Northwest Atlantic Fisheries Organization

Serial No. N5043 **NAFO SCR Doc. 04/73**

SCIENTIFIC COUNCIL MEETING – OCTOBER/NOVEMBER 2004

Abundance, Mean Size at Age and Growth of Northern Shrimp (*Pandalus borealis*) Juveniles and Males off West Greenland in 1993-2004

by

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Abstract

Length frequency distributions of northern shrimp (*Pandalus borealis*) from the West Greenland Bottom Trawl Survey in the years 1993 to 2004 were examined in order to extract mean lengths and abundance indices for age 1 to 4 by modal analysis. The original survey data were aggregated into five major regions defined by latitudinal differences in bottom temperature. Mean size at age differed considerably between regions and years. The changes in mean size at age were positively correlated with bottom temperature for all of the four age groups. A tendency towards smaller size at age and growth rate was observed for the most recent years in which stock density has increased substantially in large parts of the survey area. Abundance at age 2 correlated significantly with the fishable biomass lagged by two and three years. Thus the survey estimates of abundance of age 2 can be regarded as suitable predictors of short-term changes in recruitment to the fishery. Recruitment at age 2 decreased in 2002 and was below average in 2003 as well as in 2004, which suggests that the fishable biomass will decline in the coming years.

Introduction

Recruitment of northern shrimp (*Pandalus borealis*) at West Greenland has previously been assessed based on visual inspection of length frequencies and an abundance index comprising all individuals with a carapace length of less than 17 mm (Kanneworff and Wieland, 2001). Cohorts with a modal length between 13 and 15 mm CL have dominated this size range during the 1990s, but in 2000 smaller individuals (9-0 mm CL) became almost equally abundant. Furthermore, the contribution of larger (>15 mm CL) individuals increased in the past years as a mode between 19 and 20 mm CL has become progressively closer to the limit of 17 mm CL (Kanneworff and Wieland, 2002). Changes in growth make it difficult to assess changes in recruitment using abundance defined by a fixed size limit or by visual inspection of length frequencies. Therefore, Wieland (2002a) presented preliminary abundance indices for northern shrimp at age 1 and 2 by decomposing length frequencies from the West Greenland Bottom Trawl Survey for the years 1993-2002. This analysis has subsequently been modified and extended, and the present paper provides revised estimates of mean length at age and abundance indices for ages 1, 2, 3 and 4 on an area-disaggregated basis for the period 1993 to 2004.

Material and Methods

The West Greenland Bottom Trawl Survey for northern shrimp and fish has been conducted by the Greenland Institute of Natural Resources since 1988. The design of the survey has been subject to various changes. Major modifications include several extensions of the survey area and a reduction of the mesh size of the cod-end liner from 44 to 20 mm in 1993 (Carlsson *et al*., 2000). Due to the latter, the present analysis is limited to the years 1993 and thereafter. The survey design, fishing practice and procedure for sample analysis is described in Wieland *et al.* (2004).

Swept area estimates of northern shrimp abundance by 0.5 mm carapace length (CL) interval from the original survey strata at depths between 150 and 600 m were aggregated according to five regions (Fig. 1). The regions were defined mainly based on latitudinal gradients of bottom temperature for which pronounced differences in the survey area have been observed in particular in the past years (Fig. 2). The bottom temperatures were measured on trawl sites with a Seabird CTD in 1991-1994 and since 1995 along the trawl tracks in intervals of 30 to 60s with Seamon data storage sensors mounted on one of the trawl doors (Wieland *et al.*, 2004). Average bottom temperatures at the sampling sites were then used to calculate mean bottom temperatures weighted by stratum area for the five regions.

Modal analysis of the regional length frequencies for juveniles and males were conducted using the MIX 3.1A software (MacDonald and Pitcher, 1979; MacDonald and Green, 1988; release 3.1A by Ichthus Data Systems in 1993). No smoothing of the length frequency histograms was applied prior to the analysis. Initial estimates of the modes and the number of age groups to be considered were obtained by visual inspection of the length frequencies. The maximum recognized age in these length frequencies varied between years and regions (Table 1) reflecting differences in the length and age at sex transition (Wieland, 2004). A constant coefficient of variation for length at age was used in the MIX analysis during a first run. However, because the first age group was not well represented in many of the samples, a part of the larger males had already changed sex and differences in growth between cohorts were likely, varying coefficients of variation were used in another run. This gave almost more realistic results. In some cases, the mean length of a specific age group was fixed in the MIX analysis, and these values were discarded from further evaluation of length at age and growth.

Two of the five regions, in which differences in average bottom temperature related to bathymetry were observed in most of the years (Wieland and Kanneworff, 2002), were divided into a shallow (150-300 m) and a deep (300-600 m) part. Modal analyses were carried out for the two depth intervals separately and, for subsequent analysis, mean lengths at age for these two regions were calculated weighted by abundance of the specific age group in the respective depth range.

Spearman rank correlation analysis, which avoids the assumption of linearity and which is robust against outliers (Sokal and Rohlf, 1995), was applied to study the potential effect of bottom temperature on length at age. Averages of annual mean bottom temperatures, which included the current year as well as one, two, three and four preceded years were used for age 1, 2, 3 and 4, respectively, in order to cover the period from the year of settling until the year in which they were caught. Spearman rank correlation analysis was also used to analyse possible relationships between growth rate and stock density, and Pearson product moment correlation analysis, which assumes a linear relationship (Sokal and Rohlf, 1995), was carried out additionally for one of the survey regions in which high stock densities were observed in the past years.

Results

Mean size and growth

Length frequencies of northern shrimp (juveniles and males) by region and year with fitted Gaussian components for age 1, 2, 3, 4 and 5+ are shown in Fig. 3 to 14. Further results of the modal analysis, i.e. mean length, its standard deviation and the corresponding coefficient of variation, are listed in Tables 2 to 5 for the different age groups.

The Gaussian components fitted the observed distribution in the size range of the different age groups reasonably well in almost all years and regions. However, difficulties occurred in the analysis for the 1-group in region 1 in some years and for both, the 1- and the 2-group in region 5 in most of the years. In both cases the encountered problems were due to low abundance of individuals in the corresponding size range.

Annual differences in the mean length at age between the five regions were as large as 3.7 mm CL for age 1, 3.3 mm CL for age 2, 3.9 mm CL for age 3 and 4.1 mm CL for age 4. The coefficients of variation corresponding to the estimates of mean length at age were about 0.09 for age 1 and 2 and about 0.06 for age 3 and age 4 on average.

In general, mean length at age was lower in the north than in the south. In all regions mean length at age increased during the second half of the 1990s but decreased again in the most recent years (Tables 2-5). Spearman rank correlation coefficients indicated a highly significant effect of bottom temperature for all of the four age groups considered (Fig. 15). However, a considerable variation in length at age without a corresponding change in bottom temperature was found for all ages in regions 2, 3 and 4 as well as for age 1, 3 and 4 in region 5 for the most recent years, and it is noteworthy that length at age 2, 3 and 4 did not increase further when temperature exceeded approximately 3°C.

Despite a high variability of length increments from age 1 to age 2 for all year-classes (1992-2003), a continuous decrease in growth was found in region 2 for all years after 1998 (Fig. 16). Growth rates varied considerably also for age 2 (year-classes 1991-2002) and age 3 (year-classes 1990-2001), but a consistent trend towards slower growth was detected in almost all regions since the late-1990s when temperature was stable at a relative high level. Spearman rank correlation coefficients indicate that the decline in growth rate is significantly related to an increase in stock density with all regions and years included only for age 1. In region 2, however, significant linear correlations were observed for age 1 and age 2 in the past years at stock densities above 4.5 g/m² (Fig. 16).

Abundance indices

High abundance of age 1 was regularly observed in region 4 (offshore between 61°45’ and 65°45’N) and since 1997 also in regions 2 (Disko Bay/Vaigat) and 3 (offshore between 65°45’ and 69°30’N) while the contributions from regions 1 (offshore north from 69°30’N) and 5 (offshore south from 61°45’N) to the total abundance for the entire survey area were negligible in almost all years (Fig. 17). Total abundance of age 1 was exceptional high in 2000 whereas the 2004 value amounts only to about 15% of the average of the time series.

At age 2, northern shrimp was found in regions 3 and 4 in all years and since 1996 with considerable numbers also in region 2 (Fig. 17). It is worth to note that region 2, which accounts only for about 7% of the total survey area, contributed between 30 and 44% to the total abundance of this age group in the period 1997 to 2002. In addition, the 2-group was fairly abundant in region 1 in the years 1999 to 2001, 2003 and 2004 whereas it was nearly absent in region 5 throughout the entire time series. Total abundance of age 2 has increased since 1997 to the highest value on record in 2001, decreased in 2002 and 2003 and was 13% below average in 2004.

Age groups 3 and 4 occurred regularly in regions 2, 3 and 4, and in most of the years also in region 5, but were found in region 1 with increasing quantities first in the last four years (Fig. 17). Total abundance of age 3 and age 4 was highest in 2002 and 2003, respectively, and the 2004 values are still considerably above average.

Relative year-class strength as measured at ages 1, 2, 3 and 4 can well be identified in the time series of the abundance indices (Fig. 17), except for the 1994 and the 2000 year-class, which appeared rather small at age 1. It is further remarkable, that the 1994 year-class was weaker at age 3 than expected from the age 2 abundance index in 1996. Nonetheless, abundance at age 2 was significantly correlated with abundance at age 1 a year before and with abundance at age 3 in the following year and even a closer correlation was found between year-class strength measured at age 3 and 4 (Fig. 17).

Recruitment at age 2 and fishable biomass in subsequent years

The abundance indices for age 2 showed significant correlations with the fishable biomass (all shrimp >17 mm CL) two and three years later (Fig. 18). Other time lags, i.e. one and four years, did not yield such significant results. The relationship obtained for a lag of three years suggests a decrease of fishable biomass from its record high level of about 582000 t in 2004 to approximately 410 000 tons in 2005, 305 000 tons in 2006 and 320 000 tons in 2007, but the large confidence and prediction intervals of the linear regression indicate that these estimates are attributed with a high uncertainty.

Discussion

Length frequency distributions of northern shrimp from a stratified-random survey were aggregated into five regions, which were defined by differences in mean bottom temperature. The regional length frequencies allowed the extraction of mean size and abundance for ages 1 to 4 by modal analysis with the aid of MIX (MacDonald and

Green, 1988). In general, reasonable fits of Gaussian components were obtained. Some uncertainties concerning the interpretation of the length frequencies remain, but these are limited to regions and years with low numbers of individuals in the corresponding size range and thus their effect on the estimates of total abundance in the survey area can be regarded as small.

Mean lengths at age 1, 2, 3 and 4 were significantly correlated with bottom temperature, which supports the option used in the modal analysis rejecting constant coefficients of variation for different cohorts. The duration of the egg-bearing period, which amounts to about 8 to 9 months in West Greenland waters (Horsted and Smidt, 1956), is inversely related with temperature (Bergström, 2000). The increase in mean size in the initial years when the temperature changed to relative warm conditions may thus have been a result of earlier larval hatch and a longer feeding period during the first year of life. But in the most recent years in which temperature was almost stable at a relative high level, a decrease in mean length at age and a tendency towards lower growth rates was observed. This was likely related to an increase in stock density and the decrease in size at age and growth was most pronounced in those parts of the survey area in which the highest densities have been recorded. The results on the effect on temperature and stock density on size at age and growth, however, should be regarded as preliminary due some uncertainty in the modal analysis mentioned above. The length frequencies for the Disko Bay/Vaigat area appear to be most promising for further analysis, e.g. concerning spatial heterogeneity within that region. Furthermore, an extension of the analysis, which includes the female stages, may provide results on temperature and density-dependent effects for a detailed comparison with findings for other shrimp stocks.

