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Growth, Size- and Age-at-Maturity of Shrimp, *Pandalus borealis*, at Svalbard Related to Environmental Parameters

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Abstract

Modal analyses of carapace length frequency distributions reveal differences in growth and age at first female maturity of shrimp, *Pandalus borealis*, at Svalbard. The shelf slope west and north of Svalbard within a depth range of 200–600 m was divided into seven Areas. Between seven and ten age groups of shrimp were identified in each Area. The slowest growth was observed in Isfjorden. Age at female maturity (L_{50}) varied from six to eight years between Areas. The differences in growth and age at female maturity between Areas could be explained by differences in bottom temperature. In Areas dominated by cold water, and where Atlantic and Arctic water alternate causing variations in the environmental conditions, shrimp showed slower growth and a higher age at female maturity. To ensure that inter-annual variations both within and between Areas are revealed, we suggest that shrimp ageing should be done separately for all seven Areas defined in this paper.

Key words: environment, growth, maturity, shrimp, Svalbard

Introduction

In Svalbard waters (Fig. 1), the shrimp (*Pandalus borealis*) fishery is regulated by 1) minimum landing size (15 mm carapace length), 2) limitations on the amount of by-catch of commercial fish species and 3) various effort limitations. One reason for not regulating the shrimp fishery with a TAC (Total Allowable Catch) has been the lack of knowledge about stock structure and problems in defining suitable management units.

The shrimp stock at Svalbard shows great variation in growth and maturity both spatially and over time (Nilssen and Hopkins, MS 1991). Although stocks have not been identified genetically in this area, it was thought possible to define management units as areas wherein shrimp have similar life history traits, (Martinez *et al*., MS 1997) including growth and maturity characteristics. The aim of this study was therefore to describe the spatial variation in growth and age at first female maturity of the shrimp, *Pandalus borealis,* at Svalbard.

Materials and Methods

Study area and survey design

The study area, west and north of Svalbard (75°00'–81°00'N and 07°00'–20°00'E), is characterized by a narrow continental shelf. The main shrimp areas are found on the steep slope of the shelf from 200 m to 600 m depth (Fig. 1). The hydrography of the area is dominated by warm Atlantic water along the western off shore side of Spitsbergen and by cold Arctic water along the northern and eastern coast of Svalbard (Fig. 2). There is also a cold coastal current along the western side of Spitsbergen.

Annual trawl surveys of the study area were carried out in the summer months from 1992 to 1998. The total area off Svalbard (9 257 naut. m^2) was surveyed with approximately 80 stations selected by stratified random sampling. Strata were chosen by depth intervals of 200–299 m, 300–399 m and 400–600 m within each degree latitude (18 areas in total). This stratification was later combined into seven larger Areas when analyzing composite length distributions (Fig. 2). This combination was based on an examination of modal analyses of shrimp length frequencies for each of the 18 areas. This resulted in similar modal distributions within each one degree latitude block.

The fishing gear used for all surveys was a Campelen 1800 meshed bottom trawl fitted for shrimp surveys (30 m headline, 19 m groundline, 42 mm mesh size in the body, and 20 mm in the codend). To ensure the capture of small shrimp, a small-mesh bag (0.8 mm)

