Changes in Size Composition of Male Crabs (*Chionoecetes opilio*) Participating in the Annual Breeding Migration in Bonne Bay, Newfoundland

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Abstract

The mean size of male snow crabs, Chionoecetes opilio, in sexual pairs collected by SCUBA divers during the annual spring breeding migration to shallow water in Bonne Bay, Newfoundland decreased from 118.6 mm carapace width (CW) in 1983 to 100.3 mm in 1987. This decrease in mean size is due to an increase in the percentage of males <95 mm CW participating in the migration from 1.5 in 1983 to 32.3 in 1987. This change appears to have resulted from a reduced abundance of commercial size (≥95 mm CW) males due to a rapid development of an illegal fishery on this previously unfished population and, as a consequence, less competition between males for possession of females. The mean size of paired females has remained the same at around 70 mm.

The percentages of spermathecae containing new spermatophores (indicating recent mating) for females paired with males <95 mm CW (67%) and those with males ≥95 mm (79%) were not significantly different. We assume that each female with new spermatophores had recently mated with the male with which it was paired but this was impossible to confirm.

Observations on selected male/female pairs held in captivity demonstrated that males <95 mm CW are capable of mating successfully with both primiparous and multiparous females. Our results indicate that small mature males can replace large males in normal breeding activity in a snow crab population. We conclude that in the male only snow crab fishery in Atlantic Canada with a minimum legal size of 95 mm CW, population reproductive potential is maintained at a very high level despite removal by fishing of a large proportion of commercial males each year.

Résumé

La largeur moyenne de la carapace (LC) des crabes des neiges (Chionoecetes opilio) mâles accouplés, recueillis en plongée autonome pendant la migration de reproduction printanière vers les eaux peu profondes de la Bonne-Baie (Terre-Neuve), est passée de 118,6 mm en 1983 à 100,3 mm en 1987. Cette biasse de la largeur moyenne est le résultat d'une augmentation du pourcentage de mâles migrateurs de moins de 95 mm LC qui est passé de 1,5 en 1983 à 32,3 en 1987. Cette variation semble avoir été entraînée par une baisse du nombre de mâles de taille commerciale (≥ 95 mm LC) résultant de l'expansion rapide de la pêche illégale dont fait l'objet cette population antérieurement sous-exploitée. Le nombre réduit de mâles signifie aussi qu'il y a moins de compétition entre eux pour les femelles. Dans le cas de femelles accouplées, la largeur moyenne de la carapace est demeurée la même soit environ 70 mm.

Chez les femelles accouplées avec des mâles < 95 mm (67%) et ≥ 95 mm (79%) LC, le pourcentage de spermatothèques contenant de nouveaux spermatophores (indicateurs d'un accouplement récent) n'était pas significativement différent. On formule l'hypothèse que chaque femelle porteuse de nouveaux spermatophores s'était récemment accouplée avec son partenaire sexuel mais cette hypothèse n'a pu être confirmée.

L'observation de certaines paires mâle-femelle gardées en captivité a révélé que les mâles < 95 mm LC peuvent s'accoupler avec succès avec des femelles primipares ou multipares. Les résultats obtenus indiquent que les petits mâles matures peuvent prendre la place de gros mâles pendant l'accouplement normal. On formule la conclusion que dans le cadre de la pêche annuelle du crabe des neiges dans le Canada atlantique, orientée uniquement vers les mâles mesurant au moins 95 mm LC, le potentiel de reproduction est maintenu à un niveau très élevé malgré l'élimination par pêche d'un grand nombre relatif de mâles de taille commerciale.

Introduction

During April-May each year, sexually paired snow crabs, Chionoecetes opilio, migrate into shallow water (10-30 m) in Bonne Bay, Newfoundland from depths possibly as great as 150 m. Various behavioral, ecological and biological aspects of this spring breeding migration are described by Taylor et al. (1985) and by Hooper (1986) based on observations and sampling in 1982, 1983 and 1984. This snow crab population is small and apparently isolated from populations elsewhere in the Gulf of St. Lawrence by a 35 m deep sill at the mouth of the bay. There had been no commercial fishery and in 1984 the population was still considered to be in a virgin state (Taylor et al. 1985).

