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Growth Performance, Size and Age-at-maturity of Shrimp, *Pandalus borealis*, in the Svalbard Area Related to Environmental Parameters

by

H.Ø. Hansen and M. Aschan
Norwegian Institute of Fisheries and Aquaculture Ltd., (Fiskeriforskning),
N-9291 Tromsø

Abstract

Modal analyses (MIX 3.0) of carapace length reveals variations in growth and age at first female maturation of shrimp, Pandalus borealis, in Svalbard. The study area was the shelf slope West and North of Svalbard north of 75°00' N and within a depth range of 200-600 m. The area was divided into seven main areas proceeding from south to north. Between seven and ten age groups were identified in each area. The slowest growth was observed in the Isfjorden. The carapace length where 50% of the shrimp were matured females, termed L50, was calculated from a line fitted to the length frequency of each area. There was no variation in L50 between areas in this study. However, age at sex change variated between six and eight years. The variations on growth and age at sex change were mainly explained by variations in temperature. In areas dominated by cold polar water, and where Atlantic and polar water alternate causing variations in the environmental conditions, shrimp show a slower growth and a higher age at sex change. The life history of shrimp in Svalbard varies not only geographically, but also over time. A suggestion on how to handle this plasticity in assessment is discussed.

Introduction

In the Svalbard zone the shrimp fishery is regulated by smallest allowable shrimp size (15mm carapace length), limited number of young commercial fish allowed in the catch, by number of vessel licenses and fishing days given. One reason for not regulating the shrimp fisheries 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 in the Svalbard area shows great plasticity and variation in growth and maturity both spatially and over time (Nilssen and Hopkins, MS 1991). A definition of sub areas with shrimp showing the same growth and maturity performance would make the management of the shrimp stock in Svalbard more easier.

Although management units can not be identified genetically they may be defined as areas with shrimp having the same life history (Martinez *et al*., MS 1997). General conclusions on life history of shrimp has been presented by Shumway *et al*. (1985), Apollonio *et al*. (1986) and Nilssen and Hopkins (MS 1991) and for the development of the shrimp stock in the Barents Sea and Svalbard area Aschan *et al*. (MS 1996). Studies on growth performance of shrimp has been conducted by Parsons *et al*. (1989) and work on L50 for shrimp was first done by Skuladottir *et al*. (MS 1990) in the Icelandic waters.

The aim of this study is to describe the spatial and historical variation in growth and age at first female maturity of the shrimp, Pandalus borealis. This study includes shrimp sampled West and North of Svalbard in the period 1992-98. Length frequency distributions were examined using the program MIX 3.0 to analyse the age structure of shrimp. This gave us the opportunity to compare the average growth for each sub area and to calculate the carapace length, L50, where 50% of the shrimp are matured females. These results are finally discussed in relation to temperature and biomass density.

Materials and Methods

The study area West and North of Svalbard (75°00'-81°00'N and 07°00'-20°00'E) is characterised 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 in the area is dominated by warm Atlantic water along the western coast of Spitsbergen and cold polar water from North East and into Storfjordrenna (Fig. 2). The study area has been surveyed annually from 1992 to 1998. In the years 1993-1997 the annual survey was conducted in June while in 1992 and 1998 the survey was conducted in August.

The stratification was done allowing the depth intervals 200-300 m, 300-400 m and 400-600 m in each latitude interval of one degree to constitute the main strata system. In addition the southern and northern intervals have been divided in eastern and western strata. This stratification was then gathered into seven larger sub areas according to the difference in abiotic factors. The Isfjorden sub area was defined as the area east of 12°07'E (Fig. 2).

A semi-systematic approach has been developed by sampling the same stations, originally chosen by stratified random sampling, each year. Approximately 80 stations have been surveyed annually, when covering the total area of Svalbard.

The sampling trawl was a Campelen 1800 bottom trawl standardized for shrimp surveys. To ensure the presence of small shrimp in the trawl samples, a mesh bag (0.8 mm) with a 1m² opening was attached to the under belly (Nilssen *et al*., MS 1986). At each station, towing for 20 minutes with 3 knots (1.0 naut. mile) was conducted. A detailed description of stratification, sampling procedures, trawl rigging and technology and biological sampling is given in Aschan & Sunnanå (MS 1997).

