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Abundance of Young (Age 1, 2 and 3) Northern Shrimp (*Pandalus borealis*) off West Greenland (NAFO Subareas 0+1) in 1993-2003, and Changes in Mean Size-at-age Related to Temperature and Stock Size

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 2003 were examined in order to extract mean lengths and abundance indices for age 1, 2 and 3 by modal analysis. The original survey data were pooled 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 were positively correlated to bottom temperature for all of the three age groups and a trend towards smaller size at age and slower growth was observed for the most recent years in which population density has increased substantially in large parts of the area. Abundance at age 2 correlated significantly with the fishable biomass lagged by two years and the survey estimates of abundance for this age can thus be regarded as suitable to assess short-term changes in recruitment to the fishery. Recruitment at age 2 deceased after 2001 and was below average in 2003, which suggests that the fishable biomass will decline in the coming two years.

Introduction

Recruitment of northern shrimp (*Pandalus borealis*) at West Greenland has 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). A single size group with a modal length of between 13 and 15 mm CL has dominated this size range during the 1990s, but in 2000 smaller individuals (9 mm CL) were almost equally abundant. Furthermore, the contribution of larger individuals with a modal length of about 19 to 20 mm CL increased in the past years as this peak in the length frequencies 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 (2002) 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 been modified and extended, and the present paper provides revised estimates of mean length at age and abundance indices for ages 1, 2 and 3 on an area-disaggregated basis for the years 1993 to 2003.

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. A detailed description of the current survey design, fishing practice and sample analysis is given in Kanneworff and Wieland (2003).

Swept area estimates of northern shrimp abundance by 0.5 mm carapace length (CL) interval from the original sampling 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).

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. Average bottom temperatures at the sampling sites were then used to calculate mean bottom temperatures weighted by stratum area for the five regions (Wieland and Kanneworff, 2002).

Modal analysis of the regional length frequencies for juveniles and males were conducted using the MIX 3.1A software (MacDonald and Pitcher, 1979). No smoothing was applied prior to analysis, and initial estimates of the modes and the number of age groups to be considered (Table 1) were obtained by visual inspection of the length frequencies. The maximum age of the males recognized in the length frequencies varied between years and regions reflecting differences in the length at sex transition (Wieland, in prep.). 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 gave more realistic results in almost all cases. Values of mean length, which had to be kept fixed in the final MIX run, were discarded from further evaluation of length at age and growth.

Two of the five regions, in which a heterogeneous distribution of bottom temperature related to their bathymetry was 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 these two regions separated by depth range and, for subsequent analysis, mean lengths at age for the entire region were calculated weighted by abundance of the specific age group in the respective depth range.

Spearman rank correlation analysis (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 and three preceded years were used for age 1, 2 and 3, respectively, in order to cover the period from settling to the year of catch.

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 and 4+ are shown in Fig. 3-13. Further results of the modal analysis, i.e. mean length and coefficient of variation, are listed in Tables 2-4 for age 1, 2 and 3, respectively. For regions 1 to 4, the Gaussian components fitted the observed distribution in the size range of the 2-group reasonably well in almost all years. Problems occurred in the modal analysis for both, the 1- and the 2-group in region 5 in most of the years 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, 3.4 mm CL for age 2 and 3.9 mm CL for age 3. 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 on average. For age 2, however, deviations from the average coefficient of variation were observed in region 4 in a few cases.

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 2-4). Spearman rank correlation coefficients indicated a highly significant effect of bottom temperature for all of the three age groups considered (Fig. 14). However, a considerable variation in length at age without a corresponding change in bottom temperature was found for age 2 in regions 2, 3 and 4 as well as for age 1 and age 3 in region 5.

Length increments from age 1 to age 2 for all year-classes (1992-2001) were highly variable and showed no consistent trend over time while growth from age 2 to age 3 (year-classes 1991-2000) appeared to be more stable (Fig. 15). However, a trend towards slower growth is visible in region 2 as well as in region 3 for both, age 1 and age 2, in the most recent years.

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. 16). Total abundance of age 1 was exceptional high in 2000, and the 2003 value amounts to about 50% of the average of the time series.

The 2-group was found in regions 3 and 4 in all years and since 1996 with considerable numbers also in region 2 (Fig. 16). In addition, the 2-group was fairly abundant in region 1 in the years 1999 to 2001 and in 2003 while it was nearly absent in region 5 throughout the entire time series. Total abundance of age 2 increased since 1997 to the highest value on record in 2001 and decreased in 2003 to a level just below average.

The 3-group occurred regularly in regions 2, 3 and 4, and in most of the years also in region 5 while it was found in region 1 with increasing quantities first in the last three years. Total abundance of age 3 was highest in 2002 and the 2003 value is still above average.

Relative year-class strength as measured at age 1, 2 and 3 can well be identified in the time series of the abundance indices (Fig. 15) except for the 1994 and the 2000 year-class, which appeared to be low 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 (Fig. 17).

Furthermore, the abundance indices for age 2 showed a highly significant correlation with the fishable biomass (all shrimp >17 mm CL) as well as with the total survey biomass the two years later (Fig. 18). Other time lags, i.e. one and three years, did not yield significant results. The obtained relationships (Fig. 18) suggest a decrease of fishable biomass and total survey biomass from their record high levels in 2003 to 358 and 409 kt in 2004 and to 267 and 301 kt in 2005, respectively.

Discussion

Length frequency distributions of northern shrimp from original sampling strata were pooled into five topographic regions, which were defined by differences in mean bottom temperature. The pooled length frequencies allowed the extraction of mean size and abundance for ages 1, 2 and 3 by modal analysis. In general, reasonable fits of Gaussian components were obtained. Some uncertainties concerning the interpretation of the length frequencies occurred, but these were 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 and 3 were significantly related with bottom temperature, which is biologically plausible supporting the results of the modal analysis. A decrease in mean length at age and a trend towards slower growth was detected in the most recent years. This was likely related to high population density as the effect was pronounced in those parts of the area in which a substantial increase in density has been observed in the last years (Kanneworff and Wieland, 2003).

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, 2002), escapement of juveniles beneath the footrope (Nilssen, 1986) and immigration from settling areas located at depths shallower than 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 changes in growth have occurred and the 2-group is not fully retained in the survey trawl. The age 2 abundance indices can thus be regarded as suitable to assess the recruitment to the fishery.

The time lag of two years in the correlation between recruitment at age 2 and fishable biomass as well as total biomass is reasonable considering that in both cases the main contribution comes from individuals in the size range of age 3, 4 and 5 (Kanneworff and Wieland, 2003). However, annual changes in the age distribution beyond age 2 resulting from natural causes and from changes in the fishery contribute to the observed variability. Although the relationships between recruitment at age 2 and fishable biomass or total survey biomass two years later were highly significant, it must be kept in mind that the predictions for 2004 and 2005 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.

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Table 1. Age groups considered in the MIX analysis of length frequencies of northern shrimp males and juveniles off West Greenland 1993-2003 (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 - 5	1 - 6	1 - 6	1 - 5	1 - 5	1 - 5
1994	2 - 6	1 - 5	1 - 5	1 - 5	2 - 4	1 - 5	1, 3 - 5
1995	1 - 6	1 - 5	1 - 5	1 - 5	1 - 5	1 - 4	1 - 5
1996	2 - 6	1 - 5	2 - 6	1 - 4	1 - 4	1 - 4	2 - 5
1997	1 - 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, 3 - 5
1999	1 - 6	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 - 6	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

Table 2. Mean carapace length (mm) and coefficient of variation for northern shrimp at age 1 off West Greenland 1993-2003 (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	(8.75)	8.4	8.3	8.5	10.7	8.8	(10.5)
1996	-	(8.5)	-	(7.5)	9.0	9.1	-
1997	(9.0)	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)

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	(0.07)	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	(0.09)	0.09	0.08	0.09	0.07	0.08	(0.80)

Table 3. Mean carapace length (mm) coefficient of variation for northern shrimp at age 2 off West Greenland 1993-2003 (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	12.3	12.3	13.1	14.8	13.6	(14.0)
1994	(11.5)	11.6	12.3	13.2	14.7	13.8	-
1995	11.2	12.5	13.5	14.1	15.2	12.9	(12.5)
1996	11.9	12.9	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	-
1999	14.6	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	12.8	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)

coefficent of variation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	0.07	0.09	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	0.10	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	0.10	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	0.09	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)

Table 4. Mean carapace length (mm) and coefficient of variation for northern shrimp at age 3 off West Greenland 1993-2003 (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	15.7	16.1	16.1	16.5	17.5	17.3	17.2
1994	(15.5)	15.9	16.4	17.6	18.3	17.9	19.0
1995	14.7	16.3	17.7	17.4	17.6	18.0	18.6
1996	14.2	16.9	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	18.1
1999	16.8	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	17.9	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

coefficent of variation:

				Region			
Year	1	2	3 shallow	3 deep	4 shallow	4 deep	5
1993	0.07	0.07	0.09	0.06	0.07	0.08	0.05
1994	0.05	0.06	0.07	0.07	0.06	0.07	0.05
1995	0.07	0.07	0.06	0.05	0.05	0.08	0.04
1996	0.08	0.06	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	0.08
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

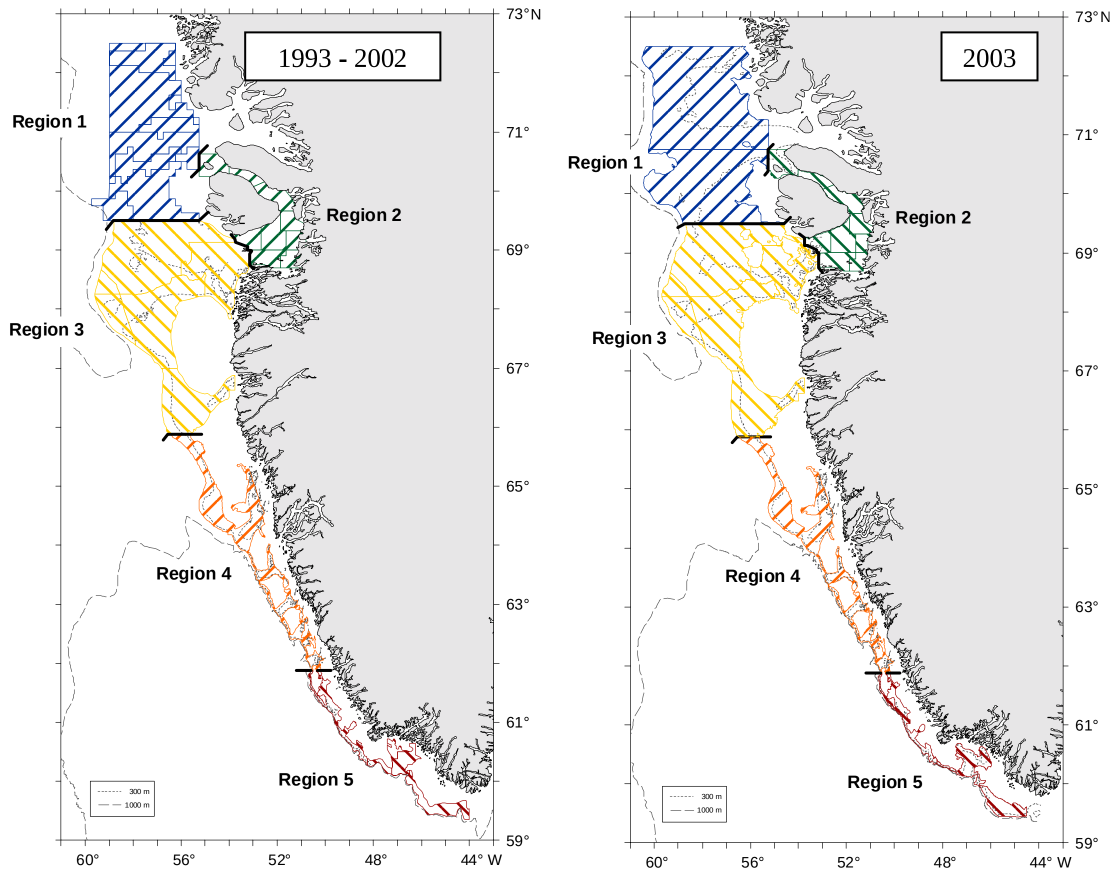

Fig. 1. Survey stratification in the West Greenland Bottom Trawl Survey for northern shrimp in 1993 to 2002 and in 2003.

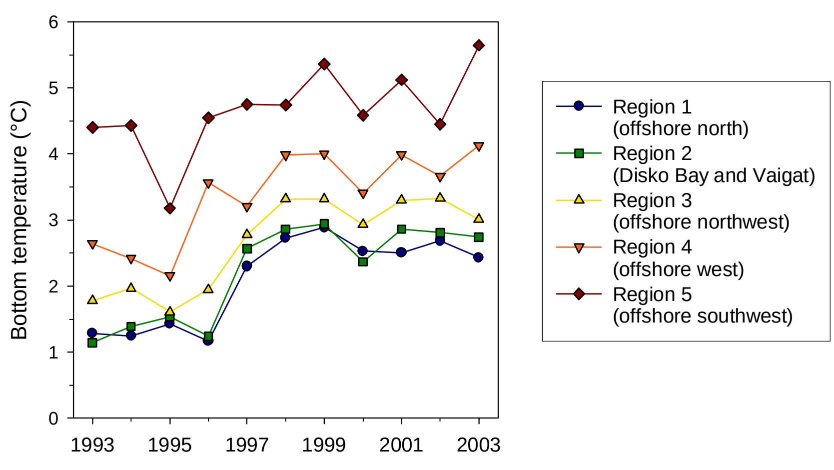

Fig. 2. Bottom temperature in the five regions of the survey area in 1993 to 2003.

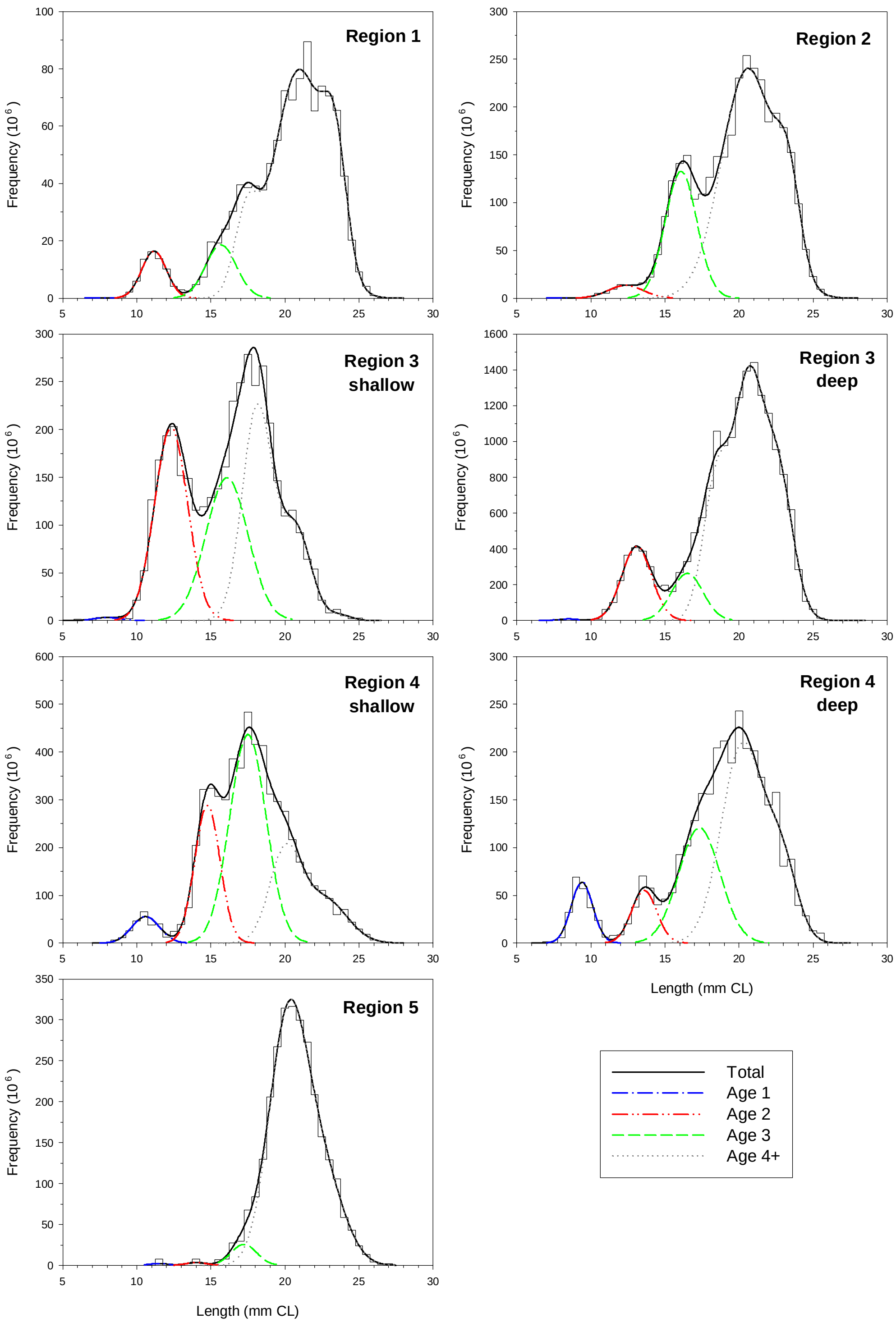

Fig. 3. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1993 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