Male snow crabs reach sexual maturity over the 51 to 72 carapace width (CW) size range (Watson 1970). However, the smallest male found paired with a female in the 1982 to 1984 sampling at Bonne Bay was 89 mm CW. Hooper's (1986) observations indicated that during the breeding migration to shallow water there is keen competition between single males and males already sexually paired for possession of the female. Under prefishery conditions this competition can be expected to eliminate small males from participating in breeding activity, however, Taylor et al. (1985) suggested that a large size differential between the male and female of a pair may be an important element of behavioral interactions during breeding activity.

In the management of the Atlantic Canada snow crab fishery, it has been assumed that, despite high levels of exploitation, reproductive potential in a stock remains at prefishery levels. The basis for this assumption is that females are protected from exploitation by the 95 mm CW minimum legal size because they do not grow to that size and also that males mature at sizes much smaller than 95 mm CW. In 1983 only one male in ~250 pairs and in 1984 only 3 males in 304 pairs collected during the breeding migration were smaller than 95 mm CW. It was unknown whether males smaller than these were capable of successful mating (i.e. functional maturity) in the absence of competition from large males. Since 1984 the Bonne Bay snow crab population has been subjected to significant exploitation and the abundance of large crabs appears to have been reduced. In this paper we present sampling data collected during the breeding migrations in 1985, 1986, and 1987 as well as observations on pairs held in cages and aquaria which relate to the question of functional maturity in small male snow crabs.

Materials and Methods

Sexually paired snow crabs were collected by SCUBA diving at depths from 10 to 20 m during the annual (April-May) breeding migration to shallow water in Bonne Bay, Newfoundland each year from 1983 to 1987. In most cases, each pair was kept in a separate mesh bag. Maximum carapace width (CW) of each crab was measured to the nearest 1.0 mm and shell condition (soft, new/hard, or old/hard) determined. The absence of legs or chelae and in females the presence of old and new grasping marks were noted. In 1986 and 1987, chelae height of males was measured to the nearest 0.1 mm. The egg masses of females were examined to approximate the extent of hatching; for those in which hatching had been completed, the presence of newly extruded eggs was noted.

Some females were also frozen and dissected in the laboratory to determine ovary condition and the presence of old and new spermatophores in the spermathecae. Trap-caught samples of crabs were also obtained from depths >60 m at different times of the year throughout 1984 to 1987. On a number of occasions both diver- and trap-caught crabs were tagged and released in the area of capture and others examined for the presence of an ectocommensal turbellarian worm, Peraclistus oofagus.

Selected male/female pairs, from trap-caught samples taken in Bonne Bay in early May 1986 near the start of the breeding migration, were kept separately in cages on the bottom at 15 m and in onshore tanks supplied with running seawater. The females were examined in detail for evidence of successful mating after 2-3 weeks. Selected pairs were also maintained separately in seawater facilities at the Northwest Atlantic Fisheries Centre in St. John's during 1987. Crabs for the latter observations were trap-caught in Conception Bay in November 1986 and males held separately from females until paired.

Results

Size of Sexually Paired Males

The mean size of males in sexual pairs collected by SCUBA divers during the annual spring breeding migration to shallow water in Bonne Bay has decreased in recent years from 118.6 mm CW in 1983 to 100.3 mm in 1987 (Table 1, Fig. 1). ANOVA demonstrated that mean sizes for some years were different ($F = 24.45$, $P = 0.0001$). A Tukey test revealed that mean sizes in 1984 and 1985 were similar to both 1983 and 1985 but mean size in 1986 was significantly smaller than in 1983 and mean size in 1987 was significantly smaller than in all previous years. The percentage of males <95 mm CW in these pairs ranged from 1.0 to 6.7% from 1983 to 1986 but increased sharply to 32.3% in 1987 (Table 1). A Tukey-type test revealed that the 1986 percentage was significantly higher than the 1984 but both were similar to those for 1983 and 1985. The percentage for 1987 was significantly higher than for each of the previous years. The paired males <95 mm CW collected in 1987 ranged from 62 to 93 mm CW ($\bar{x} = 79.5$, $N = 10$).

