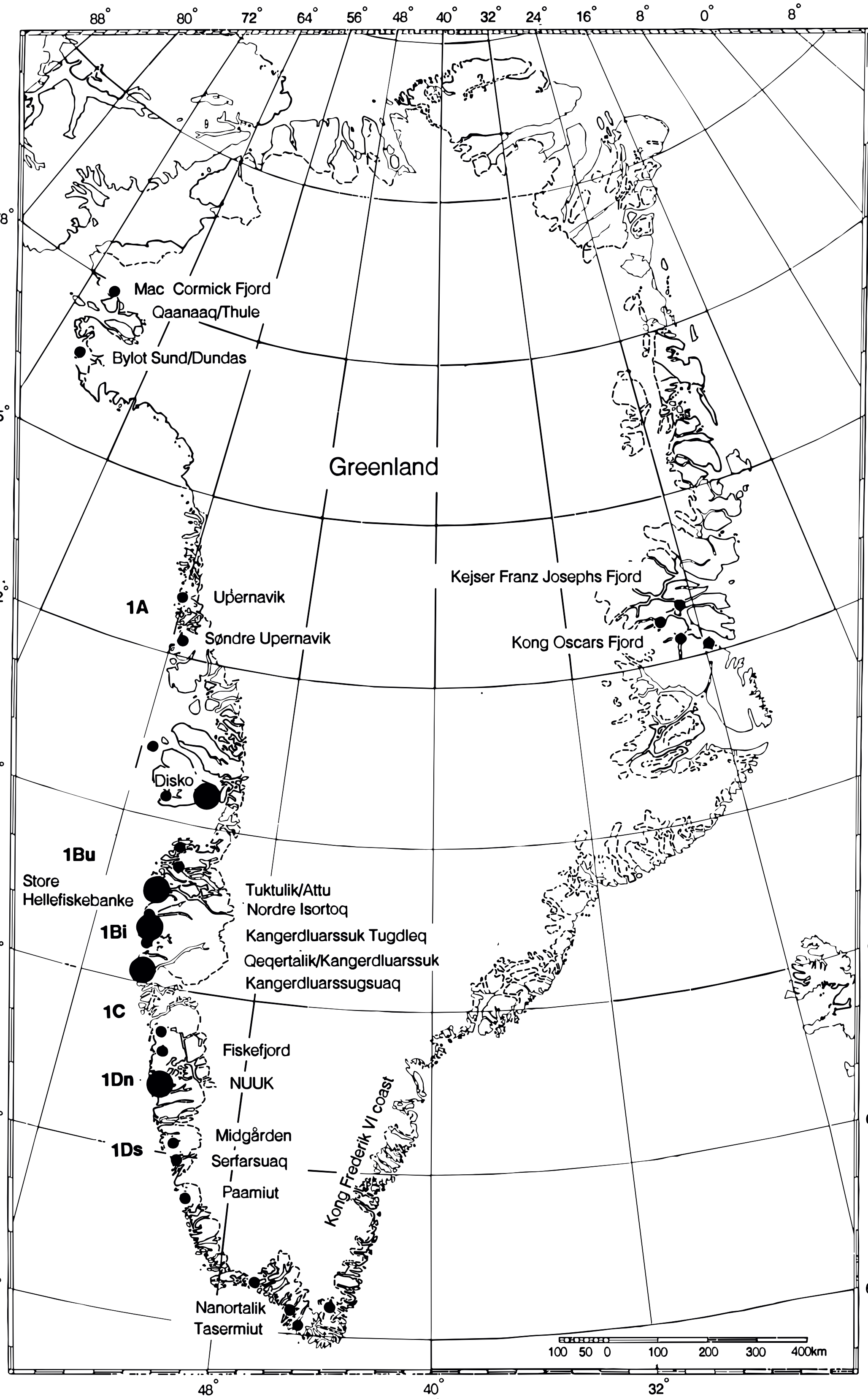

Fig. 1. Locations where Iceland scallop, *C. islandica*, populations were found at West Greenland during surveys, 1984–88. Small dots = populations of no or small importance for the commercial fishery. Large dots = populations of importance for the commercial fishery. Names obtained from sea charts.

TABLE 1. Iceland scallop landings from West Greenland, 1984–92.

Year	Landings (tons, round)
1984	410
1985	1 693
1986	864
1987	1 086
1988	720
1989	641
1990	737
1991	1 966
1992	1 913

"Manx dredge"; and (2) a Greenlandic made – "KIS Greenlandic dredge". The steelframe widths of the "Manx dredges" were between 2.0–3.6 m and equipped with a steel ring belly (ring diameter: 55–65 mm) and a polypropylene net top bag (95 or 120-mm stretch mesh). The "KIS Greenlandic dredges" were smaller having steelframe widths between 1.0–1.9 m and were equipped with a 120-mm stretch mesh polypropylene net bag. The dredge size used varied with the size and horsepower of the survey vessel.

In May 1986, an attempt was made to evaluate the overall efficiency and shell size selectivity between a "Manx dredge" (steelframe width of 2.4 m) and two "KIS Greenlandic dredges" (steelframe widths 1.2 m and 1.9 m) (Pedersen and Boje, MS 1987). Although the "Manx dredge" was found to be the most efficient, the estimated dredge efficiencies were highly variable and considered unreliable. Evaluation of dredge efficiency is problematic as dredge performance is influenced by many variables including scope, slope, current and type of bottom. The size compositions of scallops caught by the three dredges at four different locations showed great similarities among the dredges.

During the surveys, catches of live scallops from most hauls were measured for shell height (SH) with a sliding rule to the nearest mm. Samples from different areas were frozen for other measurements in the laboratory (Table 2). In the laboratory SH, length and width were measured with a sliding rule (Fig. 2). Shell weights (two values) and wet viscera weight were determined to the nearest 0.1 g. Adductor muscles and gonads were removed and weighed separately.

Age was determined by counting growth zones on the ligament (resilium) at the umbo using a binocular microscope and following the procedures described by Johannssen (1973) and Wiborg *et al.* (1974). Several scallops were aged to more than 30 years, however, the ligament from old scallops

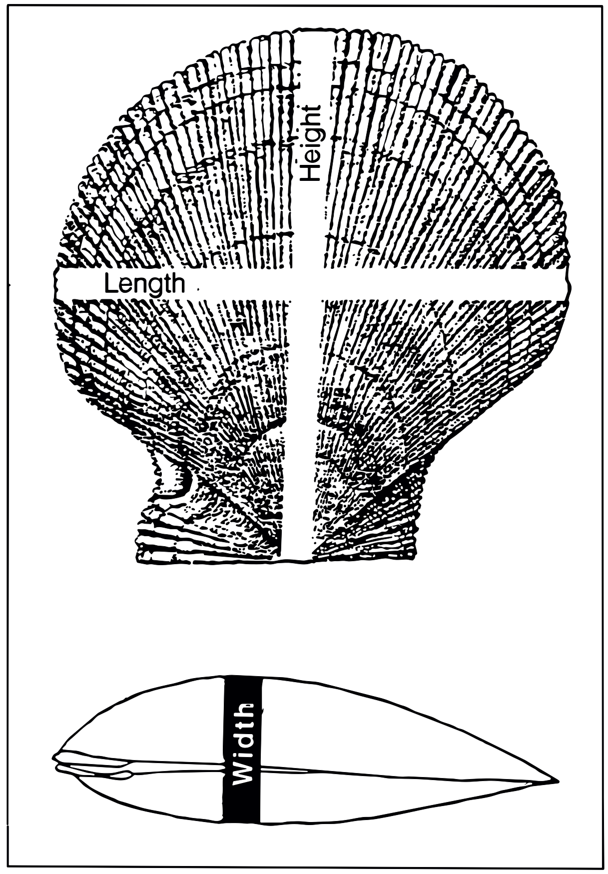

Fig. 2. Measurements of shell height, length and width obtained during this study of *C. islandica* at West Greenland.