The abundance indices for age 1 were, on average, about 50% below those for age 2, and the relation of year-class strength measured at these two ages showed a considerable variability. Low and varying catchability of the 1-group can be regarded as responsible for this. Processes involved include mesh size selection of the trawl, which appears to be most important for individuals with a carapace length less than 11 mm (Wieland, 2002b), escapement of juveniles beneath the footrope (Nilssen *et al.*, 1986) and immigration from settling areas located at depths shallower than 200 m which are less intensively covered by the survey (Wieland and Carlson, 2001). These processes are size-dependent and are thus subject to the observed change in growth. Hence, the abundance indices as well as the mean lengths and consequently the growth rates for the 1-group as presented in this study should be treated with much caution.

Year-class strength estimated at age 2 amounted to about 75% of the values obtained for age 3 a year later and the two abundance indices corresponded closely in general. This makes it likely that the assumption of constant catchability is met although the 2-group is not fully retained in the survey trawl and a decrease of its mean size was observed in the past years. Hence, the age 2 abundance indices can be regarded as suitable to assess changes in the recruitment to the exploitable stock.

The time lag of two and three years in the correlation between recruitment at age 2 and fishable biomass is reasonable considering that the main contribution comes from individuals in the size range of age 4 and 5 (Wieland *et al.*, 2004). Although the relationships between recruitment at age 2 and fishable biomass two and three years later were significant, it must be kept in mind that the predictions for coming years are only valid if the overall effect from the underlying processes like growth, natural mortality (e.g. predation by cod) and removal by the fishery relative to stock size (exploitation rate) do not change.

References

BERGSTRØM, B. I. 2000. The biology of *Pandalus*. *Advances in Marine Biology*, **38**: 56-245.

CARLSSON, D, O. FOLMER, P. KANNEWORFF, M. KINGSLEY, and M. PENNINGTON. 2000. Improving the West Greenland Trawl Survey for shrimp (*Pandalus borealis*). *J. Northw. Atl. Fish. Sci*., **27**: 151-160.

HORSTED, S.A. and E. SMIDT, 1956. The deep sea prawn (*Pandalus borealis* Kr) in Greenland waters. *Medd. Danm. Fisk. Havunders. N.S.*, Vol. **I**(11), 118 p.

KANNEWORFF, P., and K. WIELAND. 2001. Stratified-random trawl survey for northern shrimp (*Pandalus borealis*) in NAFO Subareas 0+1 in 2001. *NAFO SCR Doc*., No. 175, Serial No. N4520, 23 p.

KANNEWORFF, P., and K. WIELAND. 2002. Stratified-random trawl survey for northern shrimp (*Pandalus borealis*) in NAFO Subareas 0+1 in 2002. *NAFO SCR Doc*., No. 148, Serial No. N4777, 25 p.

MACDONALD, P. D. M., and T. J. PITCHER. 1979. Age-groups from size-frequency data: A versatile and efficient method of analysing distribution mixtures. *J. Fish. Res. Board Can*., **36**: 987-1001.

MACDONALD, P. D. M., and P. E. J. GREEN. 1988. User's guide to program MIX: an interactive program for fitting mixtures of distributions. Release 2.3, January 1988. Ichthus Data Systems, Hamilton, Ontario, 60 p.

NILSSEN, E. M., R. B. LARSSEN, and C. C. HOPKINS. 1986. Catch and size-selection of *Pandalus borealis* in a bottom trawl and implications for population dynamics analyses. *ICES C.,M. Doc*., No. 1986/K:4.

SOKAL, R. R., and F. J. ROHLF. 1995. Biometry – The principles and practice of statistics in biological research. 3rd edition. W.H. Freeman and Company, New York, 887 p.

WIELAND, K. 2002a. Abundance indices for juvenile (age 1 and 2) Northern shrimp (*Pandalus borealis*) off West Greenland (NAFO Subareas 0+1), 1993-2002. *NAFO SCR Doc*., No. 146, Serial No. N4775, 20 p.

WIELAND, K. 2002b. The use of fine-meshed bags for sampling juvenile Northern shrimp (*Pandalus borealis*) in the West Greenland Bottom Trawl Survey. *NAFO SCR Doc*., No. 145, Serial No. N4774, 11 p.

WIELAND, K. 2004. Length at sex transition in northern shrimp (*Pandalus borealis*) off West Greenland in relation to changes in temperature and stock size. *Fish. Res*., 69: 49-56.

WIELAND, K., and D. M. CARLSSON, 2001. Geographical distribution and mean size of different life stages of northern shrimp (*Pandalus borealis*) off West Greenland. *NAFO SCR Doc*., No. 178, Serial No. N4567, 15 p.

WIELAND, K., and P. KANNEWORFF. 2002. Bottom temperature on West Greenland shrimp fishing grounds in 1993-2002. *NAFO SCR Doc*., No. 162, Serial No. N4791, 5 p.

WIELAND, K., P. KANNEWORFF, and B. BERGSTRÖM. 2004. Results of the Greenland Bottom Trawl Survey for Northern shrimp (*Pandalus borealis*) off West Greenland (NAFO Subarea 1 and Division 0A), 1988-2004. *NAFO SCR Doc*., No. 72, Serial No. N5042, 31 p.

Table 1. Age groups considered in the MIX analysis of length frequencies of northern shrimp males and juveniles off West Greenland 1993-2004 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300m, deep: 300-600 m).

	Region						
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	1 - 6	1 - 6	1 - 6	1 - 6	1 - 5	1 - 5	1 - 5
1994	2 - 6	1 - 5	1 - 5	1 - 5	2 - 5	1 - 5	1 - 5
1995	1 - 6	1 - 5	1 - 5	1 - 5	1 - 5	1 - 4	1 - 5
1996	2 - 6	1 - 6	2 - 6	1 - 4	1 - 4	1 - 4	2 - 5
1997	2 - 6	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	2 - 5
1998	1 - 6	1 - 5	1 - 4	1 - 5	1 - 5	1 - 5	1 - 5
1999	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 4
2000	1 - 5	1 - 4	1 - 4	1 - 4	1 - 4	1 - 5	1 - 4
2001	1 - 6	1 - 4	1 - 4	1 - 4	1 - 4	1 - 5	1 - 5
2002	2 - 5	1 - 5	1 - 4	1 - 4	1 - 4	1 - 4	1 - 4
2003	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 4	1 - 5
2004	2 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5	1 - 5

Table 2. Mean carapace length (mm) and coefficient of variation for northern shrimp at age 1 off West Greenland 1993-2004 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m; ( ): fixed, -: not present).

mean:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	(7.5)	(8.0)	8.0	8.5	10.6	9.4	(11.5)
1994	-	7.8	7.8	(8.0)	-	8.8	(11.5)
1995	(8.8)	8.4	8.3	8.5	10.7	8.8	(10.5)
1996	-	(8.5)	-	(7.5)	9.0	9.1	-
1997	-	8.5	9.1	8.9	10.2	8.7	-
1998	8.2	9.5	9.6	9.6	10.9	11.3	11.8
1999	9.2	10.2	9.3	9.2	10.3	11.6	11.8
2000	7.9	8.8	8.7	9.1	9.2	(11.0)	10.9
2001	8.4	8.8	7.6	8.0	8.7	(8.5)	11.4
2002	-	8.6	8.6	9.0	9.1	10.1	10.4
2003	6.7	8.1	8.2	7.7	8.8	9.8	(10.5)
2004	-	7.8	(9.5)	9.5	9.2	(10.0)	11.5

standard deviation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	(0.50)	(0.50)	0.85	0.67	0.92	0.72	(0.60)
1994	-	0.48	0.48	(0.80)	-	0.84	(0.55)
1995	(0.60)	0.56	0.69	0.96	1.05	0.87	(0.50)
1996	-	(0.80)	-	(0.70)	0.61	1.03	-
1997	-	0.73	0.98	0.71	1.19	0.88	-
1998	0.85	0.81	0.88	0.90	1.14	1.15	0.85
1999	0.78	1.11	0.87	0.81	1.27	0.72	0.83
2000	0.61	0.86	0.73	0.79	0.86	(0.75)	0.60
2001	0.74	1.00	0.85	0.94	1.12	(0.70)	0.56
2002	-	0.74	0.66	0.81	0.88	1.17	0.82
2003	0.65	0.71	0.69	0.70	0.63	0.81	(0.80)
2004	-	0.89	(0.79)	(0.90)	0.85	(0.60)	

coefficent of variation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	(0.07)	(0.06)	0.11	0.08	0.09	0.08	(0.05)
1994	-	0.06	0.06	(0.10)	-	0.10	(0.05)
1995	(0.06)	0.07	0.08	0.11	0.10	0.10	(0.05)
1996	-	(0.07)	-	(0.09)	0.07	0.11	-
1997	-	0.09	0.11	0.08	0.12	0.10	-
1998	0.10	0.09	0.09	0.09	0.11	0.10	0.07
1999	0.08	0.11	0.09	0.09	0.12	0.06	0.07
2000	0.08	0.10	0.08	0.09	0.09	(0.07)	0.05
2001	0.09	0.11	0.11	0.12	0.13	(0.08)	0.05
2002	-	0.09	0.08	0.09	0.10	0.12	0.08
2003	0.10	0.09	0.08	0.09	0.07	0.08	(0.80)
2004	-	0.11	(0.08)	(0.09)	0.09	(0.06)	(0.80)

Table 3. Mean carapace length (mm) coefficient of variation for northern shrimp at age 2 off West Greenland 1993-2004 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m; ( ): fixed, -: not present).

mean:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	11.2	12.6	12.3	13.1	14.8	13.6	(14.0)
1994	(11.5)	11.6	12.3	13.1	14.7	13.8	-
1995	11.2	12.5	13.5	14.1	15.2	12.9	(12.5)
1996	11.9	13.0	14.2	13.9	13.9	14.6	(14.0)
1997	12.9	12.9	14.2	14.2	14.6	14.3	(13.0)
1998	12.5	13.9	14.0	14.8	15.6	16.2	(15.0)
1999	14.5	15.2	15.0	14.9	15.0	15.8	(15.5)
2000	13.9	14.9	14.8	14.9	14.8	15.9	(13.0)
2001	14.0	13.1	13.2	13.5	13.7	(15.0)	(13.5)
2002	13.1	12.6	12.8	12.7	14.8	(15.0)	(13.5)
2003	11.9	12.4	13.0	12.6	14.3	13.7	(14.5)
2004	12.0	11.6	12.3	13.0	14.2	(15.5)	15.1

standard deviation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	0.82	1.30	1.11	1.00	0.83	0.84	(0.70)
1994	(0.70)	1.10	1.17	1.15	0.99	1.64	-
1995	0.79	0.99	1.40	1.37	0.79	1.35	(0.60)
1996	0.80	1.05	1.05	1.19	1.64	1.39	(0.70)
1997	1.16	1.08	1.17	1.11	1.22	1.63	(0.60)
1998	1.51	1.36	1.07	1.65	1.01	1.10	(0.80)
1999	1.35	1.29	1.19	1.46	1.43	1.22	(0.70)
2000	1.50	1.34	1.19	1.43	1.50	1.09	(0.90)
2001	1.54	1.24	1.31	1.25	1.10	(0.80)	(0.70)
2002	1.30	1.12	1.30	1.41	1.45	(0.80)	(0.65)
2003	0.99	1.26	1.20	1.15	1.18	1.13	(0.90)
2004	1.09	1.00	1.06	1.30	1.27	(0.70)	0.65

coefficent of variation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	0.07	0.10	0.09	0.08	0.06	0.06	(0.05)
1994	(0.06)	0.09	0.09	0.09	0.07	0.12	-
1995	0.07	0.08	0.10	0.10	0.05	0.10	(0.05)
1996	0.07	0.08	0.07	0.09	0.12	0.09	(0.05)
1997	0.09	0.08	0.08	0.08	0.08	0.11	(0.05)
1998	0.12	0.10	0.08	0.11	0.06	0.07	-
1999	0.09	0.08	0.08	0.10	0.10	0.08	(0.05)
2000	0.11	0.09	0.08	0.10	0.10	0.07	(0.07)
2001	0.11	0.09	0.10	0.09	0.08	(0.05)	(0.05)
2002	0.10	0.09	0.10	0.11	0.10	(0.05)	(0.05)
2003	0.08	0.10	0.09	0.09	0.08	0.08	(0.08)
2004	0.09	0.09	0.09	0.10	0.09	(0.05)	0.04