In the 1987 sample, the mean size of females paired with males <95 mm CW was 68.3 mm ($N = 10$) which was not significantly different from the 70.7 mm ($N = 21$) mean size of females paired with males ≥95 mm ($F = 0.89$, $P = 0.24$). Similar mean sizes for females paired with these male size groups were also obtained when the 1984 to 1987 samples were combined.

In only two of the 616 pairs collected from 1983 to 1987 were the males smaller than the females with which they were paired. Both were taken in 1987. In one pair the carapace widths were 62 and 66 mm and in the other 67 and 73 mm for the male and female, respectively. In the latter female, the spermatheca contained old and new spermatophores indicating recent mating. In all other pairs the male was at least 5 mm CW larger than the female.

Female Reproductive Condition

All sexually paired females reported here were multiparous. Among females whose spermathecae were examined, 67% (N = 12) of those paired with males <95 mm contained new spermatophores compared with 79% (N = 76) for those paired with males ≥95 mm in the same (1985-87) samples (Table 2). The difference was not significant (χ^2_C = 0.328, P > 0.50). Observations on external egg masses of females also indicate no negative effects on hatching of eggs or extrusion of new eggs associated with being paired with small males. For 1984 to 1987 samples combined, among 17 females paired with males <95 mm the egg mass was partly hatched in 12%, completely hatched in 64% and of these latter, one female was extruding new eggs while among 492 females with males ≥95 mm these percentages were 14 and 36, respectively and of the latter, seven females were extruding new eggs (Table 3).

Observations on Cage- and Tank-held Pairs

Observations reported here for pairs held in cages and in tanks at Bonne Bay involved females carrying old eggs (i.e. multiparous). Examination of 17 such females collected at the same time revealed that none had new spermatophores in their spermathecae. Among cage-held females when subsequently examined, spermathecae contained new spermatophores in 30% (N = 10) of those that had been paired with males <95 mm CW (80-93 mm, $\bar{x}$ = 88.1) compared to 50% (N = 8) for those paired with males ≥95 mm; these percentages were 50 and 67, respectively among the tank-held females (Table 4). Differences in percentages between females paired with the smaller males and those paired with the larger males were not significant for either the cage- (χ^2_C = 0.143, P > 0.50) or tank-held (χ^2_C = 0.028, P > 0.75) animals. Among the tank-held animals, actual pairing (male grasping female) was observed in 75% of the pairs involving males <95 mm (73-92 mm, $\bar{x}$ = 82.6) and in 83% of those involving males ≥95 mm; copulation was observed in 25 and 17%, respectively (Table 4).

Ten male/female pairs in which the males ranged from 62 to 75 mm CW were held in tanks at the Northwest Atlantic Fisheries Centre. These had been selected from trap-caught specimens in which males and females had been held separately for 1-12 months before pairing. Three of these involved females that had molted immediately before pairing. Copulation was observed in 2 of these, all 3 extruded new eggs and of the 2 females whose spermathecae were examined, both contained new spermatophores. The remaining 7 pairs involved females that were carrying or in the process of hatching old eggs. One of these pairings took place 3 months, the others 11-12 months, after the females had been obtained from the wild. The spermathecae of all 7 females contained old and new spermatophores when examined after being paired for a few days up to 3 weeks.

Observations on Morphometric Maturity

All of the 11 paired males collected by divers in 1986 were morphometrically mature as per Conan and Comeau (1986). In 1987, one male out of the 31 pairs collected was morphometrically immature. It was 99 mm CW and its chela height was 17.5 mm. The spermatheca of the female with which this male was paired contained old spermatophores only, although in the spermathecae of 14 of the other 17 paired females collected the same day, there were old and new spermatophores. Three of the 10 males which were paired and mated in tanks at the Northwest Atlantic Fisheries Centre were morphometrically immature. These were 62, 62 and 72 mm CW with chela heights of 9.8, 10.1 and 11.8 mm, respectively. The spermathecae of all 3 of the females with which these had been paired contained old and new spermatophores.