was often porous and difficult to read, and therefore scallops with more than 21 annual zones were given the age 21+. It was often difficult or impossible to discern growth zones for the first 1 or 2 years on old individuals, and this was a source of error in age determination. On smaller scallops (<50 mm) the first annulus was often most visible on the shell surface and the age of these individuals was therefore checked by reading these annual marks.

Sex was determined visually by the colour of the gonads; orange or reddish gonads as females, and pale-whitish gonads as males. Degenerated (brownish) gonads were categorized to immature. According to Wiborg (1963) and Vahl (1981), *C. islandica* is dioecious and the sex is easily distinguished throughout the year. Sex ratios by SH, age and area were tested using the one sample chi-square (χ^2) test (H_o: the population has a 1:1 female to male ratio).

SH was analyzed by a three-way analysis of variance (ANOVA) where effects (age, area and sex)

TABLE 2. Origin of West Greenland Iceland scallop samples measured and aged in the laboratory. NAFO Divisions 1A-D were assigned as 1Bi = 1B (inshore), 1Bu = 1B (offshore), 1Dn = 1D (north) and 1Ds = 1D (south).

NAFO Division	Area	Month	Year	No. of scallops	Depth (m)
1A	Upernavik (UPR)	Sep	1987	673	30-100
1Bi	Tuktulik/Attu (ATU)	Jun	1986	92	30-50
	Nordre Isortoq (ISO)	Jun	1986	58	30-130
	Nordre Isortoq (ISO)	May	1988	100	40-60
	Kangerdluarssuk Tugdleq (KAT)	May	1988	99	30-60
	Qeqertalik/Kangerdluarssuk (HOL)	Mar	1985	81	30-60
	Qeqertalik/Kangerdluarssuk (HOL)	May	1988	349	30-60
1Bu	Store Hellefiskebanke (NHM)	Jul	1986	186	40-130
1C	Kangerdluarssugsuaq (SUK)	Jul	1985	49	20-60
	Kangerdluarssugsuaq (SUK)	Oct	1986	128	20-60
	Kangerdluarssugsuaq (SUK)	Oct	1987	278	20-60
	Fiskefjord (FFJ)	Sep	1986	70	30-60
1Dn	Nuuk (NUK)	Jun	1984	89	30-60
	Nuuk (NUK)	May	1986	98	30-60
	Nuuk (NUK)	Jun	1986	16	30-60
	Nuuk (NUK)	Oct	1986	36	30-60
	Nuuk (NUK)	Nov	1986	579	30-60
	Nuuk (NUK)	Mar	1987	1 149	30-60
1Ds	Midgården (MID)	Jun	1988	78	30-60
	Serfarsuaq (SAF)	Jun	1988	152	30-60

were regarded as class variables in the model (Anon., 1988, GLM Procedure):

$$SH_{ijkl} = \text{Overall mean} + Age_i + Area_j + Sex_k + Err_{l(ijk)}$$

where i = (2 to 21+), j = (NAFO Divisions 1A–D assigned as 1A, 1Bi, 1Bu, 1C, 1Dn, 1Ds), k = (Males, Females) and $Err_{l(ijk)}$ = error. The model was investigated for main effects and interactions, and reduced to a two-way ANOVA by excluding the sex effect. Growth comparisons among areas were confounded by the various times of year when the scallops were caught. However, because of large variations in the SH-at-age data and the generally old scallops, this error was found to be of minor importance and SH was not standardized to a given time period.

The von Bertalanffy growth function (VBGF) (Ricker, 1975) and the Gompertz growth function (GGF) (Ricker, 1975; Fitzhugh, 1975) were fitted to the mean SH-at-age data by non-linear least squares regression (Anon., 1988, NLIN Procedure, DUD method). The VBGF was formulated as:

$$SH_t = SH_\infty [1-\exp(-K(t-t_o))]$$

where SH_t is the SH (mm) at age t (years), SH_∞ is the asymptotic SH, K is a growth constant, and t_o is the intercept of the growth curve on the age axis. The GGF was formulated as:

$$SH_t = SH_\infty \exp[-a \exp(-Kt)]$$

where SH_∞ is the asymptotic SH, a and K are constants.

Adductor muscle, gonad, shell and whole wet weight of scallops cleaned of epiflora and epifauna were related to SH by the equation:

$$W = \alpha * SH^\beta$$

where W is wet weight and α, β are constants obtained by least squares regression of weight on SH after logarithmic (base 10) transformation of the two variables. Variations in adductor muscle and gonad weights by sex, sampling locality and month were analyzed by a standardized volume index:

$$W_{index} = (W / SH^3) * 10^5$$

A t-test was used for testing the hypothesis that the means of the W_{index} by sex, sampling locality and month were equal (Anon., 1988, TTEST and GLM Procedures).

Results

Distribution and size composition

The southernmost aggregation of live scallops in the area surveyed at West Greenland was at Nanortalik in the Tasermiut fjord (60°16'N and 44°47'W) and the northernmost occurrence was at Qaanaaq (Thule) in Mac Cormick fjord (77°38'N and 69°55'W) (Fig. 1). However, it is likely that scallop aggregations occur farther south and north since only a few dredge hauls were made beyond these locations. Live scallops were caught at depths from 15 to 130 m. The largest scallop concentrations generally occurred at depths between 20 and 60 m in the outer regions of fjords between islands and in narrow sounds on substrates consisting of shells, shell gravel, gravel, stones, rocks, sand or less frequently mud. Bottom temperatures in the areas range from about -1.5° to 4°C (Smidt, 1979; Buch, 1984). The areas were associated with strong tidal currents. In the inner regions of fjords scallops were only found in narrow sounds with strong tidal currents, e.g. Godthåbsfjord, Midgården and Fiskefjord. Several of the West Greenland fjords can be characterized as mud fjords and these contained no scallops, e.g. Søndre Strømfjord. Larger scallops (>55 mm) were generally overgrown with barnacles, bryozoans, hydroids, tubiferous annelids and sponges, as well as different species of algae. The epigrowth, of barnacles especially, sometimes exceeded the weight of the scallop. The scallops were often attached by byssus to other individuals or to empty shells, stones or other objects, but generally the byssal attachment of larger scallops was forcibly severed in the dredge-caught animals. The size compositions of scallops caught in the surveyed areas were strongly skewed to larger scallops in the range of 60–110 mm SH with the majority between 75 and 100 mm (Fig. 3).