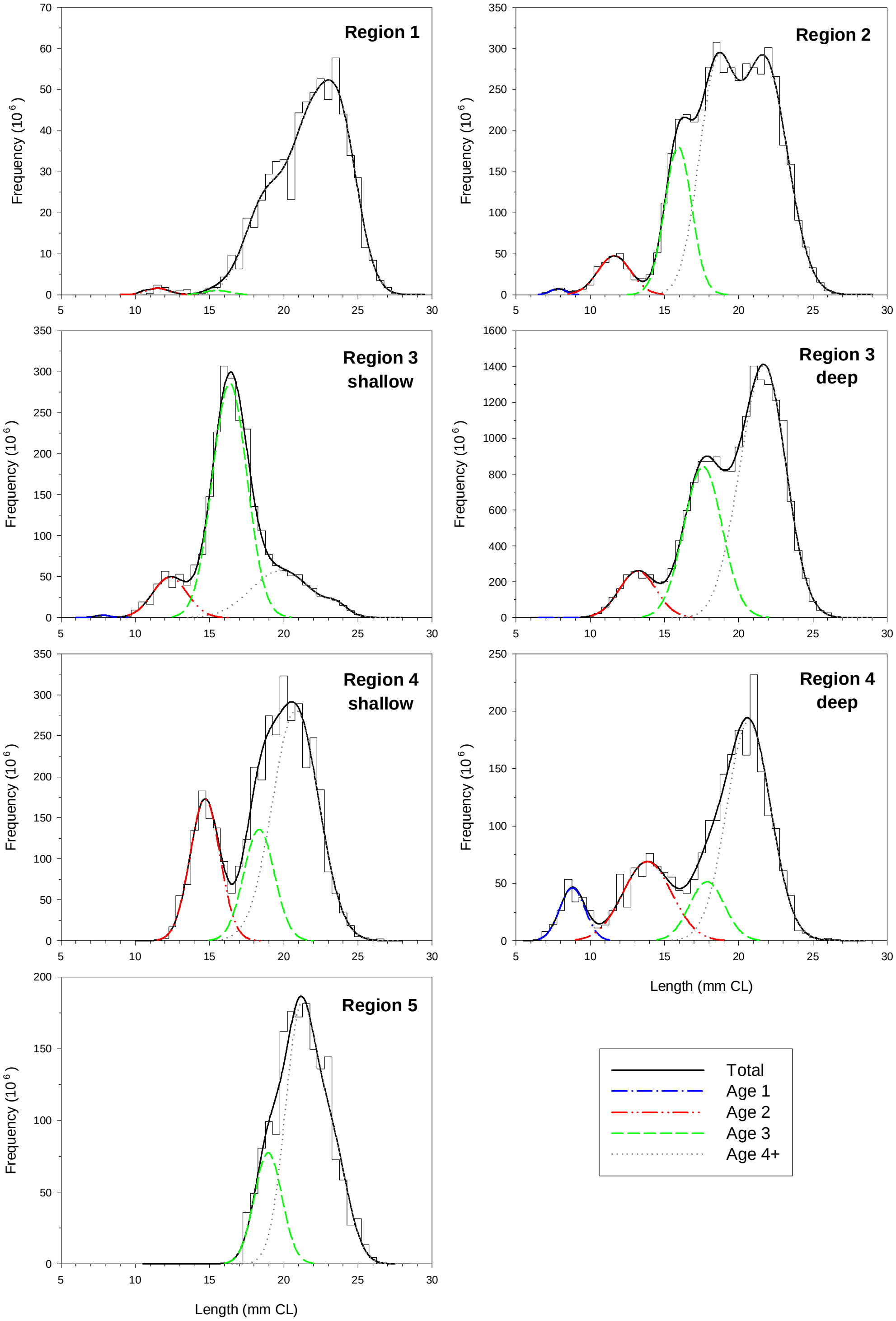

Fig. 4. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1994 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

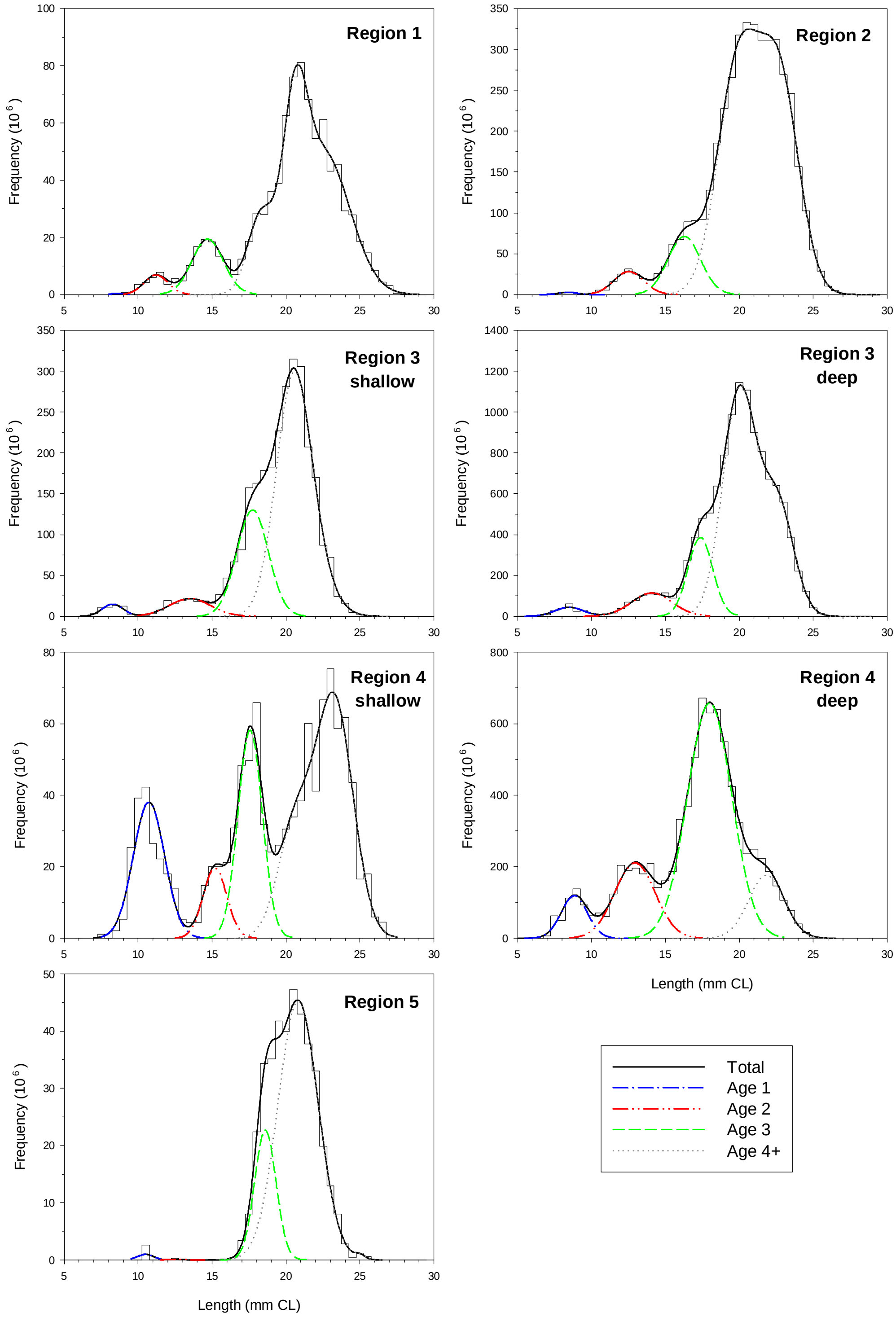

Fig. 5. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1995 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