Table 4. Mean carapace length (mm) and coefficient of variation for northern shrimp at age 3 off West Greenland 1993-2004 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m ( ): fixed).

mean:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	16.0	16.0	16.1	16.5	17.5	17.3	17.2
1994	(15.5)	15.9	16.4	17.8	18.6	17.9	19.0
1995	14.7	16.3	17.7	17.4	17.6	18.0	18.6
1996	14.2	16.7	17.3	17.7	17.2	18.4	(16.5)
1997	16.0	17.1	17.3	17.7	18.4	17.8	18.2
1998	16.4	17.4	16.7	17.8	17.2	18.5	17.5
1999	(18.5)	18.0	17.8	18.2	18.6	19.7	19.1
2000	17.8	18.7	18.8	18.9	18.0	19.1	17.9
2001	17.5	18.1	18.0	18.6	18.5	18.7	18.2
2002	17.7	16.6	16.8	17.8	18.0	18.6	17.4
2003	16.5	15.7	15.8	16.3	18.0	18.9	18.3
2004	15.5	15.3	16.5	17.8	18.4	18.7	18.6

standard deviation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	1.18	0.95	1.41	1.05	1.22	1.37	0.85
1994	(0.80)	0.89	1.15	1.45	1.15	1.17	0.91
1995	1.05	1.09	1.06	0.82	0.81	1.49	0.70
1996	1.14	0.90	0.70	0.90	1.03	0.90	(0.80)
1997	1.12	0.95	1.42	1.43	1.19	0.95	0.77
1998	1.25	1.08	1.11	0.88	0.90	1.03	0.89
1999	(1.10)	1.07	0.96	1.08	1.22	1.35	1.20
2000	1.54	1.00	0.93	1.05	1.18	1.55	1.24
2001	1.09	1.08	0.94	1.15	1.41	1.21	1.08
2002	1.22	1.09	1.10	1.19	1.01	1.04	1.33
2003	1.29	1.35	1.14	1.34	1.21	1.11	1.35
2004	1.01	1.47	1.35	1.45	1.40	1.18	0.80

coefficent of variation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	0.07	0.06	0.09	0.06	0.07	0.08	0.05
1994	(0.05)	0.06	0.07	0.08	0.06	0.07	0.05
1995	0.07	0.07	0.06	0.05	0.05	0.08	0.04
1996	0.08	0.05	0.04	0.05	0.06	0.05	(0.05)
1997	0.07	0.06	0.08	0.08	0.06	0.05	0.04
1998	0.08	0.06	0.07	0.05	0.05	0.06	0.05
1999	(0.06)	0.06	0.05	0.06	0.07	0.07	0.06
2000	0.09	0.05	0.05	0.06	0.07	0.08	0.07
2001	0.06	0.06	0.05	0.06	0.08	0.07	0.06
2002	0.07	0.07	0.07	0.07	0.06	0.06	0.08
2003	0.08	0.09	0.07	0.08	0.07	0.06	0.07
2004	0.07	0.10	0.08	0.08	0.08	0.06	0.04

Table 5. Mean carapace length (mm) and coefficient of variation for northern shrimp at age 4 off West Greenland 1993-2004 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m ( ): fixed).

mean:

	Region						
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	18.1	18.4	18.1	18.5	20.0	20.2	20.2
1994	18.9	18.5	19.6	21.7	20.9	20.7	21.1
1995	18.3	20.0	20.5	20.0	20.6	21.8	20.8
1996	17.2	18.8	19.5	21.3	20.0	21.6	20.9
1997	17.8	19.7	18.7	19.8	20.6	20.0	20.6
1998	18.9	19.9	20.5	20.0	20.1	20.7	20.2
1999	(21.1)	20.2	19.7	19.9	20.9	22.0	21.4
2000	19.5	21.6	20.9	21.5	20.6	21.2	21.4
2001	19.3	21.0	20.6	21.4	21.2	21.0	20.2
2002	20.5	20.5	20.0	21.2	20.4	21.1	20.5
2003	19.8	18.8	19.0	19.4	20.9	21.0	20.0
2004	18.5	18.7	18.9	19.8	21.3	21.3	20.9

standard deviation:

	Region						
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	1.10	0.77	1.01	0.89	1.06	1.40	1.28
1994	1.42	1.18	1.52	1.00	1.20	1.48	1.02
1995	0.89	1.40	1.18	1.43	1.14	1.20	1.35
1996	1.05	0.89	0.74	1.50	1.44	1.37	1.34
1997	0.82	0.85	0.90	1.06	1.60	0.92	1.27
1998	0.95	0.90	1.27	1.16	1.40	1.17	1.15
1999	(1.20)	1.28	1.10	1.05	1.35	1.00	1.28
2000	0.90	1.48	1.21	1.24	1.37	1.25	1.34
2001	1.10	1.04	1.26	1.16	1.18	1.02	1.00
2002	0.86	1.48	1.53	1.28	1.37	1.07	1.47
2003	1.16	1.30	1.32	1.12	1.11	1.35	1.15
2004	1.16	1.71	1.30	1.27	0.94	0.95	0.90

coefficent of variation:

	Region						
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	0.06	0.04	0.06	0.05	0.05	0.07	0.06
1994	0.08	0.06	0.08	0.05	0.06	0.07	0.05
1995	0.05	0.07	0.06	0.07	0.06	0.05	0.07
1996	0.06	0.05	0.04	0.07	0.07	0.06	0.06
1997	0.05	0.04	0.05	0.05	0.08	0.05	0.06
1998	0.05	0.05	0.06	0.06	0.07	0.06	0.06
1999	(0.06)	0.06	0.06	0.05	0.06	0.05	0.06
2000	0.05	0.07	0.06	0.06	0.07	0.06	0.06
2001	0.06	0.05	0.06	0.05	0.06	0.05	0.05
2002	0.04	0.07	0.08	0.06	0.07	0.05	0.07
2003	0.06	0.07	0.07	0.06	0.05	0.06	0.06
2004	0.06	0.09	0.07	0.06	0.04	0.04	0.04

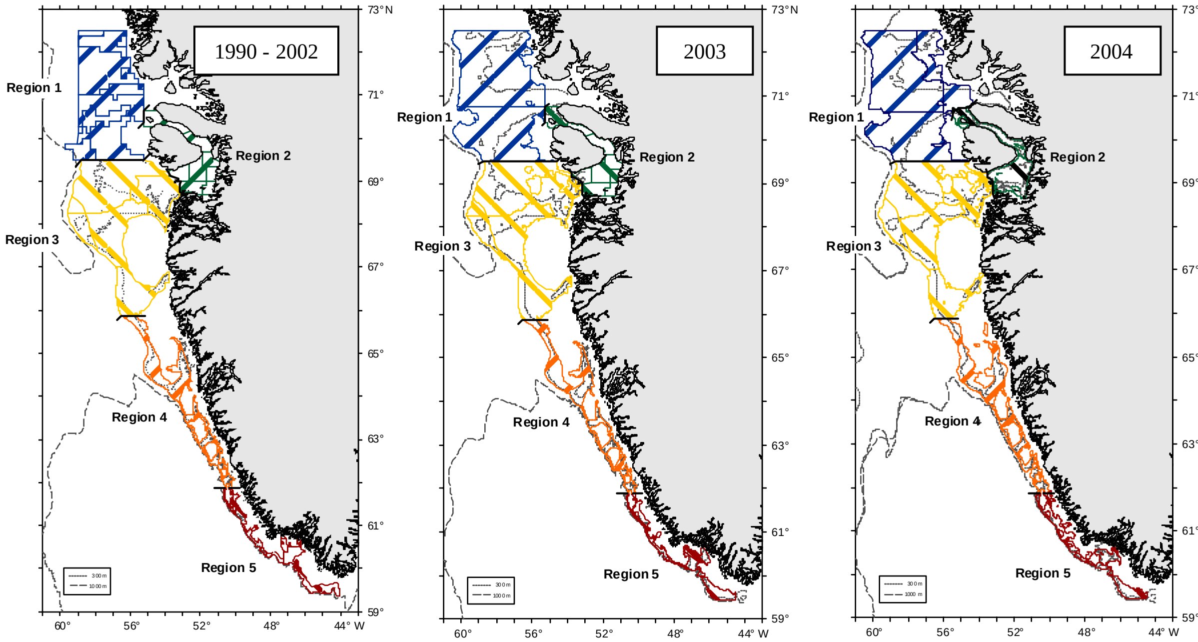

Fig. 1. Survey stratification in the West Greenland Bottom Trawl Survey for northern shrimp in 1990 to 2002, in 2003 and in 2004

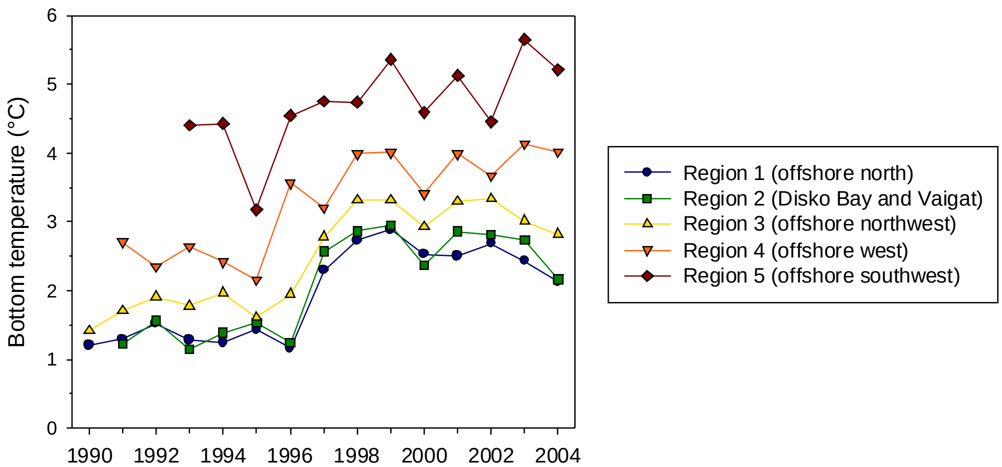

Fig. 2. Bottom temperature in the five regions of the survey area in 1990 to 2004.

