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Growth of the Northern Shrimp (*Pandalus borealis*) in NAFO Division 3K

by

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Abstract

The growth of shrimp in Division 3K was described using data from studies of larval growth, sizes of juvenile shrimp found in cod stomachs and size-groups of adult shrimp from resource surveys. The methodology provided growth data from all life history stages and produced results which conformed to the theory of organic growth. Von Bertalanffy growth parameters were estimated at $L\infty$ = 33.34 mm, K = 0.21 and to = -0.04. The results also suggested that in some previous interpretations of shrimp growth from length frequency data, ages might have been underestimated. More information is needed on moulting frequency and the number of female age groups.

Résumé

La croissance des crevettes dans la division 3K à été décrite à partir de données provenant d'études sur la croissance larvaire, sur la taille des crevettes juvéniles trouvées dans l'estomac de morues et sur les groupes de tailles des crevettes adultes déterminés à la suite d'enquêtes concernant les ressources. La méthodologie a fourni des données de croissance pour tous les stades du cycle vital et a donné des résultats qui sont conformes à la théorie de la croissance organique. Les paramètres de croissance de Von Bertalanffy ont été estimés comme suit : $L\infty$= 33,34 mm, K = 0,21 et to = -0,04. Les résultats indiquent aussi que certaines interprétations antérieures de la croissance des crevettes à partir des données sur la fréquence des longueurs ont peut-être entraîné une sous-estimation des âges. D'autres renseignements sont nécessaires sur la fréquence des mues et sur le nombre de groupes d'âges des femelles.

Introduction

The problems involved in the interpretation of age and growth of the northern shrimp, Pandalus borealis, have been identified as a major obstacle in assessing the status of exploited populations (eg. ICES 1978, NAFO 1980). No hard structures are maintained through the moulting process and, thus, no analogues of the otoliths and scales of finfish are available from which growth in crustaceans can be determined. Yano and Kobayashi (1969) used the number of lamellae in the cuticle of the crab, Gaetice depressus, as an indicator of age but the interpretation of a stepwise increase in the number of lamellae with carapace length appears subjective.

Early descriptions of the growth of P. borealis were made by Berkeley (1930) and Hjort and Ruud (1938). Haynes and Wigley (1969) compared growth curves of shrimp from various parts of the North Atlantic and North Pacific Oceans. These early interpretations were primarily based on Petersen's (1891) method which followed the displacement of various size groups over time. In recent years, the separation of shrimp samples into age groups has been accomplished by analyzing polymodal length distributions and interpreting stages of sexual development. Overviews of the various methodologies can be found in Garcia and LeReste (1981), Pope and Angus (1981) and Fréchette and Parsons (1983). Skúladóttir (1981) modified the deviation method used by Sund (1930) on cod for use with shrimp. This method requires, however, a time-series to construct a mean length distribution against which individual frequencies are compared. More recently, Teigsmark (1983) used his own method for separating age groups from length frequencies, conducted a detailed statistical analysis of survey data from the Barents Sea and found three distinct populations with different biological and ecological characteristics.

Notably lacking in most studies on shrimp growth are data on development of larvae and juveniles. Most research trawl samples are not representative of the smaller sizes (younger ages) because these shrimp are neither fully selected by the gear nor fully recruited to the grounds where adult shrimp occur. Development and growth of larvae are not well documented, especially in the Northwest Atlantic, but such information is necessary before available data on juveniles and adults can be interpreted correctly.

The purpose of this exercise is to describe the growth of shrimp off northeast Newfoundland-southern Labrador (NAFO Div. 3K), including the development of larvae and juveniles as well as adults. To accomplish this, data from plankton sampling, stomach content studies of shrimp predators and a shrimp research trawl survey are incorporated to the analysis.

Materials and Methods

During the summer of 1981, zooplankton was sampled from several inshore stations in the Pack's Harbour and Domino regions of the Labrador coast (Fig. 1) as part of a study on the inshore abundance of Atlantic cod (Buchanan et al. 1982). Six stations (three at each of Pack's Harbour and Domino) located at total water depths of 20, 40, and 60 m were alternately sampled between 26 June and 19 September when weather permitted. Samples obtained after August 23 contained less than 5 larvae. Attempts were made to sample the water column at 10 m depth. High speed Miller samplers (10 cm diameter opening) with a 1000 μm mesh size were towed by a 16 m chartered vessel at an approximate speed of 1.5 m/s for 10 minutes. The Miller sampler was retrieved by hand winch at an approximate speed of 1 to 1.5 m/s with the vessel drifting. Samples were preserved in 10% buffered formalin. Detailed sampling information is described by Chaput (1984).

Stomachs were collected from Atlantic cod (Gadus morhua) caught during stratified-random bottom-trawl surveys in NAFO Div. 3K in autumn 1977-83. Stomachs were collected opportunistically in 1977. In 1978, a stratified-random sample of 5 fish per 10 cm length-group was taken from the catch of every set. In subsequent years, the sample size was reduced to 3 fish per 10 cm length-group. Cod stomachs also were collected from commercial catches and a research cod tagging survey in winter (March-April) 1983 and during a July 1984 shrimp survey. Only the samples from Div. 3K north of 50°N and west of 52°W are considered in the present study (Fig. 1). Cod stomachs were excised, individually tagged and preserved in 10% formalin/seawater solution. Examination involved the separation of food items into taxonomic categories. Pandalus borealis were measured to the nearest mm carapace length (CL) whenever digestive condition permitted.

During the July 1984 shrimp survey, a total of 18 successful random stations were fished in Div. 3K (Fig.1 and 2). A Sputnik 1600 shrimp trawl, with a 13 mm liner in the codend, was towed at 3.5 knots for 30 minutes. A random sample of the shrimp catch was obtained for each set and carapace lengths were measured to the nearest 0.1 mm. A length frequency representing the total number of shrimp caught was compiled for modal analysis by the Macdonald and Pitcher (1979) method. A random sample of 1128 shrimp was separated into male and female components by examination of the endopod of the first pleopod (Rasmussen 1953). Females were further separated into first time and multiple spawners based on the condition of sternal spines (McCrary 1971).

Mean length-at-age was determined for each developmental stage assuming a birthdate of May 1. Von Bertalanffy (1938) growth parameters were derived (Marquardt method) using the APL program by Rivard (1982).

Results

1. Growth of Larvae

Although the shrimp larvae sampled from inshore Labrador in 1981 were collected from sites north of Div. 3K, it is assumed that growth of larvae in this area is representative of the growth of larvae which actually recruit to the 3K area. Analysis of bongo samples from several nearshore and offshore stations (approx. 52°N to 60°N) from 1979 through 1983 have shown that larvae of P. borealis are broadly distributed along the Labrador coast. In particular, high densities of larvae (to a maximum of 293 larvae per 100 m^3 of seawater) were noted at the southern edge of Div. 2J (52°21'N) (Chaput 1984).

