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Observations on Some Biological Characteristics of Shrimp (Pandalus borealis)
from the Davis Strait, 1978-81

by

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Introduction

The importance of analyzing biological data for the Subareas 0 and 1 shrimp stocks has been stressed by the Standing Committee on Fishery Science (STACFIS) of NAFO in recent years. The difficulties in applying traditional fishery models to shrimp have necessitated a dependency on annual research surveys and monitoring fleet performance to detect changes in stock size. Biological data also provide some qualitative estimates of survival and recruitment. The benefits of an in-depth study of a time series of biological data can be two-fold in that 1) any changes observed might be related to effects of the environment (eg. temperature, predators) or fishing pressure and 2) estimates of parameters for use in quantitative analyses (eg. mortality, recruitment index) might be forthcoming. More generally, in any study of the population dynamics of a species, an intimate knowledge of its biology is essential.

In response to the concerns of STACFIS, the following analyzes biological data obtained from research and commercial trawlers fishing for shrimp in Davis Strait between 1978 and 1981. The results may have some application in the assessment of the Subarea 0 + 1 shrimp stocks in advance of the 1984 fishing season.

Materials and Methods

A total of seven (7) samples was available for analysis from the Store Hellefiske Bank between 1978 and 1981 (Fig. 1, Table 1). These were taken by research (1978 and 1979) and commercial trawlers (1980 and 1981) in the August-September period. Although samples were chosen from the same general area (Div. OA and 1B), depths ranged from 260 to 350 m. Samples were pooled for each year resulting in sample sizes of 719, 806, 652, and 312 for 1978 to 1981, respectively. Pooling was considered appropriate after a cursory examination of the maturity data revealed no major differences between samples within years. The commercial samples were the only ones available for 1980 and 1981, therefore, the choice of available samples for 1978 and 1979 was limited to the range of areas and depths encountered in the former two. Since the commercial sampling was opportunistic rather than systematic, strict sampling procedures (as recommended at the Shrimp Ageing Workshop of NAFO) could not be followed.

Shrimp were measured to the nearest 0.1 mm for carapace length and, when possible, to the nearest 1.0 mm for total length. Carapace length interval was increased to 0.5 mm for most analyses. Sex was determined by observation of the first pleopod and maturity, by observation of the gonads, and for very small animals, the second pleopod. These were macroscopic examinations and, consequently, the maturity data have no histological verification other than that the descriptions followed closely those given by Berkeley (1930). Thus, sex was determined as juvenile, male, transitional or female and maturity as immature, mature and ovigerous. The size of the ovary also was noted to determine spawning potential in any particular year. Sternal spines were examined as described by McCrary (1971) and presence of abdominal parasites also was recorded. In studies of maturity and age, the latter were omitted.

A total length/carapace length relationship was derived by least squares regression for 164 animals covering a wide range of sizes. A preliminary interpretation of age was made by examining stages of sexual development and a Cassie (1954) analysis of a polymodal group of juveniles and males. Estimates of natural mortality were derived by Pauly's (1980) multiple regression equation relating M to L_{∞} and K of the von Bertalanffy growth equation and temperature.

Results

Sex and Maturity

The breakdown of sexual components for the samples in each year (Fig. 2-5) includes an undifferentiated length frequency (%/mm) and separate frequencies for males, a composite group of transitionals and first year females (interpreted to be the same age group), multiple spawners and ovigerous females. Although the frequencies differ in the relative strength of individual size/sex groups, there appears to be some similarity between years in the sizes of each component. In 1978 (Fig. 2), males (including a few juveniles) were dominant up to 24 mm. Transitionals and first year females were unimodal at 25-25.5 mm and multiple spawners averaged around 26.5 mm. No ovigerous animals were present in the August 1978 samples. The following year (Fig. 3) males again were dominant up to 24 mm but the proportion of transitionals and first year females was very low. There was a peak of multiple spawners at 26.5 mm and ovigerous females were numerous in August of 1979. These ovigerous animals occurred at the same sizes as the transitional-first year female group.

In 1980, males dominated the smaller size groups to 24.5 mm (Fig. 4). Transitionals and first year females occurred around 25.5 mm but there is some evidence (albeit only one point) of bimodality. Multiple spawners peaked at 27.0 mm and the few ovigerous females indicated bimodality at 25.5 and 27 mm. The sample size in 1981 was low compared to the other years. Males again were dominant up to 24 mm (Fig. 5), the transitional-first year female and ovigerous groups were of similar sizes and indicated bimodality. Multiple spawners were unimodal at 26.5 mm.

Pooling the data from all years permitted generalization of conditions for the four years in question (Fig. 6). The smaller size intervals consisted entirely of male shrimp with the exception of a few juveniles at the very smallest sizes. The other stages began to occur at sizes greater than 22 mm and the length at 50% males was around 24 mm (Fig. 7). Transitionals were unimodal at 25.5 mm, the few first year females (with spines) averaged 25.3 mm and, combined, both groups averaged 25.5 mm. Females which had spawned previously (no spines) were unimodal at 26.5 mm. Ovigerous females occurred around 25 mm.

The maturity data also indicated that a small percentage of the transitional and female shrimp would not spawn in a given year. The inability to spawn was interpreted from transitional and female shrimp with small, undeveloping ovaries. The percent of non-spawners of all transitional and female shrimp was 3.5, 2.9, 1.5, and 1.4 for 1978 to 1981, respectively (Table 2). The percentage for all years combined was 2.4. The data also showed that only one of these was a first-time spawner. Therefore, of the multiple spawner group, 7.0, 3.7, 2.5, and 2.4 percent might not have spawned in 1978 to 1981, respectively (Table 2). These percentages are slightly overestimated because some ovigerous multiple spawners are not included in the total.

Age Interpretation

Ageing of shrimp from these samples was attempted through an interpretation of the sexual components and a graphical breakdown of a polymodal group of juveniles and males. The pooled, four year data set (Fig. 6) was used to average length-at-age over a number of years for transitionals and female components. The Cassie analysis for males proved more difficult as size groups were not consistently represented each year and the pooled data were inconclusive. From the yearly data (Fig. 2-5), evidence of five modal groups was observed but not in each year. It was decided to pool 1978 and 1980 because the former best illustrated the first three modes and the latter the two largest male groups (Fig. 8).

As mentioned previously, the transitionals and females with sternal spines (first year females) were considered to be a single year-class and the average size of this modal group of 25.5 mm (see previous section) was chosen as the mean length-at-age. Multiple spawners (females without spines) had an average length of around 26.5 mm. This group is likely made up of a number of year-classes which cannot be separated and, therefore, the average length may be somewhat overestimated for the dominant cohort.

Results of the Cassle analysis are given in Figure 9 and Table 3. Five components were estimated for mean and standard deviation. The smallest group around 8.0 mm was interpreted to be age group 0, age 1 at 12.0 mm, age 2 - 15.0 mm, age 3 - 19.5 mm, and age 4 - 22.5 mm. The smallest/youngest group consisted of juveniles and immature males. The second size group were all immature males and the third, partly immature and partly mature. The two largest groups were exclusively mature males. A summary of length-at-age and maturity is given in Table 4.