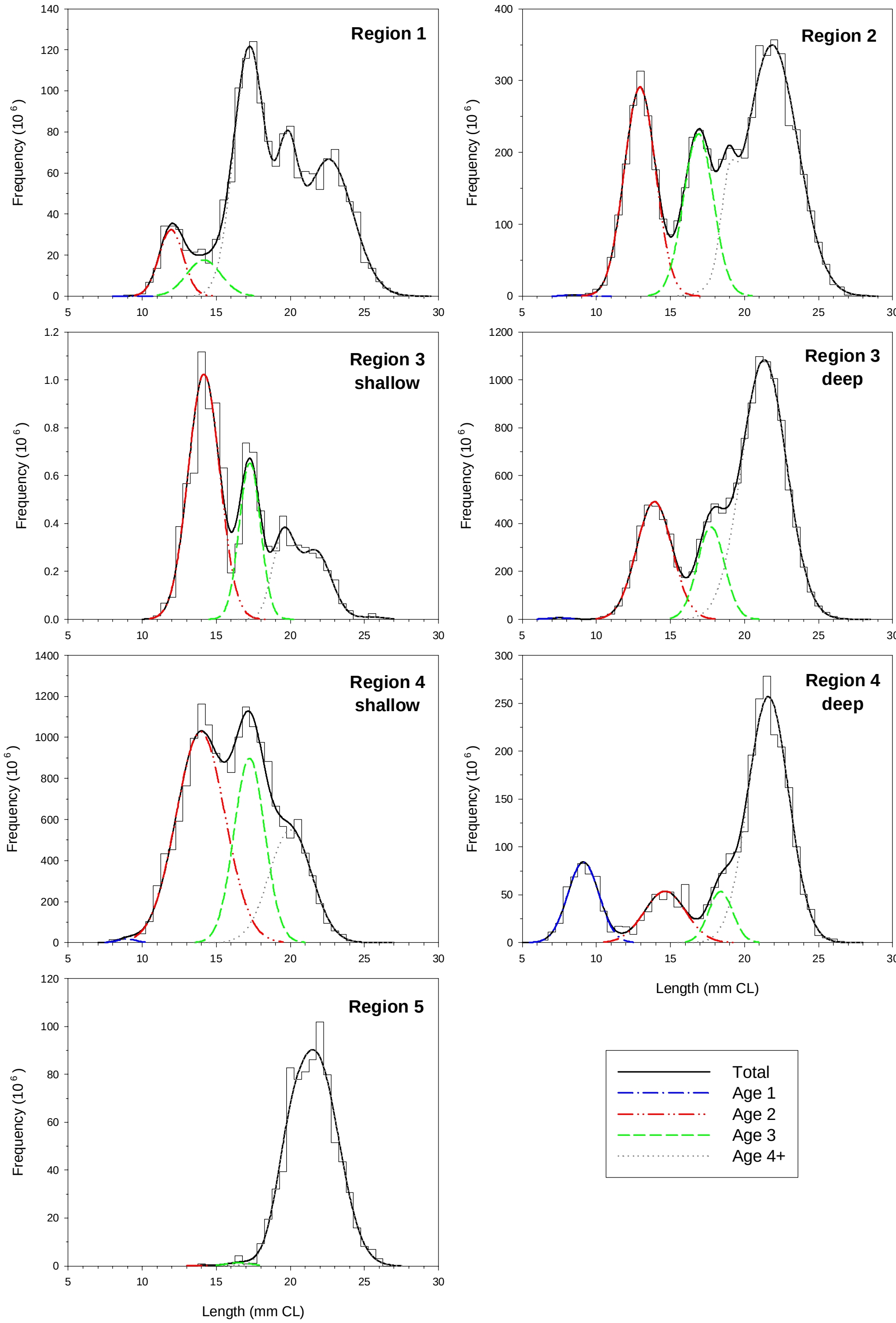

Fig. 6. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1996 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

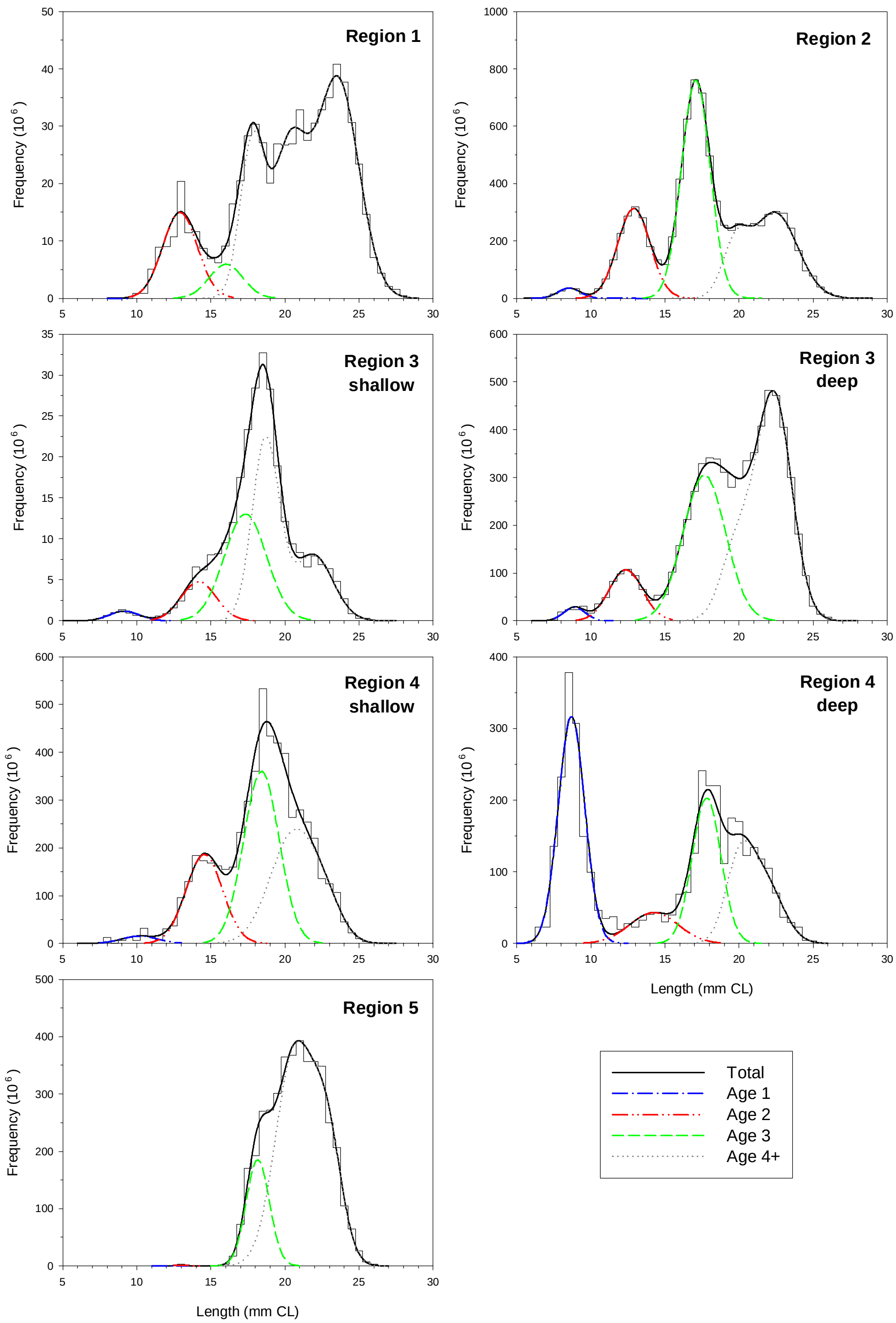

Fig. 7. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1997 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