Measurements of larvae from these stations have shown that the sizes at stage were similar at all stations and for all years (including the 1981 inshore samples), although the dominant stage on a particular date varied between years. The inshore samples for 1981 were selected because they provide the best time series (June to September) for larvae which moult frequently during the first half year before settling out of the plankton.

In 1981, stage III larvae were dominant in early July, stage IV in late July and throughout August and stage V in August and presumably September (Fig. 3). Mean carapace lengths of 1.62, 2.23, and 2.42 mm were derived for stages III, IV and V respectively (Table 1).

Corresponding ages were estimated at 2, 3, and 4 months (0.17, 0.25 and 0.33 years) assuming the May 1 birthdate. The length for stage V larvae is likely underestimated because larvae begin to settle out of the water column at stage V and beyond. Also, most of the stage V larvae measured were taken in mid August rather than early September.

2. Growth of Juveniles

Measurements of shrimp from cod stomachs sampled in fall surveys (September-December) show, in most years, a mode of very small animals about 3-4 mm (Fig. 4). A second mode at 9-10 mm also is evident in most samples. These size groups were assigned ages 0.58 and 1.58 years (7 months and 19 months), respectively. Based on pooled samples for all years (Fig. 5), the corresponding average lengths were estimated at 4.2 ($n = 80$) and 9.5 mm ($n = 472$).

Only the winter survey results in 1983 (March-April) showed a broad size range of shrimp in cod stomachs. The smallest size group occurred at 5 to 6 mm (Fig. 6). The average size of this group based on a sample size of only 6 animals was 5.5 mm and the age was estimated to be 11 months or 0.92 years. Other modes, as well, were not distinct in the samples and, consequently, no further age interpretations were made from these data.

The shrimp found in cod stomachs during the July 1984 research survey in Div. 3K showed a mode of small animals at 7 mm (Fig. 7). The average length was 6.9 mm based on a sample size of 38 animals. This group was considered to be 1.17 years (14 months). It was not possible to define age groups between 10 and 20 mm because modes were not distinct.

3. Growth of Adults

The length frequency adjusted to the total number of shrimp caught in stratified-random trawling in July 1984 (Fig. 8) was subjected to modal analysis by the Macdonald and Pitcher (1979) method. Four modes were interpreted from the figure, and the results of the analysis were not significantly different from the observed data ($\chi^2 = 20.76$, $0.50 < P < 0.75$) under this assumption. Average length, standard deviations and proportions for each modal group and their standard errors are given in Table 2. The results show that the statistical procedure had difficulty fitting four components. This is not so much reflected in the final chi-square value as in the standard errors of the parameters for the first two components. A revised run, assuming three components, produced more precise results (Table 2) but the mean lengths of the three larger modes did not change. The mean length of 13.3 mm was used, nevertheless, to represent a separate age group because of evidence in the individual length frequencies that such a mode exists. Also, cod stomach analysis shows the presence of this modal group (Fig. 4 and 5).

The length distribution for the detailed sample (Fig. 9) also showed four modes which corresponded well to those evident in the previous figure. The smallest size group was poorly represented, however. A separation of the sample into males and females showed that the first three modes were composed of maturing and mature males while the fourth was mainly females. Separation of females by condition of sternal spines was used as a means of distinguishing first time spawners from multiple spawners. The average length of each female group was 22.7 (n = 189) and 23.9 mm (n = 191), respectively.

Interpretation of the actual ages of each modal group was based on the results of the previous observations on growth of larvae and juveniles. The three modes of males were assigned ages 2.17, 3.17 and 4.17 years from smallest to largest while first time spawners and multiple spawners were interpreted to be 5.17 and 6.17 years, respectively.

4. Composite Growth Model

A summary of the observations on growth and maturity detailed above is given in Table 3. The length-at-age data were used to derive the following von Bertalanffy growth parameters; L_∞ = 33.34, K = 0.21, t_0 = -0.04 (Table 4). The observed data fit the theoretical line well, especially for the first year's growth (Fig. 10).

Discussion

The interpretation of age and growth of shrimp in Div. 3K presented in this study must be considered in relation to the data used in the model and, indeed, the model itself. The analysis neither follows the growth of a year-class over its lifespan nor describes average growth of a number of cohorts over a series of years. Data on larval growth are restricted to the 1981 year-class, juvenile growth to average lengths for a number of year-classes and adult growth to average lengths of the 1978 to 1982 year-classes in July 1984. This potpourri of information, is all that is available covering the life history of the species in this area but it is considerably more than that available for most other populations and the results described here might well apply elsewhere.

The problems of availability and selectivity in constructing representative length frequencies as described by Fréchette and Parsons (1983) have not been addressed directly here. Because the distribution analyzed by the Macdonald and Pitcher method was adjusted to the total catch obtained during the 1984 survey, these problems are, at least, minimized. This method of pooling the data accounted for changes in average size of year-classes with depth while giving appropriate weight to areas of highest abundance.

The von Bertalanffy growth model does not adequately describe the discontinuous growth of crustacea. Intuitively, one would use a step function if there were appropriate data on the frequency of moulting. Some information is available from controlled studies of larval growth in P. borealis (eg. Haynes 1979, Wienberg 1975, 1982) but the number of moults which juveniles and adults undergo annually is not well documented. Therefore, the model is used here only to approximate the growth of shrimp and to compare the observed values with those expected from theory.

The carapace length of shrimp larvae at the various stages, as sampled in 1981 from inshore Labrador, are comparable to those observed by Berkeley (1930) from southern British Columbia waters (49°N) and those reared in situ from North Sea parent stock (58°N; Wienberg 1982). However, larvae reared in situ from Kachemak Bay, Alaska, parent stock (59°N; Haynes 1979) were substantially larger than those from the North Sea and Labrador, especially at stage V. In controlled laboratory experiments on growth and development of P. borealis larvae, Wienberg (1982) noted that the rate of development of larvae increased with increasing temperature (3°C to 12°C). Larvae reared at 3°C were smaller than larvae of the same age reared at warmer temperatures. However, regardless of temperature, larvae of the same stages reached the same size.

Studies of the early life history of shrimp off northeastern Newfoundland-southern Labrador provide information which might be applied to observations made for other shrimp stocks in the northwest Atlantic. Shrimp ranging in size from 6 to 9 mm were measured from cod stomachs from the Hopedale and Cartwright Channels off Labrador in July (Bowering et al. 1984). It was thought that these shrimp might represent the young of the year. Fréchette (1982) designated individuals of 10 to 12 mm, captured in October 1980 from the Gulf of St. Lawrence, as group 0. Based on observations of larval growth from southern Labrador, it is more likely that these size groups represented one-year-olds. Similarly, 8-12 mm shrimp captured in October from Davis Strait (Fréchette and Dupouy 1979) were 1+ years-old as were shrimp of 8-9 mm captured in late August and September from West Greenland waters (Derible et al. 1980).