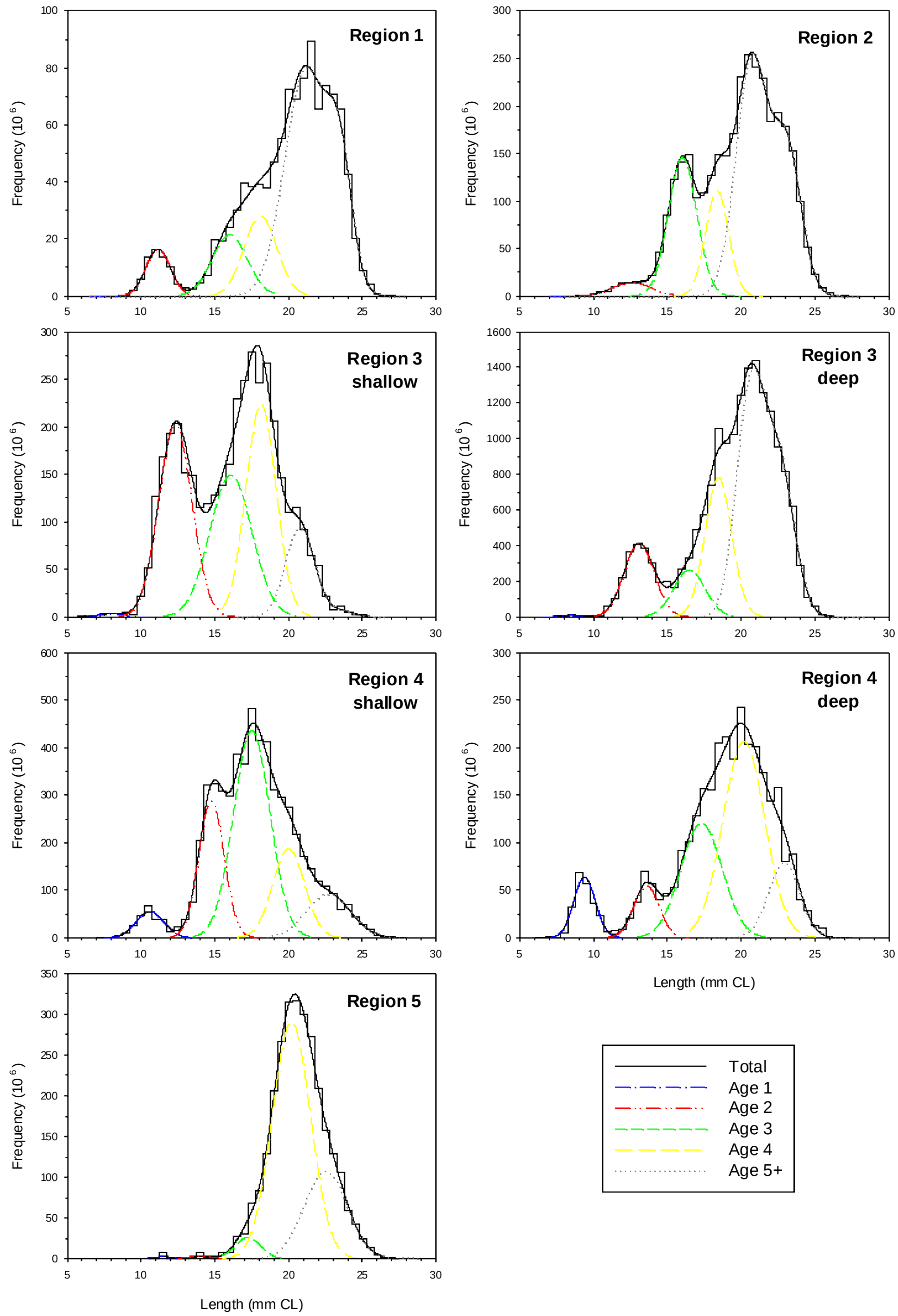

Fig. 3. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1993 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

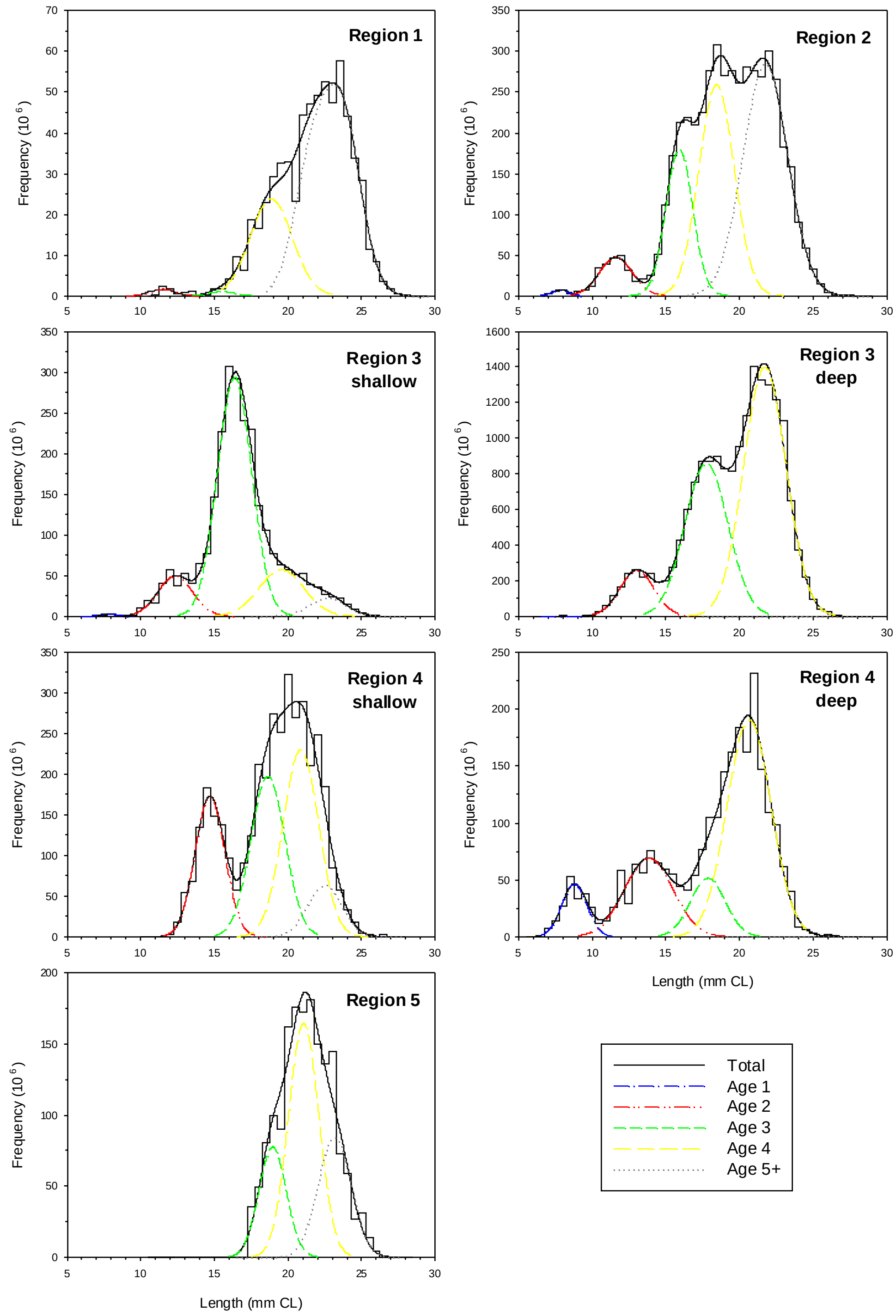

Fig. 4. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1994 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

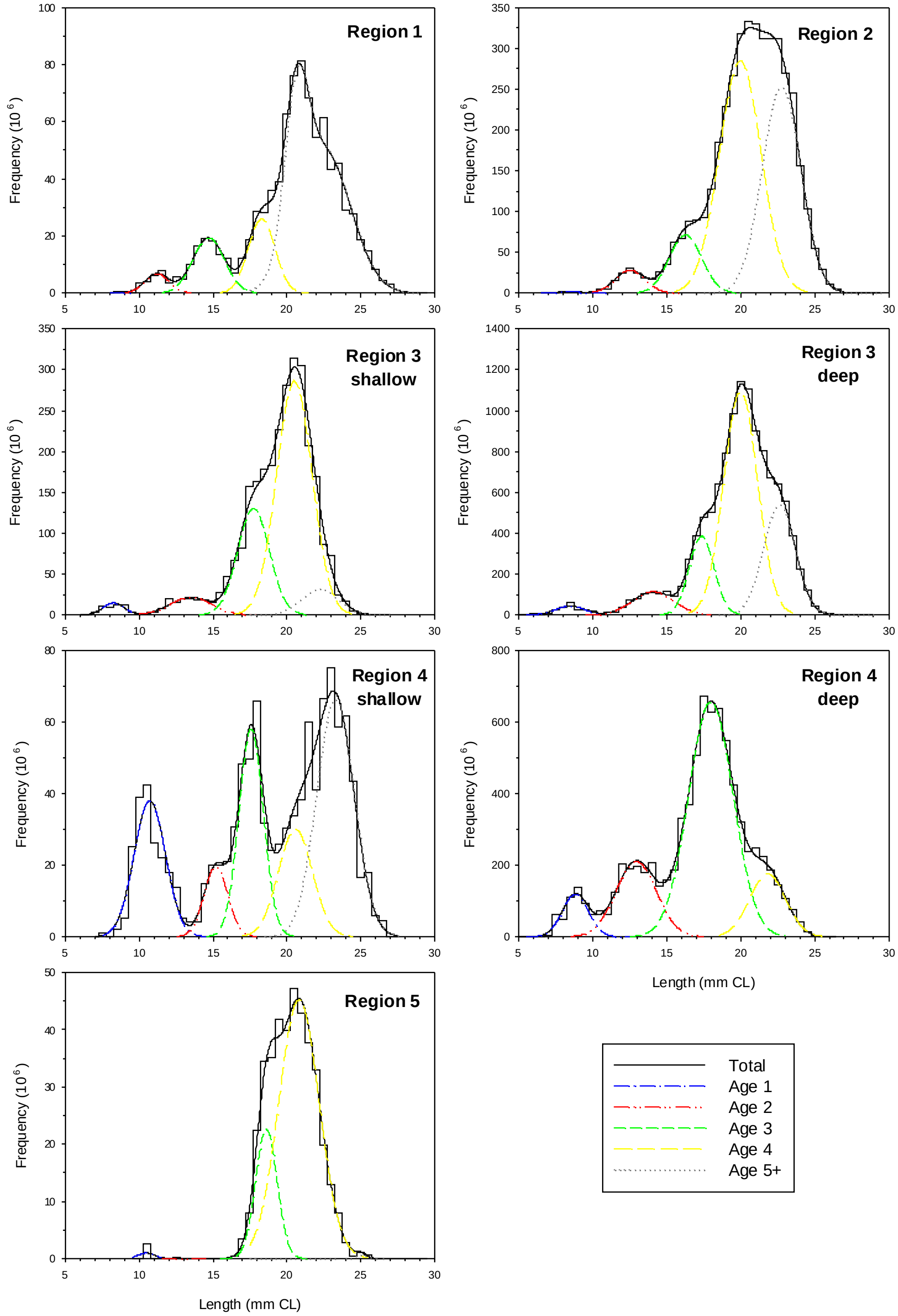

Fig. 5. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1995 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