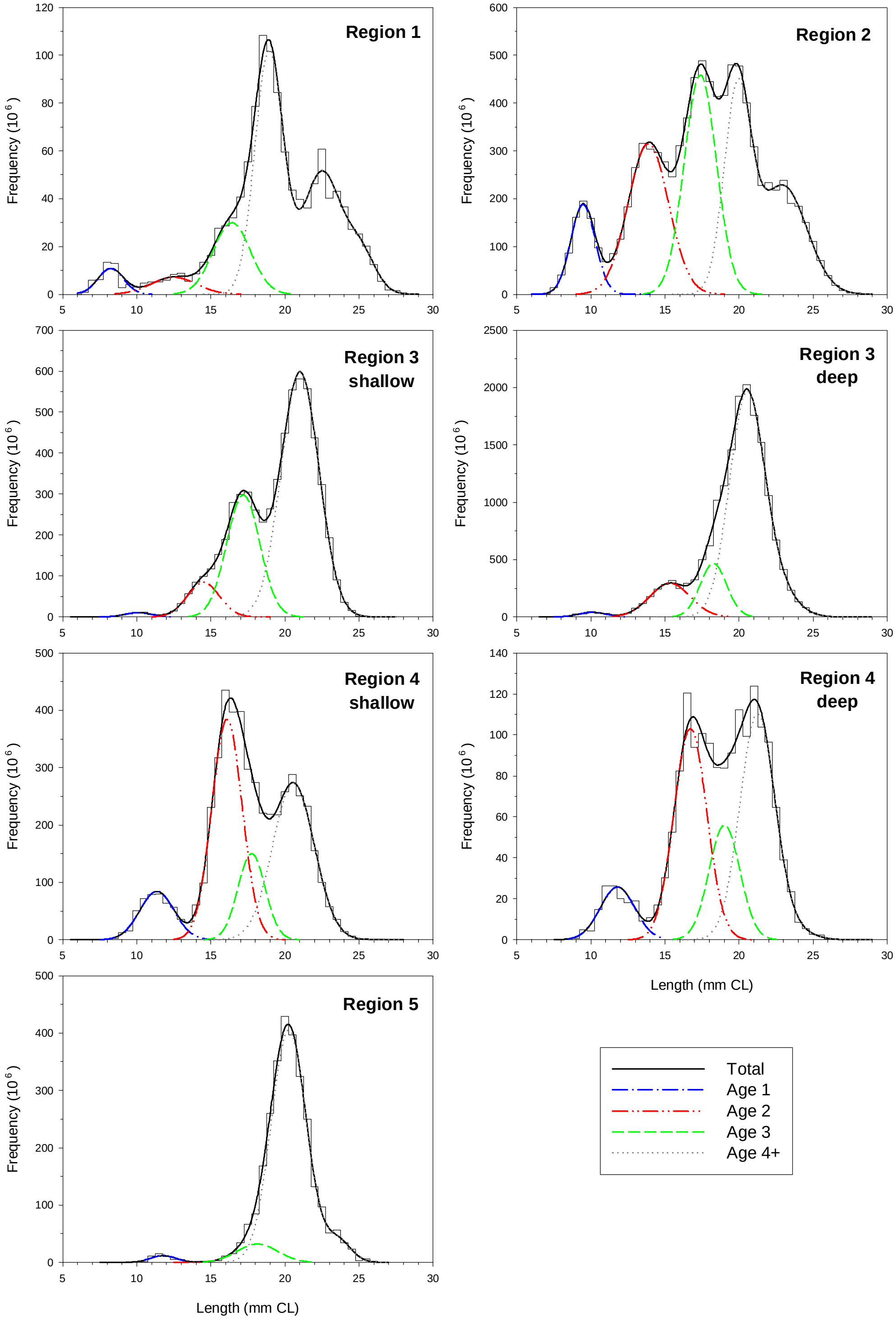

Fig. 8. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1998 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

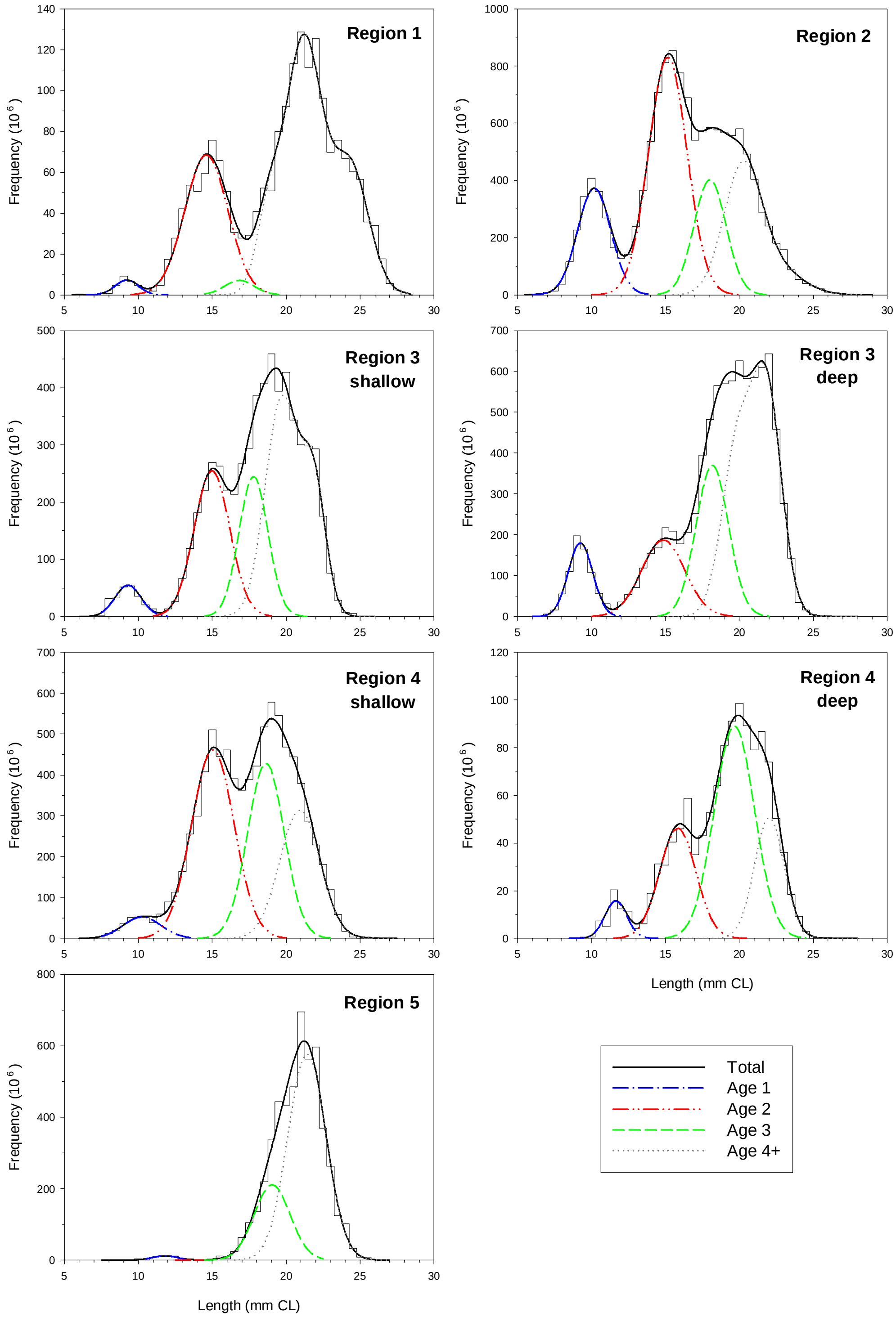

Fig. 9. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 1999 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

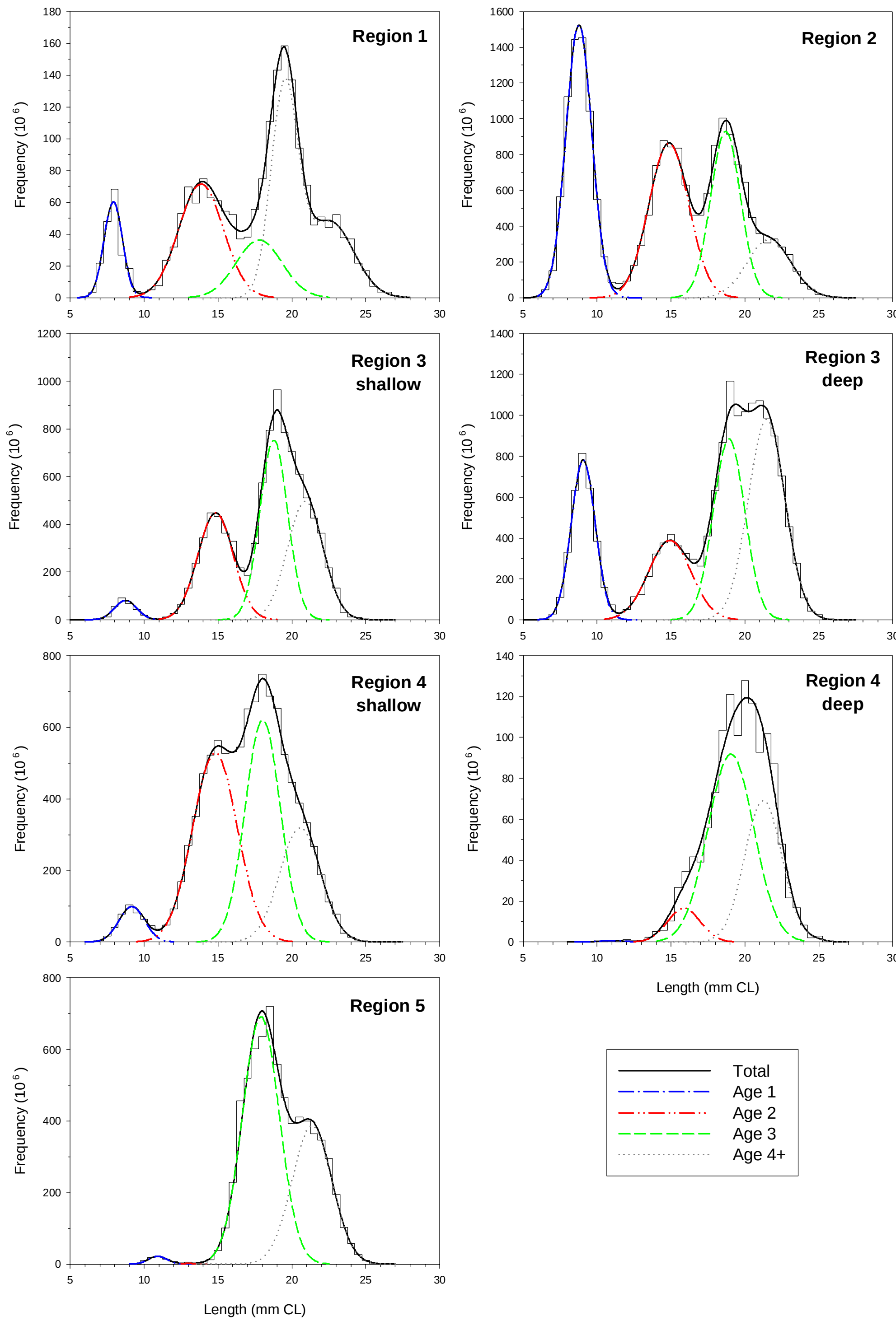

Fig. 10. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2000 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