Even at a rearing temperature of 12°C, it required an average of 7.3 days between moults for P. borealis larvae and up to 10 moults to reach the first postlarval stage (Wienberg 1982). Considering the time required for larval development, it is possible that Berkeley (1930) overestimated the growth rate of P. borealis from British Columbia waters when she interpreted shrimp around 55 mm total length (~10 mm CL) captured in September to be young-of-the-year. Rapid first year growth also has been interpreted for other populations such as in Oslo Fjord, Norway (Hjort and Ruud 1938), the Gulf of Maine (Haynes and Wigley 1969) and to a less extent, in the Bering Sea and Gulf of Alaska (Ivanov 1968). It is noted that the bottom water temperatures in these areas are generally warmer than in some areas of the Northwest Atlantic where the species occurs which alone could account for such differences in growth. However, in most of the previous studies, there is a lack of data on growth from the late larval stages up to the time the juveniles become available to the grounds where the adults occur.

By contrast, Teigsmark (1983) described growth of "4-1" and "5-2" populations of P. borealis in the Barents Sea which was similar to the growth apparent in Div. 3K. In both studies, growth in the first year was interpreted to be slower than previously reported for other populations.

The number of years females spawn and, hence, the life span of the species is still unresolved. The multiple spawner group likely comprises more than one year-class but survival rates are not well understood. The average length of six-year-olds is overestimated and actually represents the 6+ group. The situation is complicated by the fact that a small proportion of females in most stocks in the Northwest Atlantic do not spawn each year, allowing up to six months for additional growth. Therefore, even if separate modes are evident in the multiple spawner group, interpreting which year-classes they represent might be highly subjective.

Conclusions

The growth of Pandalus borealis larvae off Labrador has been described and appears similar to that reported from the North Sea and other Atlantic populations. The sampling of the stomachs of shrimp predators provides important information on the growth of post-larval shrimp from the time they settle out of the water column to the time they become available to research sampling gear. Using data from all three sources, interpretations of age can be made even when resources and/or environmental conditions prevent sampling year-round. Based on the findings of this study, it is apparent that the methodology used produced results which are not only chronologically valid but conform to the theory of organic growth, as well.

To obtain a more appropriate model of growth, data on moulting frequency for juveniles and adults are necessary. Also, it is important to determine how many age groups of multiple spawning females are present. This is particularly important in determining mortality for fully recruited ages and in constructing catch-at-age data.

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Table 1. Carapace length (mm) of shrimp larvae sampled at Pack's Harbour and Domino during the summer of 1981.

Stage	Mean length	Standard deviation	Range	n	Age[a] (years)
III	1.62	0.17	1.12-2.80	1657	0.17
IV	2.23	0.24	1.57-3.57	950	0.25
V	2.42	0.26	1.86-3.86	524	0.33

[a]Assuming a birthdate of May 1.

Table 2. Results of the Macdonald and Pitcher (1979) method for analyzing a distribution mixture from Division 3K, July 1984.

	Group	% (S.E.)	Mean length (S.E.)	Standard deviation (S.E.)
k = 4	1	4.8 (66.2)	13.3 (13.2)	1.52 (3.09)
χ^2 = 20.76	2	31.0 (73.4)	16.0 (2.9)	1.64 (2.04)
D.F. = 25	3	10.2 (7.7)	19.1 (0.2)	0.66 (0.25)
0.5<P< 0.75	4	54.0 (2.4)	22.8 (0.1)	1.78 (0.10)
k = 3	1	40.2 (2.8)	16.0 (0.2)	2.09 (0.15)
χ^2 = 19.05	2	5.5 (2.1)	19.1 (0.1)	0.43 (0.16)
D.F. = 28	3	54.3 (2.2)	22.8 (0.1)	1.80 (0.09)
0.75<P< 0.90				

Table 3. Carapace length and age of *Pandalus borealis* at different developmental stages.

Stage	Month	Length (mm)	Age (years)[a]
Larvae III	July	1.6	0.17
Larvae IV	August	2.2	0.25
Larvae V	September	2.4	0.33
Juveniles	December	4.2	0.58
Juveniles	April	5.5	0.92
Juveniles[b]	July	6.9	1.17
Juveniles[b]	December	9.5	1.58
Males	July	13.3	2.17
Males	July	16.0	3.17
Males	July	19.1	4.17
Females[c]	July	22.7	5.17
Females[c]	July	23.9	6.17

[a]Assumes a birthdate of May 1.
[b]Likely immature males by this time.
[c]Average length of first year females and multiple spawners from detailed sampling.

Table 4. von Bertalanffy parameters for growth of shrimp in Division 3K.

	Estimated parameter	Standard error	T-value
L_∞	33.3388	2.4125	13.8191
K	0.2084	0.0264	7.9109
t_0	-0.0406	0.0503	-0.8073