Two offshore surveys in 1986 found no scallop aggregations of commercial interest. On the slopes around Store Hellefiskebanke, in depths between 40 and 130 m, 237 small scallops between 20 and 80 mm SH (peaks at about 40 and 70 mm) were caught together with large quantities of empty scallop shells (Fig. 3). Small quantities were also caught on the offshore slopes west of the Disko Island.

During a survey of the scallops beds at Kangerdluarssugsuaq in June 1985, the size composition of scallops was strongly skewed to large individuals between 80 and 110 mm SH. In a second survey of the same area in October 1987 the size composition had a conspicuous peak at about 12 mm SH which was not seen in June 1985 (Fig. 3). These observations indicated settlement of a new year-class at Kangerdluarssugsuaq between 1985 and 1987. In 1985 and 1986, the scallop population at Kangerdluarssugsuaq was heavily depleted by the fishery, and the high frequency of small scallops caught in the 1987 survey might have been an effect of reduced adult densities as well as a strong year-class.

Morphometric variation

Morphometric variation was investigated by plotting the mean SH/length and the mean SH/width ratios calculated for 5-mm size groups against SH (Fig. 4). As the scallops grew in SH, they gradually became more circular and the SH/length ratio decreased from about 1.20 to about 1.08. With increasing SH from about 20 mm the SH/width ratio decreased from about 4.0 to about 2.8 at 70–110 mm SH. There seemed to be small differences between areas in both SH/length and SH/width ratios with increasing SH.

Sex ratio and maturity

Deviations from an expected 1:1 sex ratio were found for scallops from areas 1Bu (χ^2 = 7.16, P <0.01) where females dominated, and 1Dn (χ^2 = 8.17, P <0.01) where males dominated (Table 3). For the scallops from areas 1A, 1Bi, 1C, 1Ds and for all samples combined (ALL) there were no significant (χ^2 = 0.80–1.44, P >0.05) deviations from an expected 1:1 sex ratio (Table 3). Sex ratios and sexual maturity for samples from the Nuuk area combined (1Dn) showed that both male and female scallops become sexually mature from 30–55 mm SH (Fig. 5). In the Nuuk samples there were more males in the size range 30–65 mm SH (χ^2 = 15.38, P <0.01) whereas for the larger size groups there were no significant deviations from the expected 1:1 sex ratio (Fig. 5, Table 3). Sexual maturation occurred for both sexes at ages 4 to 9 years.

Growth in shell height

Large variations in SH-at-age were apparent within and between sampling areas (Fig. 6). A three-way ANOVA of SH for the mature individuals showed highly significant (P <0.0001) effects of age, area and sex (Table 4). For each area as well as for all areas combined the difference in SH-at-age between sexes was small. Overall, females averaged 1.3 mm larger than the males (Table 4), however, there was no consistent difference between the sexes over all ages (Fig. 7). With sexes combined, a two-way ANOVA showed no significant differences in mean SH-at-age between areas 1A and 1Bu (P = 0.67), 1Dn and 1Ds (P = 0.49), 1Ds and 1C (P = 0.15), whereas all other comparisons showed significant (P <0.01) differences (Table 4). The mean SH-at-age was generally smallest in area 1A, 1Bu and 1Bi, and largest in 1C, 1Dn and 1Ds (Fig. 6). With sexually immature scallops included, the two-way ANOVA explained 85% of the total variation. The means of SH-at-age were calculated for

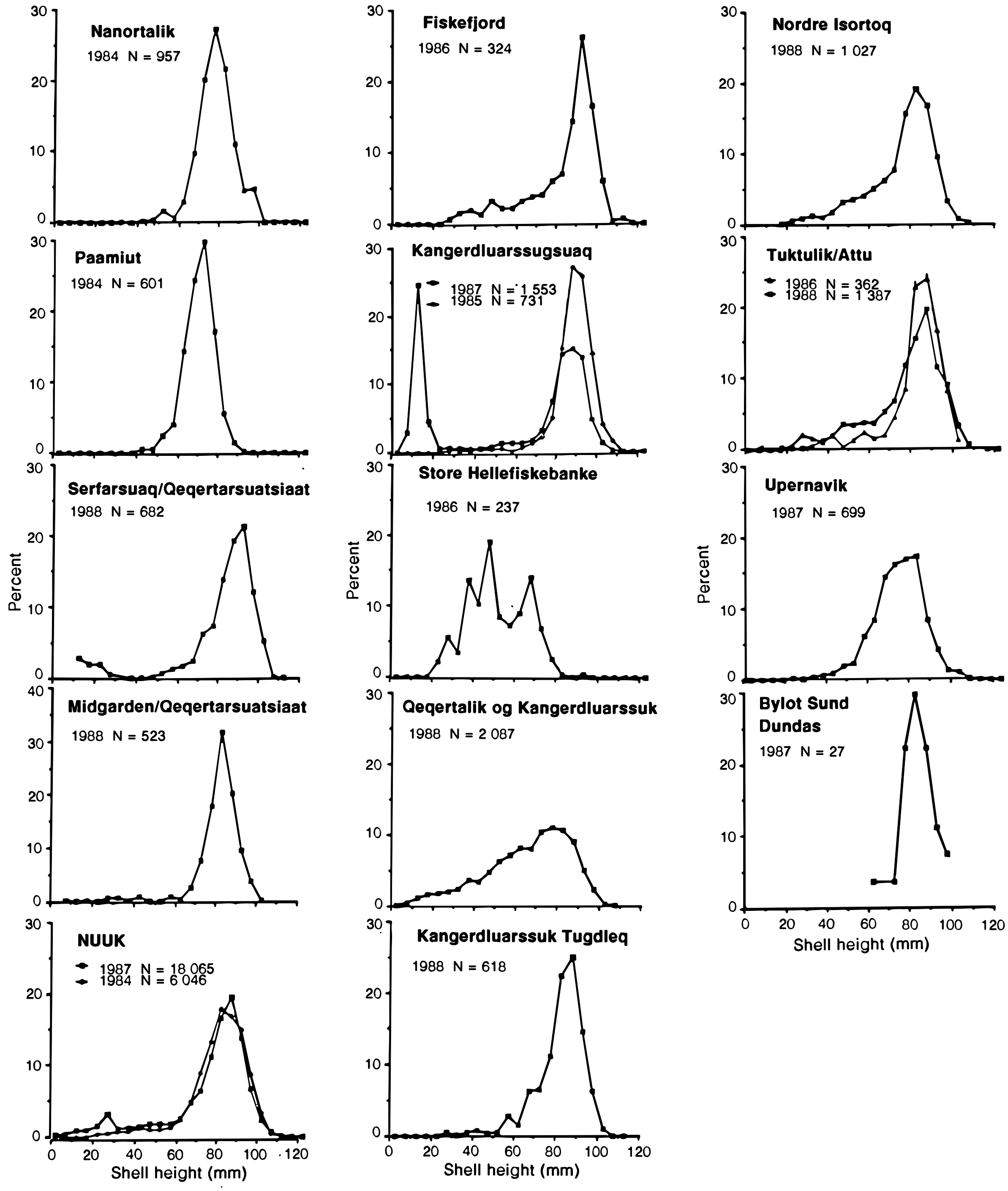

Fig. 3. Shell height frequencies of *C. islandica* caught in different areas during surveys at West Greenland, 1984-88.

all areas combined and the parameters of the von Bertalanffy growth function and the Gompertz growth function estimated by non-linear regression (Fig. 8). The Gompertz function provided a good fit to the data up to age 7, but from age 8 the von Bertalanffy function fit much better (Fig. 8).