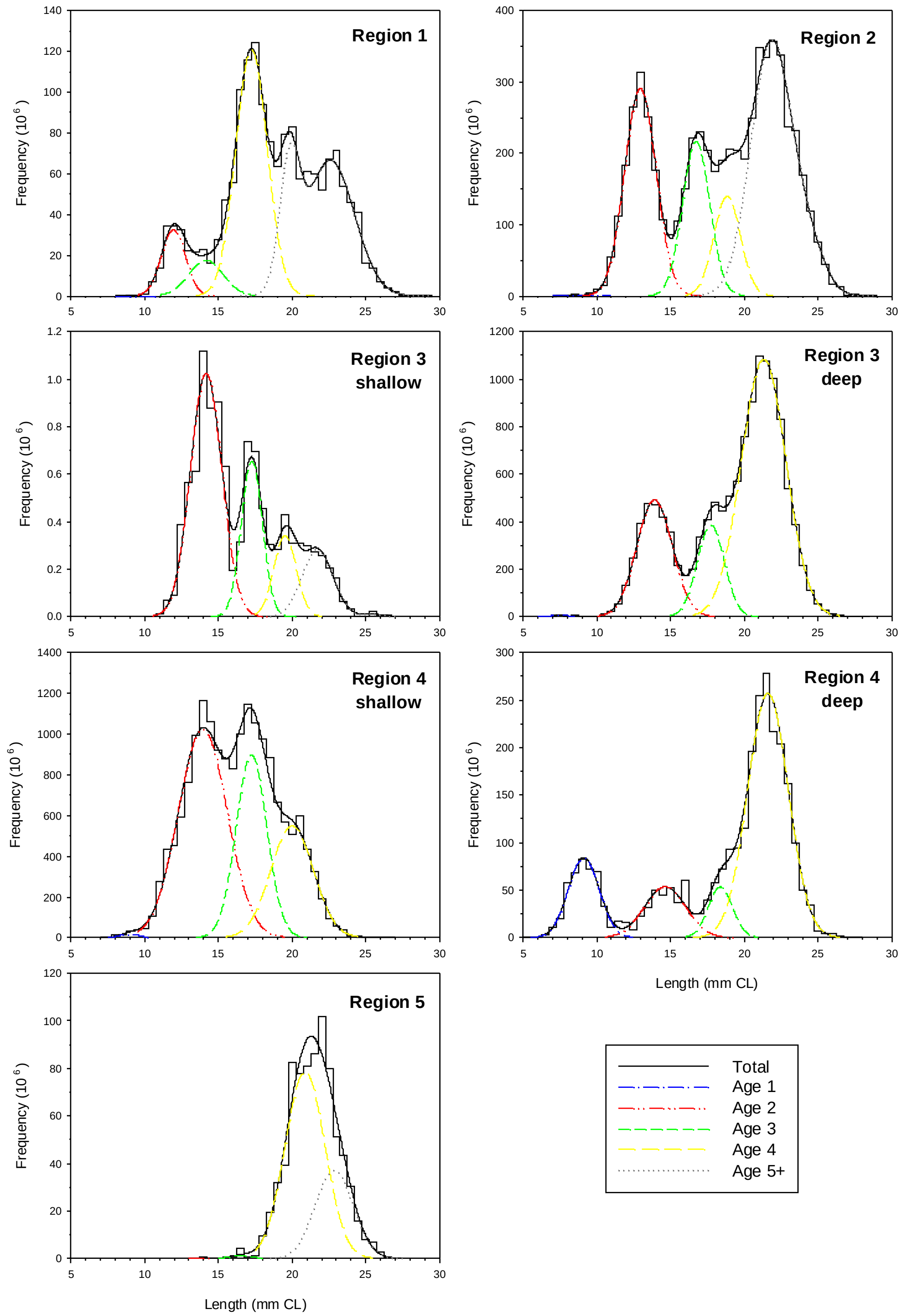

Fig. 6. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1996 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

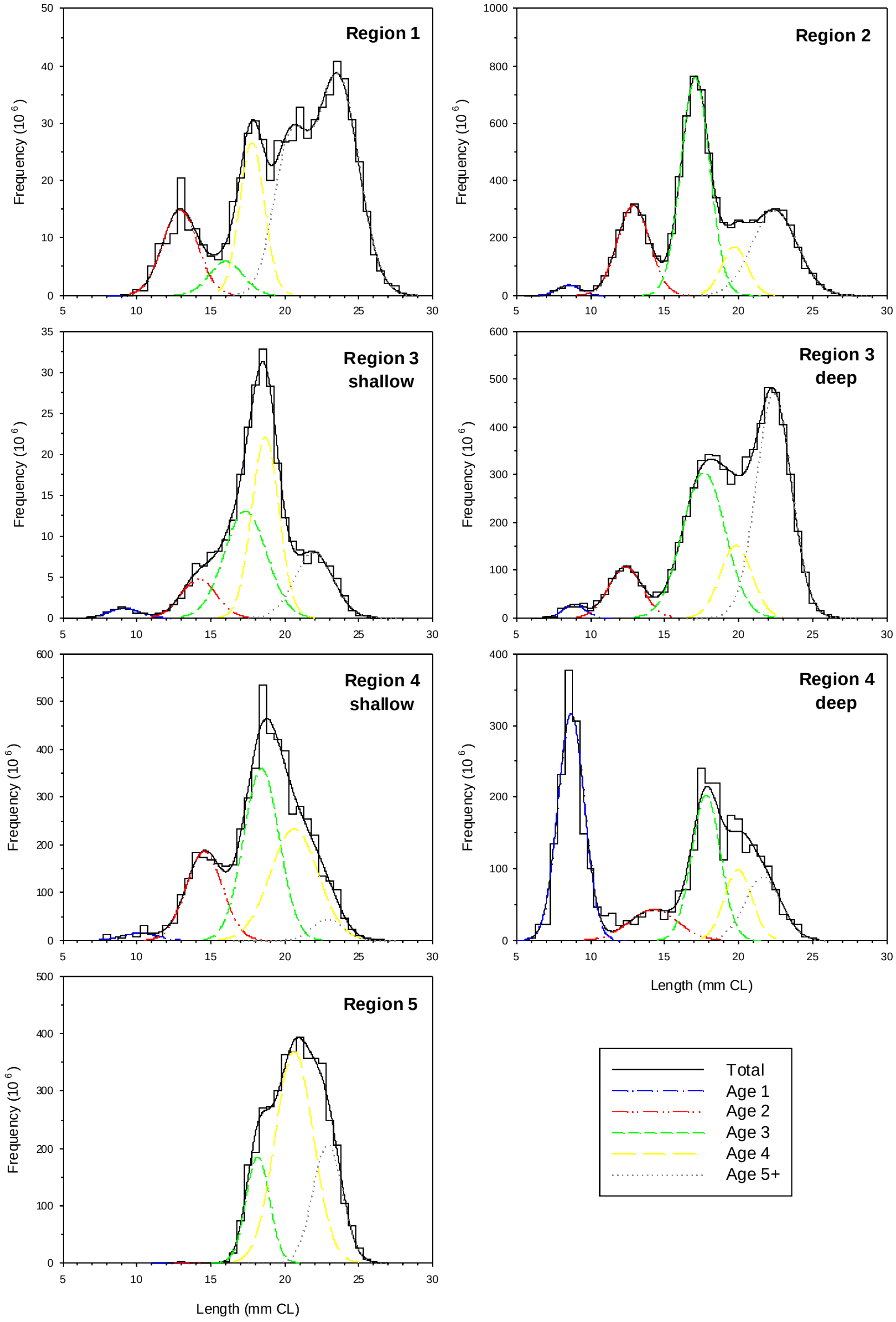

Fig. 7. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1997 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

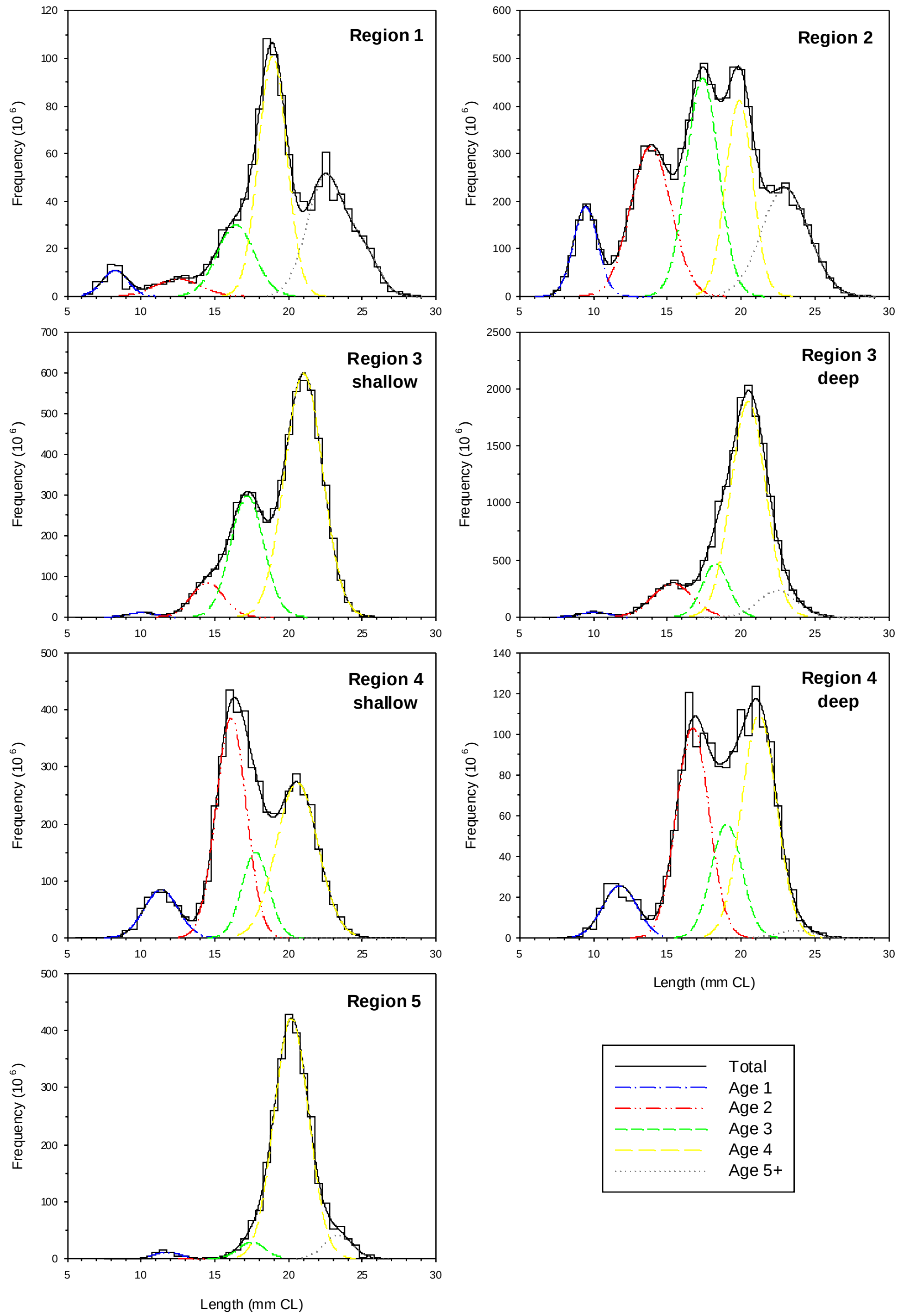

Fig. 8. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1998 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