Bottom temperatures were measured at each station with a Scanmar Tempareture Sensor attached to the Campelen trawl.

In order to provide data on carapace length (CL) and sex distribution of shrimp a sub sample of 300 shrimp was analysed at each station. Additionally, the total number of individuals from the mesh bag were sampled and measured. The carapace length was measured from the posterior margin of eyestalk to the posterior mid dorsal edge, to the nearest 0.1mm with an electronic calliper (Mitutoyo, Japan).

The biological development of shrimp was identified as seven stages by studying the endopodit of the first pleopode, the appendix on the second pleopode, sternal spines and head roe (Rasmussen 1953, Allen 1959 and McCrary 1971). Shrimp starts of as males (Stage 2) after the juvenile stage (Stage 1). Thereafter they become intersex (Stage 3) before they develop into females with head roe (Stage 4). When the females mate, the roe is spawned under the abdomen and kept there by the pleopods (Stage 5), where it stays until the larvae hatch (Stage 6). Some females then take a resting period (Stage 7) while others start on a new cycle with head roe (Stage 8).

Crustaceans have no hard, bony tissue that they bring with them through moulting and consequently direct age reading was not possible. Therefore, MIX 3.0 modal analysis of length frequencies in 0.5 mm intervals, where each mode forms an age group, was used (Macdonald and Pitcher, 1979). Several analyses were conducted with different assumed number of modes. The standard deviation was fixed to be equal for each mode in the distribution and as a rule, default values were used through the analysis. No separate analysis for females and males were made and the analysis resulted in three estimated parameters for each age group; estimated proportions of each age group in the distribution mixture, mean and standard deviation of size at age and the number of assumed age groups in the distribution.

We compared growth between sub areas and by years. When we compared the growth between years we calculated the difference in length increment between shrimp of three and four years for each *year-class* in each area.

L50 for mature females (Stage 5, 6, 7 and 8) was calculated by sub area and year (Skuladottir, 1998). These findings were combined with information on shrimp growth in responding sub areas and thereby information on age at female maturity was produced.

Temperature data were received from the Institute of Marine Research in Bergen (Aure *et al*, Havets miljø 1999).

Results

Identification of year-classes

We were generally able to detect eight modes in the samples when running MIX 3.0. However, samples from sub areas G1 and H1 showed seven modes whilst Isfjorden was the only area that showed ten modes (Table 1). The first and the last mode were not necessarily represented every year in one sub area. However, they were observed frequently and allowed us to calculate a final average carapace length over years for each sub area.

Ages were correlated to length data assuming that the smallest catchable age group falls within the length interval 6-9 mm (Table 1). The modes were separated by at least 2 mm (except for some modes representing the oldest age groups) and the range of the mean lengths in one mode did not overlap with average length in adjacent modes.

Comparison of average growth between areas

There was clearly a slower growth in Isfjorden compared with the other sub areas in this study (Fig. 3). The carapace length of six year old shrimp were larger than 21 mm in all sub areas except in Isfjorden, where shrimp at age six showed a mean carapace length at 19.24 mm (Table 1)

Length and age at maturity

There were no variations in average L50 by area and results showed that shrimp in Svalbard matured as females within the range of length 23.39-24.43 mm (Table 2). From Figure 3 we concluded that offshore populations matured at six years, except in sub area G2 where the population matured as females after seven years. The population in Isfjorden matured as eight years old.