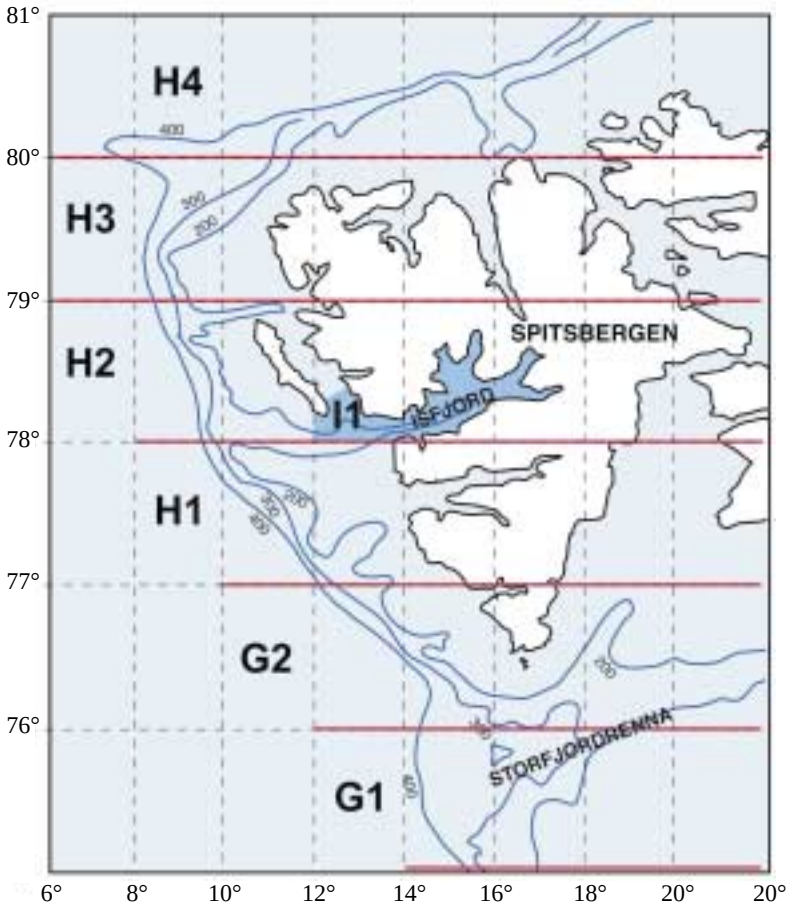

Fig. 1. Sampling Areas (G1,2,H1-4,I1) used in the Svalbard for shrimp surveys.

with a $1m^2$ opening was attached to the under belly of the trawl (Nilssen *et al*., MS 1986). At each station, the trawl was towed for 20 min at a speed of 3 knots, covering a distance over the ground of approximately 1.0 naut. mile. Bottom temperatures were measured at each station with a Scanmar temperature sensor attached to the gear. A detailed description of survey methodolgy is given in Aschan and Sunnanå (MS 1997).

Biological samples and data analysis

A sub-sample of 300 shrimp from the catch at each station was analysed for carapace length. Additionally, all individuals caught in the small-mesh bag were measured. The carapace length (CL) was measured to the nearest 0.1mm from the posterior margin of the eyestalk to the posterior mid-dorsal edge of the carapace, with an electronic calliper. Length frequencies were grouped into 0.5mm length intervals for analysis.

The sexual development stage of each shrimp was classified according to an eight-stage scale. Stages were based on the morphological characteristics of the endopodite of the first pleopod, the appendix on the second pleopod, sternal spines and head roe (Rasmussen, 1953; Allen, 1959; McCrary, 1971; Aschan *et al*., MS 1993). After the juvenile stage (Stage 1), shrimp mature first as males (Stage 2). Thereafter they become intersex or transitionals (Stage 3) before developing into females with head roe (Stage 4). After mating, the roe is extruded under the female's abdomen (Stage 5), where it stays until the larvae hatch (Stage 6). Some females then rest (Stage 7) while others start on a new cycle and develop head roe (Stage 8).

The CL data from all stations within each Area were pooled and length frequencies prepared for modal analysis. The length frequencies included samples from both the codend and the catch from the small-mesh bag. The most commonly used method for determining