Shell height-weight relationships

Plots of whole and shell weight versus SH relationships showed large individual and latitudinal variations (Fig. 9). The relationship between SH and whole, shell, muscle and gonad weights were all highly significant (P <0.0001). Except for gonads sampled in area 1A the values of the slope(β) were significantly different from 3 (isometry) (Table 5). The whole, shell and gonad weights at SH (70 mm and 90 mm) were lightest in the most northerly sample (1A) and heaviest in the most southerly (1Ds), whereas the opposite trend was seen for muscle weight (Table 5).

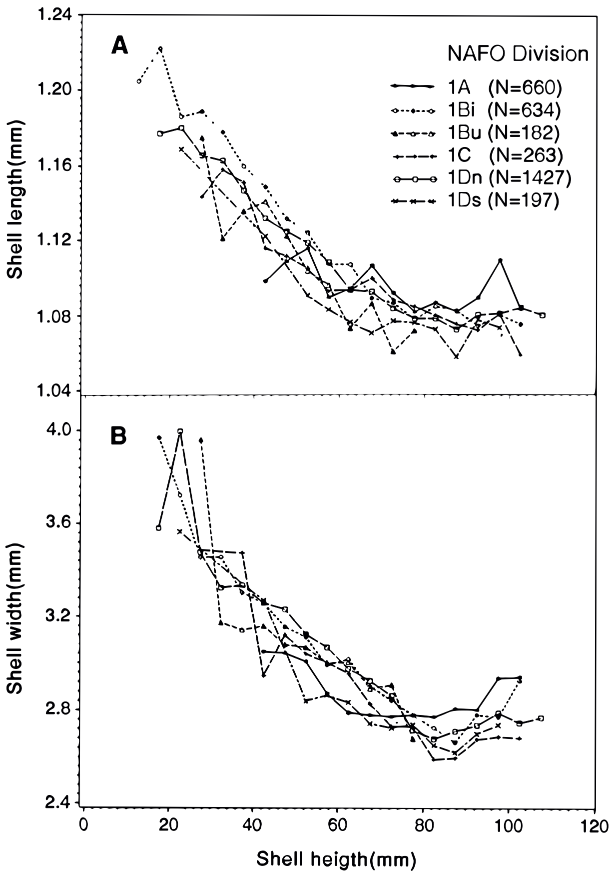

Fig. 4. SH/length ratio (**A**) and SH/width ratio (**B**) *versus* SH by area (NAFO Divisions indicated in Fig. 1) for *C. islandica* at West Greenland. Only mean values calculated from more than five measurements are included.

The t-tests of the mean standardized muscle index by sex showed a significantly higher female index for the NUK(Mar) sample (t = 4.57, P <0.01), whereas no significant (P> = 0.05), difference between the sexes were seen for other samples (Table 6). The male gonad indices were significantly higher than those for females for the UPR(Sep), HOL(May), SUK(Oct), FFJ(Sep) and NUK(Nov) samples, whereas in the KAT(May), NUK(May) and MID(Jun) samples, the female gonad indices were significantly higher than those for males (Table 6). Seasonal variation in the mean standardized muscle and gonad indices for each sex were tested for the Nuuk samples only. The muscle indices were significantly highest for the NUK(Nov) sample for both sexes and lowest for the NUK(Mar) sample for males and for the NUK(Jun) sample for females (Table 6 and 7). The gonad indices were significantly highest for the NUK(May) sample for both sexes and lowest for the NUK(Jun) sample for both sexes (Table 6 and 7).

Discussion

The West Greenland populations and commercial aggregations of *C. islandica* are generally found in coastal areas. The largest aggregations are located in the Nuuk area where most of the directed fishery has taken place. Only low concentrations of generally small scallops and large quantities of empty scallop shells have been found in offshore areas. Large quantities of empty shells indicate that offshore populations were more abundant in earlier periods. In Iceland, Canada and Norway *C. islandica* is also distributed in both coastal and offshore areas (Eiriksson, 1986; Naidu, 1988; Wiborg, 1963; Wiborg *et al.*, 1974; Rubach and Sundet,

TABLE 3. Chi-square analysis of sex ratio of Iceland scallop from West Greenland. H_o: each sampled population has a 1:1 sex ratio.

NAFO Division	Size range (SH mm)	No. of females	No. of males	Total No.	χ^2	P	d.f.
1A	40–109.9	342	312	654	1.38	>0.05	1
1Bi	30–114.9	301	285	586	0.44	>0.05	1
1Bu	30–94.9	103	68	171	7.16	<0.01	1
1C	40–114.9	234	215	449	0.80	>0.05	1
1Dn	30–114.9	647	754	1 401	8.17	<0.01	1
1Ds	40–99.9	81	97	178	1.44	>0.05	1
All	30–114.9	1 708	1 731	3 439	1.44	>0.05	1
1Dn	30–64.9	168	248	416	15.38	<0.01	1
1Dn	65–104.9	468	502	970	1.19	>0.05	1
1Dn	105–114.9	11	4	13	3.27	>0.05	1

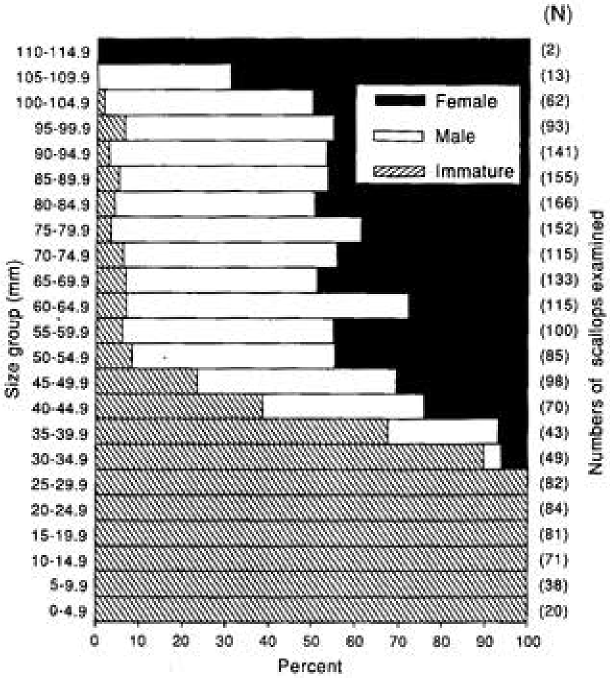

Fig. 5. Percent distribution of female, male and immature *C. islandica* by 5-mm size group for all the Nuuk samples combined (1Dn).