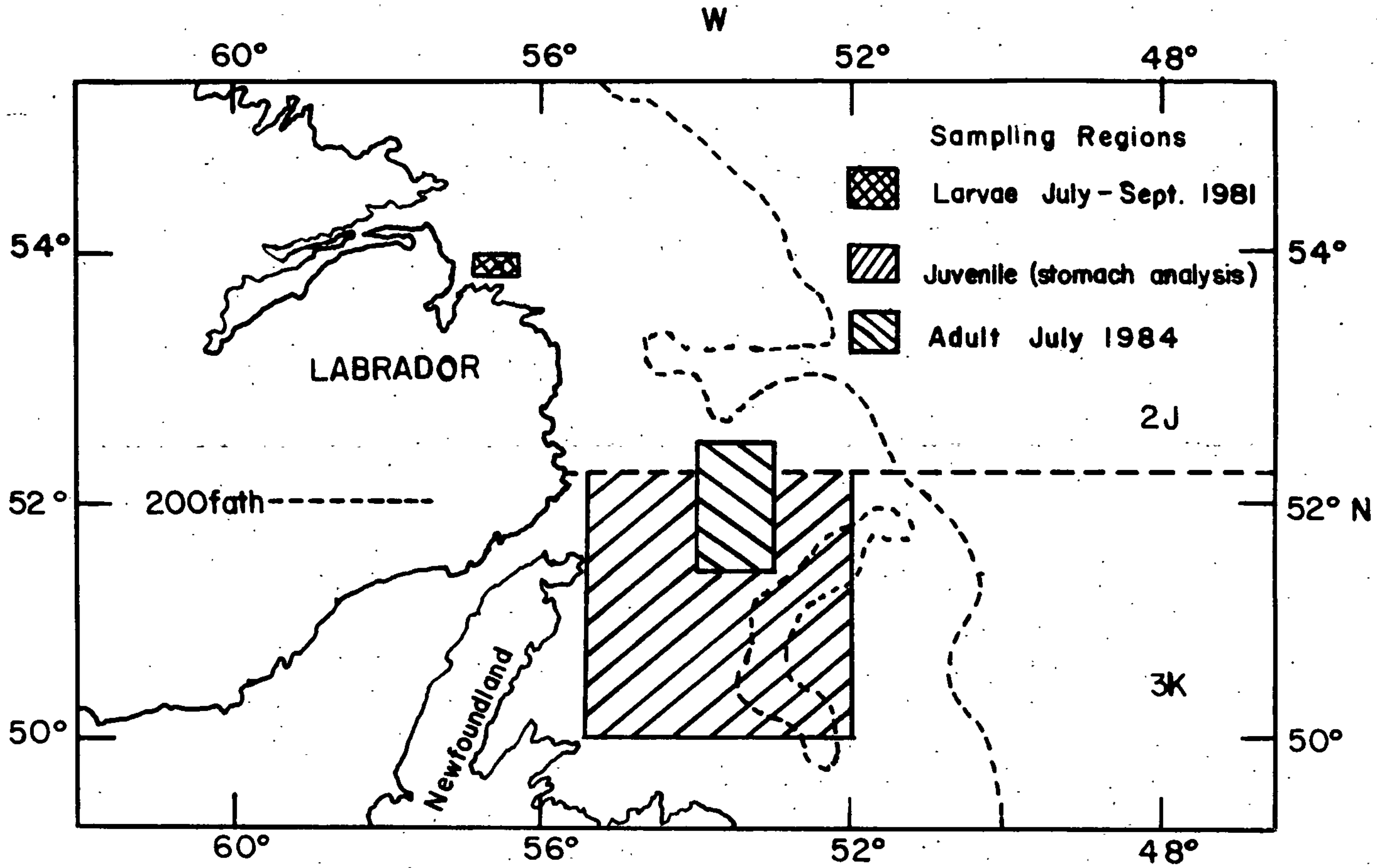

Fig.1. Locations of plankton sampling for shrimp larvae (1981), cod sampling for stomach content analysis (1977-1983), and survey for adult shrimp (1984).

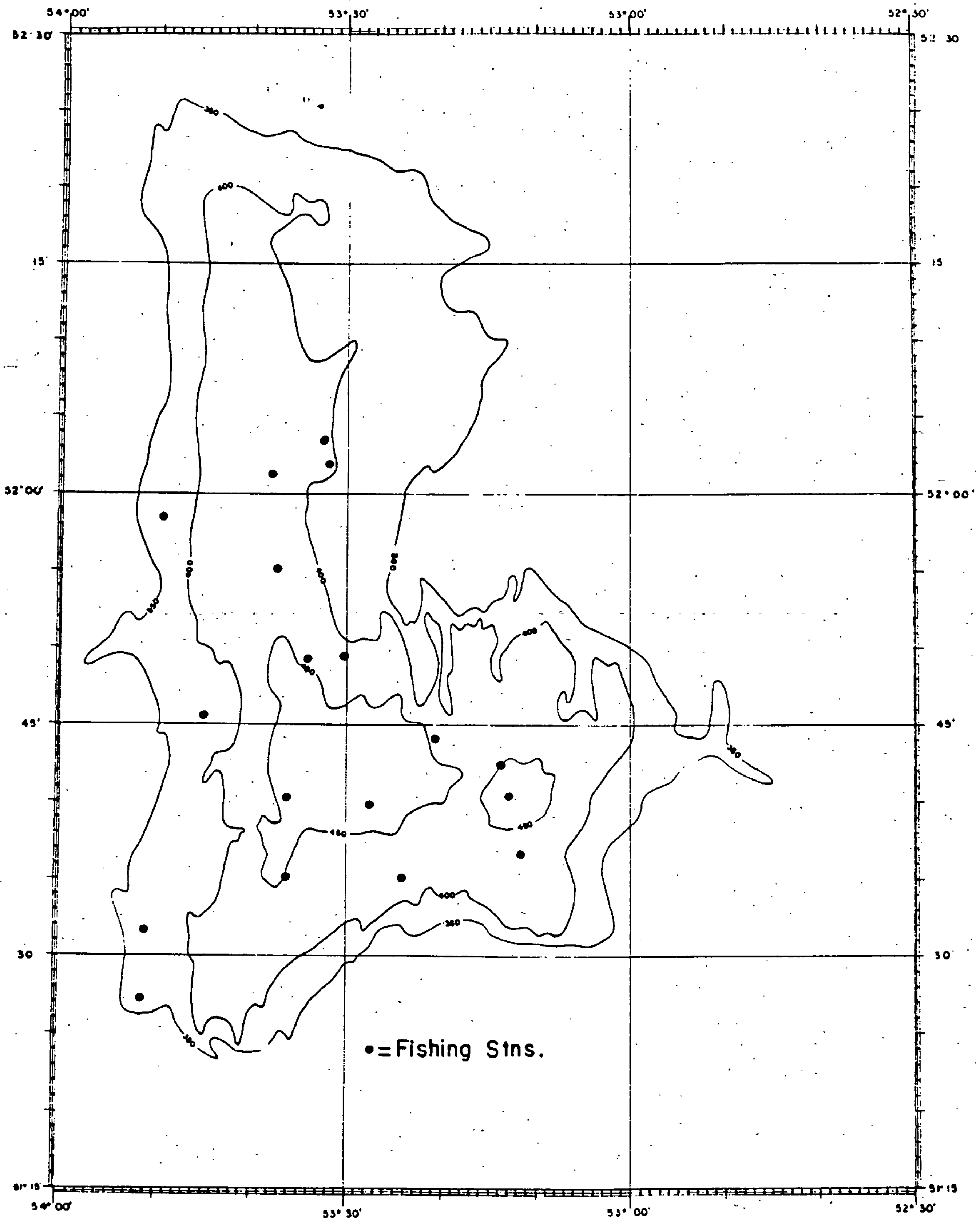

Fig. 2. Area surveyed and stations sampled for shrimp in Division 3K, July 1984.