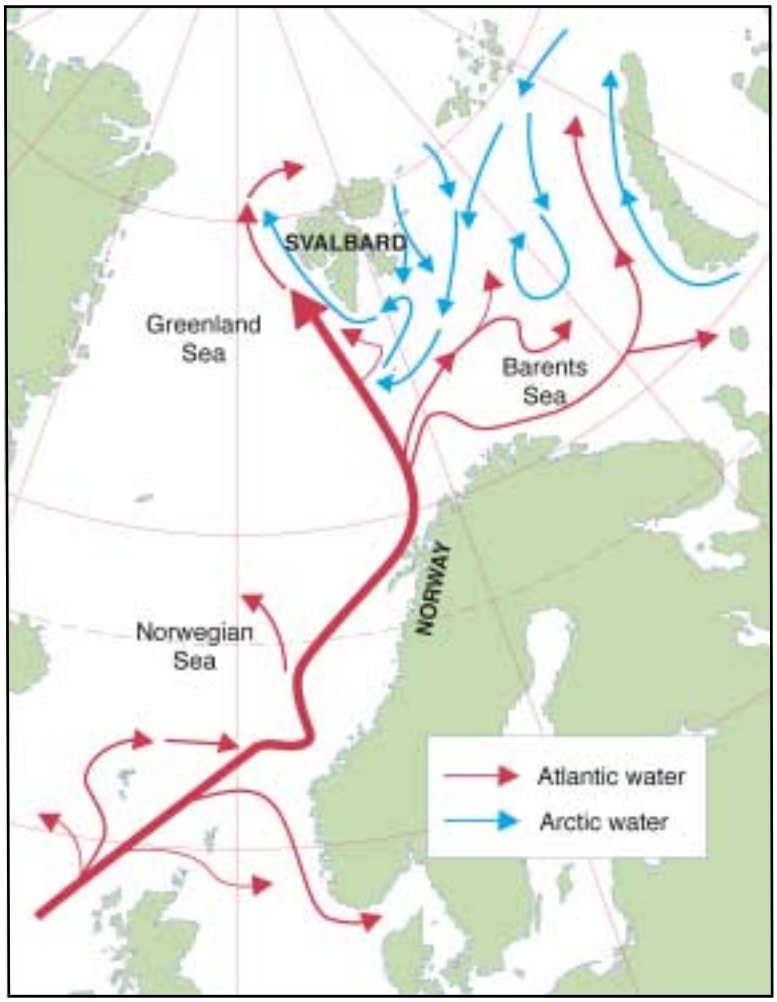

Fig. 2. The mean current systems of the Norwegian and Barents Sea.

length-at-age of shrimp is modal analysis, where each identified mode is assumed to be an age group. We followed the method of Macdonald and Pitcher (1979, MIX version 3.0). Starting values of the model parameters were based on visual inspection of the length distribution. The program iteratively computes maximum likelihood values and their standard errors including the proportions at each age group, mean length and standard deviation. We did not run the analyses with a predetermined and fixed number of modes, rather, several analyses were performed with a different assumed number of modes and the analysis with the best fit was then chosen. Results were standardized by fixing the standard deviation for each mode (age), although no constraints on default values were used throughout the analysis.

Growth was compared as average CL-at-age between Areas. The L_{50} for mature females (Stages 5, 6, 7 and 8) was calculated for each Area following the method of Skúladóttir (MS 1990, 1998). These results were then combined with information on shrimp length-at-age for each Area to give information on age at female maturity.

Results

Identification of age groups

The small-mesh bag attached to the under-belly of the trawl clearly made it easier to determine the first mode (<10mm CL). Ages were related to length data assuming that the smallest length interval was 6–10 mm (Fig. 3) and represented shrimp that hatched the

previous year. Deep stations, where largest shrimp are generally caught, were included in all Areas. Consequently no significant problems occured in fixing the oldest age groups.

Eight age groups were detected in most Areas. However, samples from Areas G1 and H1 showed seven age groups while Area I1 showed ten (Table 1). The first and the last mode were not necessarily represented every year in each Area, however, they were observed frequently enough to allow calculation of an average carapace length for each age group for each year and Area. Modes representing age groups did not overlap and except for some of the oldest, their average lengths were generally separated by at least 2 mm. Although the length distributions in each Area for each year showed great variation (Fig. 3), in general the pooled (all years) distributions in Fig. 3 agreed with the average lengths in Table 1.

Comparison of average length-at-age between areas

A comparison of average length-at-age between areas showed that shrimp older than three years in Areas I1 (Isfjorden) and G2 (Storfjordrenna) were smaller than shrimp at the same age from the other Areas (Fig. 4). Shrimp in Isfjorden showed the smallest length-at-age while those in Storfjordrenna were somewhat larger but smaller than shrimp from the rest of the Areas. Shrimp older than three years appeared to be smaller at age in southern offshore Areas (G1, G2, H1 and H2) compared to northern offshore Areas (H3 and H4) (Table 1, Fig. 4).