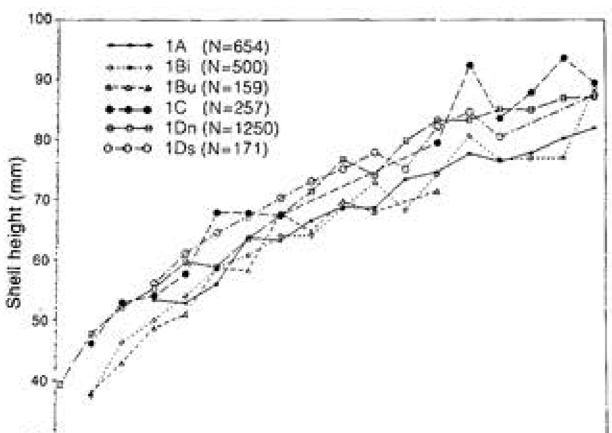

Fig. 6. Mean SH *versus* age mature for *C. islandica* by area (NAFO Divisions indicated in Fig. 1) at West Greenland. Only mean values calculated from more than five SH measurements are included.

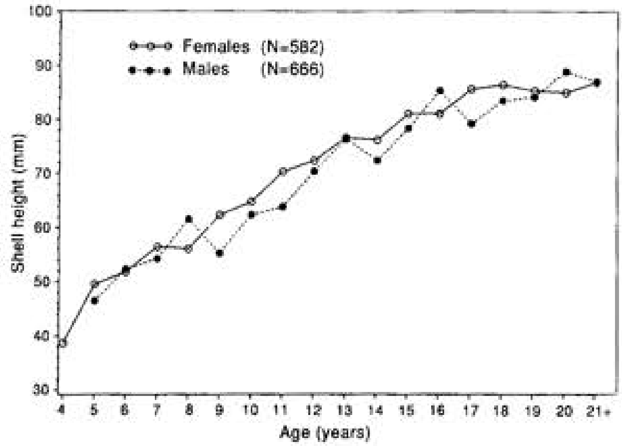

Fig. 7. Mean SH *versus* age by sex for *C. islandica* sampled from the Nuuk area (1Dn). Only mean values calculated from more than five SH measurements are included.

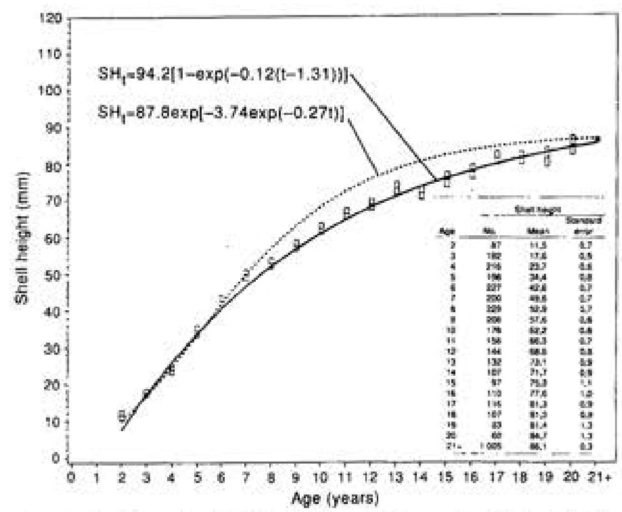

Fig. 8. Von Bertalanffy (solid line) and Gompertz (dashed line) growth curves fitted to mean SH-at-age for all *C. islandica* sampled at West Greenland for which age was determined. Symbols represent mean values with 2 standard error.

1987). In Iceland the scallop fishery takes place mostly in inshore fjords and bays while in Canada it takes place in both inshore and offshore areas and in Norway mostly in offshore areas.

Size compositions of *C. islandica* in the West Greenland survey catches were strongly skewed to larger sizes in the 60–110 mm SH range with the majority being 75–100 mm. Size selection by scallop dredges occurs over a broad range. The dredges used had steel ring diameters of 55–65 mm and/or 120 mm meshed netbags, therefore, escapement of small scallops (<55 mm) should be expected. However, because dredge ring openings often clogged and small scallops were commonly found attached by byssus to the inside of large empty shells, the size compositions presented in Fig. 3 are probably fairly representative of the populations surveyed. Comparisons with size compositions for other *C. islandica* populations in the North Atlantic indicate that West Greenland

TABLE 4. Results of the analysis of variance of shell height (SH) of Iceland scallop from West Greenland (see text for model). The least square (L_S) mean shell height (mm) at age 10 has been calculated. Results of the t-test for testing equal means between the sexes and between sampling areas are included (0.00 = (P<0.01)). P>I A I, the probability of a greater absolute value of A under the null hypothesis. The F VALUE is the ratio produced by dividing the mean square for Model (MS (MODEL)) by the mean square for Error (MS(Error)), where MS (MODEL) and MS (Error) are the Sum of Squares divided by the degrees of freedom (d.f.). An F test is a joint test that all parameters except the intercept are zero. A small significant probabilility, P>F, indicates that some linear function of the parameters is significantly different from zero.

Dependent Variable: SH

Source	d.f.	Sum of Squares	F Value	P > F
Model	24	548 272	284	0.0001
Error	3 004	241 490		
Corrected Total	3 028	789 763		r^2 = 0.69

Source	d.f.	Type III SS	F Value	P > F
Age	18	465 475	321	0.0001
Area	5	22 478	55	0.0001
Sex	1	1 289	6	0.0001

Sex:	L_s mean SH at age 10	Standard error	P > I t I H_o: L_s mean1 = L_s mean2
Female	63.7	0.46	0.0001
Male	62.4	0.45	

NAFO Division	L_s mean SH at age 10	Standard error	P > I t I H_o: L_s mean(i) = L_s mean(j) 1A	1Bi	1Bu	1C	1Dn	1Ds
1A	59.5	0.52		0.00	0.67	0.00	0.00	0.00
1Bi	61.6	0.55			0.00	0.00	0.00	0.00
1Bu	59.1	0.79				0.00	0.00	0.00
1C	68.9	0.68					0.00	0.15
1Dn	65.1	0.44						0.49
1Ds	65.6	0.78						

TABLE 5. Regression parameters for whole, shell, muscle and gonad weights *versus* SH for Iceland scallop for the most northerly area (1A), the Nuuk area (1Dn) and the most southerly area (1Ds) sampled at West Greenland (all regressions are highly significant, P <0.001).