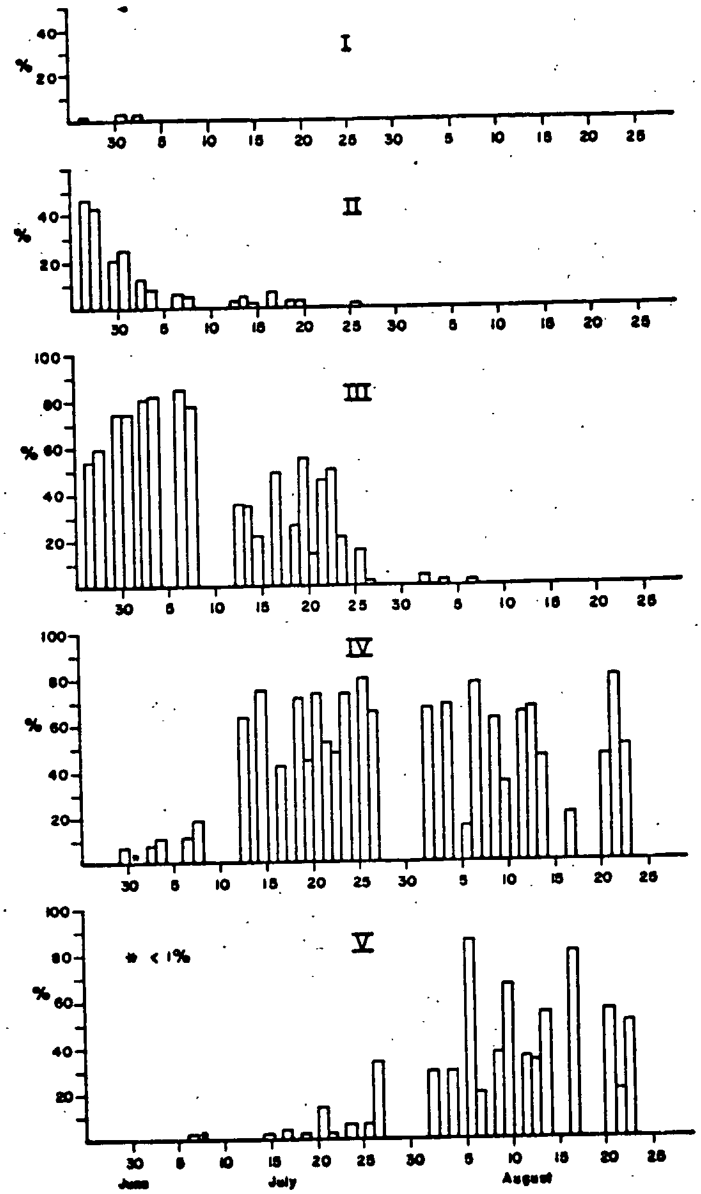

Fig. 3. Percent at stage of P. borealis larvae during the period June 26 to August 25 from Pack's Harbour and Domino (combined). Only dates when at least five larvae were captured are included.

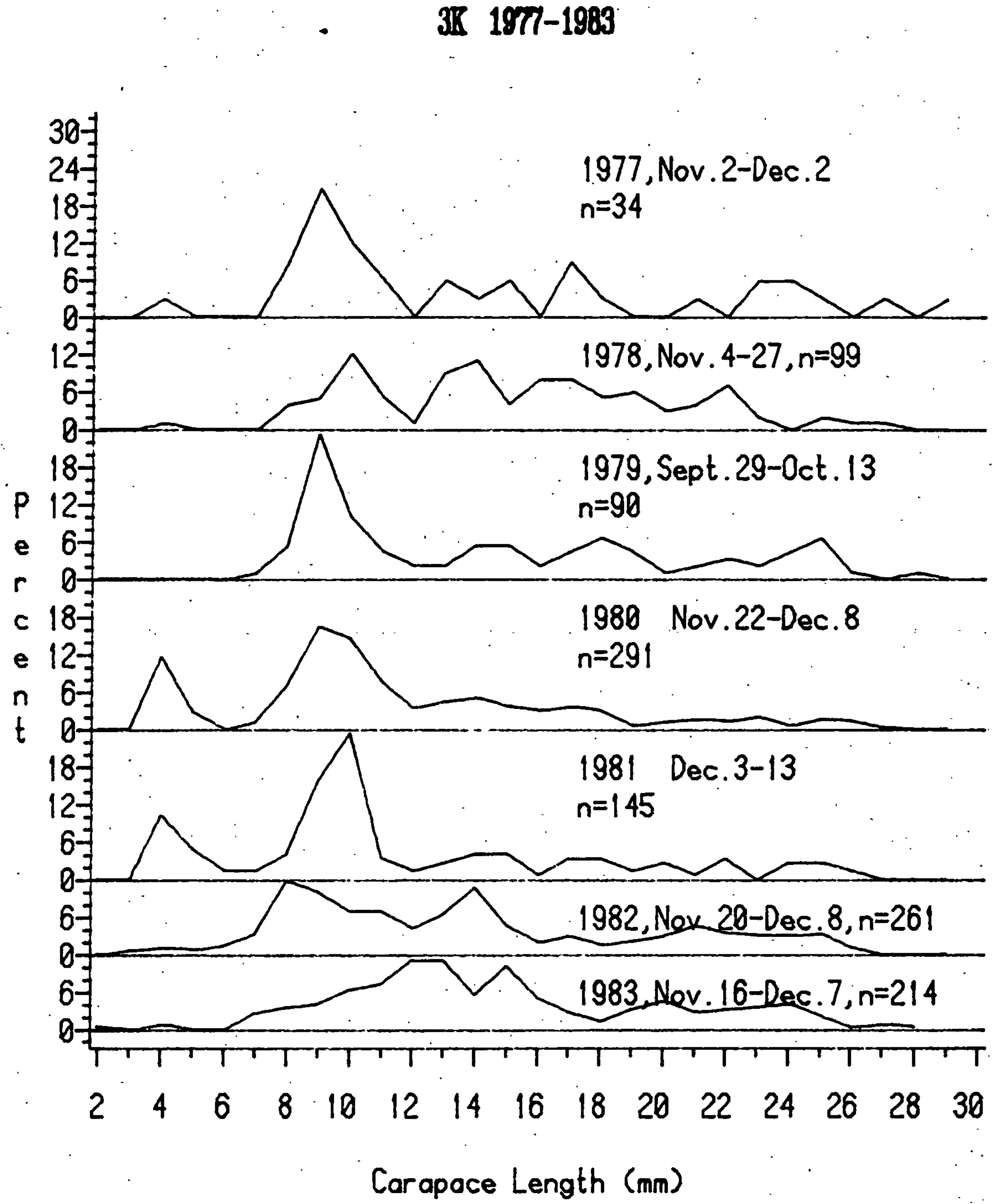

Fig. 4. Length frequencies of shrimp obtained from cod stomachs in Division 3K during autumn surveys (September-December 1977-1983).