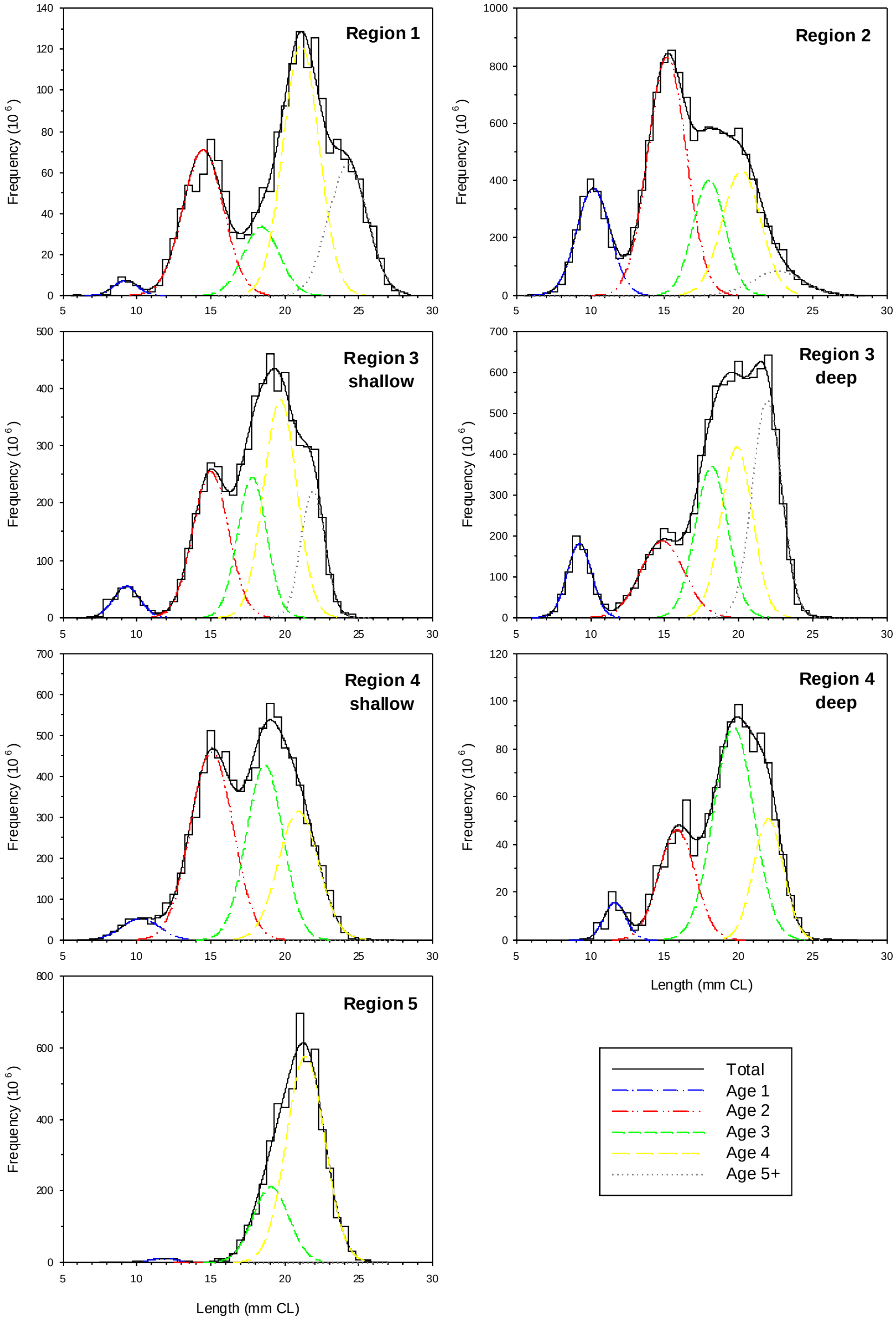

Fig. 9. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1999 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

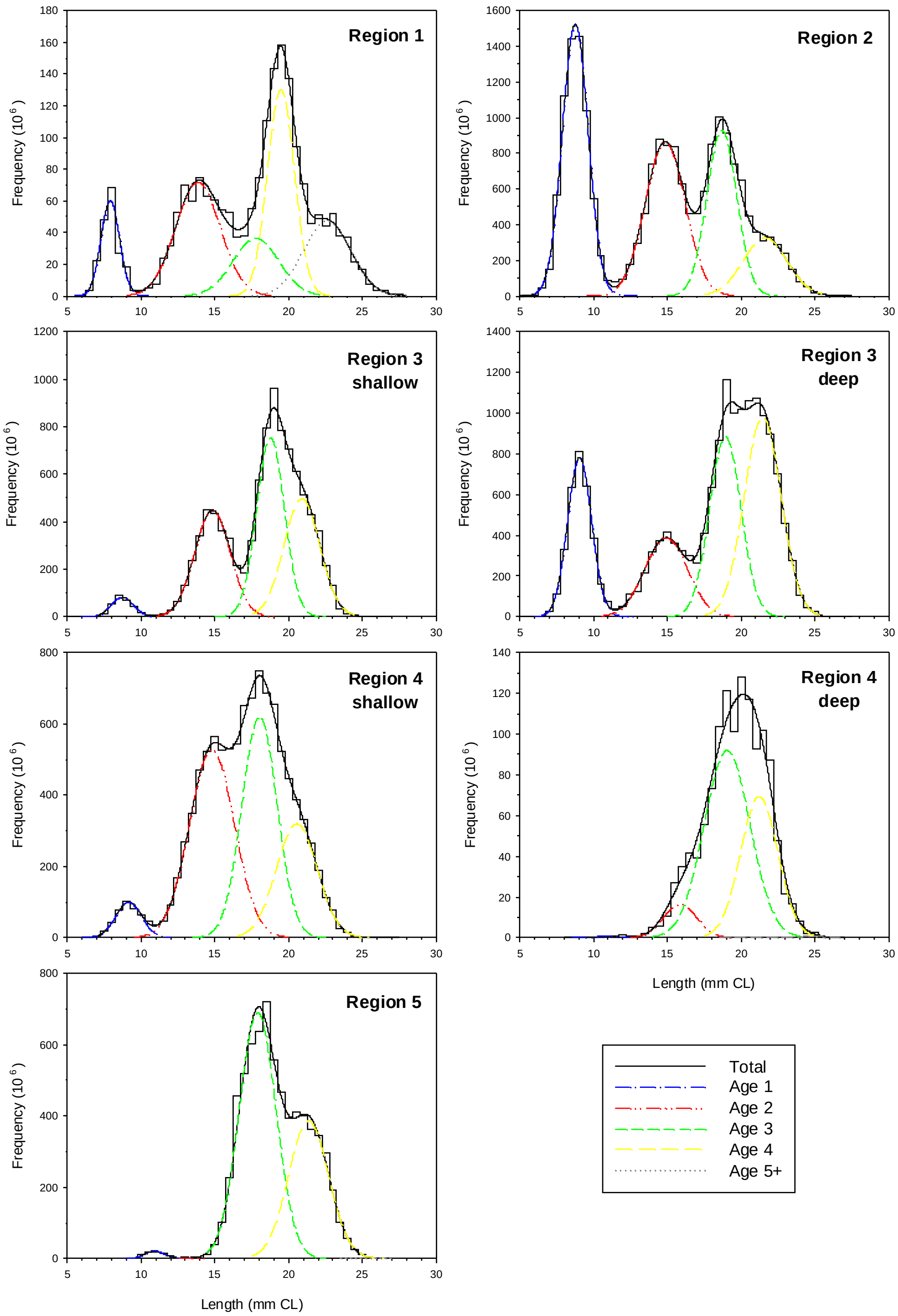

Fig. 10. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2000 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

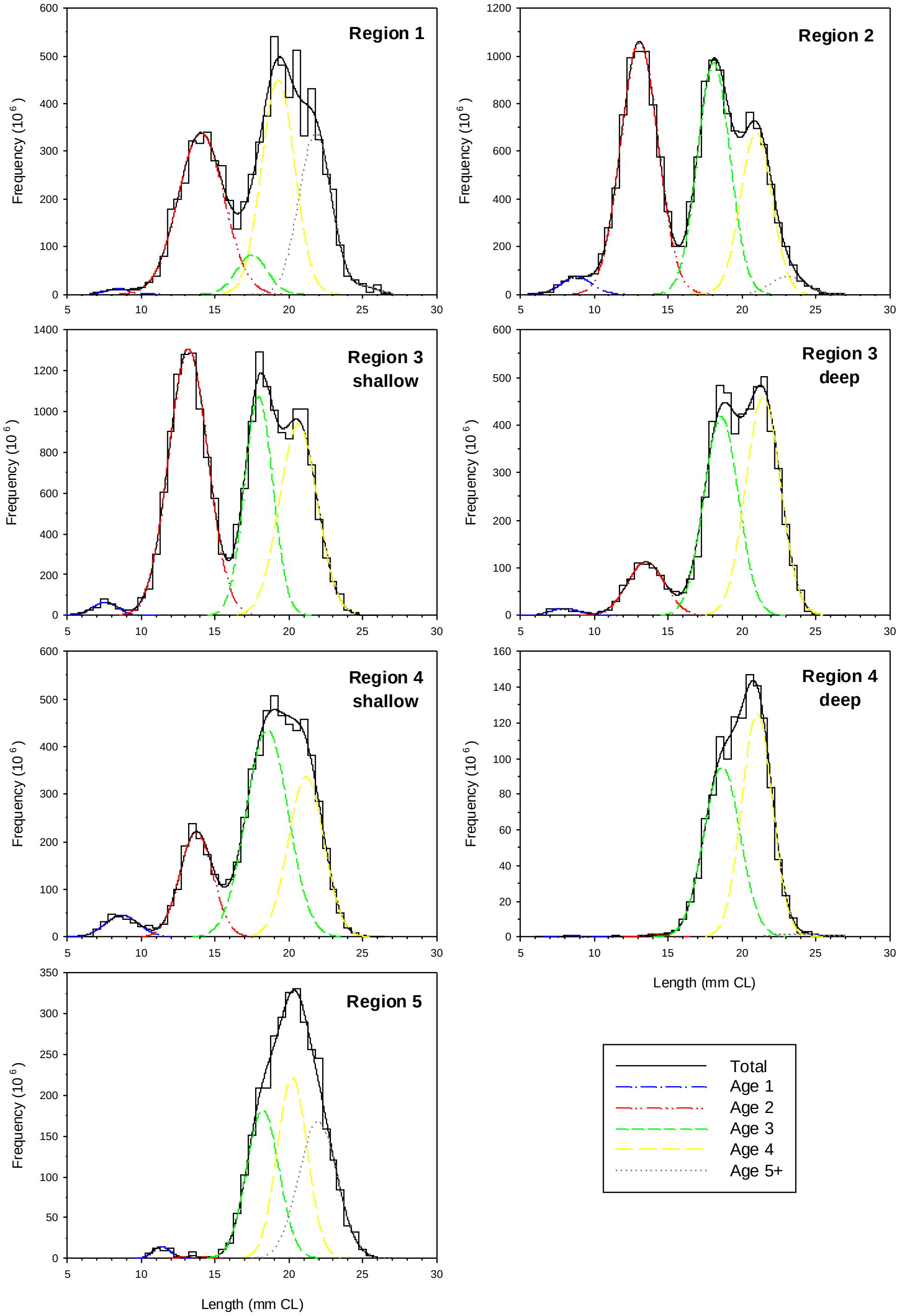

Fig. 11. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2001 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

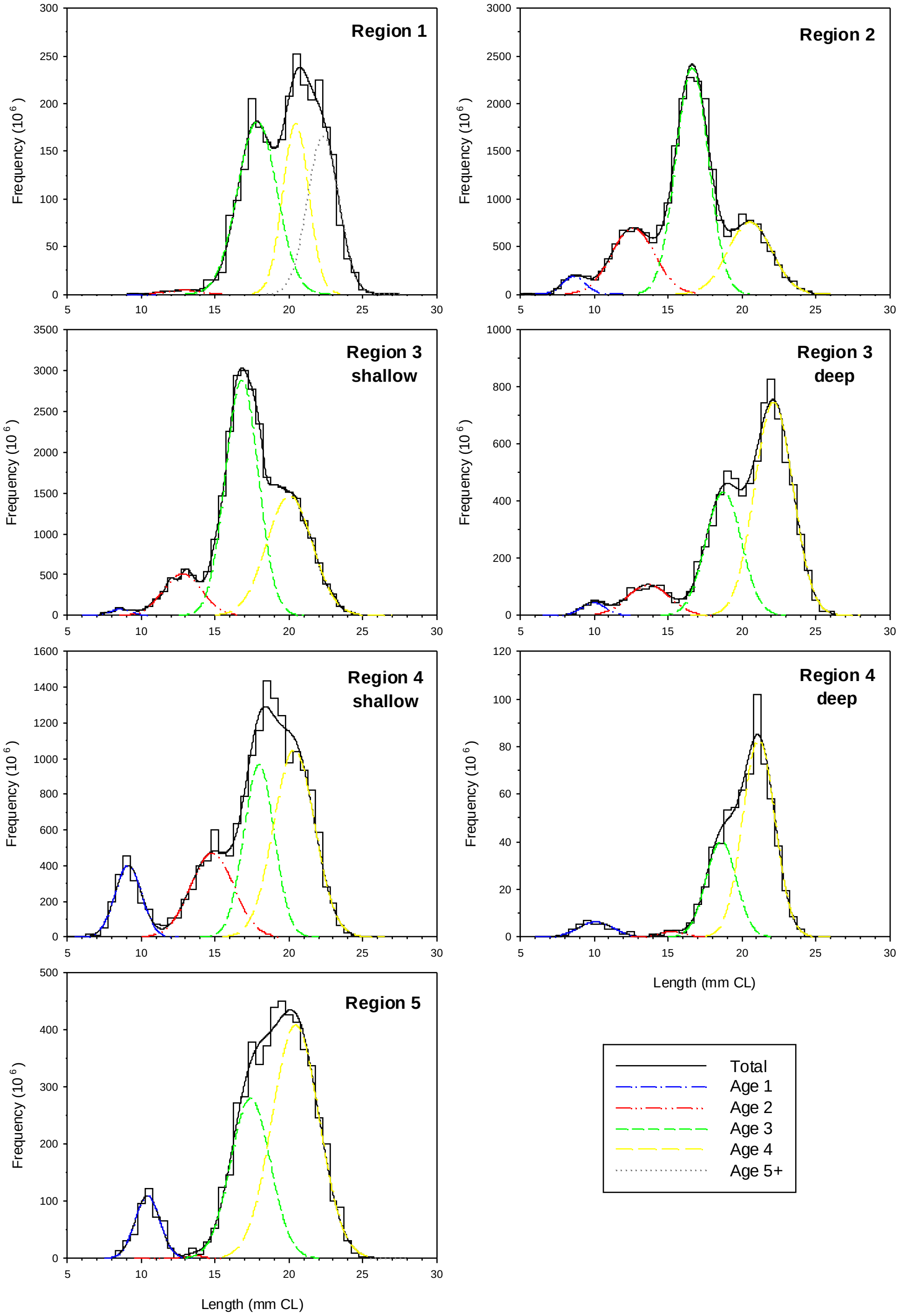

Fig. 12. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2002 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