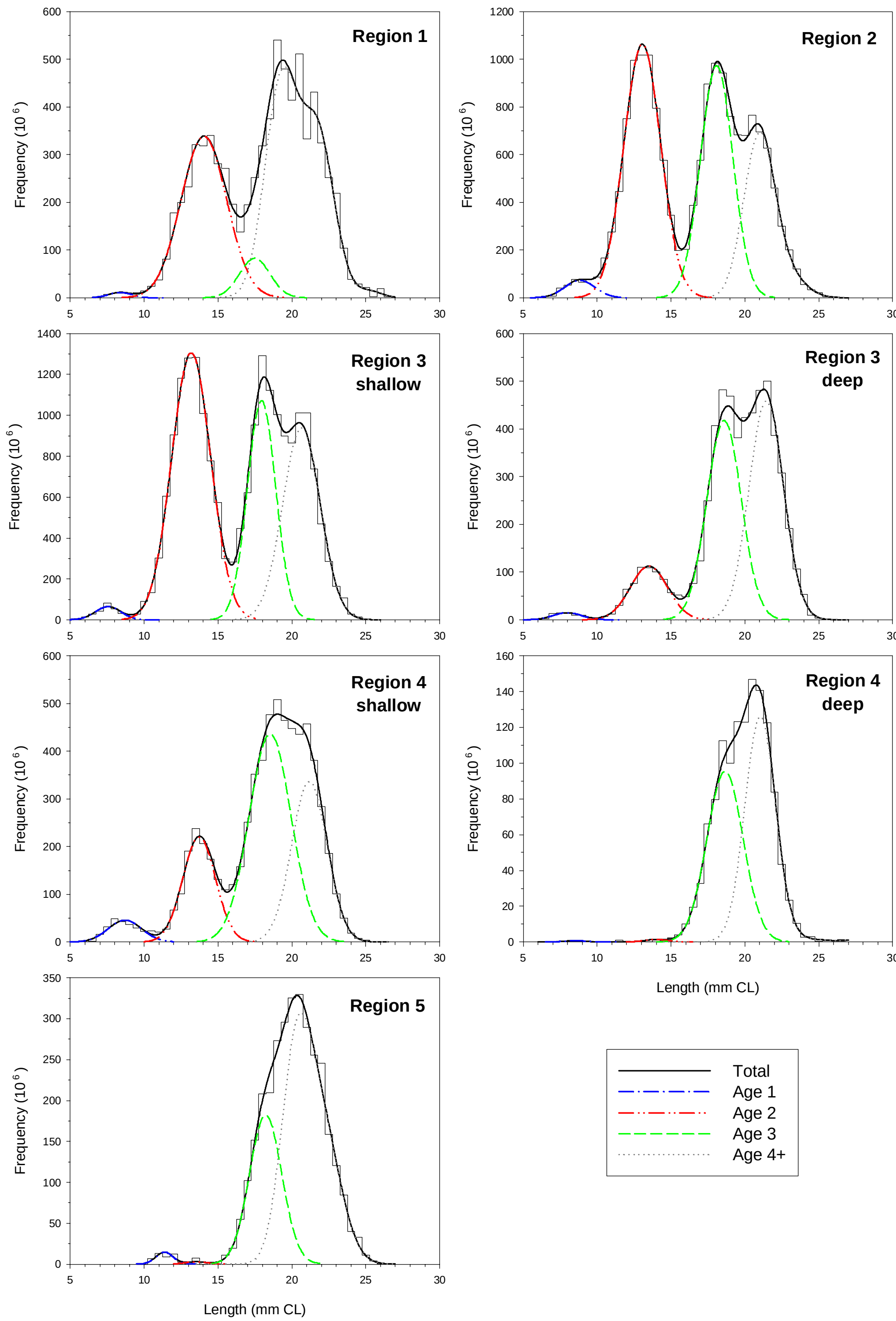

Fig. 11. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2001 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

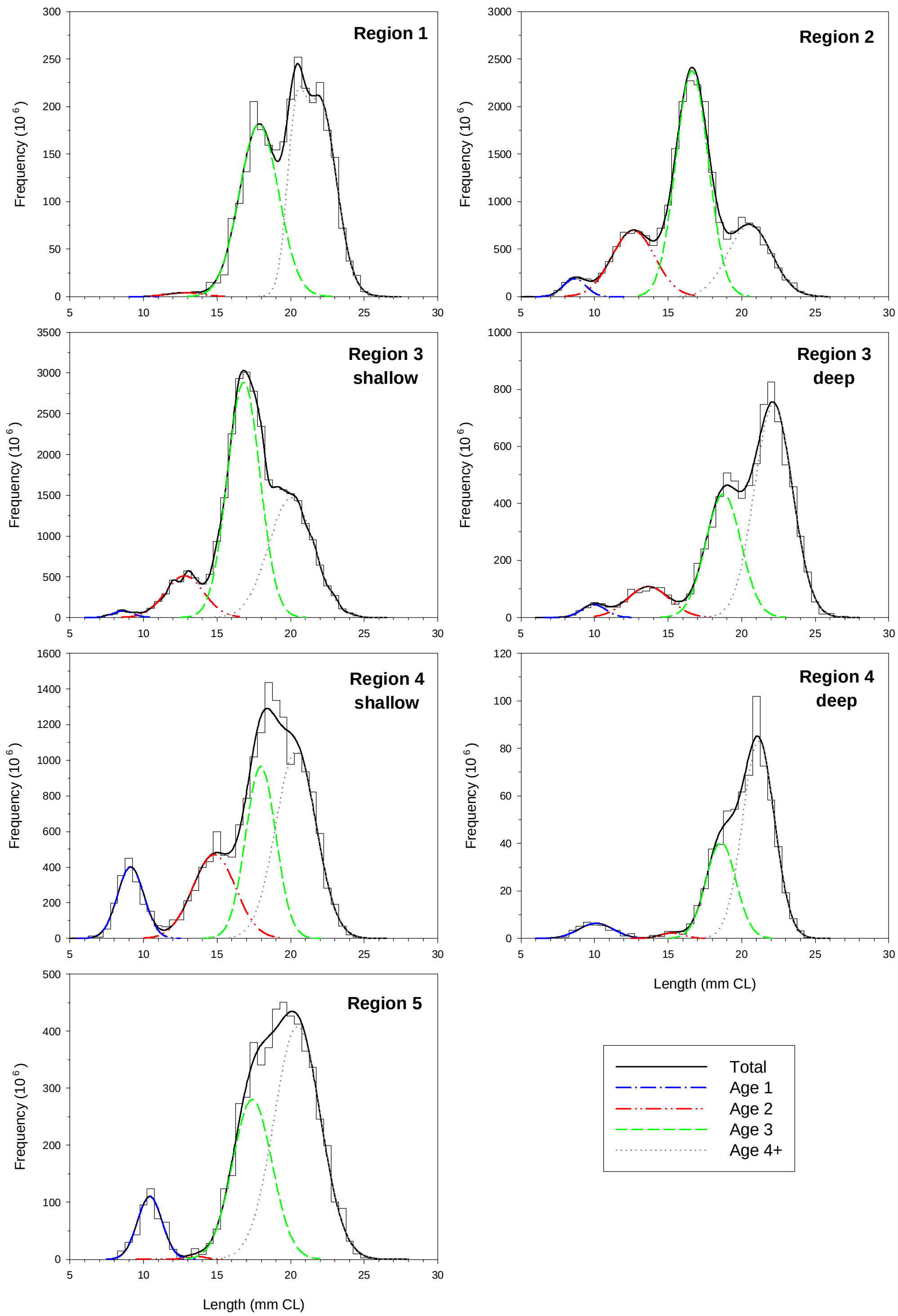

Fig. 12. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2002 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