Incidence of Peraclistus oofagus

Turbellarian worms, Peraclistus oofagus, which are a common ectocommensal of snow crabs, are transmitted from infected to uninfected crabs during mating activity. There was a high incidence of old-shelled crab, all of which were infected, in a May 1983 sample but a high incidence of new-shelled crab, very few of which were infected, in a May 1987 sample (Table 6). It is inferred from the low incidence of worms on the primiparous females in 1987 that they had mated with uninfected males. The size composition of the uninfected males in the 1987 sample (Table 5) indicates that males < 95 mm CW would have been involved in mating with these uninfected females.

Discussion

Our results demonstrate that male snow crabs (C. opilio) substantially smaller than the 95 mm CW minimum legal size applied in the fishery in Atlantic Canada are capable of mating successfully with multiparous females. In Bonne Bay, the incidence of males < 95 mm CW participating in the annual breeding migration increased substantially in 1986 and 1987. This appears to have been a direct result of reduced abundance of commercial size males caused by the rapid development of an illegal fishery and, as a consequence, less competition between males for possession of females.

Increased poaching on the Bonne Bay snow crab population in recent years is undocumented but nonetheless well known in the area. However, data from research fishing indicates that the abundance of commercial size males was substantially lower in 1987 than in preceding years. Catch rates of commercial males dropped from 32.3 per trap haul in May-June 1985 to 1.9 in May 1987 (Table 6). The ratio of commercial to undersized males in these samples changed from 2.2 to 0.13 and the incidence of new-shelled crab increased sharply, particularly for the undersized males (Table 6, Fig. 2). High levels of returns of commercial crabs tagged between April 1984 and May 1986 also indicate significant exploitation (Table 7) although a rate cannot be estimated with confidence.

In addition to their participation in the annual breeding migration which occurs in Bonne Bay, there is substantially more evidence that male C. opilio <95 mm CW are quite capable of successfully mating with multiparous females. Among the diver-caught pairs collected in Bonne Bay from 1985 to 1987, there was no difference in the proportion of spermathecae containing new spermatophores (indicating recent mating) among the females examined (all of which were multiparous) that were paired with males <95 mm and those paired with males ≥95 mm. In selected pairs from trap-caught samples obtained at the start of the breeding period and held in cages and in tanks at Bonne Bay, there was similiarly no difference between females paired with males <95 mm and those with males ≥95 mm in the proportion of spermathecae with new spermatophores when examined towards the end of the breeding period. Successful mating also occurred between selected pairs involving males <95 mm and both primiparous and multiparous females that were held in tanks at the Northwest Atlantic Fisheries Centre. Among tank-held pairs, precopulatory grasping was quite common and copulation was observed for several different pairs including some in which the males were <95 mm.

In laboratory work with the closely-related species C. bairdi, Adams and Paul (1983) mated primiparous females with males ranging in size from 65 to 140 mm CW. They reported that all females received enough sperm to fertilize a full clutch of eggs and following extrusion, 93% of the females had enough sperm remaining in their spermathecae to fertilize additional egg clutches.

Hooper (1986) observed in the wild that males sometimes held the females with which they were paired high and waved them back and forth as larvae were being released. How important this is to successful hatching is unknown. This behavior has been observed in tank-held pairs involving males <95 mm as well as larger males. Also, our observations on external egg masses of diver-caught paired females from Bonne Bay indicate little difference in the extent of hatching for females paired with males <95 mm and those paired with larger males.

Conan and Comeau (1986) concluded there is no evidence that sublegal (i.e. <95 mm CW) "morphometrically mature" males can efficiently mate in their natural environment with multiparous females. We cannot be certain that the new spermatophores found in the spermathecae of diver-caught females paired with males <95 mm CW in Bonne Bay resulted from mating with those particular males. However, our observations on cage- and tank-held selected pairs demonstrate that males <95 mm are capable of mating successfully with multiparous females and we conclude that this occurs in the wild as well.