Length and age at female maturity

Results from the L_{50} calculations showed that shrimp at Svalbard matured as females in the 23.13–24.43 mm length range (Table 2). Shrimp within this range were estimated to be six to eight years of age depending on Area (Table 1). Average L_{50} showed that shrimp matured as females after six years in all offshore Areas except in Storfjordrenna where they matured after seven years. Shrimp in Isfjorden matured at eight years.

Discussion

Length-at-age and age at first female maturity clearly differed between Areas at Svalbard. A comparison of length-at-age (Fig. 4) showed that shrimp older than three years in Isfjorden and Storfjordrenna were smaller than shrimp at the same age from the other offshore areas. This could be explained by the influence of cold water in these areas compared to the other offshore areas, which are influenced by warmer Atlantic water (Fig. 2, 4). Slower growth, delayed maturity and increased longevity in these areas support this argument (Rasmussen, 1953; Allen, 1959; Nilssen and Hopkins, MS 1991; Skúladóttir, 1999). However, shrimp from southern Areas (G1, G2, H1 and H2) were generally smaller than shrimp from northern Areas (H3 and H4) and there appeared to be a south-north gradient of increasing length-at-age at Svalbard. Whether this was due temperature alone or an effect of other influences such as depth or fishing pressure is uncertain and will require further investigation.

Shrimp at Svalbard matured as females in the 23.13–24.43 mm length range at ages between six and eight years. Maturity at age six for offshore shrimp was similar to other northern areas (Table 2) including St. Anthony Basin in the Northwest Atlantic (Parsons *et al*., 1989), Nordurkantur in Icelandic waters (Skúladóttir, 1998) and in the neighbouring Barents Sea area (Teigsmark and Øynes, MS 1983; Nilssen and Hopkins, MS 1991). Delayed maturity found in Davis Strait (Parsons *et al*., 1989) and Denmark Strait (Skúladóttir, 1998) was similar to our results from Isfjorden and Storfjordrenna (eight and seven years at first female maturity respectively). Different ages at first female maturity between areas have been related to differences in temperature and growth (Rasmussen, 1953; Appolonio *et al*., 1986; Skúladóttir, 1999). Survey bottom temperature data shows that both Isfjorden and Storfjorderenna are influenced by cold water (Fig. 4). Low temperatures reduce growth rates which results in higher age at female maturity, assuming that this always occurs at the same size. Since the difference in L_{50} between the Areas at Svalbard was smaller than the overall annual length increment, we conclude that there is little variation in average L_{50} between Areas and that shrimp at Svalbard mature at the same size but at different ages, depending on growth.

Differences in length-at-age and age-at-maturity for shrimp at Svalbard indicate that a relatively fine spatial resolution in the data is required to detect changes which may reflect changes in stock status. We recommend that shrimp aging should be carried out separately for all seven Areas defined in this paper.