Natural Mortality

Pauly (1980) developed the following equation for the estimation of natural mortality (M) for fish stocks:

$$\log M = -0.0066 - 0.279 \log L^{\infty} + 0.6543 \log K + 0.4634 \log T$$

where L^{∞} and K are parameters of the von Bertalanffy growth equation and T is an estimate of mean water temperature where the fish live.

Subsequently, Pauly et al. (1981) applied the same equation to estimate M for Penaeid shrimp stocks. The equation was used in this analysis to derive an estimate of M for the shrimp stocks in Subareas 0 + 1.

Based on mean length-at-age from the previous section, the von Bertalanffy growth equation was derived (Marquardt method) using the APL program by Rivard (1982). Pauly's procedure recommends that L^{∞} be expressed in cm, preferably using total length. A total length/carapace length relationship was derived from the 1978-81 samples (Fig. 10).

$$tl = 4.53 cl + 15.34 \quad (r^2 = 0.96)$$

Von Bertalanffy parameters were estimated both for carapace length and total length (Table 5). Length at age 0 was not included because it is very likely that problems of selectivity and availability of this size/age group significantly influence the observed mean size. L^{∞} was estimated at 38.4 mm cl and 189.7 tl while K was estimated at 0.17. The values $L^{\infty} = 18.97$ cm, $K = 0.17$ and $T = 4.0^{\circ}\text{C}$ were used in Pauly's equation which generated an estimate of $M = 0.26$. The value 4° was used as an estimate of effective physiological temperature as recommended by Pauly (1980) for cold water species. This corresponds to the environmental temperature range of 3-4°C for shrimp concentrations in the Davis Strait (eg. Kannevorff 1983, Dupouy et al. 1979, Parsons 1979). Even with this conversion, Pauly (1980) suggests an additional conversion factor of 1.3 for polar fishes which would increase the above estimate to 0.34.

The equation also was used with carapace length, although Pauly suggests that total length is preferable. Despite the large discrepancy between 3.84 cm cl and 18.97 cm tl, the estimate of M using the former only increases to 0.40 and when multiplied by 1.3, to 0.52.

Discussion

The foregoing represents preliminary interpretations of a limited time series of biological information on shrimp in Subareas 0 + 1. Other interpretations are possible and hopefully will be put forward as this study receives critical review. Nevertheless, some discussion of the results as presented here is warranted.

No obvious differences between years were noted in the sizes of shrimp at different stages of sexual maturity. Certainly, no differences in size/age of sex change as noted by Charnov (1980) in a developing shrimp fishery at Skagerrak were apparent from the Davis Strait samples. These similarities between years might indicate some stability in the stock under exploitation.

The 1979 data suggest that females spawning for the first time deposit their eggs earlier than the females which had spawned in the previous year(s). This is reflected in the size of ovigerous animals which coincides very well with the sizes of the transitional and first year female group. This also may be interpreted from the 1981 sample, although sample size is low relative to other years.

The maturity data presented here are consistent with those of Dupouy et al. (1981) which indicated that most transitionals and females have well-developed ovaries. Non-spawners were less than 5% of all transitionals and females examined for each year and most had spawned previously. Dupouy and Fontaine (1983) observed lower percentages of ripening ovaries in 1982 than in previous years and suggested that up to 50% of females without spines might not have spawned in that year. This potential 'spawning failure' is much greater than that observed in previous years from both the French and Canadian data. Departure from 'average' conditions of this magnitude should be seriously considered in assessing the status of the stock. Indeed, the French authors qualitatively predicted low recruitment because of the conditions observed in 1982. [It should be noted, however, that some late season commercial length frequencies did not suggest spawning failure of this magnitude (Parsons et al. 1983)]. Data from the fishery and research surveys should be analyzed in detail, especially during the next few years, to verify this prediction as soon as possible. Such analyses of future and historic data also should include the determination of the proportions of non-viable eggs which may be another indicator of reproductive success.

The determination of first year spawners versus multiple spawners is not possible after the eggs have been deposited. In fact, during the periods considered in this study (August-September), some females were very close to laying eggs and had moulted into 'breeding dress'. It is possible that the proportion of first year females has been underestimated if sternal spines were lost just prior to egg laying. Smidt (Horsted and Smidt 1956) stated that 'the best picture of growth, sexual maturity, and sex reversal is given by the samples collected in August, because at this time all year-classes and development stages are represented'. Since that time, however, McCrary (1971) showed that first year spawners could be separated from multiple spawners based on the condition of the sternal spines. If it is desirable to make this distinction, then a better time for sampling might be a little earlier in the year, perhaps late July, before the eggs are laid and before females acquire full breeding dress.

The significance of bimodality (if any) in the transitional-first year female group in 1980 (and to some extent 1981) is uncertain. Variation in the data is one explanation but differences in growth rates and maturity of various age groups also are possible. Difficulties in age interpretation which may result from the latter have been addressed in part by averaging (pooling) the data over four years.

The interpretation of age given here involved a number of assumptions. 1) The transitionals and first year females (with spines) were considered to be a single year-class. Only a few first year females were found in most samples and their sizes corresponded to the sizes of the transitional group. As well, development of the ovaries were similar in both groups. The only distinguishing feature was the remnants of the inner lobe of the first endopod in the transitionals. 2) The group of females which had spawned previously is likely a composite age group. An extrapolation of the von Bertalanffy relationship determined here suggests that the largest animals encountered (31-32 mm) might be 9 to 10 years old. This perhaps is possible, but as Dupouy and Fontaine (1983) suggest, females which do not spawn in a given year likely grow, perhaps accounting for these larger sizes. 3) Another assumption is that the five modes of juveniles and males represent age groups and are not merely artifacts of the data. Dupouy et al. (1981) indicated three modes of male shrimp from the French commercial data. Dupouy and Fontaine (1983) indicated that the smallest group was age class 1, thereby conceding that the young of the year were not available to the commercial gear. It is possible that age class 0 is partially represented by the mode at 8.0 mm in these samples. These sizes of shrimp also were found in cod stomachs off Labrador and interpreted likely to be young of the year by Bowering et al. (1983). However, five age groups have not been interpreted from previous data. If five do exist, it will have some effect on predictions of recruitment made during previous meetings. The interpretation of age in this study predicts sex change at age 5 which corresponds with Type A development described by Smidt (Horsted and Smidt 1956) for the Disko Bay and Godthaab District. Although the Disko Bay is, more or less, adjacent to the area where the samples in this study were taken, hydrographic conditions may differ greatly.

The estimate of natural mortality of 0.34 from Pauly's (1980) equation applied to total length is low compared to mortality after spawning of 1.5 used in a previous assessment (ICNAF 1977). The estimate of 0.52 using carapace length falls within the range estimated for shrimp

In the Gulf of St. Lawrence (Fr chet te and Parsons 1983). The relationship is not extremely sensitive to either parameter, especially L_{∞} , and even with approximate values, reasonable estimates of M may be obtainable. If mortality for females is relatively high after second spawning, then K might be underestimated and consequently M as well. As the von Bertalanffy equation only provides an approximation of the discontinuous growth of shrimp (Fr chet te and Parsons 1983), estimates of M by the above method are only as biologically meaningful as the parameters L_{∞} and K , themselves.