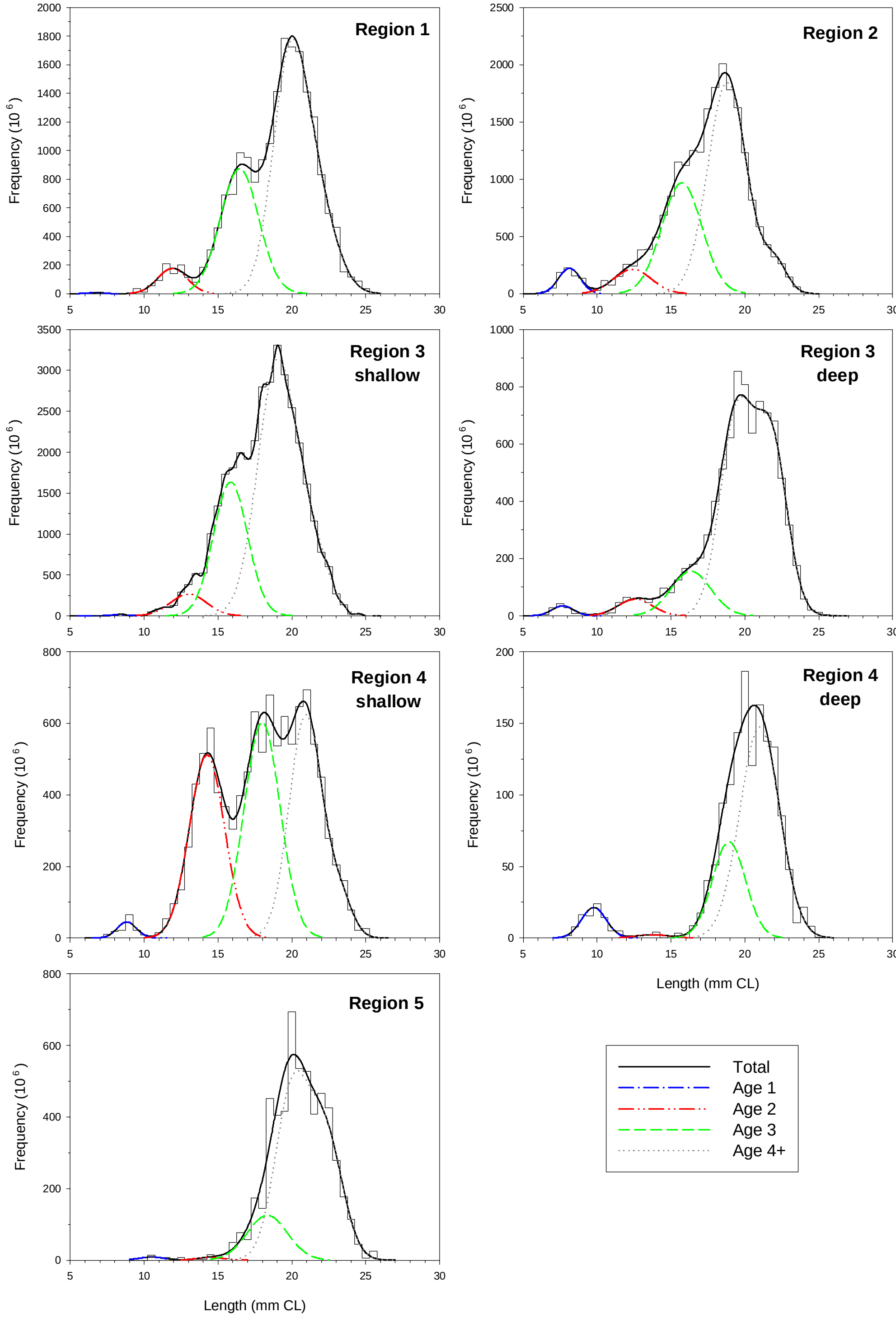

Fig. 13. Regional length frequencies of northern shrimp (juveniles and males) off West Greenland in 2003 (regions 1, 2 and 5: 150-600 m; regions 3 and 4 shallow: 150-300 m, deep: 300-600 m).

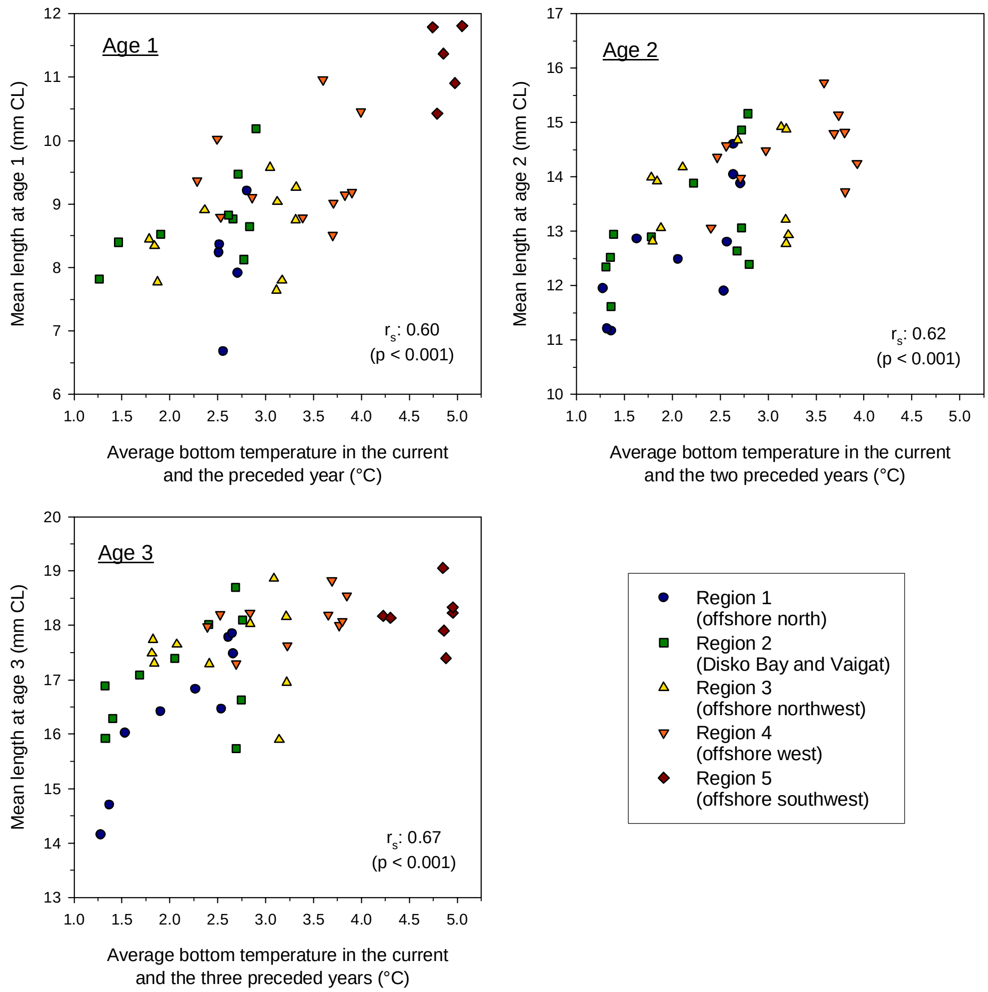

Fig. 14. Effect of bottom temperature on mean length of northern shrimp at age 1, 2 and 3 off West Greenland, 1993 - 2003 (only mean lengths included which were not fixed in the modal analysis, see Tabs. 2-4; r_s: Spearman's rank correlation coefficient).

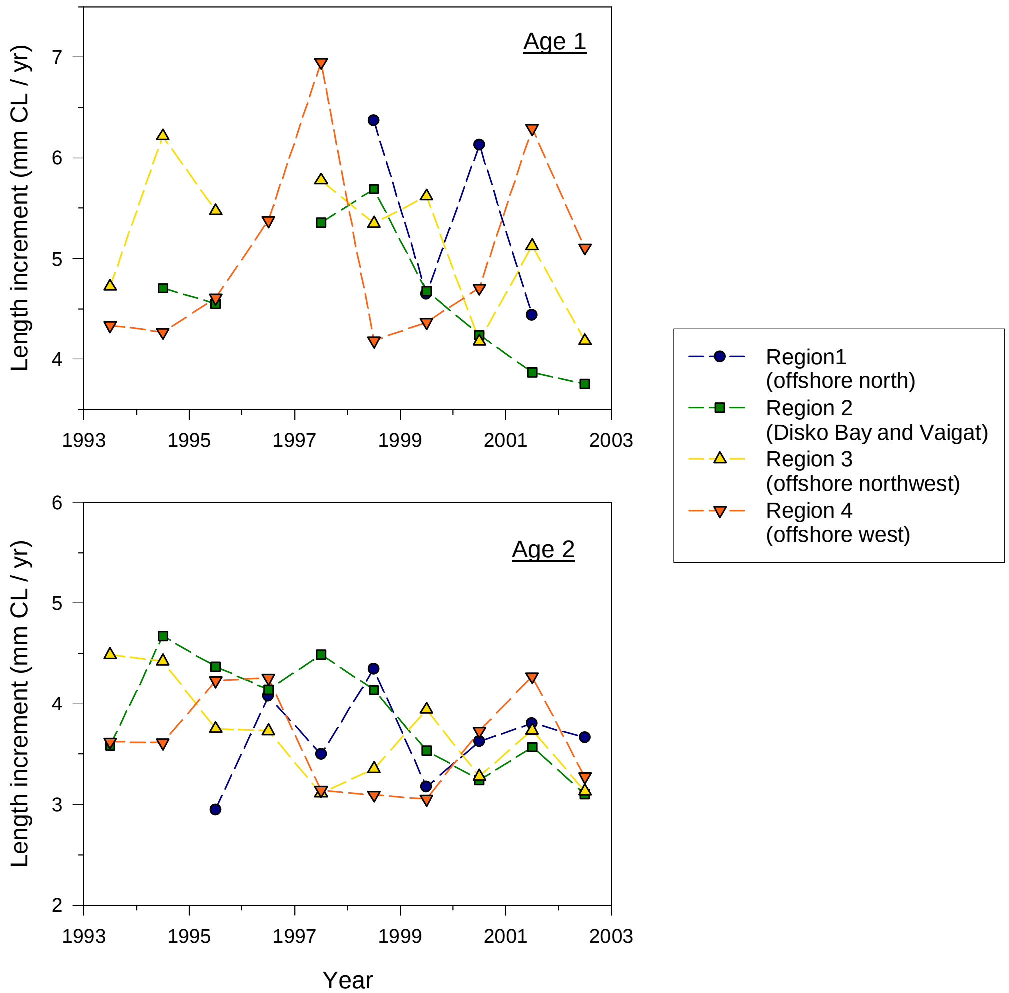

Fig. 15. Growth of northern shrimp at age 1 and 2 off West Greenland 1993 – 2003 (only year classes considered for which mean lengths at age were not fixed in the modal analysis, see Tabs. 2-4).