NAFO Division		No.	Slope(β)	Standard Error S.E.(β)	Intercept (log α)	r^2	P(β = 3)	Calculated SH 70 mm	Calculated SH 90 mm
1A	Whole	661	2.93	0.03	-3.78	0.94	P<0.02	42.3	88.3
	Shell	670	3.07	0.04	-4.25	0.92	P<0.001	26.0	56.2
	Muscle	669	2.85	0.05	-4.36	0.84	P<0.002	7.9	16.2
	Gonad	655	2.99	0.14	-5.32	0.41	P=0.92	1.6	3.3
1Dn	Whole	1 698	3.25	0.01	-4.32	0.98	P<0.001	47.5	107.5
	Shell	1 432	3.34	0.01	-4.74	0.98	P<0.001	26.5	61.3
	Muscle	1 641	3.07	0.02	-4.78	0.95	P<0.001	7.7	16.6
	Gonad	1 501	3.52	0.06	-6.03	0.69	P<0.001	2.9	7.1
1Ds	Whole	214	3.24	0.01	-4.29	0.99	P<0.001	48.8	110.1
	Shell	214	3.23	0.03	-4.51	0.99	P<0.001	28.2	63.4
	Muscle	185	2.83	0.06	-4.39	0.92	P<0.01	6.8	13.8
	Gonad	177	3.40	0.18	-5.53	0.66	P<0.03	5.5	13.0

populations are generally composed of larger individuals (Eiriksson, 1986; Naidu *et al.*, MS 1982; Naidu and Cahill, MS 1992; Wiborg, 1963; Wiborg *et al.*, 1974; Rubach and Sundet, 1987). West Greenland populations are composed mainly of old, slow growing scallops that have accumulated over

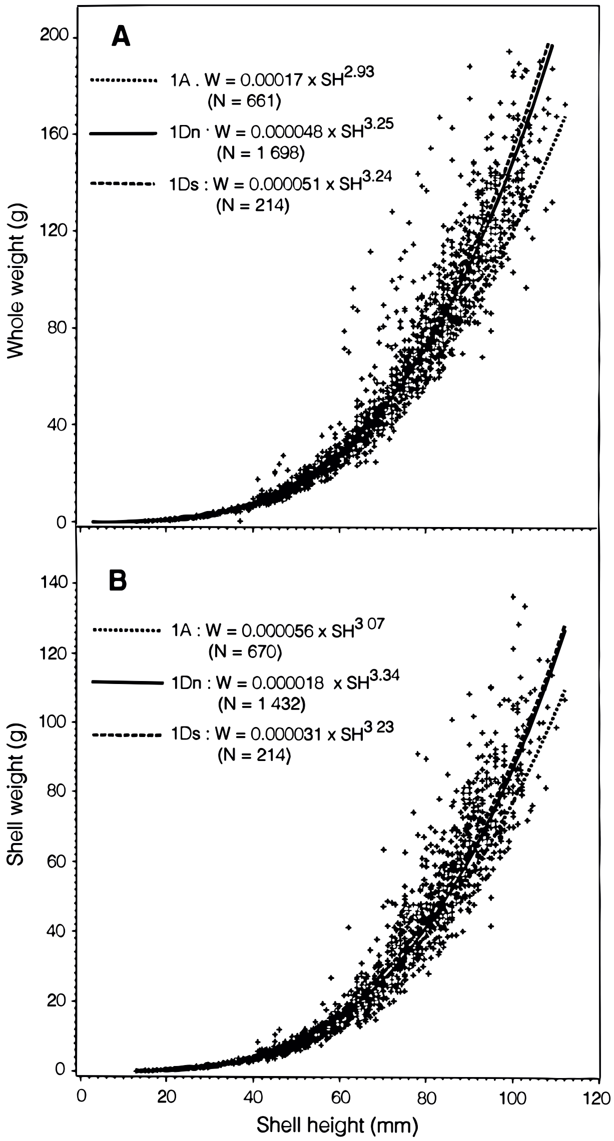

Fig. 9. Whole weight (**A**) and shell weight (**B**) versus SH relationships for all *C. islandica* sampled from the Nuuk area (1Dn). Symbols represent measurements for individual scallops in the Nuuk samples. Dashed lines are the relationships found for samples from the most northerly (1A) and the most southerly (1Ds) areas.

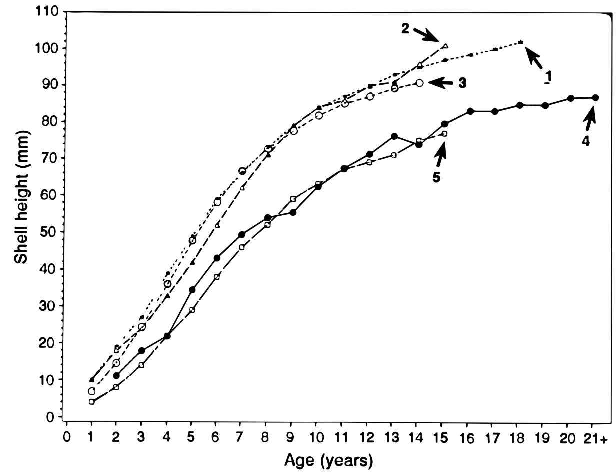

Fig. 10. Mean SH *versus* age for *C. islandica* from different areas of the North Atlantic. **1** = Iceland (Eiriksson, 1986), **2** = Northern Norway, Andamsfjord (Wiborg, 1963), **3** = Canada, northeastern Gulf of St. Lawrence (Naidu, 1988), **4** = West Greenland, Nuuk area (this study), **5** = Spitsbergen (Wiborg *et al*., 1974).

time and have a low level of recruitment. Experience from the commercial scallop fishery has shown that single scallop beds become depleted in a short time. Depletion of a bed may result in increased recruitment to the population due to a lower density-dependent mortality rate for eggs and newly-settled spat (Ricker, 1954). For *C. islandica* in northern Norway Vahl (1982) found recruitment to be almost entirely determined by the density of adults.

In bivalves there are usually morphometric variations between areas. In northern Norway (Wiborg, 1963) found differences in the shell proportions in *C. islandica*; those from the Andamsfjord being wider than those from the Kjøfjord. The SH/length and SH/width ratios against SH found in West Greenland in this study are similar to those found by Wiborg (1963) in Kjøfjord. According to Wiborg (1963) the Kjøfjord scallops are representative of those from other areas in northern Norway.

In West Greenland *C. islandica* populations the sex ratio was generally 1:1. Both males and females became sexually mature at 30–55 mm SH at ages 4–9 years. For populations from Norwegian coastal waters Wiborg (1963) and Vahl (1981) found the same sex ratio. They found maturity to occur at ages 3–6 years, with all individuals mature at a size of 50 mm. The faster growing individuals reached maturity first (Vahl, 1981).

The SH growth rates found at West Greenland were comparable to those at Jan Mayen, Bear Island and around Spitsbergen, but generally slower than for populations in Iceland, Canada and Norway (Fig. 10) (Wiborg *et al*., 1974; Rubach and Sundet, 1987; Eiriksson, 1986; Naidu, 1988; Wiborg, 1963). The West Greenland scallops were aged to greater ages than scallops from other areas of the North Atlantic, however, it is noted the SH growth curves presented in Fig. 10 are based on different age determination methods. The growth curves for Canada, Iceland and Norway are from back

TABLE 6. Standardized muscle index and gonad index for Iceland scallop from West Greenland calculated by sex and sampling location. Only mature scallops (>55 mm SH) are included. Results of t-test for testing equal means between the sexes are included (0.00 = (P <0.01)). P> I A I, the probability of a greater absolute value of A under the null hypothesis.