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Table 1. Biological samples from Subareas 0 + 1, 1978-81.

Sample no.	Type	Date	Lat. (N)	Long. (W)	Depth (m)	Time NST	Div.	n
1	Research	09/08/78	68°29.2'	56°59.3'	351	0839	1B	452
2	Research	10/08/78	67°32.0'	58°09.2'	265	0713	0A	267
3	Research	11/09/79	68°01.7'	57°00.1'	262	1023	1B	451
4	Research	14/09/79	67°41.3'	57°42.7'	261	1121	1B	355
5	Commercial	26/08/80	67°51.0'	57°56.0'	300	0925	1B	345
6	Commercial	17/09/80	68°04.0'	58°33.0'	335	0630	0A	307
7	Commercial	21/09/81	68°10.0'	58°46.0'	285	1255	0A	312

Table 2. Incidence (n) of non-spawners estimated from samples taken in Subareas 0+1, 1978-81.

	1978	1979	1980	1981	All years
Transitionals and females	256	243	333	144	976
Non-spawners	9	7	5	2	23
Percent	3.5	2.9	1.5	1.4	2.4
Multiple spawners ¹	128	161	199	82	570
Non-spawners	9	6	5	2	22
Percent	7.0	3.7	2.5	2.4	3.9

¹ Ovigerous animals not included.

Table 3. Results of Cassie (1954) analysis on pooled data for juveniles and males, 1978 and 1980.

Group	A Length* at 50%	B Length* at 99.99%	C B-A	s C/3.72	% of total	n
0	8.0	10.0	2.0	0.54	2.3	17.8
1	12.0	14.5	2.5	0.67	4.7	36.3
2	15.0	19.0	4.0	1.08	10.0	77.3
3	19.5	23.5	4.0	1.08	27.0	208.7
4	22.5	27.5	5.0	1.34	56.0	432.9
TOTAL					100.0	773

* lengths estimated to the nearest 0.5 mm.

Table 4. Mean length-at-age and maturity for shrimp from Subarea 0+1, 1978-81.

Age	Carapace length	Maturity
0	8.0	Juveniles and immature males
1	12.0	Immature males
2	15.0	Immature and mature (maturing) males
3	19.5	Mature males
4	22.5	Mature males
5	25.5	Transitionals and first year females
6+	26.5	Multiple spawners

Table 5. Estimation of von Bertalanffy growth parameters for shrimp from Subarea 0+1, 1978-81.

Age	Carapace length (mm)		Total length (mm)	
	Observed	Expected	Observed	Expected
0*	8.0		51.6	
1	12.0	11.6	69.7	67.9
2	15.0	15.8	83.2	86.9
3	19.5	19.4	103.6	103.0
4	22.5	22.4	117.2	116.5
5	25.5	24.9	130.8	127.9
6+	26.5	27.0	135.3	137.6
L_{∞}	38.4		189.7	
K	0.17		0.17	

* length at age 0 not used in estimation of parameters.

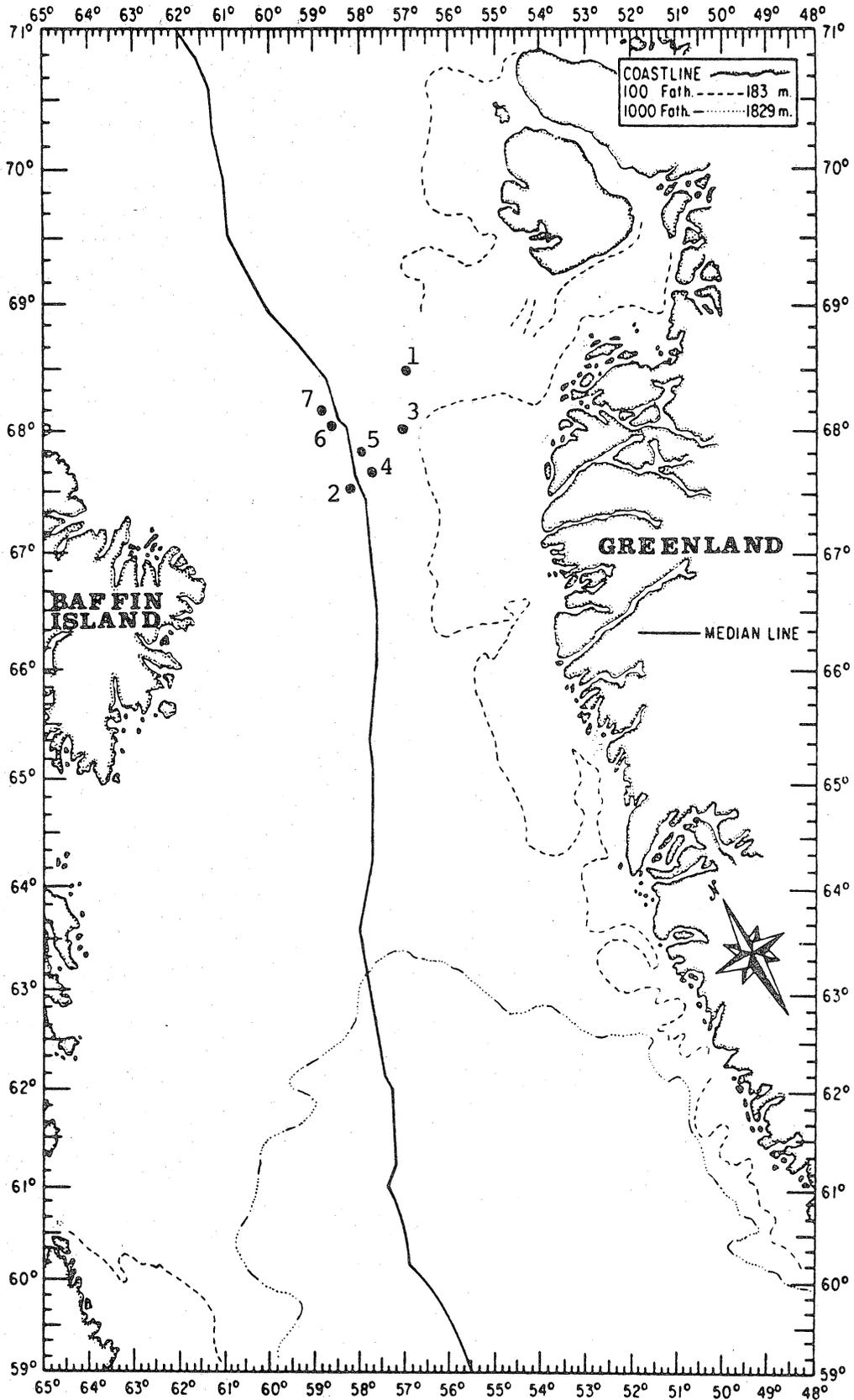


Fig.1. Stations for detailed shrimp sampling, Subareas 0 + 1, 1978-1981 (No's. refer to set details given in Table 1.)