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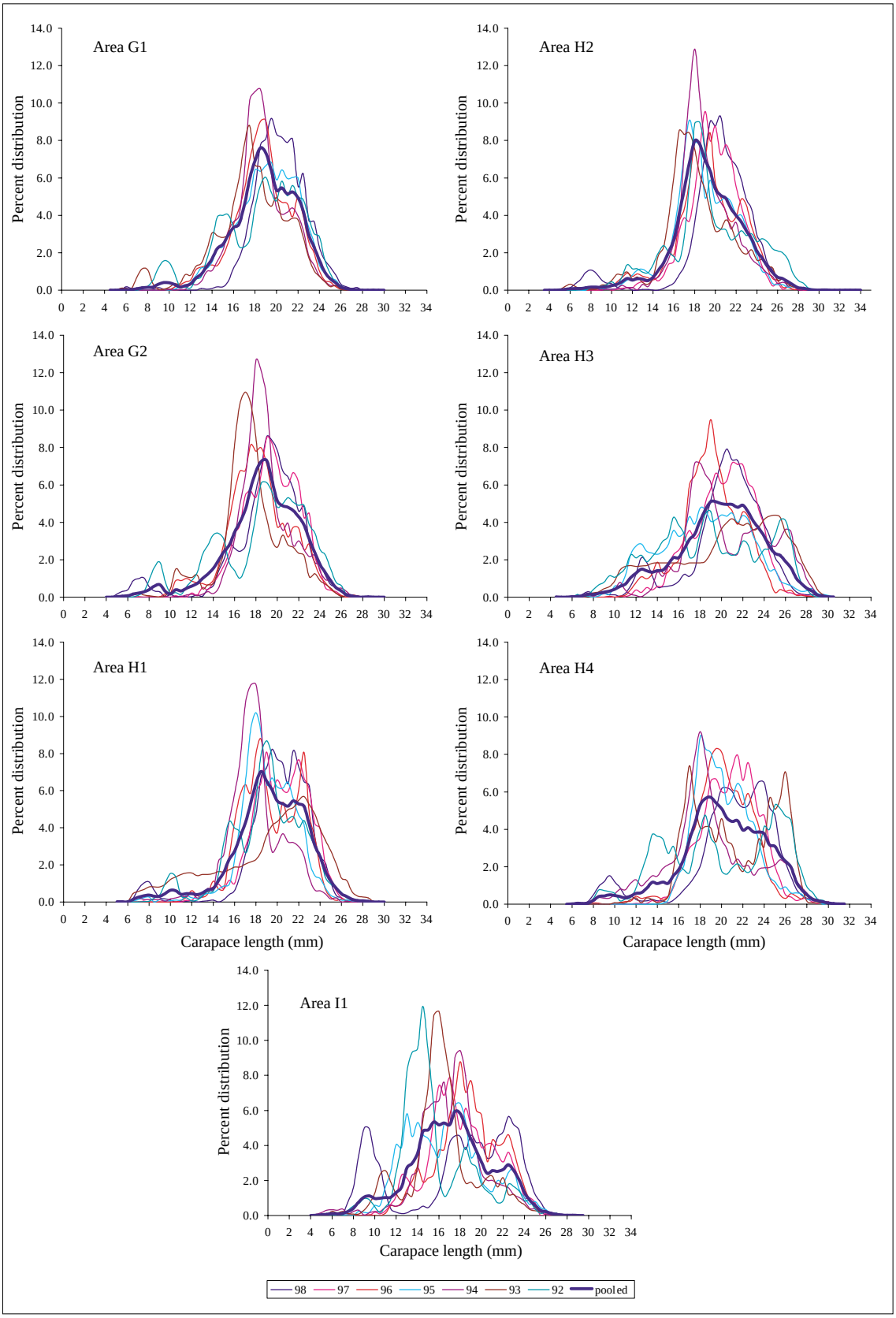

Fig. 3. Length distributions (% shrimp in each 0.5 mm interval) of *P. borealis* from each of the seven Areas by years. The blue thick line is the pooled distribution from the years 1992–98.

TABLE 1. Mean carapace length (mm) of *P. borealis* estimated by modal analysis (MIX 3.0) and calculations of average lengths in seven Areas off Svalbard.