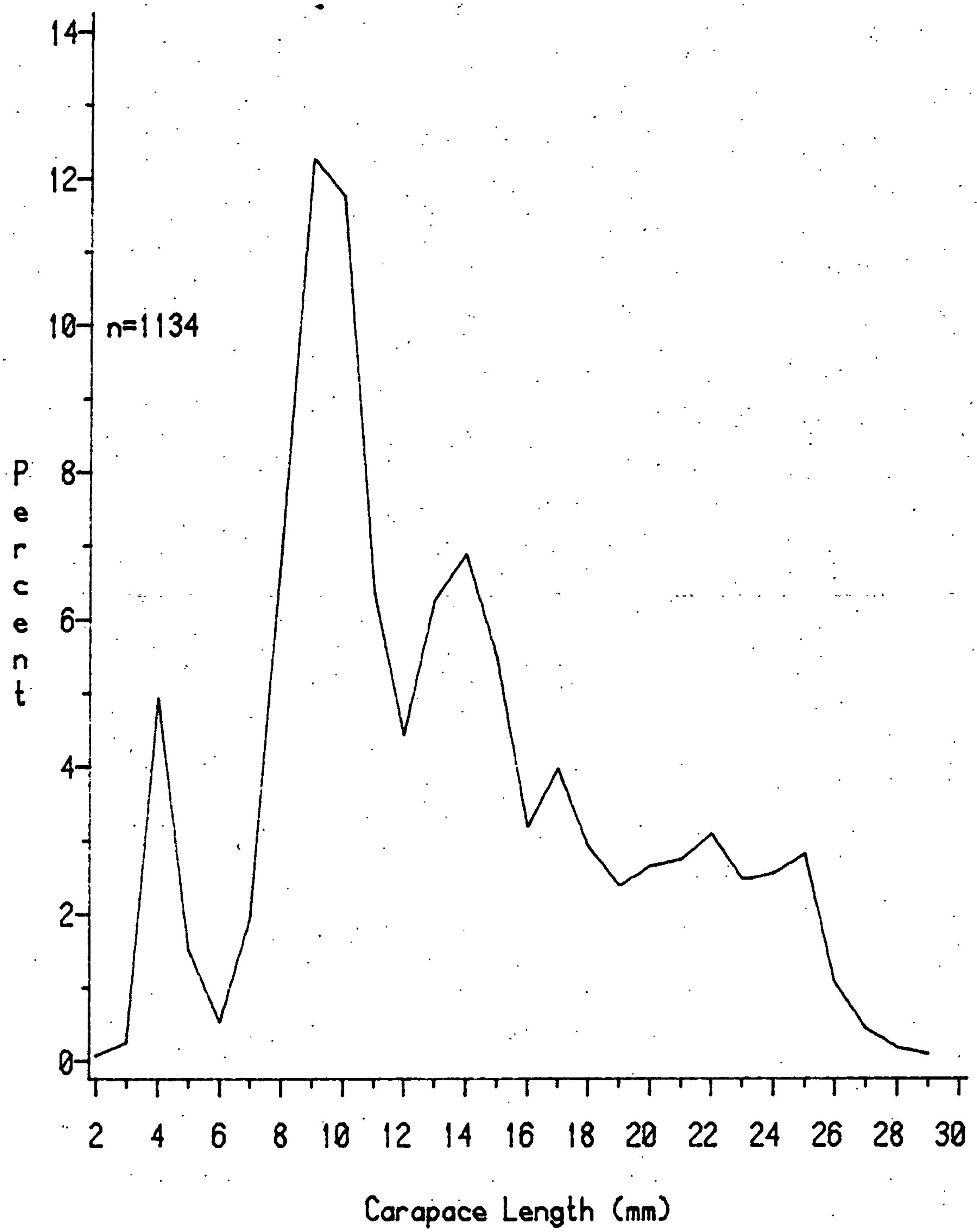

Fig. 5. Length frequency of shrimp obtained from cod stomachs in Division 3K during autumn survey, all data in Fig. 4 combined.

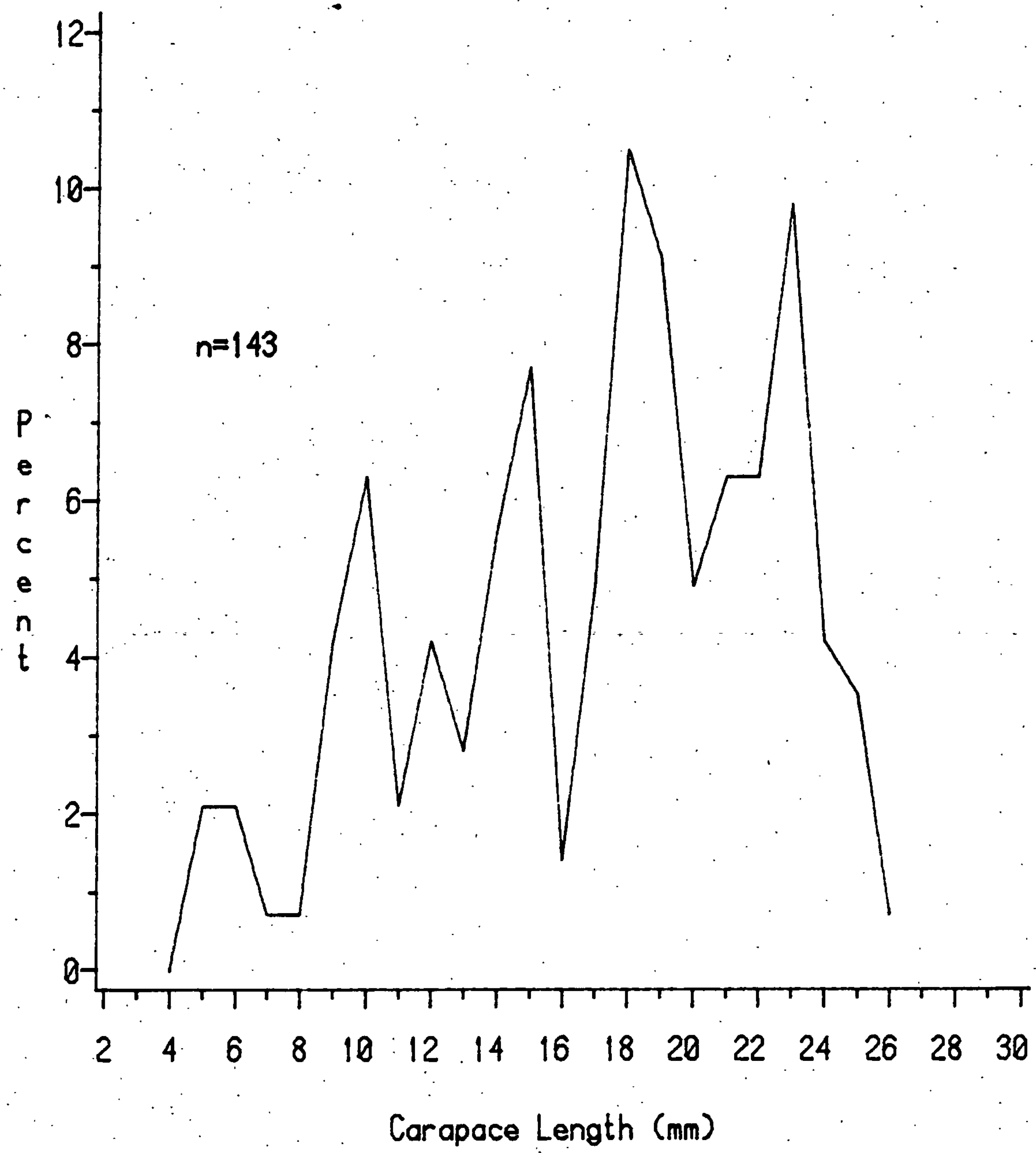

Fig. 6. Length frequency of shrimp obtained from cod stomachs in Division 3K during a winter survey in 1983 (March-April).