Discussion

Growth studies of shrimp, P. borealis, are difficult because there is no exact way to determine age as a result of no hard body structures (Shumway *et al*, 1985). The most used method for determining growth of shrimp is the identification of modes in length frequency distributions. Length frequency analyses by MIX 3.0 were performed by giving starting values of the parameters based on a visual inspection of the length distribution and the program then computed iteratively maximum likelihood parameters (Macdonald and Pitcher, 1979). One of the critical points here, was to set the mean of the first mode properly (Fréchette and Parsons, 1983). In that sense, it was crucial that the length distribution contained enough observations of the smallest shrimp (1 year olds). We usually had no problems sampling shrimp smaller than 10 mm because of the little net which was attached to the under belly of the trawl. This advantage clearly made it more easy to determine the first mode, and we consider shrimp in the length interval 6-9 mm in August in Svalbard to be shrimp that hatched the year before. As deep stations are included in all sub areas, no significant problems occured in fixing the oldest age group as is the case in the shallower areas of the Barents Sea (Aschan, MS 1999).

The results in this study indicate that there are variations in growth for shrimp in the Svalbard area (Fig. 3). This may be explained by influence of cold water in Isfjorden compared to the other offshore areas that will be more influenced by warmer Atlantic water. Other similar results have shown that shrimp in areas influenced by cold water show slower growth, delayed maturity and increased longevity would strengthen this argument (Allen, 1959; Rasmussen, 1953; Nilssen and Hopkins, MS 1991).

We could not detect any variations in L50 between sub areas in the Svalbard area (Table 2). Shrimp in Svalbard seem to mature as female within the range of length 23.39-24.43 mm. This is clearly smaller than shrimp from Denmark Strait (Skuladottir, 1998) and Bering Strait (Ivanov, 1969) but very similar to results from the Northwest Atlantic (Parsons *et al*., 1989) and Nordurkantur (Skuladottir, 1998).

Maturity at the age of six for offshore shrimp in Svalbard is not very different from other results for age and female maturity in shrimp populations in northern areas (Table 3). Similar results are found in St. Anthony Bay in

Northwest Atlantic (Parson *et al*., 1989), in Nordurkantur and Denmark Strait in Icelandic waters (Skuladottir, 1998) and in the neighbouring Barents Sea area (Teigsmark, MS 1983, Nilssen and Hopkins, MS 1991 and Aschan, MS 1999). Parsons *et al*. (1989) did also find delayed maturity in Davis Strait which is comparable to our results from Isfjorden and sub area G2 (eight and seven years at first female maturity respectively).

Although we could not detect any variations in L50 between sub areas, there are some indications of variations in length at first maturity as females between years which again may be related to fluctuations in temperature (Table 2).

From 1990 to 1995 the temperature in the Barents Sea was higher than the mean temperature for the last 20 years (Fig. 4). In 1996 the temperature dropped below the mean temperature and it then remain relatively cold for the next three years, until 1998. In the winter 1999 there was observed a significant inflow of warm Atlantic water which again resulted in a pronounced increase in temperature during spring West of Svalbard (Aure *et al*., Havets miljø 1999). The effects of variations in temperature on growth would traditionally be most pronounced in the early life stages. Slow growth as juvenils may have effect on the time spent as males and therby have effect upon age at first female maturation (Anderson, 1991). To detect these variations it is necessary to identify *year-class* growth. This seems to be difficult, but our results show some indications on what to expect when environmental parameters change.

We tried to show how the standarized growth (the length increment for shrimp between three and four years) relates to temperature and biomass density (tons/ naut. mile^2). Low temperature and high biomass density seem to supress growth in Svalbard (Table 3). However, further knowledge about growth on *year-class* level is needed. This reveals the need for a better tool in analysing time series of length frequency data. We would need a model with a linear function and the possibility to include differences in growth as a factor specific for each year (eg. related to temperature).

The very clear difference in growth for shrimp in Isfjorden area compared to the offshore areas will justify the separation of Isfjorden into its own sub area. The delayed maturity in sub area G2 further indicate that Storfjorden is an area that experience larger fluctuations in temperature than the rest of the offshore areas, and therby also justfies a separation into its own sub area. The rest of the offshore areas (G1, H1, H2, H3 and H4) show no differences in growth and age at first female maturation. The lack of variations between these offshore areas are probably a result of the research period. Our results are mainly based on a period when the temperature was high in the Svalbard area and this has probably stabilized the situation in the offshore areas. Since it is nescesary to keep a high solution for detecting changes in growth and maturity performance in time and space, we suggest that the ageing of shrimp should be done separately for all the seven sub areas defined in this paper.