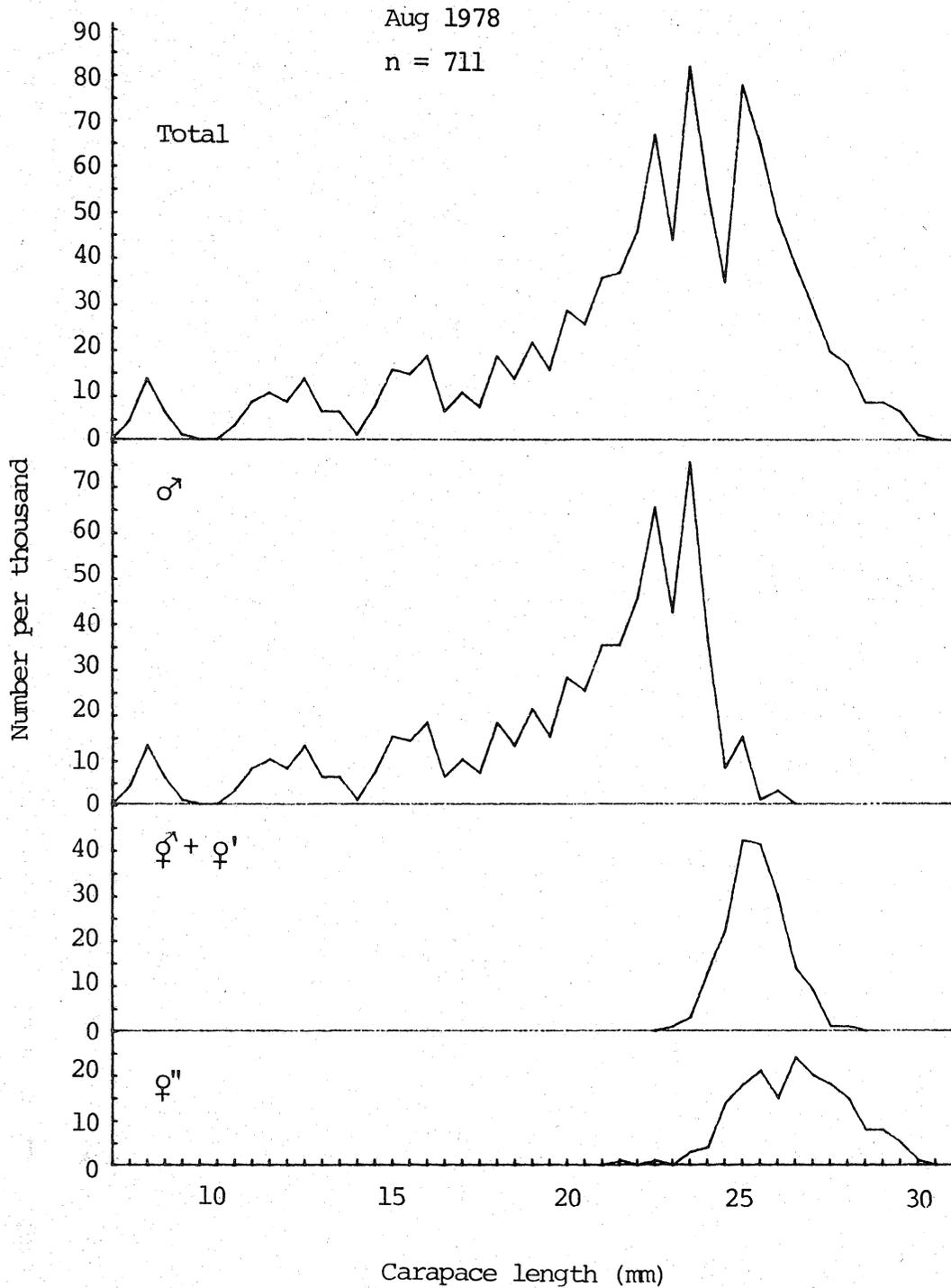


Fig.2. Separation of length distribution by stages of sexual development for a sample of *P. borealis* from Davis Strait 1978. ♂ = male, ♀ = transitional, ♀¹ = females with sternal spines, ♀² = females without sternal spines, ♀° = ovigerous females.

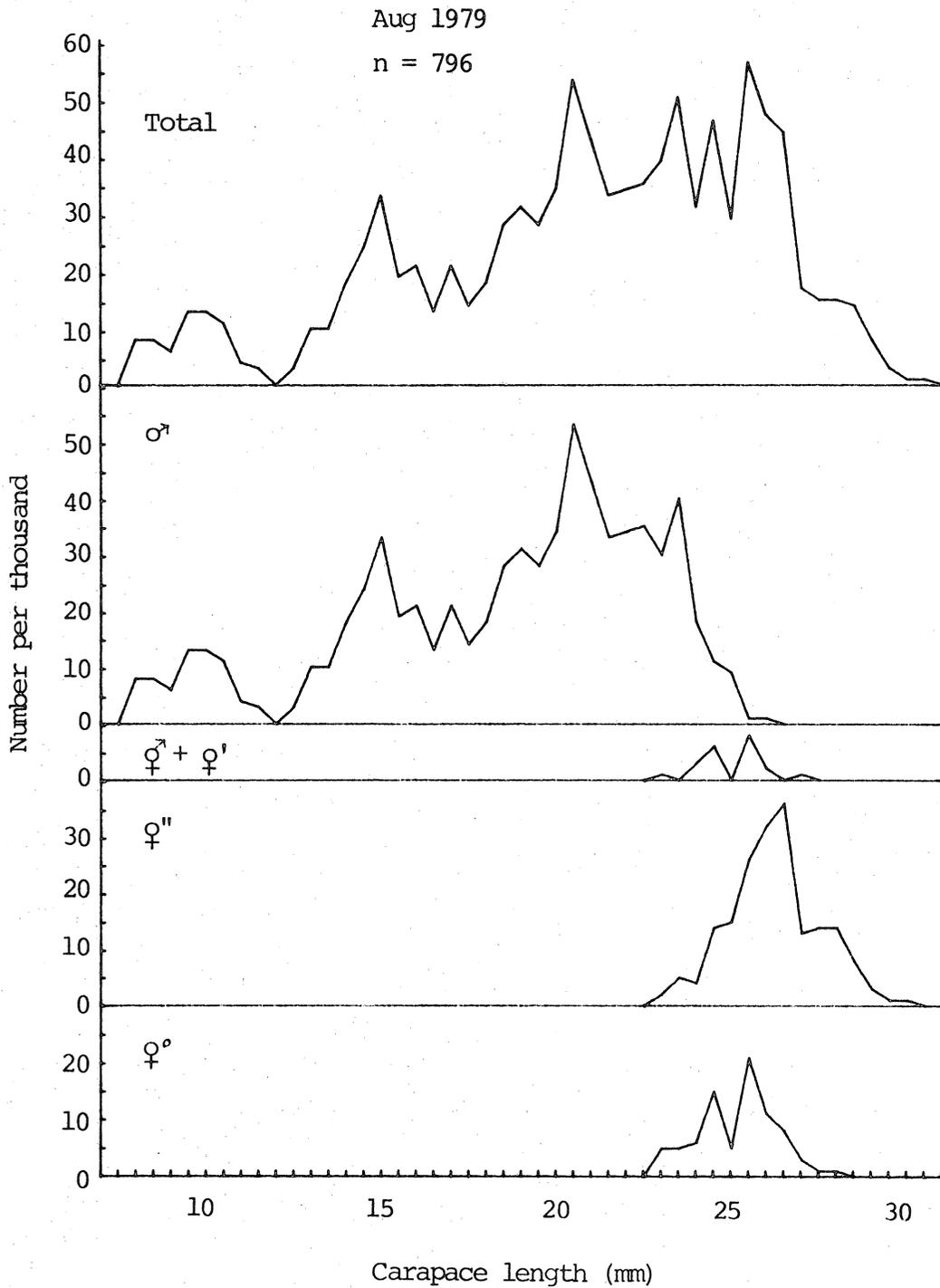


Fig.3. Separation of length distribution by stages of sexual development for a sample of *P. borealis* from Davis Strait 1979. ♂ = male, ♀ transitional, ♀' = females with sternal spines, ♀'' = females without sternal spines, ♀° = ovigerous females.