	Age group									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Year	G1									
1992	8.55	13.83	14.83	17.97	18.60	21.07	–	–	–	–
1993	7.35	11.72	14.12	16.99	19.25	21.52	23.82	–	–	–
1994	–	13.11	15.34	18.01	21.33	24.07	–	–	–	–
1995	–	13.06	15.43	17.76	19.41	21.56	23.96	–	–	–
1996	–	12.81	16.03	18.40	21.64	24.03	–	–	–	–
1997	–	–	15.87	18.55	20.94	–	–	–	–	–
1998	–	–	–	18.75	21.07	23.46	–	–	–	–
Average	7.95	12.91	15.27	18.06	20.32	22.62	23.89			
Year	G2									
1992	7.65	11.92	13.43	16.11	17.71	19.65	–	–	–	–
1993	6.76	11.22	14.65	16.66	18.58	21.04	23.54	–	–	–
1994	–	12.18	16.00	18.10	20.78	22.84	25.07		–	–
1995	9.71	11.80	14.43	16.42	18.52	21.30	23.57	–	–	–
1996	–	11.28	13.72	16.06	18.26	21.27	23.11	–	–	–
1997	–	12.47	14.82	16.74	18.41	21.08	22.14	24.34	–	–
1998	–	–	15.23	18.07	19.26	21.28	23.55	27.36	–	–
Average	7.21	11.81	14.64	16.96	18.83	21.19	23.09	25.85		
Year	H1									
1992	9.24	13.40	15.22	18.28	20.49	22.08	–	–	–	–
1993	8.16	11.24	14.16	16.71	19.79	22.58	25.19	–	–	–
1994	7.37	11.34	15.21	17.40	21.01	23.58	–	–	–	–
1995	7.60	11.63	14.20	17.73	20.87	23.43	–	–	–	–
1996	11.87	13.92	16.30	18.16	20.36	22.35	24.58	–	–	–
1997	–	13.80	16.48	18.21	20.78	23.09	–	–	–	–
1998	–	–	16.90	18.60	21.03	23.75	–	–	–	–
Average	8.85	12.56	15.50	17.87	20.62	22.98	24.59			
Year	H2									
1992	8.60	9.99	14.21	18.04	20.26	22.04	23.73	–	–	–
1993	6.05	10.91	14.80	16.58	18.35	21.01	23.84	26.26	–	–
1994	6.59	11.05	14.91	17.71	20.04	21.95	24.03	26.23	–	–
1995	8.39	12.59	15.15	17.47	20.53	22.79	26.68	–	–	–
1996	–	11.73	16.07	18.60	22.51	26.12	–	–	–	–
1997	–	13.06	16.06	18.23	20.71	22.87	25.70	–	–	–
1998	–	–	15.88	18.08	19.69	21.55	24.10	25.70	–	–
Average	7.64	11.57	15.31	17.82	20.08	22.10	24.86	26.06		
Year	H3									
1992	8.44	11.51	14.49	17.90	21.27	24.99	–	–	–	–
1993	9.02	11.32	14.31	17.16	20.57	23.79	26.15	–	–	–
1994	9.43	–	14.74	18.05	–	22.47	25.74	–	–	–
1995	7.89	12.21	15.65	18.36	21.40	23.97	27.41	–	–	–
1996	7.43	13.91	16.70	18.71	22.05	25.78	26.19	–	–	–
1997	–	11.99	15.96	18.45	21.11	23.00	26.17	–	–	–
1998	–	–	15.86	18.67	20.79	22.95	24.60	27.51	–	–
Average	8.44	12.19	15.39	18.19	21.20	23.85	26.04	27.51		

TABLE 1. (Continued). Mean carapace length (mm) of *P. borealis* estimated by modal analysis (MIX 3.0) and calculations of average lengths in seven Areas off Svalbard.

	Age group									
	I	II	III	IV	V	VI	VII	VIII	IX	X
Year	H4									
1992	8.02	12.17	13.85	17.37	20.49	23.57	24.78	–	–	–
1993	–	11.99	16.73	19.12	20.72	23.42	25.52	29.17	–	–
1994	8.61	11.46	14.44	17.76	20.78	23.30	25.66	28.19	–	–
1995	–	–	17.02	18.47	21.06	22.78	25.45	27.26	–	–
1996	7.49	12.61	17.01	19.33	21.36	22.63	26.17	27.85	–	–
1997	–	12.85	16.09	18.94	21.42	23.07	26.18	28.72	–	–
1998	–	–	16.60	18.79	20.74	23.32	25.42	28.36	–	–
Average	8.04	12.22	15.96	18.54	20.94	23.16	25.60	28.26		
Year	I1									
1992	7.95	12.51	13.86	–	17.45	19.45	22.17	–	–	–
1993	6.35	10.70	13.76	15.59	17.16	20.06	22.11	24.77	–	–
1994	6.11	8.28	11.48	14.91	17.56	20.81	22.96	25.87	–	–
1995	9.08	11.79	12.89	14.55	17.23	19.09	22.23	24.78	–	–
1996	–	11.90	13.70	15.48	17.59	19.20	21.29	22.79	24.92	–
1997	–	10.48	12.43	15.15	16.92	18.81	20.54	22.29	24.01	–
1998	–	–	12.04	13.63	15.39	17.28	19.41	21.62	23.13	25.33
Average	7.37	10.94	12.88	14.95	17.04	19.24	21.53	23.69	24.02	25.33