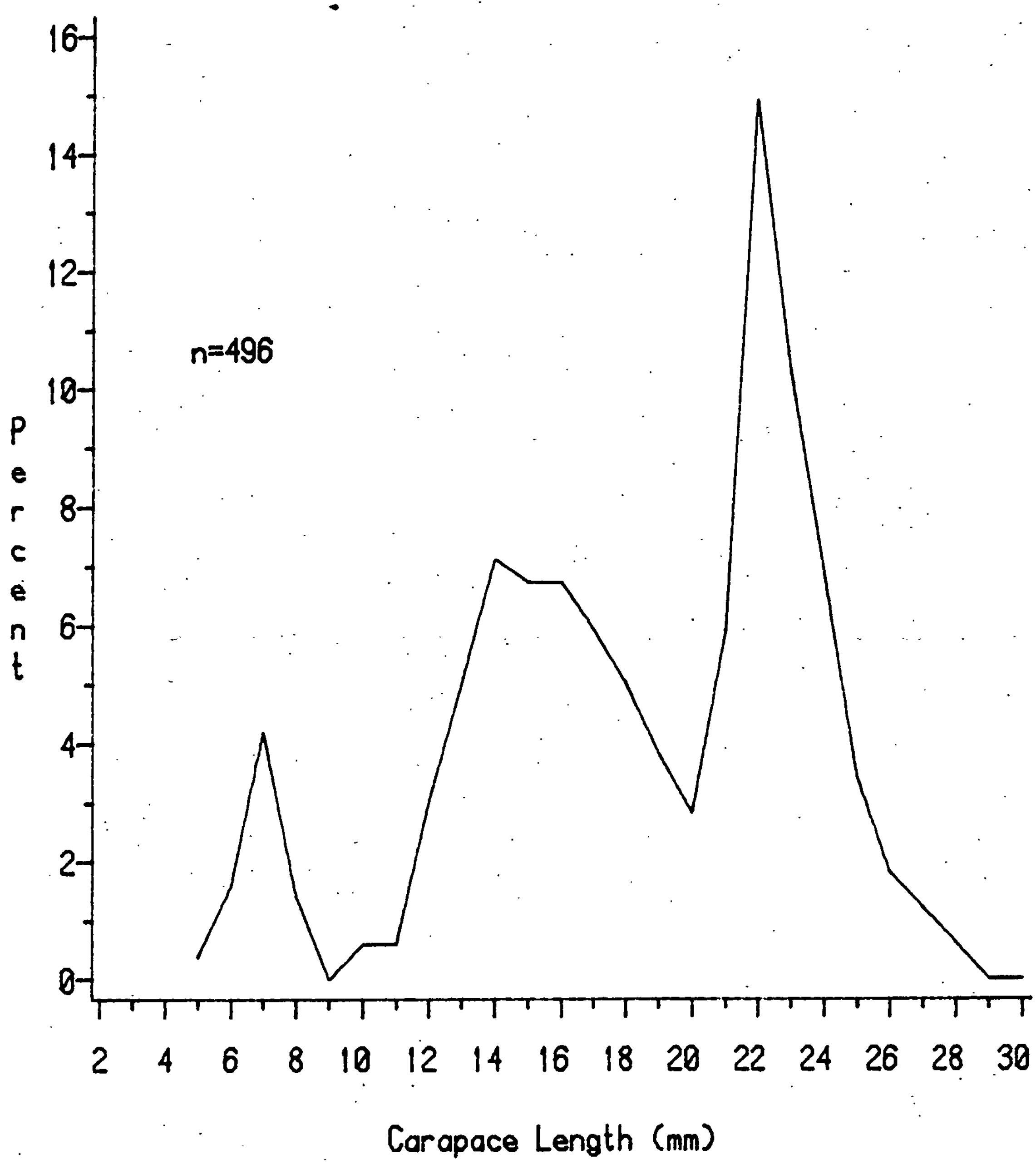

Fig. 7. Length frequency of shrimp obtained from cod stomachs in Division 3K during a July survey in 1984.

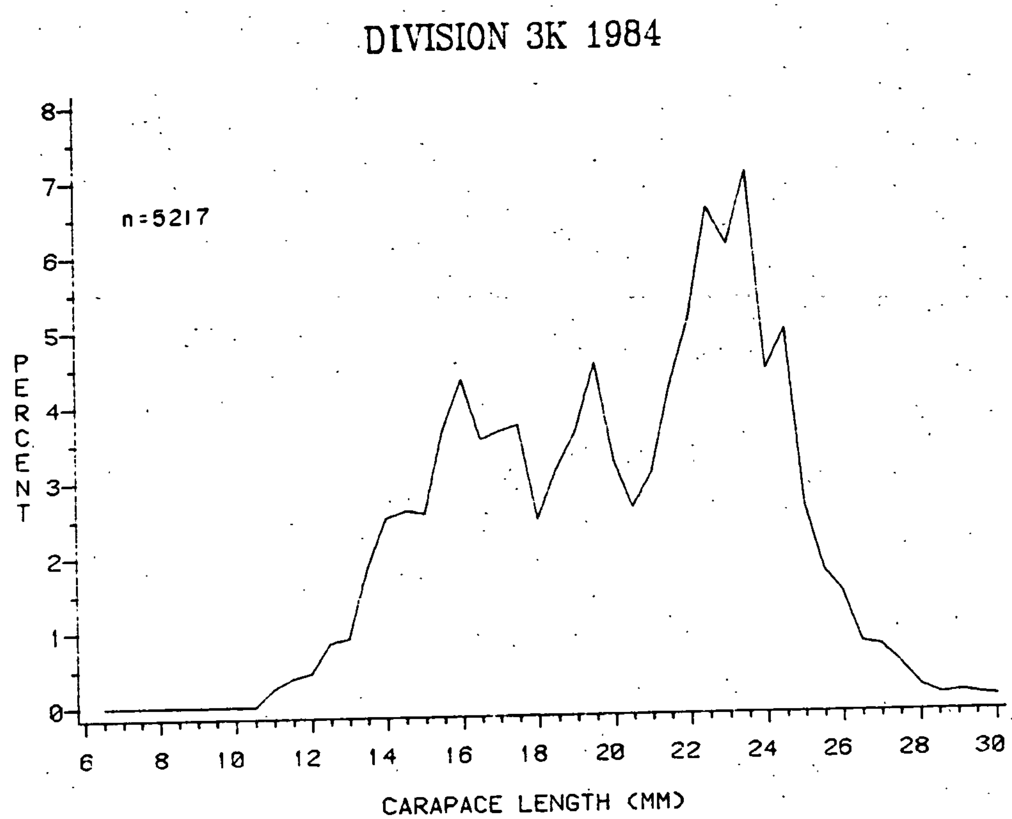

Fig. 8. Length frequency of a number of shrimp caught during a stratified random survey in Division 3K, July 1984.