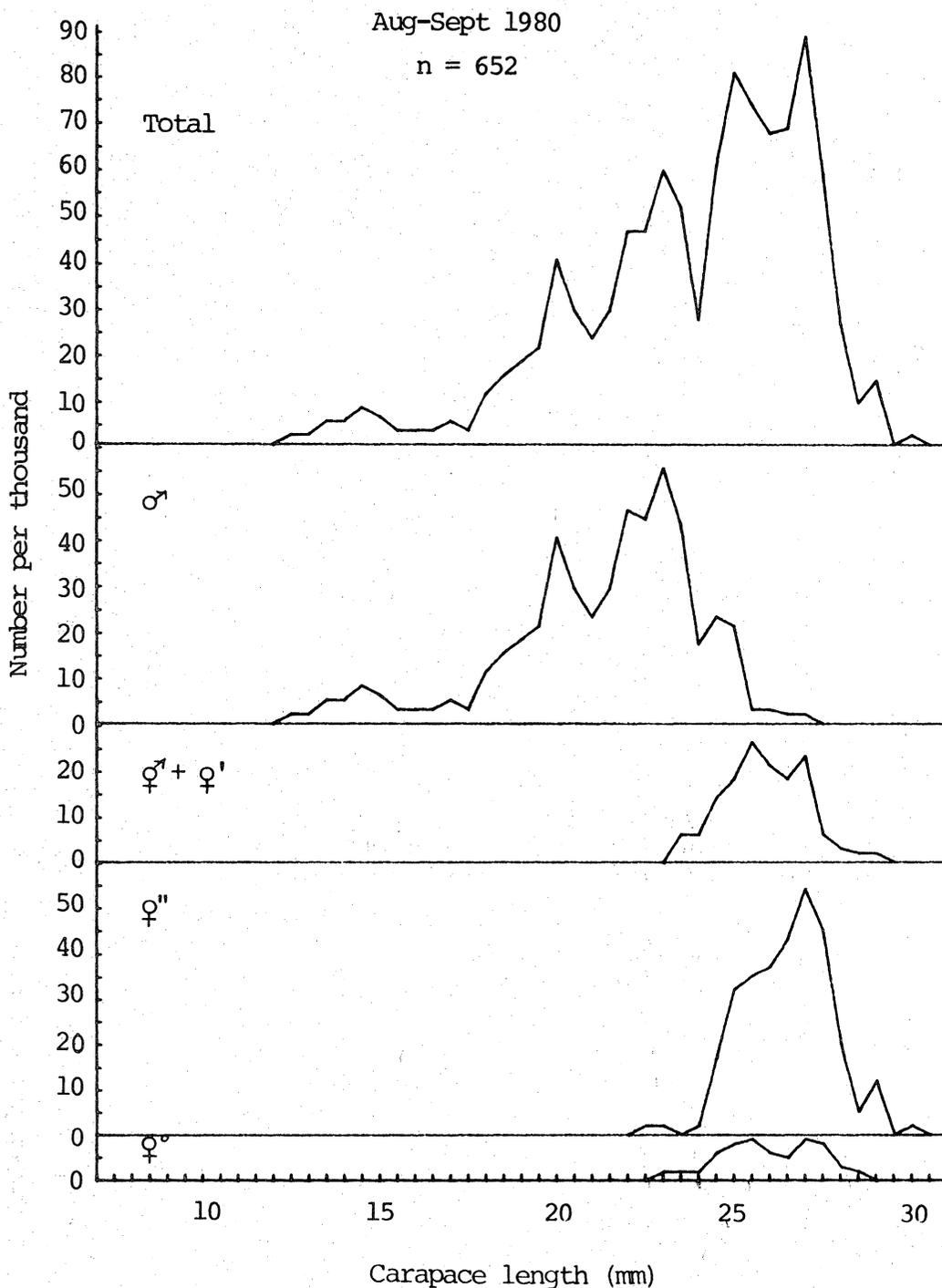


Fig.4. Separation of length distribution by stages of sexual development for a sample of *P. borealis* from Davis Strait 1980. ♂ = male, ♀ = transitional, ♀['] = females with sternal spines, ♀^{''} = females without sternal spines, ♀[°] = ovigerous females.