Since the shrimp growth and age at first maturity as females (six years) in the offshore areas has been quite stable over the warm period in the 1990s, we may run one VPA or one production model for the whole offshore area (execept for sub area G2) for the period 1992-98.

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

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. Calculated L50 (mm) of *P. borealis* by area and year of Svalbard

	sampling year							
area	**92**	**93**	**94**	**95**	**96**	**97**	**98**	**mean (area)**
G1	22,82	22,81	22,95	24,47	24,18	-	24,87	23,68
G2	23,29	22,45	24,63	24,02	25,84	25,42	24,92	24,36
H1	23,03	21,82	22,77	22,98	23,07	25,76	24,32	23,39
H2	23,65	22,28	24,55	25,37	24,72	25,86	23,75	24,31
H3	23,61	22,92	23,45	25,00	24,28	25,34	24,00	24,09
H4	23,77	24,66	23,90	25,21	24,53	25,30	23,64	24,43
H5	22,58	23,87	22,84	-	24,97	-	22,93	23,44
I1	20,73	23,00	30,72	23,47	24,40	-	24,08	24,40
mean (year)	22,94	22,98	24,48	24,36	24,50	25,54	24,06	

TABLE 3. Some life history parameters of *P. borealis* in seven different sub areas in Svalbard from 1992-1998. Mean L50 is the mean carapace length where 50% of the population are matured females (females in stage 5-8), AFM is the age at first female maturation, T, is the mean temperature in °C, D is biomass density in t/nm^2 and G is the length increment (mm) between three and four years old shrimp.

Area	Mean L50	AFM	Year	T	D	G
			92	4,6	1,8	2,16
			93	4,4	1,0	3,89
			94	4,4	1,1	2,42
G1	23,68	6	95	4,9	3,0	2,97
			96	3,6	3,2	2,52
			97	3,8	2,8	2,88
			98	3,7	2,3	
			92	4,6	3,4	3,23
			93	4,4	3,7	3,45
			94	4,4	2,1	0,42
G2	24,36	7	95	4,9	3,4	1,63
			96	3,6	4,7	3,02
			97	3,8	3,5	3,25
			98	3,7	2,4	
			92	4,6	5,0	1,49
			93	4,4	3,5	3,24
			94	4,4	1,8	2,52
H1	23,39	6	95	4,9	1,3	3,96
			96	3,6	2,5	1,91
			97	3,8	2,4	2,12
			98	3,7	5,2	
			92	4,6	2,1	2,37
			93	4,4	4,9	2,91
			94	4,4	1,9	2,56
H2	24,31	6	95	4,9	1,7	3,48
			96	3,6	6,9	2,07
			97	3,8	5,4	2,02
			98	3,7	17,5	
			92	4,6	1,0	2,67
			93	4,4	3,2	3,74
			94	4,4	1,8	3,62
H3	24,09	6	95	4,9	2,0	3,06
			96	3,6	8,8	1,75
			97	3,8	4,8	2,71
			98	3,7	9,7	
			92	4,6	5,9	5,27
			93	4,4	5,8	1,03
			94	4,4	4,9	4,03
H4	24,43	6	95	4,9	2,1	2,31
			96	3,6	4,1	1,93
			97	3,8	2,8	2,70
			98	3,7	2,7	
			92	4,6	4,3	1,73
			93	4,4	5,5	1,15
			94	4,4	5,9	3,07
I1	24,40	8	95	4,9	9,5	2,95
			96	3,6	4,6	1,45
			97	3,8	4,8	1,20
			98	3,7	2,5	