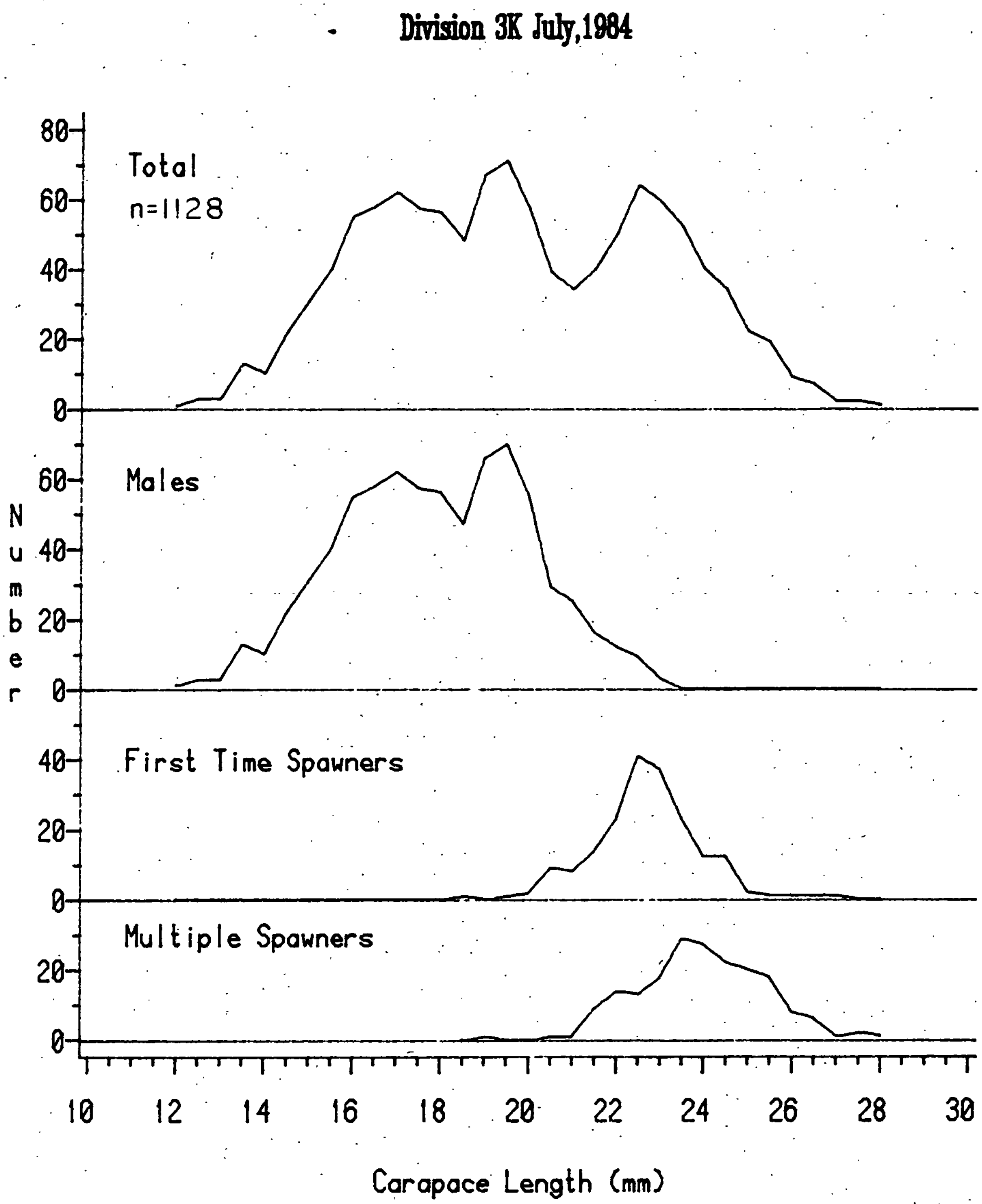

Fig. 9. Separation of a shrimp sample obtained in Division 3K, July 1984 by stages of sexual development. First time spawners include transitionals and first year females. Five ovigerous females were not included.

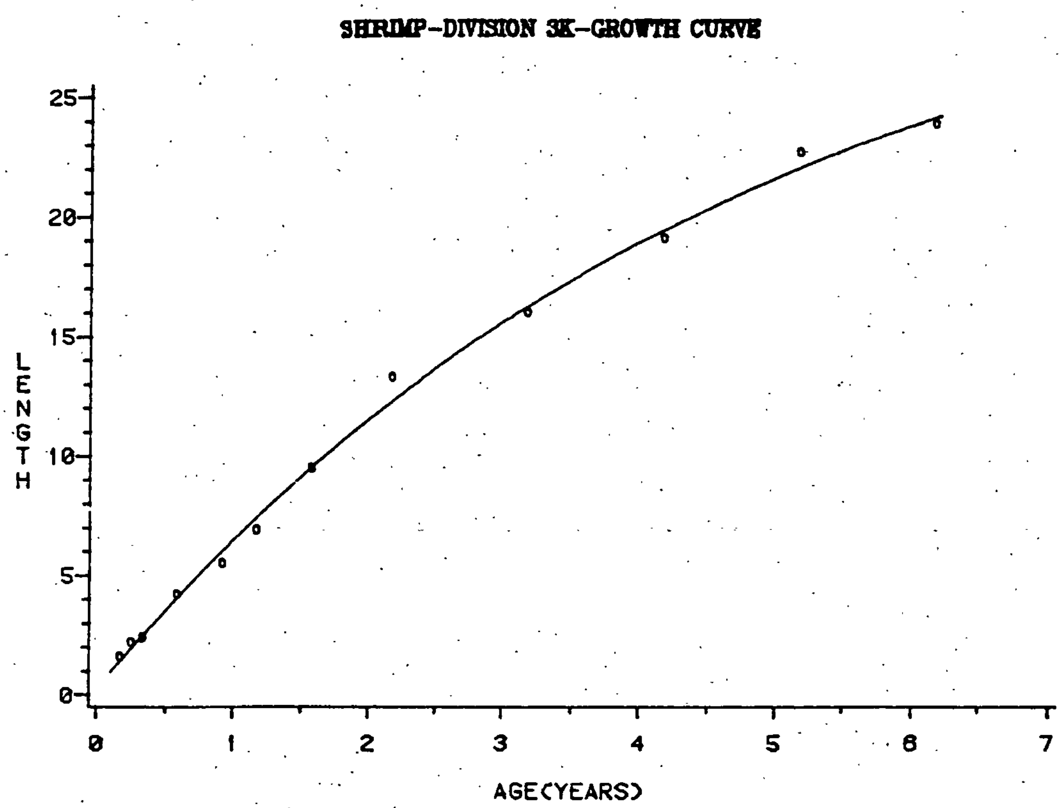

Fig. 10. Von Bertalanffy growth curve and mean length (mm) at age for shrimp in Division 3K constructed from data on larval development, observations of sizes of shrimp in cod stomachs and an analysis of a length distribution mixture.