There is no doubt that sublegal size males can substitute for larger commercial size males in normal mating activity in a C. opilio population, even in the annual breeding migration to shallow water in Bonne Bay where a large difference in size between the paired male and female appeared to be important (Taylor et al. 1985). Our results indicate that reproductive potential (i.e. annual production of fertilized eggs) in a snow crab population is maintained at a high level despite removal by fishing of a large proportion of commercial

size males each year. Although snow crab fishery management in Atlantic Canada has assumed this to be the case, there is no basis to suspect that recruitment to the fishery would be adversely affected if reproductive potential were not maintained at its maximum. In fact, it would be reasonable to suggest that reproductive potential could be substantially reduced without recruitment being adversely affected. From the available evidence, we conclude that production of viable eggs, even in heavily fished C. opilio stocks, is maintained to the right of the ascending limb of a stock-recruitment curve whatever its general shape might be for this species.

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Table 1. Carapace widths of sexually paired male and female Chionoecetes opilio collected by scuba divers in Bonne Bay, Newfoundland, 1983-87.

		Males			Females	
Year	N	$\bar{x}$ ± S.D. (mm)	Range	% <95 mm	$\bar{x}$ ± S.D. (mm)	Range
1983	67	118.6 ± 7.6	94-136	1.5	70.6 ± 5.3	55-85
1984	304	116.6 ± 8.3	89-140	1.0	70.0 ± 5.6	55-86
1985	199	113.8 ± 9.5	76-132	2.0	69.9 ± 5.0	60-90
1986	15	111.1 ± 9.9	94-123	6.7	69.1 ± 4.4	64-82
1987	31	100.3 ± 17.4	62-126	32.3	69.9 ± 5.2	58-82

Table 2. Percentage of spermathecae containing new spermatophores in sexually paired female Chionoecetes opilio collected by scuba divers in Bonne Bay, Newfoundland, May-June, 1984-87.

	Females with males <95 mm CW		Females with males ≥95 mm CW	
Year	N	% new sperm	N	% new sperm
1984	-	-	42	93
1985	2	50	45	80
1986	1	0	10	80
1987	9	78	21	76

Table 3. Observations on external egg masses of sexually paired female Chionoecetes opilio collected by scuba divers in Bonne Bay, Newfoundland, May-June, 1984-87.

		Observations on external eggs (%)			
Male CW	N	None hatched	Some hatched	All hatched	All hatched and extruding new eggs
<95 mm	17	18	12	64	6
>95 mm	492	49	14	36	1

Table 4. Observations on selected male/female pairs of Chionoecetes opilio held in cages and in tanks at Bonne Bay in 1986.

	Pairs with males <95 mm CW				Pairs with males >95 mm CW			
	N	Pairing observed	Copulation observed	% with new spermatophores	N	Pairing observed	Copulation observed	% with new spermatophores
Cage-held	10	-	-	30	8	-	-	50
Tank-held	12	9	3	50	6	5	1	67

Table 5. Incidence of Peraclistus oofagus on Chionoecetes opilio obtained in research fishing in Bonne Bay during May 1983 and May 1987.

	No. old-shelled	% with P. oofagus	No. new-shelled	% with P. oofagus	CW range and mean (mm)
1983 males	34	100	1	0	105-136, 120
1983 females	24[1]	100	2[2]	0	63-85, 71
1987 males	1	100	22	0	59-118, 75
1987 females	4[1]	75	70[2]	3	46-78, 63

[1] multiparous

[2] primiparous

Table 6. Observations on catches of Chionoecetes opilio males obtained in research fishing at depths >110 m using small-mesh traps in Bonne Bay during May-June 1985 to 1987.

	Males ≥95 mm CW				Males <95mm CW		
Year	N	$\bar{x}$ CW	# per trap haul	% new-shelled	N	$\bar{x}$ CW	% new-shelled
1985	619	115.7	32.3	6.0	283	73.0	1.4
1986	447	116.4	21.0	5.1	64	80.4	18.8
1987	19	113.6	1.9	31.6	144	70.8	94.4

Table 7. Summary of tag-recapture data for commercial snow crab in Bonne Bay.