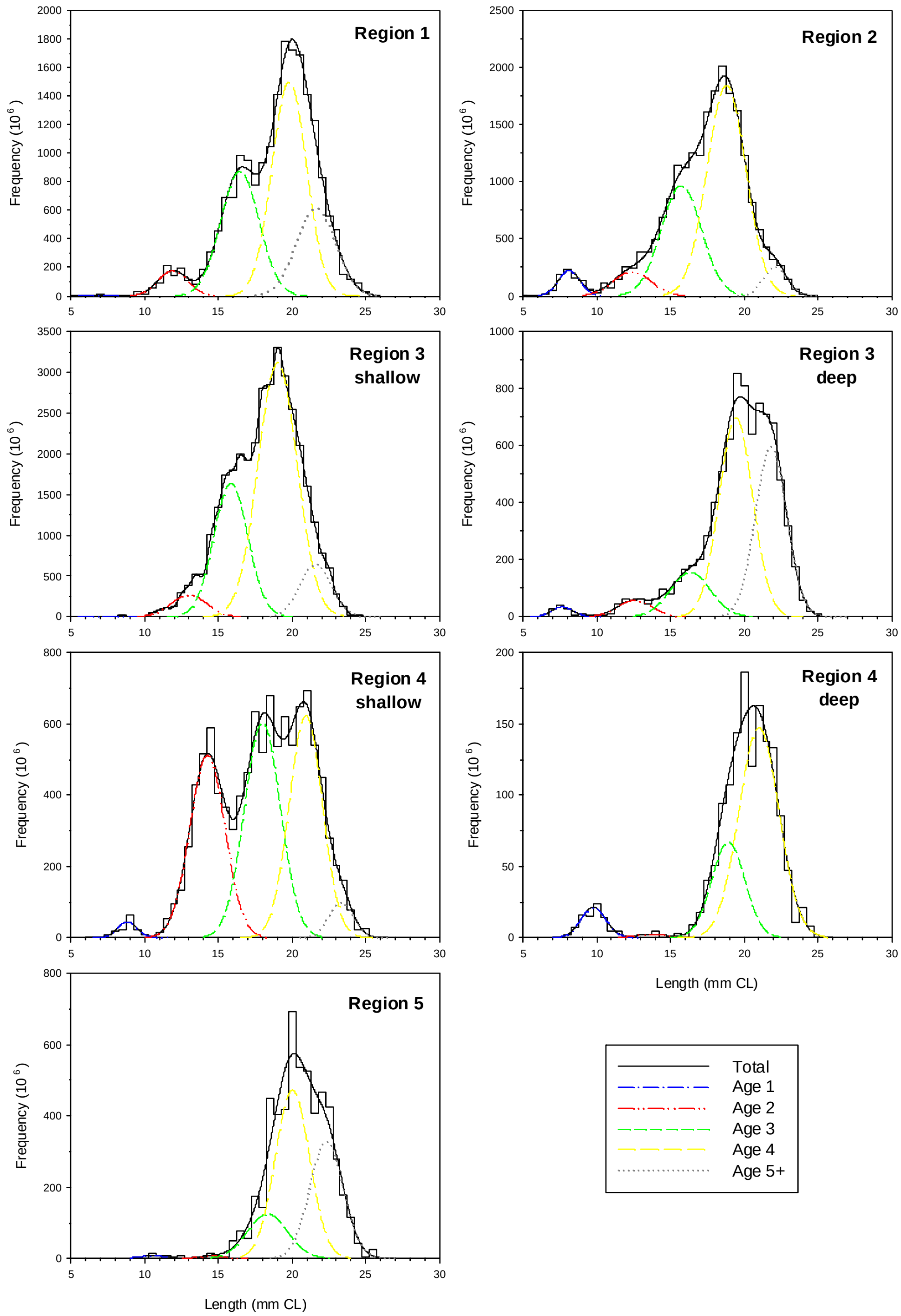

Fig. 13. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2003 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

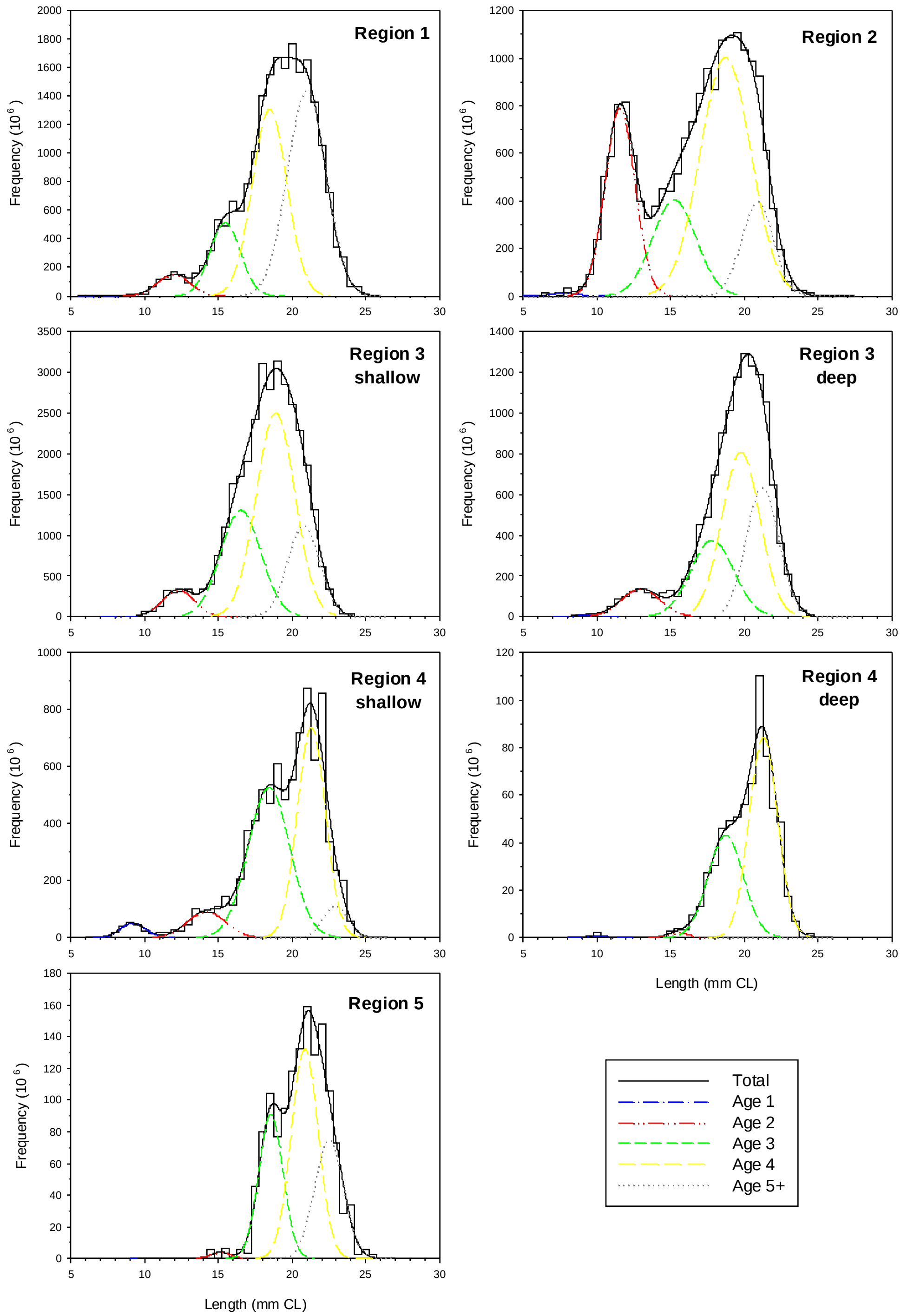

Fig. 14. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2004 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

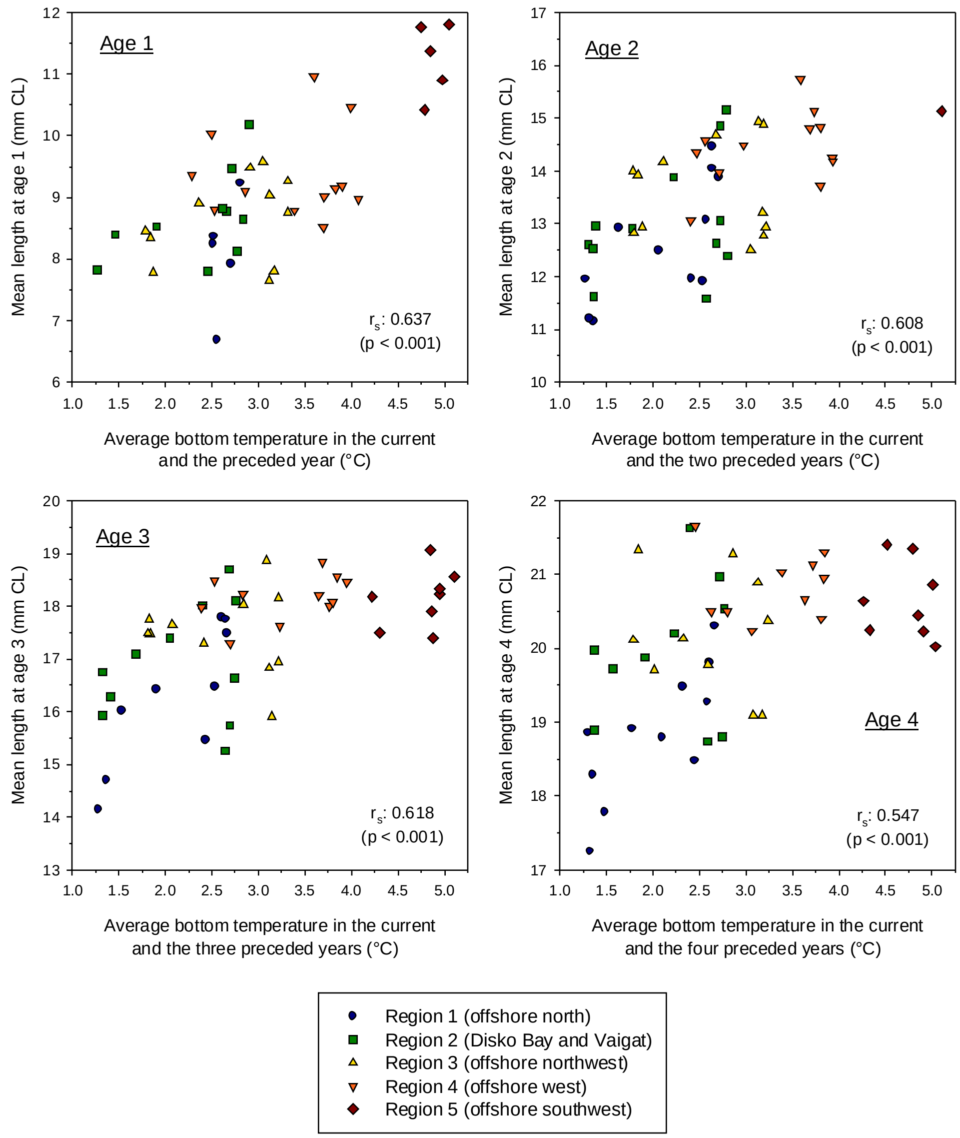

Fig. 15. Effect of bottom temperature on mean length of northern shrimp at age 1, 2, 3 and 4 off West Greenland, 1993-2004 (only mean lengths included which were not fixed in the modal analysis, see Tables 2-5; r_s: Spearman's rank correlation coefficient).