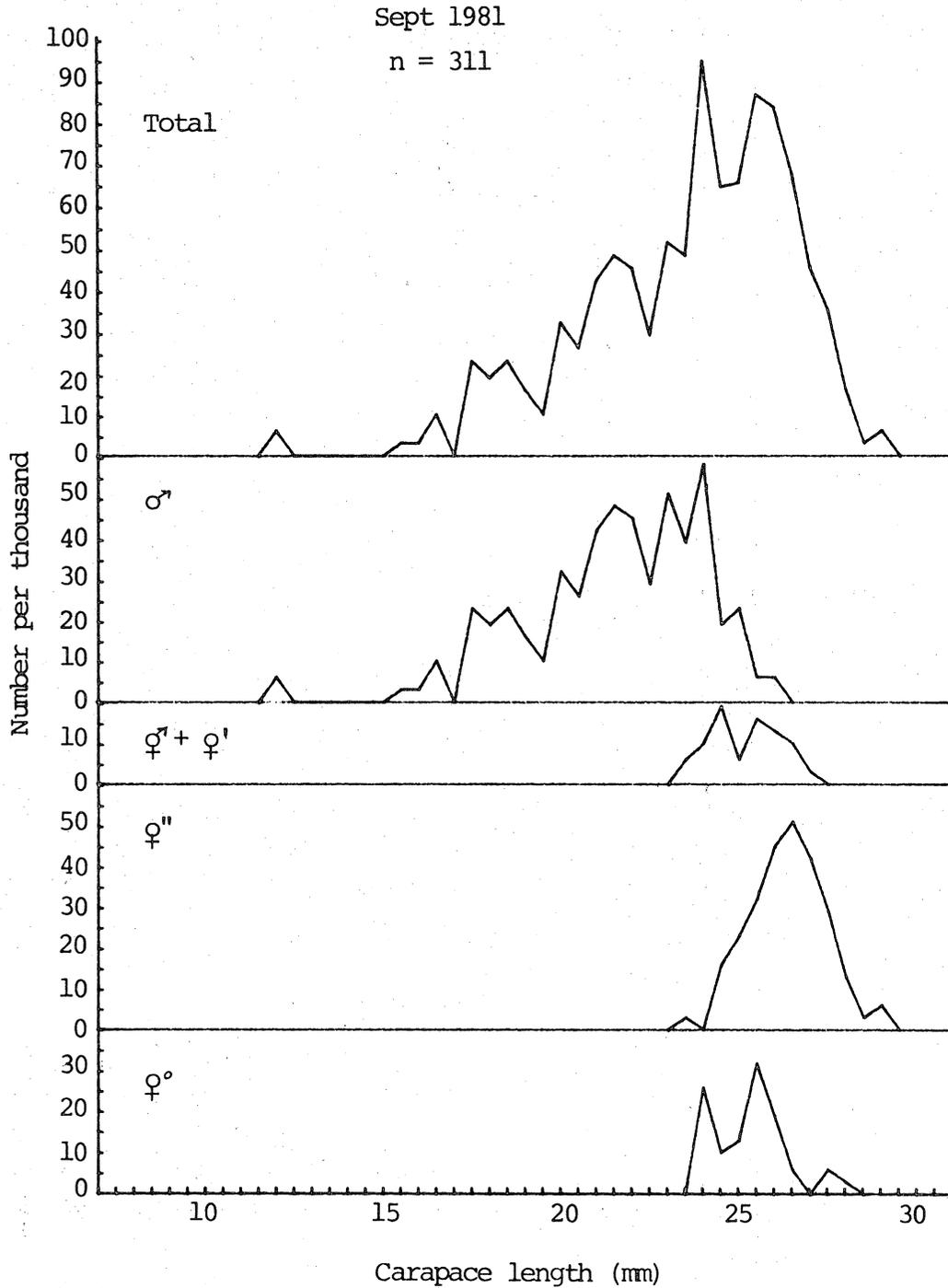


Fig.5. Separation of length distribution by stages of sexual development for a sample of *P. borealis* from Davis Strait 1981. ♂ = male, ♀ = transitional, ♀' = females with sternal spines, ♀'' = females without sternal spines, ♀° = ovigerous females.

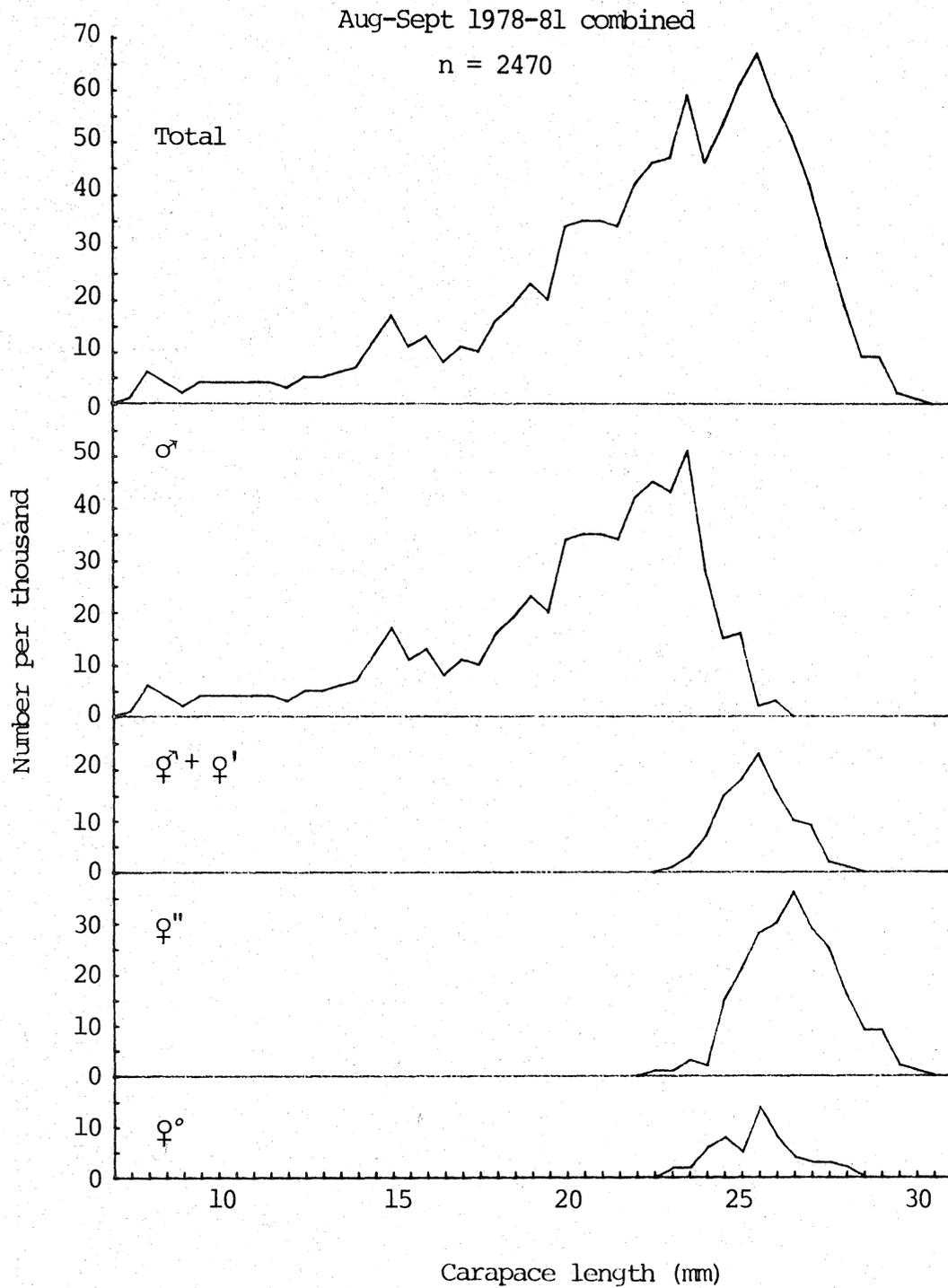


Fig.6. Separation of length distribution by stages of sexual development for a sample of *P. borealis* from Davis Strait 1978-1981 combined. ♂ = male, ♀¹ = transitional, ♀' = females with sternal spines, ♀'' = females without sternal spines, ♀° = ovigerous females.