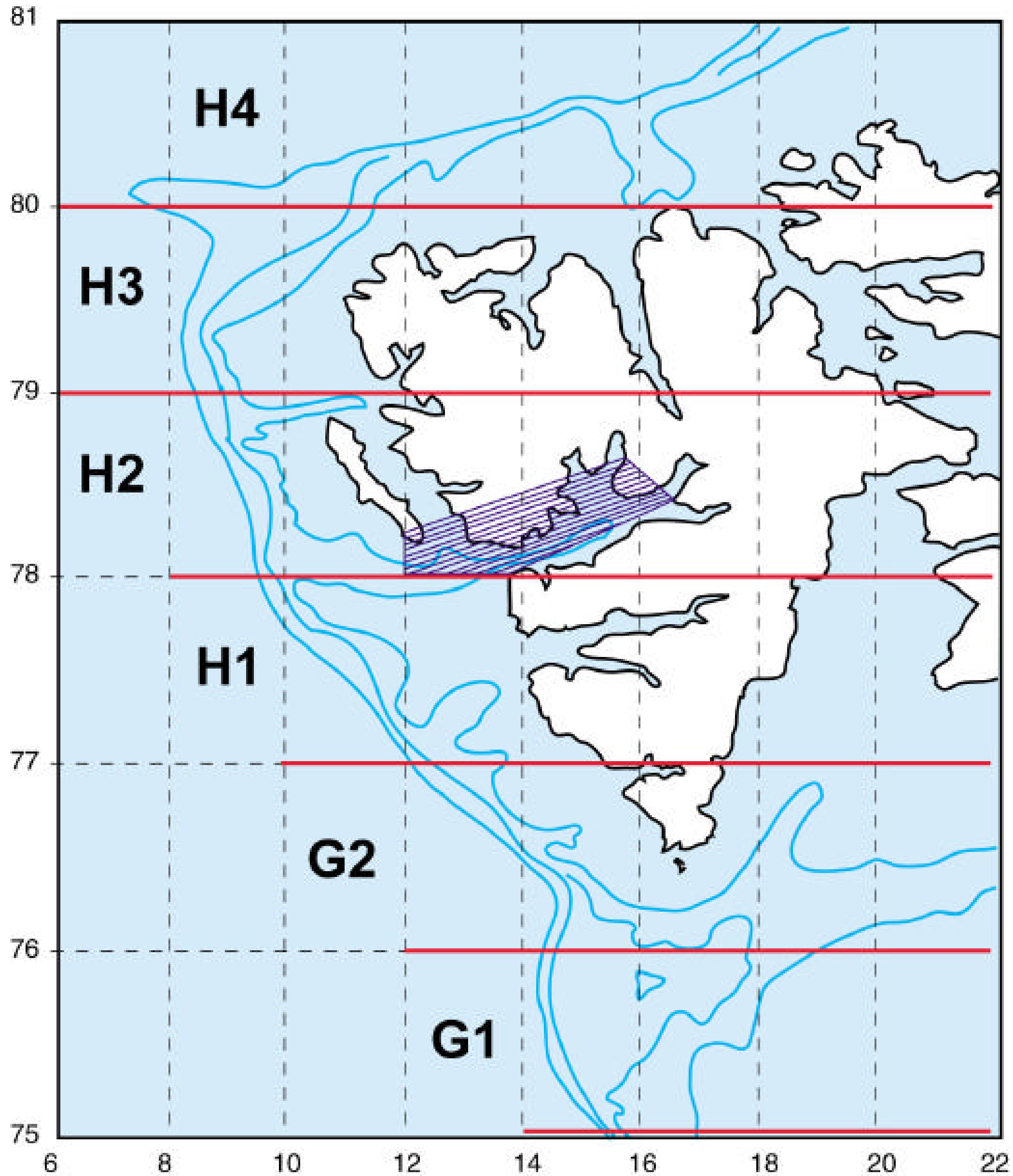

Fig. 1. Sampling strata used in the Svalbard area for shrimp surveys.