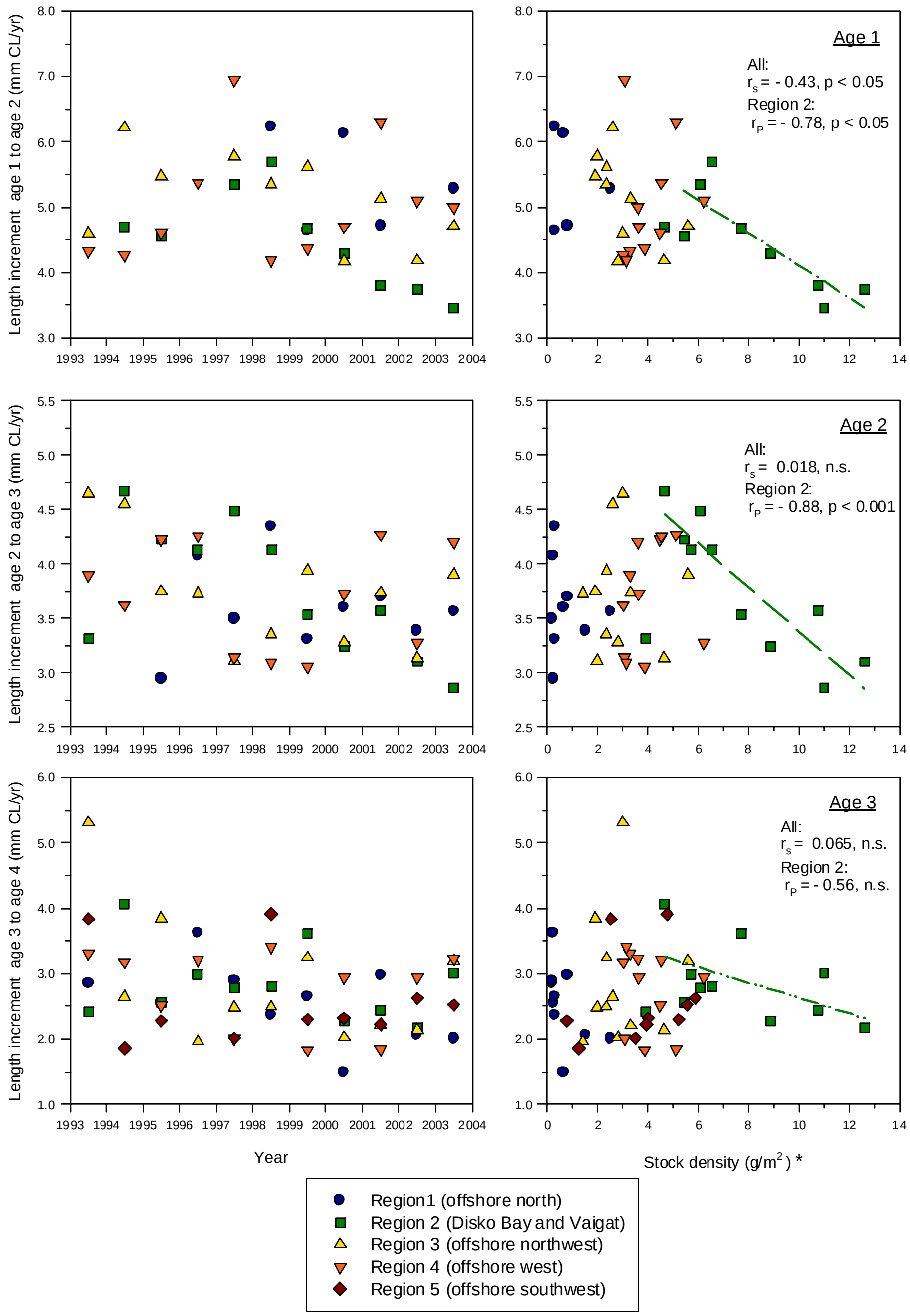

Fig. 16. Growth of northern shrimp at age 1, 2 and 3 off West Greenland 1993 - 2004 in relation to stock density (years with fixed mean lengths in the modal analysis not considered, see Tables 2-5; r_s: Spearman's rank correlation, r_p: Pearson product moment correlation for stock densities >4.5 kg/m² in region 2 (range of linear regressions indicated by dashed lines), *: average of the current and the preceded year).

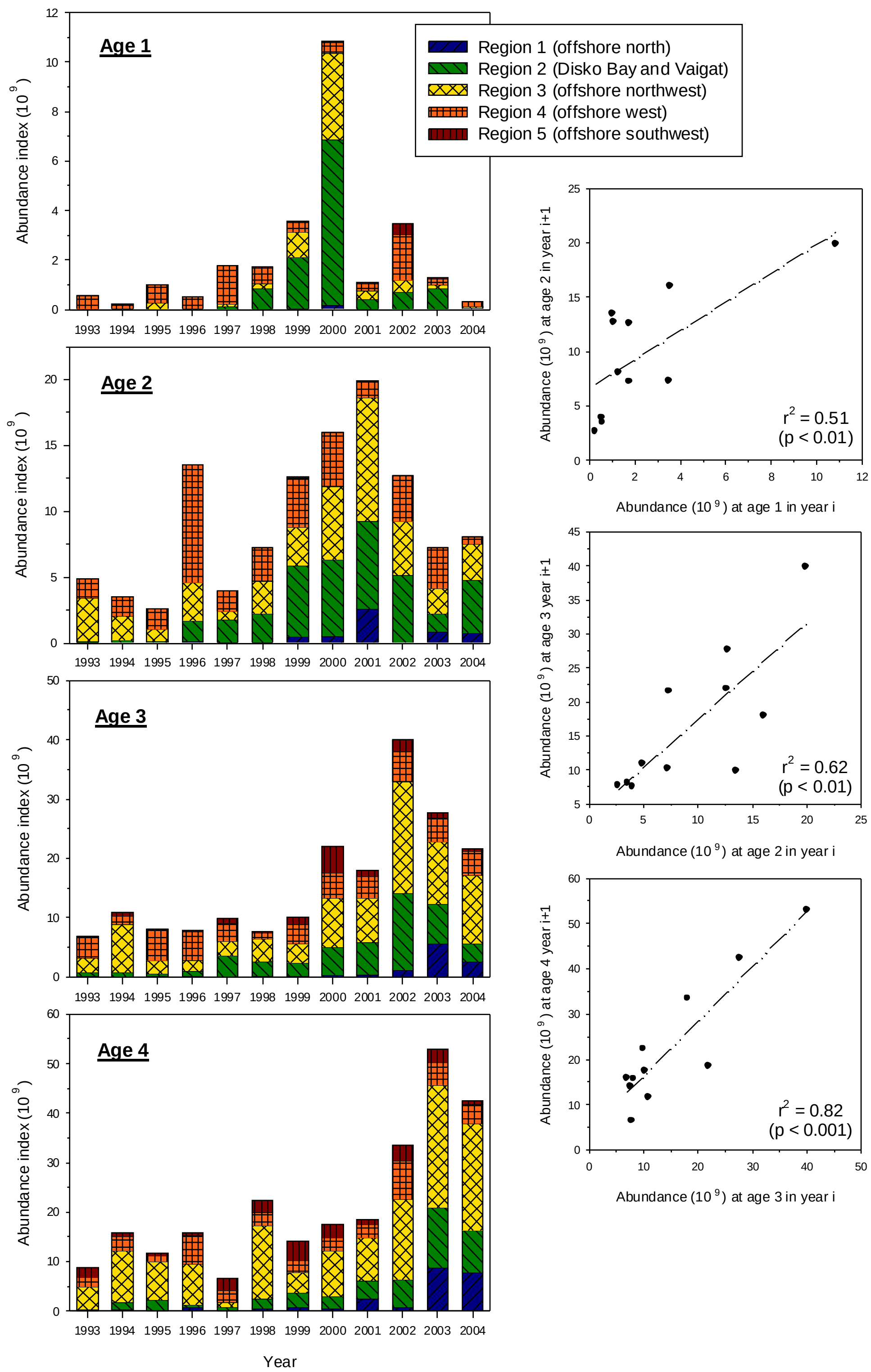

Fig. 17. Abundance indices for northern shrimp at age 1, 2, 3 and 4 and comparison of year-class strength as measured at these ages off West Greenland, 1993-2004.

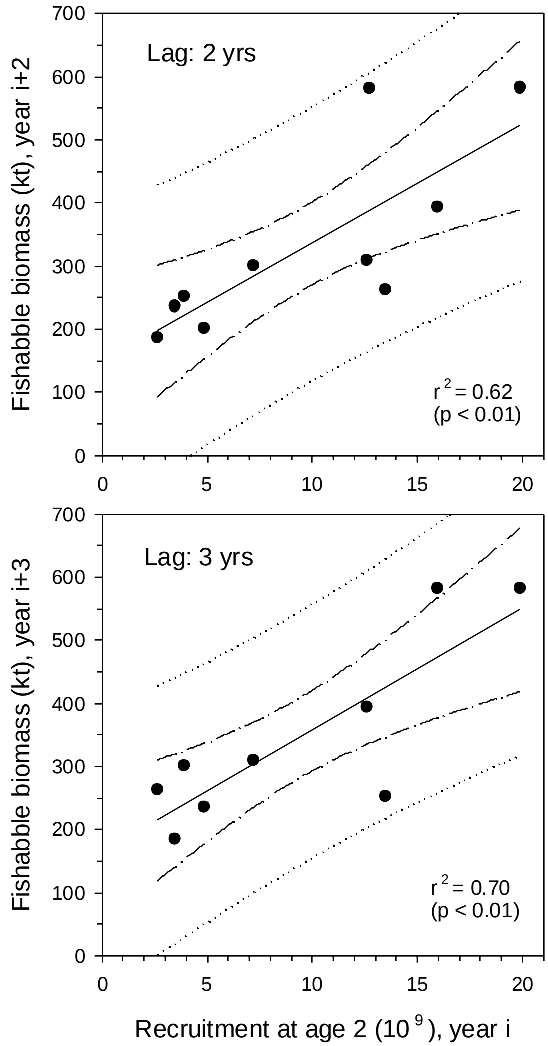

Fig. 18. Relation between abundance at age 2 and fishable biomass (all individuals ≥17 mm CL; Wieland *et al.*, 2004) two and three years later for northern shrimp off West Greenland, 1993-2004 (lines: linear regression with 95% confidence and prediction intervals).