Date of tagging	Sampling gear	No. tagged and released	$\bar{x}$ CW	No. recaptured	$\bar{x}$ CW
April-May 1984	Scuba	147	116.4	19	113.8
May 1985	Scuba	56	112.1	212	118.0
May 1985	Small mesh traps	484	115.5		
October 1985	Commercial traps	775	119.5	137	118.7
May 1986	Small mesh traps	327	116.2	209	118.0
May 1986	Commercial traps	613	119.3		

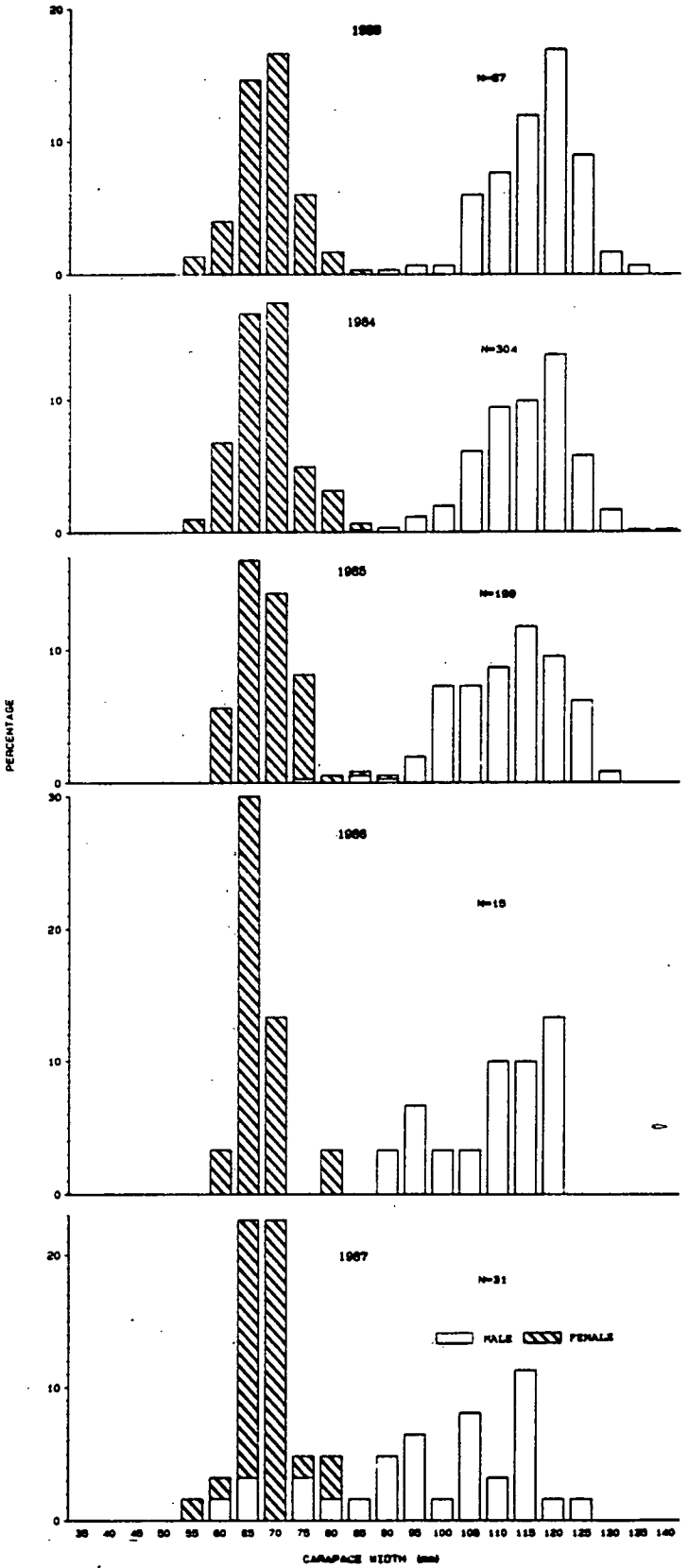

Fig. 1. Size frequency distributions for sexually paired male and female Chionoecetes opilio collected by scuba divers in Bonne Bay, Newfoundland, 1983-87.