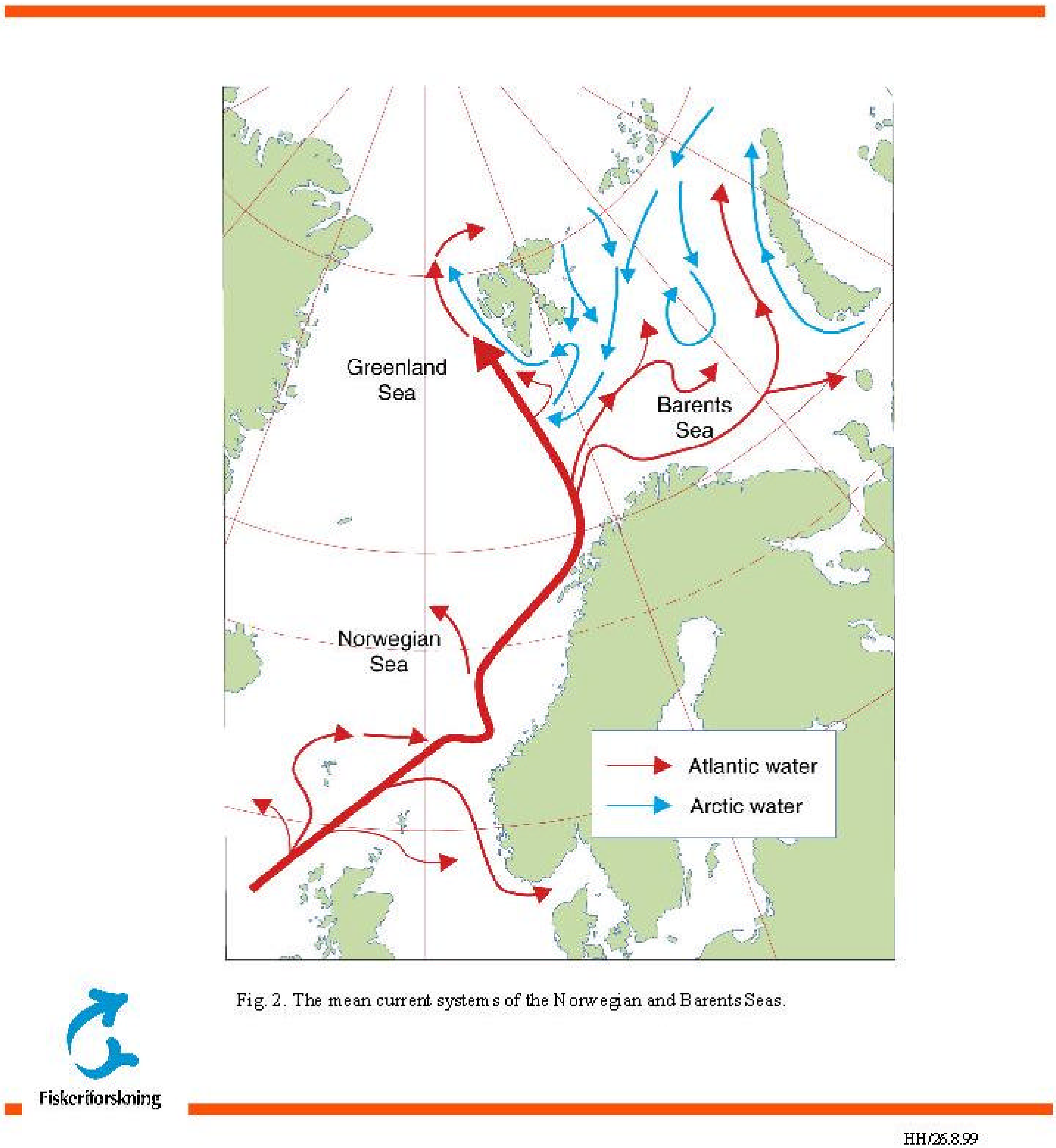

Fig. 2. The mean current systems of the Norwegian and Barents Sea. Based on a figure from Aure *et al*., Havets miljø 1999, FiskenHav, Særnr. 2:1999, 104 pp.