Area	Females			Males			t-test: H_o: F(m) = M (m)	
(month)	No.	Mean	Std. err.	No.	Mean	Std. err.	t / d.f.	P > I A I
Muscle Index								
UPR (Sep)	331	2.37	0.03	294	2.32	0.03	1.31/623	0.19
ATU (Jun)	28	2.31	0.05	28	2.40	0.08	-0.87/54	0.39
ISO (May)	32	2.13	0.06	37	2.13	0.05	0.03/67	0.97
KAT (May)	37	2.27	0.07	48	2.29	0.05	-0.28/83	0.78
HOL (Mar)	46	2.12	0.09	25	2.09	0.25	0.13/69	0.89
HOL (May)	86	1.92	0.05	65	2.09	0.06	-2.26/149	0.03
NHM (Jul)	58	2.90	0.07	27	2.68	0.12	1.75/83	0.08
SUK (Jul)	30	2.68	0.08	19	2.66	0.05	0.26/47	0.79
SUK (Oct)	101	2.62	0.04	89	2.59	0.05	0.39/188	0.70
FFJ (Sep)	24	1.83	0.06	27	1.90	0.06	-0.89/49	0.38
NUK (Mar)	261	2.17	0.02	294	2.03	0.02	4.57/553	0.00
NUK (May)	10	2.14	0.08	9	2.24	0.08	-0.99/17	0.34
NUK (Jun)	29	2.07	0.04	43	2.23	0.06	-1.99/70	0.05
NUK (Nov)	237	2.67	0.04	266	2.65	0.04	0.47/501	0.64
MID (Jun)	29	1.70	0.04	30	1.84	0.06	-1.90/57	0.06
SAF (Jun)	48	2.12	0.05	62	2.22	0.04	-1.64/108	0.10
Gonad Index								
UPR (Sep)	331	0.39	0.01	294	0.67	0.02	-15.10/623	0.00
ATU (Jun)	28	1.41	0.10	28	1.23	0.07	1.49/54	0.14
ISO (May)	32	1.32	0.07	37	1.23	0.06	1.01/67	0.32
KAT (May)	37	1.38	0.07	48	1.21	0.05	2.08/83	0.04
HOL (Mar)	46	0.67	0.05	25	0.64	0.10	0.29/69	0.77
HOL (May)	86	0.89	0.06	65	1.17	0.08	-2.73/149	0.00
NHM (Jul)	58	1.14	0.11	27	1.06	0.10	0.43/83	0.67
SUK (Jul)	30	1.71	0.13	19	2.03	0.12	-1.67/47	0.10
SUK (Oct)	101	0.86	0.03	89	1.15	0.04	-5.67/188	0.00
FFJ (Sep)	24	0.30	0.02	27	0.55	0.03	-7.00/49	0.00
NUK (Mar)	262	1.05	0.03	294	1.07	0.03	-0.37/554	0.71
NUK (May)	10	2.17	0.17	9	1.20	0.09	4.83/17	0.00
NUK (Jun)	29	0.83	0.11	43	0.76	0.09	0.49/70	0.63
NUK (Nov)	237	0.88	0.03	266	1.10	0.03	-5.25/501	0.00
MID (Jun)	29	1.44	0.09	31	1.11	0.06	3.04/58	0.00
SAF (Jun)	48	2.06	0.07	62	2.15	0.07	-0.94/108	0.35

TABLE 7. Results of t-test for testing equal means of muscle and gonad indices between samples of Iceland scallop from Nuuk area (see Table 6) for each sex (0.00 = (P <0.01)).

	P > I t I H_o: Mean(i) = Mean(j)							
	Muscle Index				Gonad Index			
i/j	Mar	May	Jun	Nov	Mar	May	Jun	Nov
Females								
Mar		0.81	0.23	0.00		0.00	0.01	0.00
May			0.67	0.00			0.00	0.00
Jun				0.00				0.52
Nov								
Males								
Mar		0.23	0.02	0.00		0.40	0.00	0.47
May			0.96	0.00			0.01	0.50
Jun				0.00				0.00
Nov								

measurements of size-at-ring formation read on the upper valve of selected shells. This method excludes age determination of most of the scallops in a sample because of epigrowth, e.g. calcareous algae and barnacles. The growth curves for West Greenland and Spitsbergen are from age determinations obtained by counting growth zones in the ligament of individual scallops. With this method no individuals are excluded because of epigrowth on the shell. The growth curves presented in Fig. 10 are not strictly comparable because of the different age determination methods. Since no scallops are excluded using the ligament to age individuals, this method probably provides a better description of the growth rate in a scallop population. During sampling from February to April 1971 of a *C. islandica* population in northern Norway, Johannssen (1973) found two size groups of small scallops, 1.1–2.8 mm SH and 7.1–10.7 mm SH. He concluded that the smaller size group was spawned in June–July of the previous year and the other was 1 year older. These results led Wiborg et al. (1974) to conclude that his earlier age determinations (e.g. Wiborg, 1963) should be increased by 1 year. Therefore, should the growth curve for northern Norway in Fig. 10 accordingly be shifted 1 year to the right, it becomes more comparable to those for West Greenland and Spitsbergen.

For mature scallops at West Greenland there were seasonal variations in both muscle and gonad weights and differences between sexes. For scallops sampled from the Nuuk areas, muscles were heaviest in November. Compared to muscle weights, seasonal variation in gonad weights was much greater. For the Nuuk samples the gonads were heaviest in May and lightest in June. Male gonads were heavier than female gonads in November but were lighter in May. Variations in muscle and gonad weight are related to seasonal growth (food availability) and the annual reproductive cycle. Large seasonal variations in muscle and gonad weights have also been described for *C. islandica* in Norway (Skreslet and Brun, 1969; Wiborg *et al.*, 1974; Sundet and Vahl, 1981; Sundet and Lee, 1984). For a coastal population in northern Norway, Sundet and Vahl (1981) found a maximum in both the dry weight and glycogen content of muscles collected during July–September. The gonad weight of both sexes in this population increased most rapidly in spring during March to May. Male gonads were heaviest in May while female gonads were heaviest in July just before spawning (Skreslet and Brun, 1969; Sundet and Vahl, 1981; Sundet and Lee, 1984). In coastal areas spawning appears to be triggered by short-term variations in temperature brought about by vernal meltwater discharge (Skreslet, 1973). The gonads of both sexes start to recover immediately after spawning, but male gonads gain weight faster than female gonads (Sundet and Lee, 1984). Both the development of glycogen reserves in the muscle and gonadal development during spring are probably dependent upon food provided by the spring phytoplankton bloom (Sundet and Lee, 1984). Little is known about spawning time for scallops at West Greenland. However, spawning (gonads running) scallops have been reported from catches in Kangerdluarssuk Tugdleq fjord in July 1989 and in the Nuuk area at the end of April 1991 (Skipper A. Idd Jensen, M/S *Bjal*, Nuuk and Skipper I. Johansen, M/S *Anna Beni*, Nuuk, pers. comm.) They report that spawning scallops were caught on a single bed but not on other nearby beds in the same fjord. In the Nuuk area the phytoplankton bloom starts in March (Smidt, 1979), whereas at higher latitudes, e.g. in the Kangerdluarssuk Tugdleq fjord, the phytoplankton bloom starts later in spring. At West Greenland the later start of the phytoplankton bloom is probably the reason for the later spawning observed at the higher latitude.