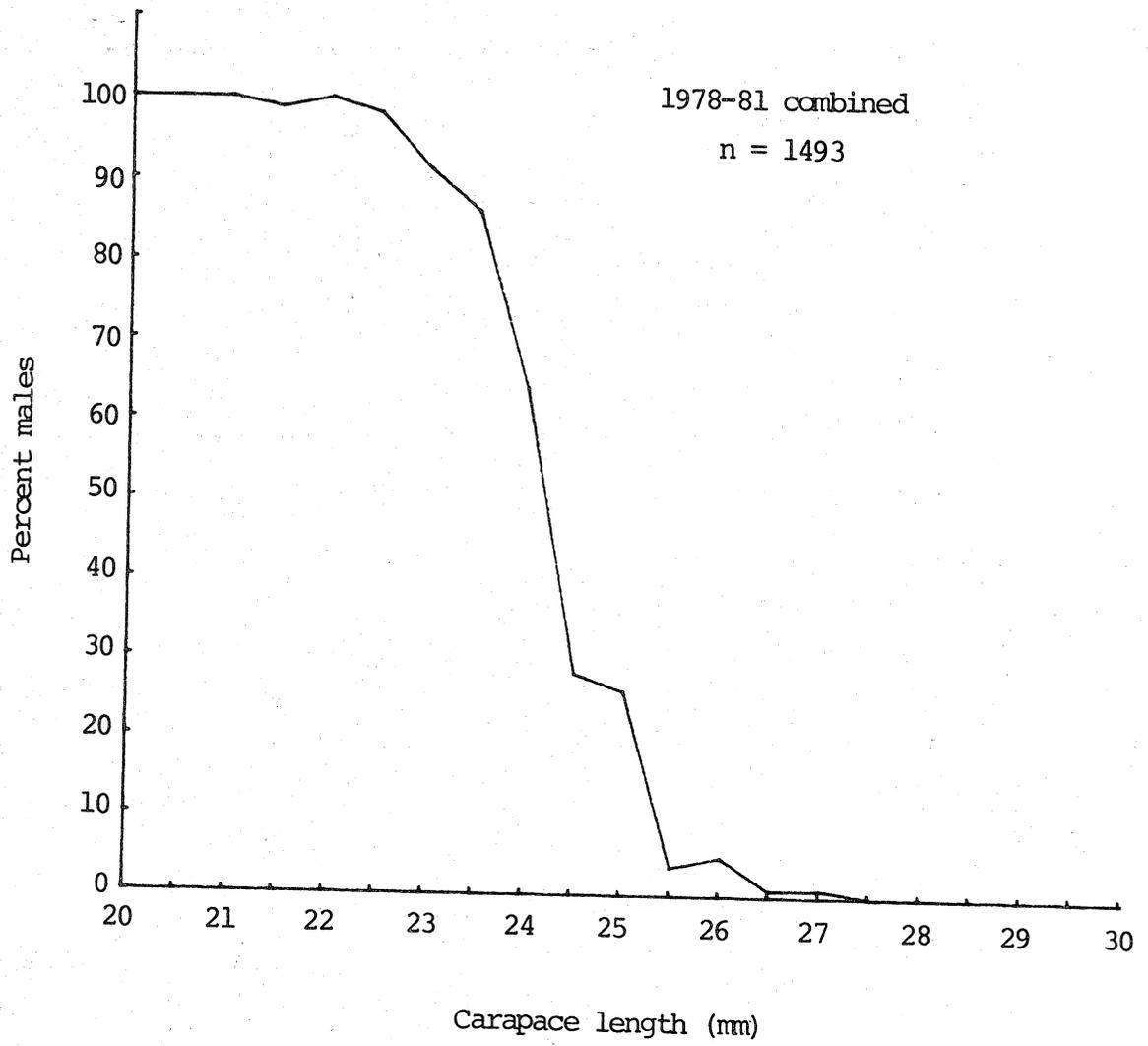


Fig.7. Percent males at length, Subareas 0 + 1 1978-1981 combined.

1978 + 1980 males combined

n = 773

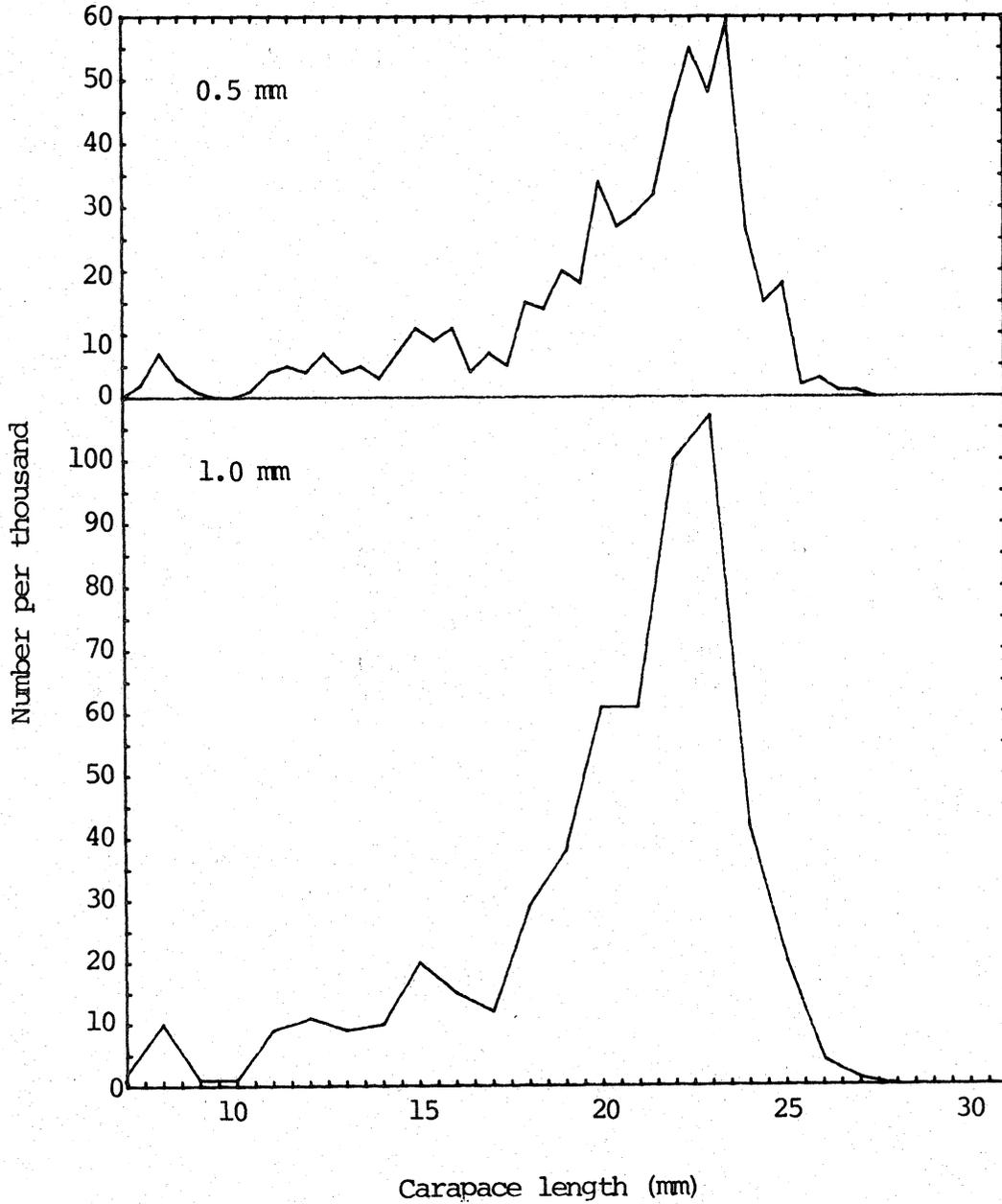


Fig.8. Length frequencies (0.5mm and 1.0mm intervals) for male shrimp, Subareas 0 + 1, 1978 and 1980.