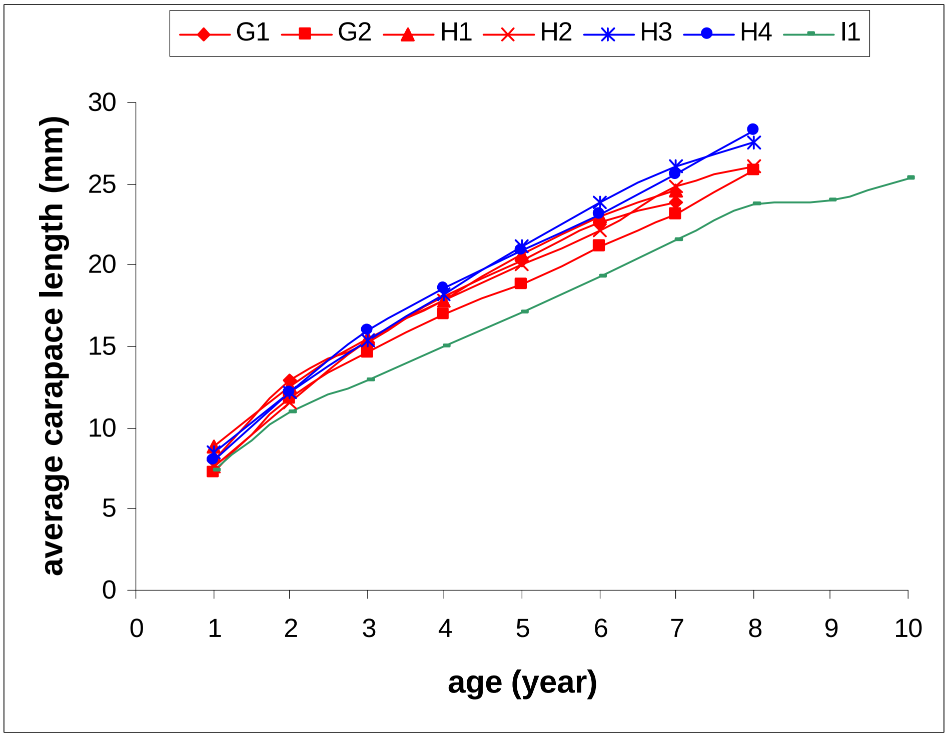

Fig. 3. Average carapace length of P. borealis (mm) by area in Svalbard.

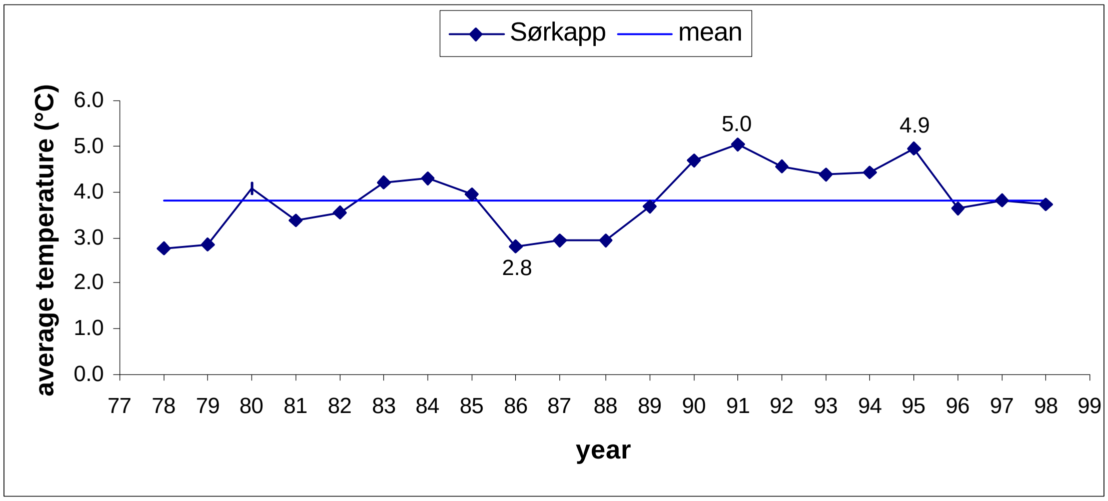

Fig. 4. Average temperature (°C) in each year of Sørkapp, Svalbard. The straight line represent the total mean temperature (3.8°C) from 1978-1998.