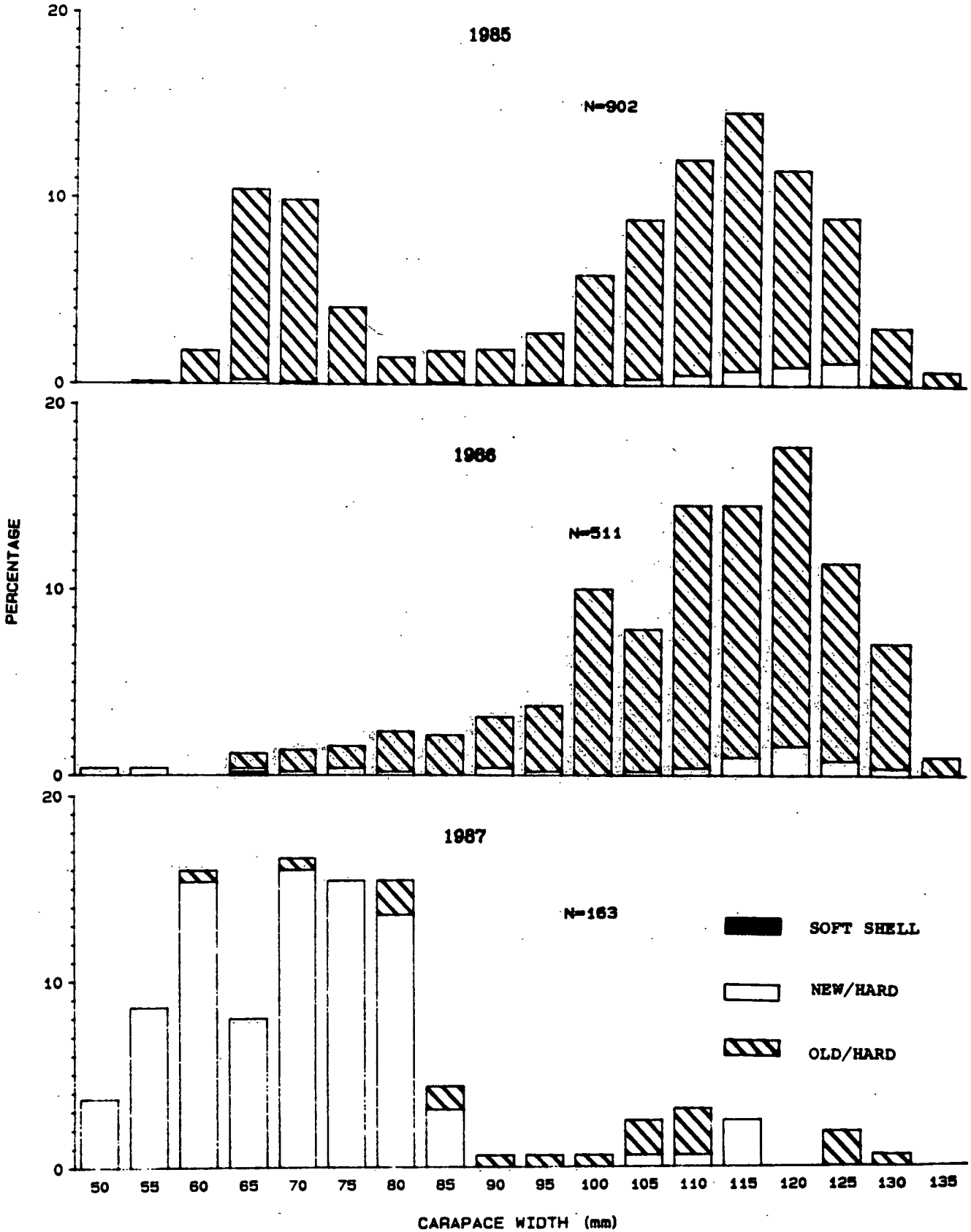

Fig. 2. Size frequency distributions and shell conditions for catches of Chionoecetes opilio males obtained in research fishing at depths >90 m using small-mesh traps in Bonne Bay during May-June 1985-87.