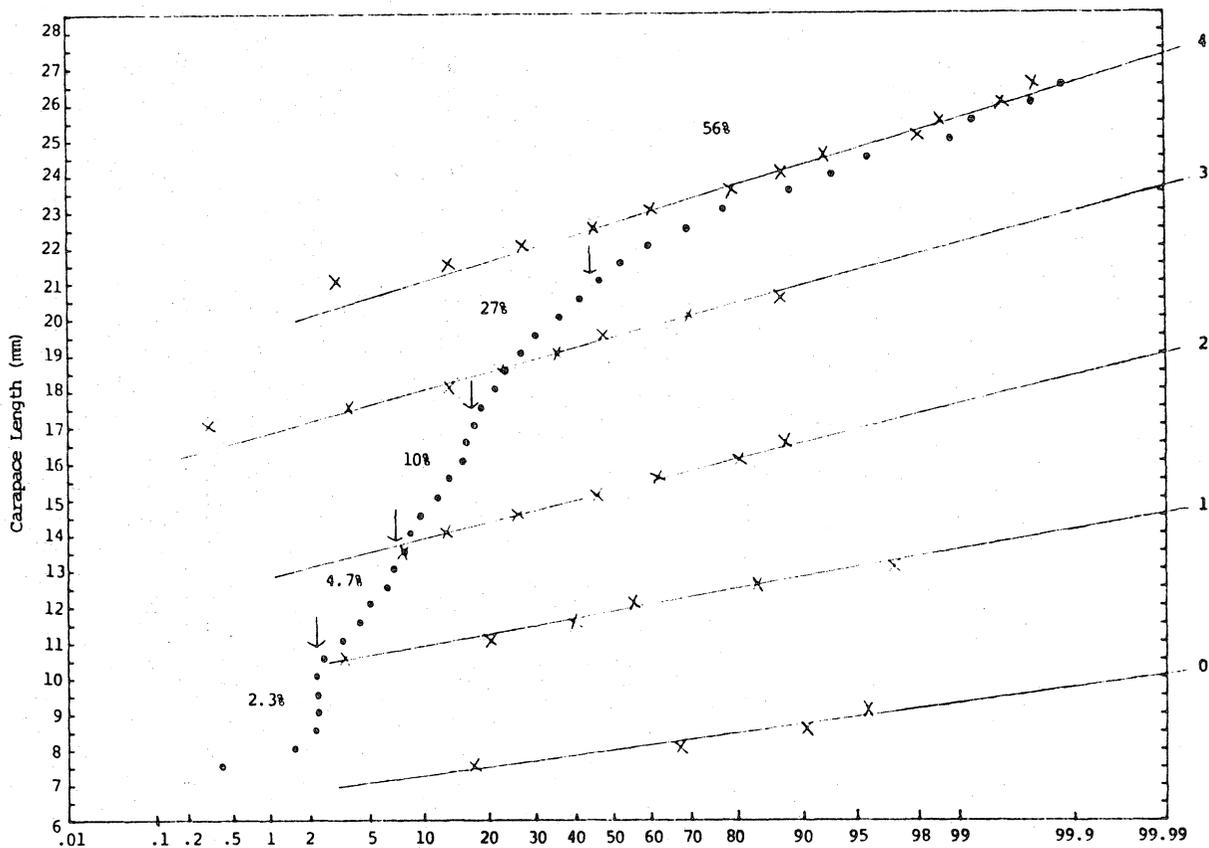


Fig.9. Cassie analysis of polymodal length frequency of male shrimp given in Fig.8. (0.5mm precision).

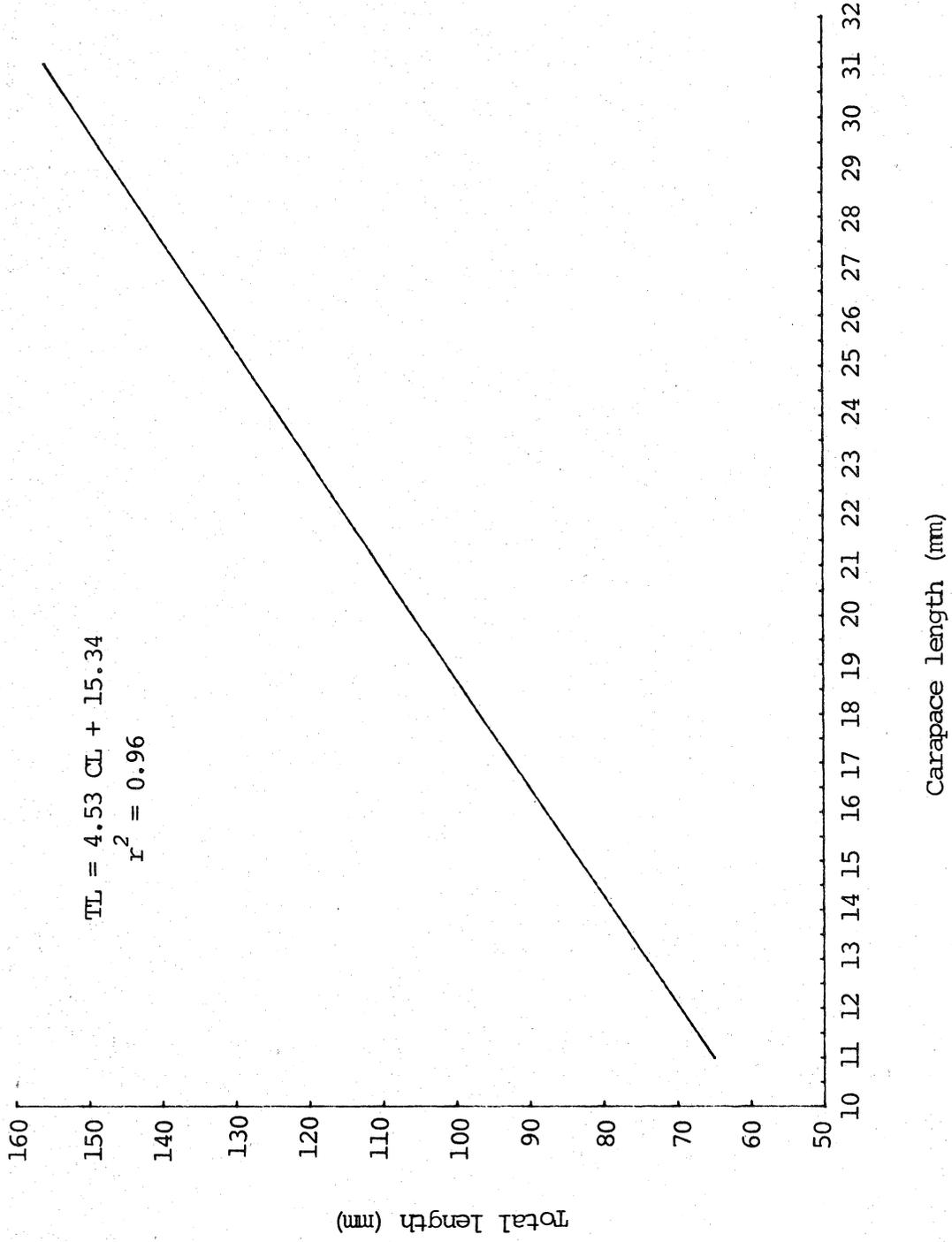


Fig.10. Total length/carapace length relationship for shrimps from Subareas 0 + 1, 1978-1981.