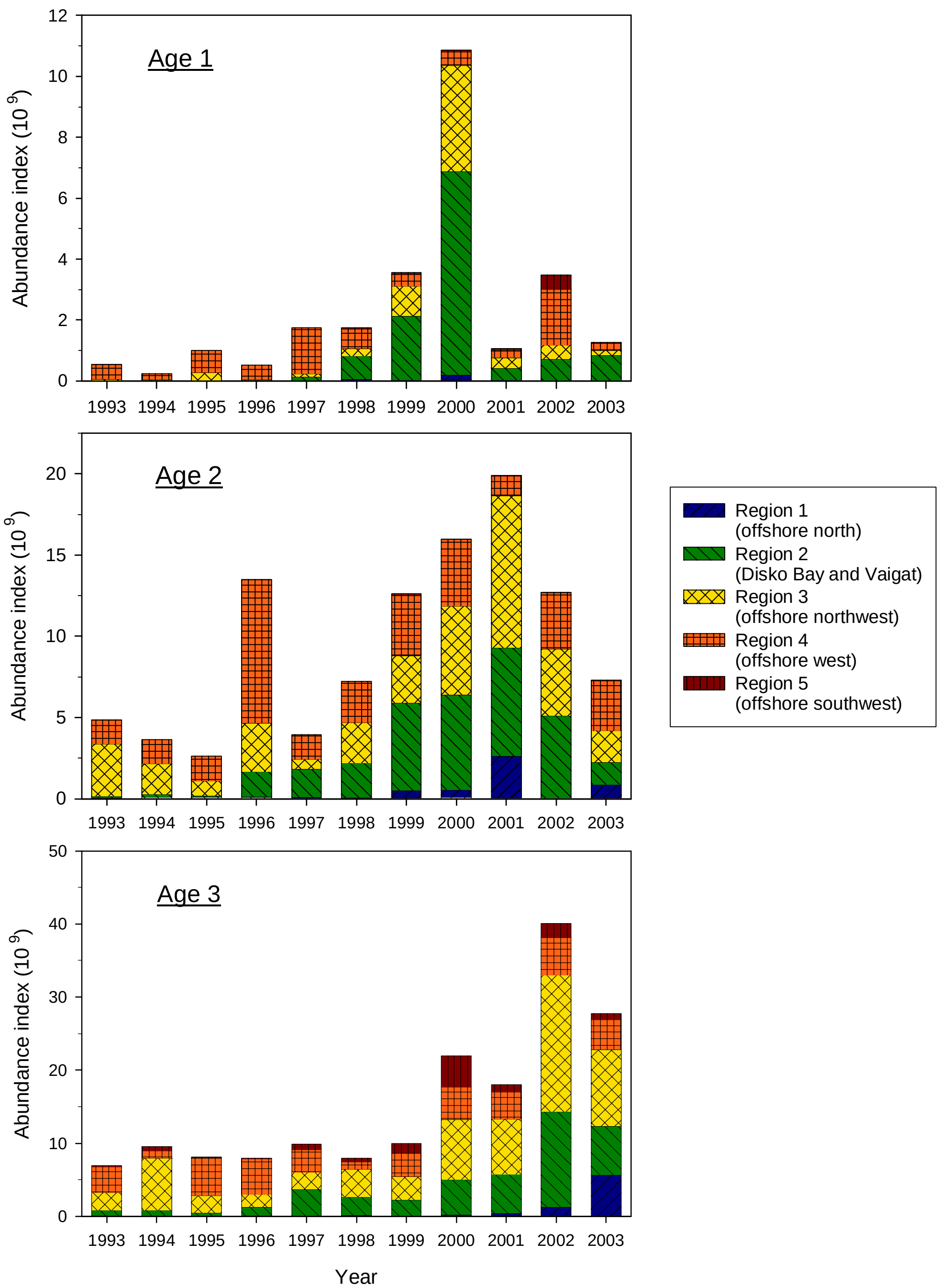

Fig. 16. Abundance indices for northern shrimp at age 1, 2 and 3 off West Greenland, 1993 - 2003.

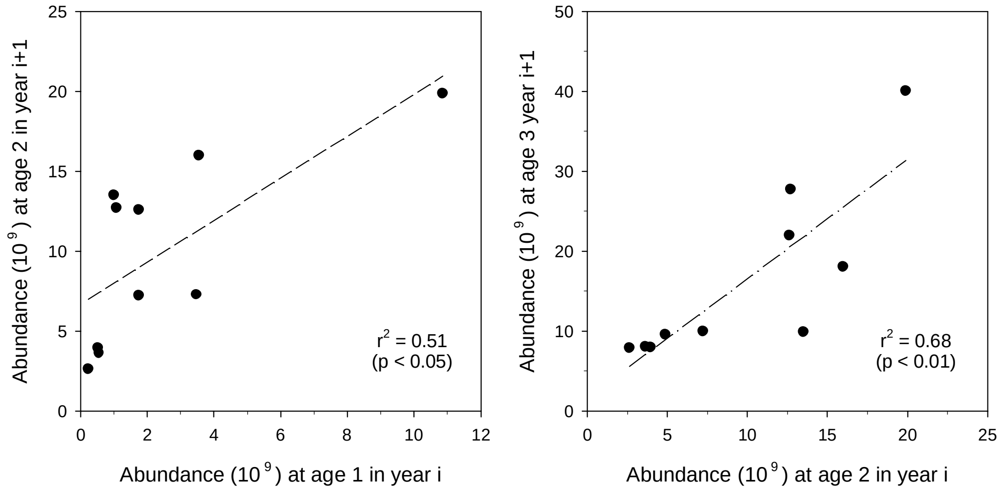

Fig. 17. Comparison of year class strength northern shrimp as measured at age 1, 2 and 3 off West Greenland, 1993 - 2003.

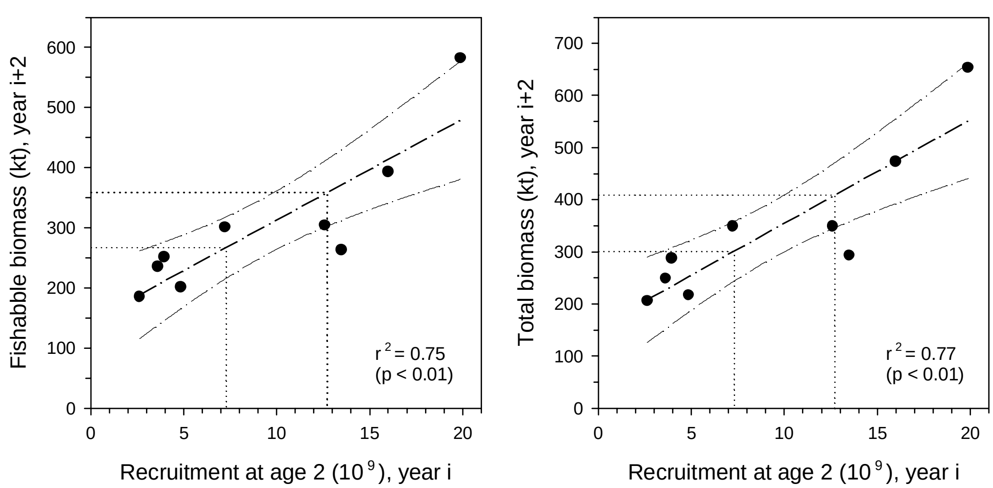

Fig. 18. Relation between abundance at age 2 and fishable biomass (all individuals ≥17 mm CL) as well as total survey biomass (Kanneworff and Wieland, 2003) two years later for northern shrimp off West Greenland, 1993-2003 (solid symbols: recruitment 1993-2001, biomass 1995-2003; dash-dot lines: linear regressions with 95% confidence intervals; dotted lines: expected biomass in 2004 and 2005 based on recruitment observed in 2002 and 2003).