TABLE 2. Summary of length at female maturity, age at first female maturity and temperature from various studies and geographical areas. Note that data from Skúladóttir (1998), Ivanov (1969) and this study are L_{50} values (the length where 50% of the shrimp within one length interval were females without spines) the other are data based on mean length of primiparous females calculated directly from sampling data.

Author Area	CL at female maturity (mm)	Age at female maturity (years)	Mean bottom temperature (°C)
Parson *et al*. (1989)			
St. Anthony Basin	22.6	6	2–4
Davis Strait	25.4	7	1–4
Skúladóttir (1998)			
Ísafjardardjúp	18.9	3	4.5
Nordurkantur	23.9	6	0
Denmark Strait	27.9	7	0–2
Ivanov (1969)			
Bering Sea	27.0	5.5	1.7
Teigsmark and Øynes(1983)			
Barents Sea	20.5–21.4	5.5	0
Hansen and Aschan (this study)			
Svalbard:			
G1	23.68	6	1.6
G2 (Storfjordrenna)	24.36	7	0.8
H1	23.39	6	2.0
H2	24.31	6	1.7
H3	24.09	6	1.4
H4	24.43	6	1.4
I1 (Isfjorden)	23.13	8	1.4

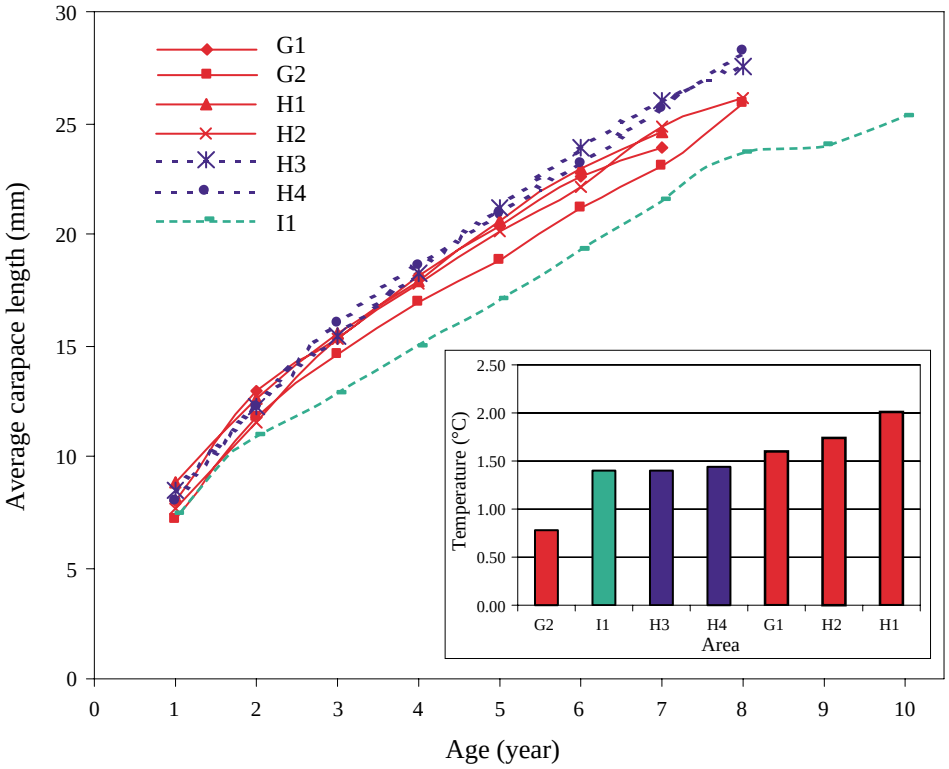

Fig. 4. Average carapace length-at-age (mm) of *P. borealis* and mean bottom temperature (°C) in each area at Svalbard from 1992 to 1998.

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