Several factors could account for the areal variations in growth rates observed for the Iceland scallop, e.g. temperature, food availability, density dependent competition for food or space, currents, depth, the nature of the sediment. For *C. islandica* in the Balsfjord in northern Norway, Vahl (1980) suggests that growth mainly is limited by the inability of scallops to sort the trapped particles into organic and inorganic fractions while the amount available and the quality of phytoplankton or other digestible particulate organic matter exceed requirements.

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References

ANON. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute Inc., Raleigh, N.C., 1028 p.

BUCH, E. 1984. Variations in temperature and salinity of West Greenland waters, 1970–82. *NAFO Sci. Coun. Studies*, **7**: 39–43.

EKMAN, S. 1953. Zoogeography of the sea. Sidgwick and Jackson, London, 417 p.

EIRIKSSON, H. 1986. Horpüdiskurinn, *Chlamys islandica*, Müller (Iceland scallop). Hafrannsöknir, 35. hefti, bls. 5–40. Reykjavik, Hafrannsoknastofnunin, 1986. (in Icelandic, with English Abstract, 40 p.).

FITZHUGH, H. A. Jr. 1975. Analysis of growth curves and strategies for altering their shape. *J. Anim. Sci.*, **42**: 1036–1051.

JENSEN, Ad. S. 1912. Lamellibranchiata (Part I). *Danish Ingolf-Exped.*, Vol. II, No. 5: 15–19.

JOHANNSSEN, O. H. 1973. Age determination in *Chlamys islandica* (Müller). *Astarte*, **6**: 15–20.

NAIDU, K. S. 1988. Estimating mortality rates in the Iceland scallop, *Chlamys islandica* (O. F. Müller). *J. Shell. Res.*, **7**(1): 61–71.

NAIDU. K. S., F. M. CAHILL, and D. B. LEWIS. MS 1982. Status and assessment of the Iceland scallop, *Chlamys islandica*, in the northeastern Gulf of St. Lawrence. *CAFSAC Res. Doc.*, No. 2, 66 p.

NAIDU, K. S., and F. M. CAHILL. MS 1992. A re-examination of the abundance of Iceland scallops, *Chlamys islandica*, along the northern edge of St. Pierre Bank (NAFO Div. 3Ps). *CAFSAC Res. Doc.*, No. 31, 23 p.

OCKELMANN, W. K. 1958. The zoology of East Greenland. 4. Marine Lamellibranchiata. *Medd. Grønl. Kom. Ledel. Geol. Geogr. Unders. Grønl.*, **122**(4): 1–256.

PARSONS, G. J., M. J. DADSWEL, and E. M. RODSTROM. 1991. Fisheries and aquaculture. Scandinavia. *In*: Scallops: biology, ecology and aquaculture. S. E. Shumway (ed.) *Dev. Aquacult. Fish. Sci.*, **21**: 763–772.

PEDERSEN, S. A. MS 1988a. Inshore scallop resources, *Chlamys islandica*, in the Nuuk area West Greenland. *ICES C.M. Doc.*, No. K:17, 22 p.

MS 1988b. Kammuslinger, *Chlamys islandica*, ved Vestgrønland. [Iceland scallop, *Chlamys islandica* at West Greenland]. Rapport til Grønlands Hjemmestyre fra Grønlands Fiskeriundersøgelser, December 1988 (in Danish), 61 p.

PEDERSEN, S. A., and J. BOJE. MS 1987. Kammuslinger, *Chlamys islandica*, ved Vestgrønland. Undersøgelse af redskabseffektivitet for kammuslingeskrabere. [Iceland scallops, *Chlamys islandica*, at West Greenland. Investigation of gear efficiency for scallop dredges.] Grønlands Fiskeri- og Miljøundersøgelser, Januar 1987 (in Danish), 21 p.

POSSELT, J. P. 1899. Grønlands Brachiopoder og Bløddyr. *Medd. Grønl. Kom. Ledel. Geol. Geogr. Unders. Grønl.*, **23**(1): 1–298 (in Danish).

RICKER, W. E. 1954. Stock and recruitment. *J. Fish. Res. Board Can.*, **11**(5): 559–623.

1975. Computation and interpretation of biological statistics of fish populations. *Bull. Fish. Res. Board Can.*, **191**: 382 p.

RUBACH, S., and J. H. SUNDET. 1987. Ressurskartlegging av haneskjell (*Chlamys islandica* (O. F. Müller)) ved Jan Mayen og i Svalbardsonen i 1986. [Resource inventory of Iceland scallops (*Chlamys islandica* (O. F. Müller)) in the Jan Mayen and Spitsbergen areas during 1986.] IFF, Universitetet i Tromsø, Serie B: Ressursbiologi 1987 (in Norwegian), 41 p.

SKRESLET, S. 1973. Spawning in *Chlamys islandica* (O. F. Müller) in relation to temperature variations caused by vernal meltwater discharge. *Astarte*, **6**(1): 9–14.

SKRESLET, S., and E. BRUN. 1969. On the reproduction of *Chlamys islandica* (O. F. Müller) and its relation to depth and temperature. Astarte, **2**(1–2): 1–6.

SUNDET, J. H., and O. VAHL. 1981. Seasonal changes in the dry weight and biochemical composition of the tissue of sexually mature and immature scallops, *Chlamys islandica*. *J. Mar. Biol. Assoc. U.K.*, **61**: 1001–1010.

SUNDET, J. H., and J. B. LEE. 1984. Seasonal variations in gamate development in the Iceland scallop, *Chlamys islandica*. *J. Mar. Biol. Assoc. U.K.*, **64**: 411–416.

SMIDT, E. L. B. 1979. Annual cycles of primary production and of zooplankton at Southwest Greenland. Meddelelser om Grønland, *Bioscience*, **1**: 1–53.

VAHL, O. 1980. Seasonal variations in seston and in the growth rate of the Icelandic scallop, *Chlamys islandica* (O. F. Müller) from Balsfjord, 70°N. *J. Exp. Mar. Biol. Ecol.*, **48**: 195–204.

1981. Energy transformations by Icelandic scallop, *Chlamys islandica* (O. F. Müller), from 70°N. I. The age-specific energy budget and net growth efficiency. *J. Exp. Mar. Biol. Ecol.*, **53**: 281–296.

1982. Long term variation in recruitment of the Icelandic scallop, *Chlamys islandica*, from northern Norway. *Neth. J. Sea. Res.*, **16**: 80–87.

WALLER, T. R. 1991. Evolutionary relationships among commercial scallops (Mollusca: Bivalvia: Pectinidae). *In*: Scallops: biology, ecology and aquaculture. S. E. Shumway (ed.). Chapter 1. *Dev. Aquacult. Fish. Sci.*, **21**: 1–72.

WIBORG, K. F. 1963. Some observations on the Iceland scallop, *Chlamys islandica* (Müller) in Norwegian waters. *Rep. Norweg. Fish. Mar. Invest.*, **13**(6): 38–53.

WIBORG, K. F., K. HANSEN, and H. E. OLSEN. 1974. Iceland scallop, *Chlamys islandica* (O. F. Müller) at Spitsbergen and Bear Island – investigations in 1973. *Fiskets Gang*, **11**, p. 209–217 (in Norwegian, with English Abstract, p. 209).